SEISMIC LIMIT STATES AND RESISTANT MECHANISM OF THE SOIL-CEMENT BRICKS CONFINED MASONRY

Nicolas GUEVARA[1]
MEE07156

Supervisor: Hiroshi FUKUYAMA[2]

ABSTRACT

Performance based philosophy is proposed to verify the seismic design of the soil-cement confined masonry. Experimental wall data considering in-plane and out-of-plane behaviors have been used to propose three seismic limit states: Serviceability, Reparability and Safety. Besides that, two design seismic forces, one given in the current special normative for designing and construction of housing and another taken from recorded earthquakes, have been applied to the basic constructed house modulus to verify the safety as well as to verify its seismic design using current normative where the soil cement is not considered as infill element.

Keywords: Performance based, soil-cement brick, confined masonry

INTRODUCTION

Burnt clay bricks have been traditionally used in El Salvador as unreinforced masonry and as infill element in confined masonry. However, its use has been pointed out as harmful for the environment. The crystallization process through firing the bricks using firewood has been devastating the forest in the country. To reduce this growing problem, bricks made of soil and cement mixture have been currently used as infill element in confined masonry instead of clay bricks. Initially, research studies were focused on finding out the best soil-cement proportion without study the seismic behavior of the masonry system. Due to the earthquakes in January and February of 2001, one cooperation project started, sponsored by the Japanese International Cooperation Agency (JICA). As part of this project “Enhancement of the technology for the construction and dissemination of popular earthquake resistant housing”, known as Taishin Project, which has been already executed in its first phase; the soil-cement bricks system has been studied recently under the objective of to find out its mechanical properties. Besides that, the necessity of upgrading the design philosophy, the Performance Based Design has been currently included as target for second phase of the mentioned project. The experimental research on the soil-cement has been already carried out, covering differences stages since the survey of soil around the country until decide the best soil-cement mix, construction of walls and experimental test, which is used to reach the objectives of this study. Therefore, the present study is devoted to propose performance levels or seismic limit states like Serviceability, Reparability and Safety, by using the experimental wall data obtained during the research study on soil-cement. Since the Collapse of masonry houses should be prevented, two seismic design forces are applied to the basic house modulus, one demand is taken from the recommendations given by

[1] University Professor, University of El Salvador (UES), El Salvador.
[2] Chief Research Engineer, Department of Structural Engineering, Building Research Institute (BRI), Japan.

the special normative for designing and construction of houses, and another is taken from recorded past earthquakes.

DATA

This research study is based on the experimental study executed to the soil-cement system. Beforehand, sixteen mixtures of soil-cement were widely studied to find out the best mix, taking into account for the selection, parameters like strength, crack pattern, etc. Such proportions of soil-cement are shown in table 1.

Table 1. Soil-cement proportions

Percentage of volume		Proportions
Sand	Silt	Cement-soil ratio
100	0	1:8, 1:10, 1:13, 1:16
75	75	1:8, 1:10, 1:13, 1:16
50	50	1:8, 1:10, 1:13, 1:16
25	75	1:8, 1:10, 1:13, 1:16

Around 70 brick units with dimension of 7x14x28cm were manufactured for each proportion, this means around 1120 units in total. The manufacturing procedure followed was the one proposed by FUNDASAL. The laboratory test carried out for prism and bricks are shown in table 2.

Table 2. Laboratory test of brick unit and prisms

Description	Test	No of specimen
Bricks	Water absorption	80
	Compression	80
	Flexure	80
Prisms	Compression	64
	Diagonal compression	64
Mortar	Compression	36

Besides, four prisms for compression and four for diagonal compression were manufactured for each mix; 128 prisms in total. The mortar used to bond the bricks has a sand-cement ratio of 3:1, which is popularly used to bond bricks. Several scanning procedures were used to select the best soil-cement proportion; even though, the last evaluations were done for four proportions, shown in table 3. Taking into account mechanical properties observed as well as the facility to measure them in field, the proportion using 1:16 cement-soil and 50:50 sand-silt was selected to construct the wall specimens shown and described in table 4.

Table 3. Experimental results in preliminary study

Description	Laboratory Test	Cement:soil ratio (1:13)		Cement:soil ratio (1:16)	
		Average result 25-75	Average result 50-50	Average result 25-75	Average result 50-50
Bricks	Water absorption (%)	28.9	21.8	21.2	34.1
	Compression (MPa)	3.20	7.1	3.60	5.20
	Flexure (MPa)	0.09	0.18	0.07	0.13
Prisms	Compression (MPa)	4.80	4.70	4.80	3.60
	Diagonal compression (MPa)	0.81	0.67	0.81	0.55
Mortar	Compression (MPa)	----	----	22.7	12.7

The reinforcement of the columns and the beams was similar and consisted of 4 longitudinal bars with 9mm diameter, with stirrups of 6mm diameter. The interval of the stirrups was constant in both, beams and columns, and equal to 150mm. The dimensions of concrete sections were 150x150mm for the columns and beams. The panel dimensions were 3x3m approximately and were formed by 36 courses of bricks with 10 units per course. In case of SPP specimen, three walls formed the unit, the lateral walls were similar to the other models and the main panel had beam at the height of 3m.

Table 4. Wall specimens

			
Wall specimen SPM	**Wall specimen SPC**	**Wall specimen SPCI**	**Wall specimen SPP**

Besides, there are soil-cement houses already constructed before and after the current research. The basic model of popular houses has rectangular dimensions of 6.04x4.21m, measured from the exterior edges. It has two doors and two windows as openings in the larger direction. The structural system of the roof consists of channels “C” with 4x2 inches and steel bars with 9mm diameter. The steel bars are welded to the channels to avoid the slipping. Those channels are supported by the ridge beam. In practical construction, the ridge beam is fabricated welding two channels “C”. The roof consists of fibrocement sheets placed over the steel bars and channels. The confinement elements with dimensions of 0.15x0.15m and reinforcement as explained above.

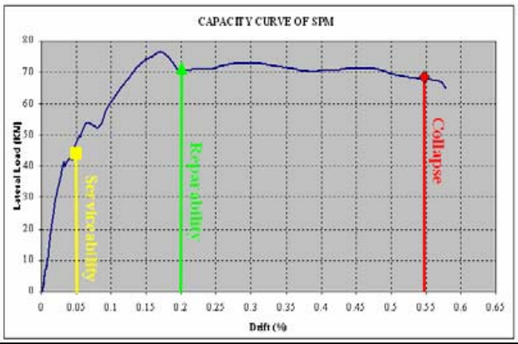
THEORY AND METHODOLY

The last decade has witnessed a clear trend towards “performance-based” seismic design, which can be thought of as an explicit design for multiple limit states or performance levels. Analyzing structures for various levels of earthquake intensity and checking some local and/or global criteria for each level has been a popular academic exercise for the last couple of decades, but the crucial development that occurred relatively recently was the recognition of the necessity for such procedures by a number of practicing engineers influential in code drafting. The approach involves the definition of one or more limit states and their associated performance criteria and design checks in a precise and quantitative manner. Seismic limit states recognized in structural design are defined by the damage pattern, which depends on the deformation level reached for structural and nonstructural elements. Therefore, their definition for this system requires the study of parameter like drift, stiffness, resistance and functionality of the structure, which becomes thresholds when the buildings are being evaluated. Three seismic limit states are being proposed in this study: Serviceability, Reparability and Safety. In order to give the best definition for this system, experimental data of in-plane and out-of-plane tests will be analyzed to find out the damage sequence as well as its severity level. Seismic limit states are proposed for each specimen but also proposed for the masonry system. Besides that, two seismic design forces will be applied to the basic house modules with the main targets of checking the seismic design and the prevention of collapse limit state.

RESULTS AND DISCUSSION

The seismic limit states proposed for each specimen has been established through the evaluation of the damage level for all specimens. The results shown in table 5 are similar, SPM and SPC specimens have the same drift level for the serviceability and reparability limit states; however, due to the application of load in only one direction, the collapse drift level is higher for the SPM. Higher drift for each limit state is proposed when the mid-beam is used in construction.

Table 5. Summary of performance levels

<table>
<tr><th colspan="1">SPM</th><th colspan="4">SPC</th></tr>
<tr><td>


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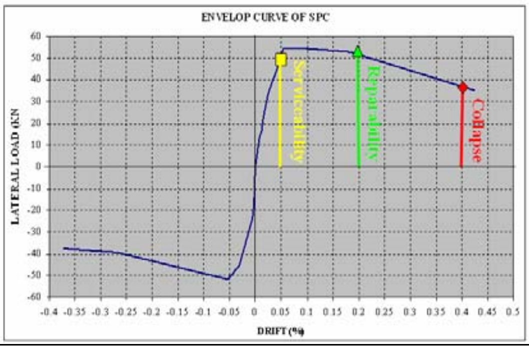

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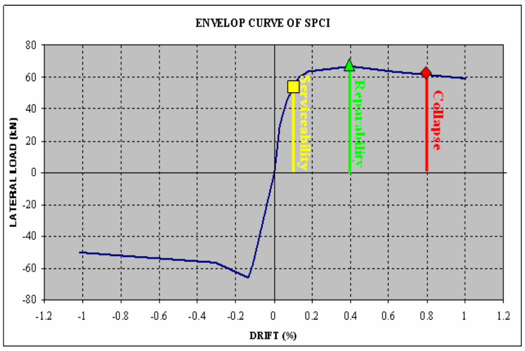
<tr><th>SPCI</th><th colspan="4">SPP</th></tr>
<tr><td>


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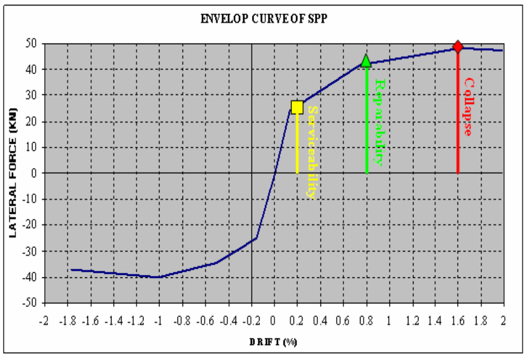
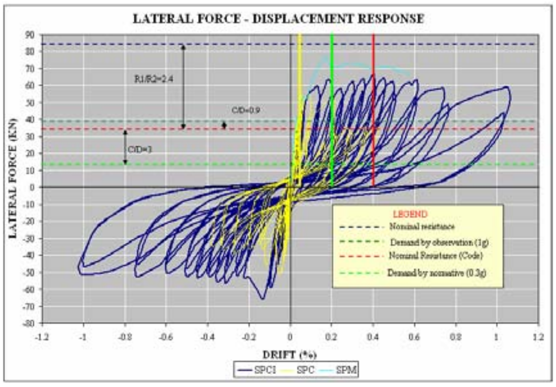


</td></tr>
<tr><th>Seismic Limit States in Drift (%)</th><th>SPM</th><th>SPC</th><th>SPCI</th><th>SPP</th></tr>
<tr><td>Serviceability</td><td>0.05</td><td>0.05</td><td>0.10</td><td>0.20</td></tr>
<tr><td>Reparability</td><td>0.20</td><td>0.20</td><td>0.40</td><td>0.80</td></tr>
<tr><td>Safety</td><td>0.55</td><td>0.40</td><td>0.80</td><td>1.60</td></tr>
</table>

With this element the structure has twice the ductility of SPC, which means that the structure will be less damaged reaching large displacements. In case of the out-of-plane behavior, the drift levels are higher than the drift for in-plane behavior; however, due to differences in definition of both drift, any comparison can be carried out. Even so, it can be said that the lateral failure will occur first, which also agree with the design philosophy where the out-of-plane failure is avoided. After having proposed the seismic limit states, the verification of the collapse house is necessary. To do that, two design seismic forces have been imposed in the in plane and out of plane direction, by using the base shear coefficient provided for the special normative for housing and by using high acceleration observed in past earthquakes. The soil-cement system has shown accepted behavior for both motioned seismic forces in-plane of walls, see table 6. Even by applying the acceleration of 1g, the capacity of the system is enough to withstand the input motions. Damage could be expected for seismic motion with 1g acceleration, but the structure will keep its functionality and the damage will be repaired in short time. In case of the out-of-plane behavior, the serviceability limit state is exceeded by using the recorded acceleration of 1g acceleration. The structure will remain functioning, even when some cracks could have developed in the masonry. Using the base shear coefficient of 0.3 provided for the normative, the structure will behave elastically, within the serviceability limit state.

Table 6. Summary of collapse house prevention

<table>
<tr><th>IN-PLANE</th><th>OUT-OF-PLANE</th></tr>
<tr><td>


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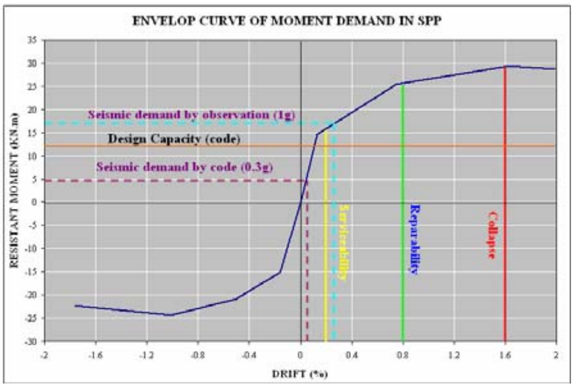

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CONCLUSIONS

Regarding the Performance Based Design philosophy, three performance levels or seismic limit states were defined through out this research, which are: Serviceability, Reparability and Safety. Serviceability limit state has been defined as the stage where the structure keeps behaving elastically, minor damage can be expected without harmful effect in the building functionality. In case of Reparability limit state, one particular definition has been chosen for this study, which has to do with the development of steady crack pattern with the first yielding. It is well known that the definition for the reparability limit state several factors have to be evaluated, and that is why its definition range depends on the selected parameters. The Collapse limit state has been defined as the stage where the structure has lost its total capacity, lateral and vertical. However, during the test, this level was not reached due to the existing risk when the wall fall down, then this level has been defined as the stage where the maximum capacity has decreased around 20%, which also involves yielding and severe crack pattern in masonry. The last part of this study was devoted to the verification of the design and prediction of collapse limit state. It can be stated that the house fulfills the requirements established in the normative and also that the house will not reach the collapse for neither of the considered earthquakes. When the house is designed using the seismic demand given by the normative, its in-plane and out-of-plane behavior will keep elastically within the serviceability limit state. However, when strong earthquake struck the structure, both behaviors will keep within the reparability limit state, which means that the collapse will not be reached and also that the damage developed will be economically repairable. The capacity obtained from laboratory test has been higher than both seismic forced, which indicates that the system is strong enough to withstand strong earthquakes.

RECOMMENDATIONS FOR FUTURE RESEARCH

Since the confined masonry system with soil-cement bricks is popularly constructed without technical supervision; booklet shall be prepared to specify simply construction method, which considering reduction factors for designing to take into account the effect of construction quality to keep the house seismic behavior within the margin provided by the different between the capacity/demand ratio observed in laboratory test. During the wall test, differences between the real and predicted capacity were shown up, which have been initially attributed to the workmanship factor as well as the dispersion of quality of materials. Therefore, a properly study shall be carried out to state equations which take into account such variables. Finally, the Performance Based Design philosophy herein explained, shall be applied to the others popular systems as well as the reinforced concrete and masonry building used in El Salvador.

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