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Damage to Masonry Buildings
Caused by the El Salvador Earthquake of January 13, 2001

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ABSTRACT

Based on a field investigation conducted in the Republic of El Salvador, damage done to buildings by the El Salvador Earthquake of January 13, 2001 is briefly discussed. Special emphasis is placed on the damage to the un-reinforced adobe and brick buildings.

1. INTRODUCTION

On January 13, 2001, an earthquake of Magnitude Mw=7.7 occurred in the Republic of El Salvador in Central America. As of the 13 February 2001, the death toll was 844, 4,723 people were injured, and more than 75,000 houses were totally destroyed. These damage statistics are based on information provided by the National Emergency Committee (CDEN), El Salvador (El Diario de Hoy de El Salvador, 2001; La Prensa Grafica, 2001).

We arrived in San Salvador, the capital of the Republic of El Salvador, on February 9, 2001 to investigate structural damage to the buildings caused by this earthquake and spent five days, mainly in the most severely damaged areas of El Salvador. Non-damaged buildings also were investigated in downtown, San Salvador City on the last day before our leaving El Salvador on February 13, 2001.

Since early 1990s when one of us (Yoshimura, K.) attended the International Cooperation Project at the National Center for Disaster Prevention (CENAPRED) in Mexico City, a number of experimental and field investigations have been conducted in the Structural Engineering Laboratory of Oita University to develop much higher seismic performance of un-reinforced and confined masonry wall buildings for use in developing countries prone to earthquakes (Camacho et al., 1993, 1994; Yoshimura et al., 1995, 1996; Liu et al., 1997; Yoshimura et al., 1998, 1999a, 1999b, 1999c; Kagami et al., 1999; Yoshimura et al., 2000a, 2000b). The main objective of this reported field investigation was to collect general information about damage done to the masonry structures by the El Salvador Earthquake of January 13, 2001.

2. RECENT SEISMIC ACTIVITY IN EL SALVADOR

El Salvador is located on the western border of the Caribbean Plate. The Cocos Plate subducts under the Caribbean Plate, which is one cause of seismic activity in El Salvador. The other main cause of Salvadorian earthquakes, are the active volcanoes along the volcanic belt running from Guatemala to Costa Rica, that have produced much extensive earthquake damage in El Salvador (Lopez, 1999).

From 1965 through 1999, the most significant earthquakes that occurred in El Salvador were the 1965, 1982, and 1986 ones with respective Richter Magnitudes of Ms=6.0, 7.2, and 5.4, and respective maximum ground shaking intensities in San Salvador City of MM=VIII, VII, and VIII on the Modified Mercalli Scale (EERI and IAEE, 2001). The 1965 earthquake, whose epicenter was 10 km from San Salvador and 8 km deep, caused severe damage and killed 120 people. The epicenter of the 1982 earthquake was approximately 60 km southeast of San Salvador at a depth of 80 km. It killed eight people and damaged 1,630 houses. Although the 1986 earthquake had the smallest magnitude, Ms=5.4, of the three earthquakes, about 1,500 people were killed, 7,000 to 10,000 injured, and 100,000 affected by it. Its epicenter was just south of San Salvador at a focal depth of less than 8 km (Castillo, 1994).

3. SEISMIC AND STRUCTURAL DESIGN STANDARDS IN EL SALVADOR

After the 1965 El Salvador earthquake, the government published the first seismic design code January 21, 1966 (Official Report of the Republic of El Salvador, 1996), which was a modification of the seismic code of the city of Acapulco, Mexico. After the 1986 earthquake, the Association of Engineers and Architects in El Salvador (ASIA) published "Emergency Regulations for Seismic Design in the Republic of El Salvador", which was an improved and extended version of the 1966 code. Based on these regulations, another revised edition of the seismic design code was published in 1989 (Association of Engineers and Architects in El Salvador, 1989). The present seismic design standard was published in 1997 (Ministry of Public Works, 1997). Table 1 shows the design base shears prescribed in those three seismic design codes in El Salvador (Gracia, 1996).

In addition to the current seismic design standard, El Salvador has eight technical standards: design for wind-pressure, the design

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and construction of concrete, steel, masonry and timber structures, the design of foundations, slope-stability, quality control of structural materials, and a special standard for the design and construction of houses.

4. STRUCTURAL SYSTEMS IN USE IN EL SALVADOR

Before the 1965 earthquake, the most frequently used method of house construction in El Salvador was the timber, bamboo and mud wall construction called *bahareque*, in which mud walls were reinforced by cane, wooden plates, boards, and/or bamboo connected to each other by nails and finished with lime mortar. From the early "1940s to mid-1960s", buildings of three- to eight-stories were constructed using a structural system consisting of concrete frames and masonry walls, which was believed to automatically increase structural safety. During the 1986 earthquake, however, severe structural damage occurred to buildings constructed by this method. The *bahareque* and simple adobe brick (or dried clay-mud brick) construction method are still used in El Salvador, and in most inland cities many houses are still constructed using these simple mud wall technique. Photos 1 and 2 show a mixed timber, bamboo, and mud wall house under construction in an inland city during our field investigation.

Use of reinforced masonry walls now is more popular for construction of residences. Photos 3,4, and 5 show reinforced masonry walls, called "confined masonry wall", under construction, each wall being confined by slender reinforced concrete (R/C) columns and beams. This type of reinforced masonry wall is frequently used in house construction. Photos 6,7, and 8 show another type of reinforced masonry wall under construction. For buildings of three stories or more, reinforced concrete (R/C) frame systems usually are used. Dual systems consisting of frame and concrete wall nor steel frame systems are not common.

5. BRIEF DESCRIPTION OF THE EARTHQUAKE

The main shock of this earthquake occurred at 17:33, Saturday the 13th of January 2001. Its Magnitude was Mw=7.6. The epicenter, 100 km southwest of the city of San Miguel, El Salvador, was located off coast of Central America (Figure 1). The depth of the main shock was 39 km based on information provided by the USGS National Earthquake Information Center [http://neic.usgs.gov/neis/bulletin/01-EVENTS/010113173329/zoom-in.html].

During the main shock, a number of earthquake accelerograms were recorded by the University of Central America. Of

Table 1. Design base shears in the 1966, 1989, and 1997 El Salvador seismic design codes.

	1966 (DIA OF 66)	1989 (REDSES)	1997 (NTDS 97)
Formula of Base-shear	$V=C_S W$	$V=C_S W$	$V=C_S W$
Seismic Coefficient	$C_S=DC$ $C=f(Z, \text{Struc. type}, I)$	$C_S=DCI$ $C=f(Z, \text{Struc. type})$	$C=\frac{AIC_0}{R}\left(\frac{T_0}{T}\right)^{2/3}$ $T_0<T<6T$
Zone Factor	Z, Implicated in C	Z, Implicated in C	A 0.4, 0.3 (determined by Table)
Importance Factor	Implicated in C 1.3, 1.0, 0.0	I 1.5, 1.3, 1.0, 0.2	I 1.5, 1.2, 1.0 (determined by Table)
Factor or Coefficient of Behavior	$0.60<D<1.0$ $D=\sqrt{C/X_c}$	$0 \le D \le \frac{0.72}{T^{2/3}} \le 1.0$	R (determined by Table)
Soil Factor	None	None	C_0 and T_0 (determined by Table)
Type of Principal Analysis	Static	Static	Static
Dynamic or Elastic Modal Spectrum Analysis	Option	Option	Obligation for Irregular Structure or Height: h>70 m
Post-elastic Verification	No need	No need	No need
Micro-zonation	No need	No need	No need
Definition of Seismic Type in Step-by-step Analysis	No need	No need	No need
P-Δ Effect	No	Only when $\theta=\frac{P\Delta}{CdV_x h_{sx}}$	Only when $\theta=\frac{P\Delta}{CdV_x h_{sx}}$

Photo 1. A mixed timber, bamboo, and mud house under construction in La Paz Province.

Photo 2. Mud filling work in the house in Photo 1.

Photo 3. A confined masonry wall house under construction in La Paz Province.

Photo 4. Reinforcing details of a confining column in the building in Photo 3.

Photo 5. A confined masonry wall house under construction in Usulutan.

Photo 6. A reinforced masonry wall supermarket under construction in Santa Ana Province.

Photo 7. Reinforcing details of a masonry wall in the building in Photo 6.

Photo 8. Reinforcing details of a column in the building in Photo 6.

these, the respective peak accelerations in the E-W and N-S directions that were recorded at the ULLB (La Libertad) Station about 75 km northwest of the epicenter were 531, and 876 cm/sec^2. The peak acceleration in the U-D (Vertical) direction, recorded at the USPN (San Pedro Nonualco) Station, was 428 cm/sec^2 (Seo, 2001). These values, the maximum recorded accelerations obtained for this earthquake, will soon be published officially. Sawada et al. (2001) noted that the very short period components of the recorded ground acceleration were prominent. The vibration characteristics indicate that soil structures and low-rise buildings with short vibration periods were affected severely by this earthquake in comparison to high-rise building structures.

Preliminary maximum intensities of ground shaking in Central America during this earthquake have been reported by the Seismological Center of Central America (CASC). According to that report, the maximum ground shaking intensity in the coastal area of El Salvador, near the epicenter, was MM=VIII and in most cities of El Salvador MM=VII (Sawada et al., 2001).

According to the newspaper of February 13, 2001 and the web-site information of February 21, 2001 (source the National Emergency Committee (CDEN), El Salvador), the total number of dead was 844, 4,723 people were injured, 74,955 houses were totally destroyed, and 318 churches and 639 public buildings were damaged (El Diario de Hoy de El Salvador, 2001; La Prensa Grafica, 2001). Table 2 gives the damage statistics for this earthquake, the official information published by the government of the Republic of El Salvador on January 25, 2001.

Characteristic of this earthquake was the large number of landslides (see Photos 9 and 10). Of those landslides, the one at Santa Tecla, La Libertad Province was the worst, more than 400 of the 687 people in the Las Colinas district having been killed (Time, 2001).

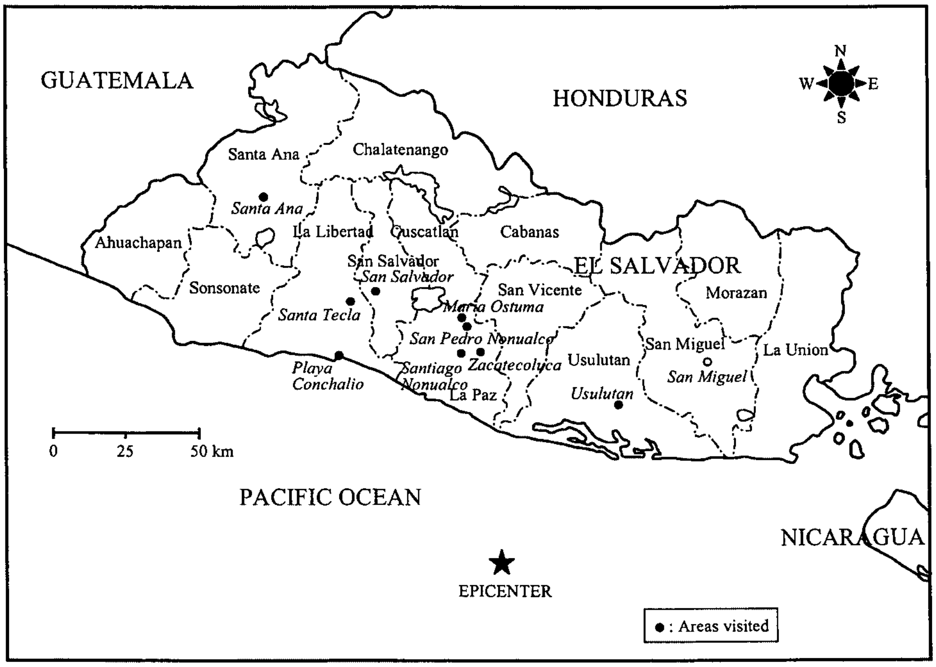

Fig. 1 Epicenter location and areas visited.

Table 2. Damage statistics (http://www.terremoto.gob.sv/informacion General/Cifras.htm).

Province	Dead	Injured	Damaged Public Buildings	Damaged Homes	Destroyed Homes	Buried Homes	Landslides	Damaged Churches	Damaged Piers	Evacuations	Hospitals	Health Units
La Libertad	527	1,025	24	10,102	9,091	687	150	5	0	12,357	1	4
La Paz	32	137	32	21,790	16,038	0	55	29	0	278	1	6
Sonsonate	44	1,276	36	9,776	6,220	0	42	14	0	3,169	1	5
Santa Ana	12	295	5	725	944	0	25	31	39	684	0	1
Cuscatlan	20	37	47	4,401	2,068	0	16	2	0	22	0	0
Usulutan	26	779	236	26,418	26,691	0	32	14	0	24,139	2	7
San Salvador	22	306	24	3,579	1,031	0	133	6	0	5,197	0	4
San Miguel	19	43	23	9,372	2,902	0	24	4	4	0	1	0
San Vicente	1	53	20	13,783	3,788	0	4	10	0	10	0	1
La Union	1	10	67	1,685	226	0	1	5	0	1	0	0
Ahuachapan	0	80	27	2,957	693	0	10	14	0	0	0	0
Cabanas	0	7	31	180	4	0	4	3	0	0	0	0
Morazan	0	3	4	30	3	0	0	0	0	0	0	0
Chalatenango	0	4	6	67	14	1	0	0	0	0	0	0
Total	704	4,055	582	104,865	69,713	688	496	137	43	45,857	6	28

6. FIELD INVESTIGATION

Field reconnaissance in the areas severely damaged by this earthquake was conducted for five days, from the 9 through 13 February 2001. The solid circles in Figure 1 show the cities visited. They are located mainly along the Pacific Coast of El Salvador. Of the Provinces visited, Usulutan, La Libertad, and La Paz were the most severely damaged by this earthquake (Table 2).

7. DAMAGE TO MASONRY BUILDINGS

7.1 Adobe construction (Photos 11-21)

One of the most severely damaged structural systems used in

Photo 12. Vertical crack at the corner of an adobe wall in Usulutan.

Photo 9. A landslide in Santa Tecla.

Photo 13. Failure of an adobe house in San Pedro Nonualco.

Photo 10. A landslide between San Salvador and Santa Ana.

Photo 14. Damage to an adobe house in Maria Otsuma.

Photo 11. Damage to an adobe house in Santiago Nonualco.

Photo 15. Inside of the house in Photo 14.

El Salvador was that of adobe construction, in which dried clay-mud brick units only are used to erect most walls, very little wall reinforcement being provided in most of them. Photos 11 through 20 show the typical damage done to this type of construction used in residences, churches, and school buildings. Vertical cracks in wall edges at intersections in the plan were presented in most of the damaged buildings. Photo 21 shows an example of a displaced block of adobe bricks 30 cm x 23 cm x 7 cm.

7.2 Mixed timber, bamboo, and mud wall housing (Photos 22-24)

The other structural system seen in the most severely damaged buildings is based on a timber wall construction method. This is a

Photo 19. Damage to an adobe church in Zacatecoluca.

Photo 16. Damage to an adobe store in Santa Tecla.

Photo 20. Damage to an adobe school in Usulutan.

Photo 17. Damage to another adobe store in Santa Tecla.

Photo 21. Adobe blocks in San Pedro Nonualco.

Photo 18. Damage to an adobe church in Maria Otsuma.

Photo 22. Damage to a mixed timber, bamboo, and mud wall house in Santa Tecla.

Photo 23. Damage to another mixed timber, bamboo, and mud wall house in Santa Tecla.

Photo 24. Damage to a mixed timber, bamboo, and mud wall school in Usulutan.

Photo 25. Damage to an un-reinforced masonry wall church in San Pedro Nonualco.

Photo 26. Slight damage to an un-reinforced masonry wall church in Santa Ana.

Photo 27. A clay brick factory in Maria Otsuma.

Photo 28. Forming clay bricks at the factory in Photo 27.

Photo 29. Hearth furnace in the factory in Photo 27.

Photo 30. A three-story confined masonry wall house in Zacatecoluca.

traditional wall structure used in house construction in various Latin American countries. The structural (and/or partition) walls are composed of timber frames and/or bamboo (*quincha* in Spanish) with mud or clay filler combined with chopped straws (or whole canes in some cases), and a plaster finish. Photos 22 through 24 show the damage typical to the mixed timber, bamboo, and mud wall type of housing. The crushed mud walls have collapsed causing acute inclination of the building in some cases. A main cause of this type of severe structural damage is the lack of adequate wall strength in both the in- and out-of-plane directions.

7.3 Un-reinforced masonry churches (Photos 25, 26)

The un-reinforced masonry wall system is a popular, boxed-wall structural system widely used throughout the world. Most of the structural and non-structural walls are built of clay bricks and mortar. No wall reinforcement (such as steel reinforcing bars) is provided within the walls in either the horizontal or vertical direction. Because these brown clay bricks usually are fired at a relatively low temperature, excellent mechanical properties such as high compressive strength can not be obtained (Photos 27, 28 and 29). Although no severe structural damage to the many buildings constructed by this structural system was observed, some church buildings showed damage; bell towers and spires cantilevered at the tops of the buildings cracked and totally collapsed.

Photo 31. A confined masonry wall house in Usulutan.

Photo 32. A two-story confined masonry wall house in Usulutan.

Photo 33. A two-story confined masonry wall house in Santa Tecla.

Photo 34. A confined masonry wall house in Santa Tecla.

Photo 35. A confined masonry wall house in San Pedro Nonualco.

Photo 36. Damage to a confined masonry wall house in San Pedro Nonualco.

7.4 Reinforced masonry buildings (Photos 30-38)

The reinforced masonry system is a typical masonry wall structural system widely used throughout Latin America and southeast Asia for low- and medium-rise houses and/or other kind of residential buildings. In this system, cast-in-place, slender R/C columns are presented at most of the extreme edges and intersections of the masonry walls. In addition, cast-in-place R/C collar beams, wall girders, or floor slabs usually are placed along the top of each masonry wall. In most cases, longitudinal Re-bars and hoops are installed in the R/C columns before the masonry wall units are placed within the wall plane. After the brick or block masonry units are connected with mortar to a height of a half or one story, the concrete columns are cast, then the R/C collar beams, wall girders, or floor slabs are constructed using cast-in-place concrete after all the masonry walls and R/C cast-in-place columns have been completed. Four longitudinal Re-bars usually are placed in each R/C column section. This type of construction is called "confined masonry walls" in Latin American countries. Photos 3, 4, and 5 show confined masonry walls under construction, at the time of our field investigation.

A large number of the buildings of confined masonry wall construction exist in El Salvador, but most were not severely damaged during the earthquake (Photos 30 through 35). A few, rare cases of damage to confined masonry buildings (Photos 36, 37,

Photo 37. Failure of a hollow concrete-block masonry wall in the house in Photo 36. The hollow concrete block units are separated from the R/C confining column.

Photo 38. Damage to a confined clay-brick masonry wall in Usulutan.

Photo 39. Damage to an adobe garden wall in Usulutan.

Photo 40. Failure of an adobe garden wall in San Pedro Nonualco.

Photo 41. An un-reinforced masonry garden wall in San Salvador (no damage).

Photo 42. An un-reinforced masonry garden wall in San Salvador (no damage).

and 38) show where hollow concrete block walls and clay masonry brick walls were severely damaged. In the building in Photo 37, a concrete block masonry wall has separated into parts due to shear cracking, and part of the wall has separated from its adjacent R/C confining column and overturned in the out-of-plane direction. Also, shear cracks formed in the clay brick masonry walls of the building in Photo 38 have penetrated the R/C confining columns. This damage seems to have been caused by pounding from a collapsed building (upper right in Photo 38) rather than by ground shaking.

7.5 Masonry garden walls (Photos 39-46)

A large number of masonry garden walls have been constructed of adobe, clay brick, or hollow concrete blocks throughout this country. Except for many built of adobe, most walls were not severely damaged. It should be noted that in El Salvador vertical wall reinforcements 40 cm apart are presented in most masonry garden walls comprised of hollow concrete block units. Damage to adobe garden walls consisted of sloughing off of finishes and the toppling of adobe blocks (Photos 39 and 40).

8. CONCLUDING REMARKS

Although a large number of buildings were damaged during the El Salvador earthquake of January 13, 2001, most human damage was caused by the total or partial collapse of relatively low-rise, boxed-wall buildings; in particular, one- and two-story houses constructed of un-reinforced dried clay-mud adobe or of timber and/or bamboo walls filled with clay-mud. In addition, because most existing buildings in El Salvador are one- and two-story residences constructed of un-reinforced adobe masonry or of timber and/or bamboo walls, damage description mainly has been focused on these most popular low-rise types of houses.

In most of the severely damaged adobe and timber and/or bamboo wall houses, none of the vertical wall-edges at **L**-, **T**-, and ＋- shaped intersections of the construction were connected to each other because no wall reinforcement is provided there. As a result, each wall behaved independently in the out-of-plane direction during the earthquake. Some walls separated from the adjacent walls at their vertical connections and overturned in the out-of-plane directions, or collapsed, resulting in severe structural damage. This means that, as these types of wall structures without adequate wall material strength, can not retain their original boxed-wall shapes during strong-motion earthquakes, considerable severe structural and human damage can be expected to occur again and again during future earthquakes.

In the this type of the boxed-wall structure, the vertical edge faces between adjacent walls, as well as the horizontal edge faces between the walls and adjacent strong collar beams must be firmly connected. Once this type of building is designed and constructed so as to retain its original box-shape configuration, each wall can be expected to develop in-plane anti-seismic capacity.

Photo 43. A confined masonry garden wall in Zacatecoluca (no damage).

Photo 44. A confined masonry garden wall in Usulutan (no damage).

Photo 45. A reinforced masonry garden wall in Santa Tecla (no damage).

Photo 46. A reinforced masonry garden wall in Santa Tecla (no damage).

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REFERENCES

Association of Engineers and Architects in El Salvador (ASIA), 1989. Emergency Regulations for Seismic Design in the Republic of El Salvador (in Spanish).

Camacho, O., Yoshimura, K., Kikuchi, K., Takano, K. and Sánchez, T. A., 1993. Experimental study on confined concrete masonry walls, *Proc. of 4th East Asia-Pacific Conference on Structural Engineering & Construction*, 619-624.

Camacho, O., Sueoka, T., Yoshimura, K. and Shirahama, T., 1994. Analytical study on seismic behavior of confined concrete masonry wall, *Trans. of Japan Concrete Institute*, Vol. 16, 241-248 (in English).

Castillo, H. D. A., Calvo, N. J. A. and Guerra, S. W. M., 1994. Evaluation of response spectra for design of structures in El Salvador, University of Central America (in Spanish).

EERI and IAEE, 2001. Encyclopedia of Housing Construction Types in Seismically Prone Areas of the World, Compact Disk.

El Diario de Hoy de El Salvador, 2001. Earthquake in image, EARTHQUAKE 7.9 (http://www.elsalvador.com/noticias/terremoto/cifras.html) (in Spanish).

Kagami, H., Ueda, Y., Sato, H., Taniguchi, H., Ishiyama, Y., Yoshimura, K., Nishigami, K. and Hayashi, H., 1999. Reconnaissance Report on the 1999 Quindio, Central Western Colombia, Earthquake and its Disasters, No. 10400018, Report supported by the Ministry of Education of Japanese Government (in English).

La Prensa Grafica, February 13, 2001 (in Spanish).

Liu, L., Kajiwara, K., Yoshimura, K., Kikuchi, K. and Sánchez, T. A., 1997. Effect of applied lateral forces and wall reinforcement on seismic behavior of confined concrete masonry walls, *Proc. of 11th International Brick/Block Masonry Conference*, 585-594.

Lopez, M. A. M, 1999. Standards for earthquake-resistant design and construction in El Salvador, Country report presented to the National Center for Disaster Prevention in Mexico (CENAPRED) (in Spanish).

Ministry of Public Works, San Salvador, 1997. Technical Standards for Seismic Design, Regulation for Structural Security and Construction (in Spanish).

Official Report of the Republic of El Salvador, 1966. Regulations for Seismic Design, No.15 (in Spanish).

Porrtill Gracia, Edwin, 1996. Background of civil engineering and evaluation of design standards in El Salvador, The Seismic Engineer in El Salvador (Seminar), University of El Salvador (in Spanish).

Sawada, S., Katsuma, H., Yamasaki, Y. and Seo, K., 2001. Preliminary report on damage caused by the El Salvador earthquake of January 13, 2001, *Japan Earthquake Engineering NEWS*, 177, 20-25 (in Japanese).

Seo, K., 2001. On earthquake damage in the January 13, 2001 in El Salvador (Report presented on the web-site of http://www.enveng.titech.ac.jp/seo/contents/research/el-salvador/report0215.html) (in Japanese).

Time, January 29, 2001. Death in the Valley of the Hammocks, 10.

Yoshimura, K. and Kikuchi, K., 1995. Experimental study on seismic behavior of masonry walls confined by R/C frames, *Proc. of Pacific Conference on Earthquake Engineering*, 97-106.

Yoshimura, K., Kikuchi, K., Okamoto, T. and Sánchez, T. A., 1996. Effect of vertical and horizontal wall reinforcement on seismic behavior of confined masonry walls, *Proc. of 11th World Conference on Earthquake Engineering (CD-ROM)*, Paper No. 191, 8pp.

Yoshimura, K., Kikuchi, K., Kuroki, M., Liu, L., Kajiwara, K. and Ushijima, M., 1998. Effect of vertical axial loads and wall reinforcements on seismic behaviour of confined concrete masonry walls, *Proc. of 23rd Conference on Our World in Concrete & Structures*, 221-228.

Yoshimura, K., Kikuchi, K., Kuroki, M. and Liu, L., 1999a. Experimental study of the effect of height of lateral forces, applied vertical axial loads and wall reinforcements on seismic behavior of confined concrete masonry walls, *Journal of Structural and Construction Engineering, Architectural Institute of Japan*, No.524, 141-148 (in Japanese).

Yoshimura, K., Croston, T., Kagami, H. and Ishiyama, Y., 1999b. Damage to building structures caused by the 1999 Quindio earthquake in Colombia. *Faculty of Engineering Research Report, Oita University*, No. 40, 17-24 (in English).

Yoshimura, K., Liu, L., Croston, T. and Ma, L., 1999c. Seismic strengthening for low-rise bamboo- and masonry-wall residential buildings in Colombia. *Faculty of Engineering Research Report, Oita University*, No. 40, 25-32 (in English).

Yoshimura, K., Kikuchi, K., Kuroki, M., Liu, L. and Ma, L., 2000a. Effect of wall reinforcements, applied lateral forces and vertical axial loads on seismic behavior of confined concrete masonry walls, *Proc. of 12th World Conference on Earthquake Engineering (CD-ROM)*, Paper No. 0984, 8pp.

Yoshimura, K., Kikuchi, K., Kuroki, M., Nonaka, H., Croston, T., Koga, S., Kim, K. T. and Ma, L., 2000b. Experimental study for higher seismic performance of masonry walls in developing countries, *Proc. of 25th Conference on Our World in Concrete & Structures*, 695-702.