PERFORMANCE OF A MASONRY HOUSE CONSTRUCTED IN A LOW PRICE HOUSING PROJECT IN GUAYAQUIL - ECUADOR.

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Abstract

During 1996-1997, the Government of Ecuador constructed a housing plan of 12,030 low-price units for people from the so-called “highly left out population” in Guayaquil. A group of 500 houses were built with masonry. A comparative study between the masonry designed system and other structural systems made of reinforced concrete frames, steel frames and wood fibre shear walls has been carried out. The authors’ conclusions are intended to be useful to the improvement of new projects needed in Ecuador in order to diminish the national deficit of more than one million houses.

Introduction

The Housing Plan was called “Un Solo Toque” (UST). The Ministry of Housing stated that any family having an annual income of less than US $720 will qualify to get a house priced about US $ 2,700. The government provided a subsidy equivalent to 75% of the total cost and the beneficiaries were asked to pay only the remaining 25%, through a 7 year credit payable by monthly dividends US $15 each.

The Government of Ecuador invited private construction companies for the execution of this project. Constructors were requested to build 12,030 houses according with a unique set of architectural requirements, they selected the structural system and construction techniques by themself. More than 30 companies were finally involved.

UST was studied by the authors as a part of the “Seismic Vulnerability of Low Cost Housing” project [1], which is being carried out by Universidad Católica de Guayaquil, under the co-ordination of The National Foundation of Science and Technology (FUNDACYT).

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The UST house

Architectural design

Each house was built on a 72 m^2 area, having a construction surface of 36 m^2, one single story, two rooms, one bathroom, one kitchen, one dinner and living room, and a roof slab that should allow the future construction of a second floor.

They were constructed in terraced blocks defining long lines of 24 units. The separation from block to block was 6 meters. In such a way, each house has a backyard of 18 square meters and a front yard of the same size.

A plan of a single house is shown in Figure No. 1.

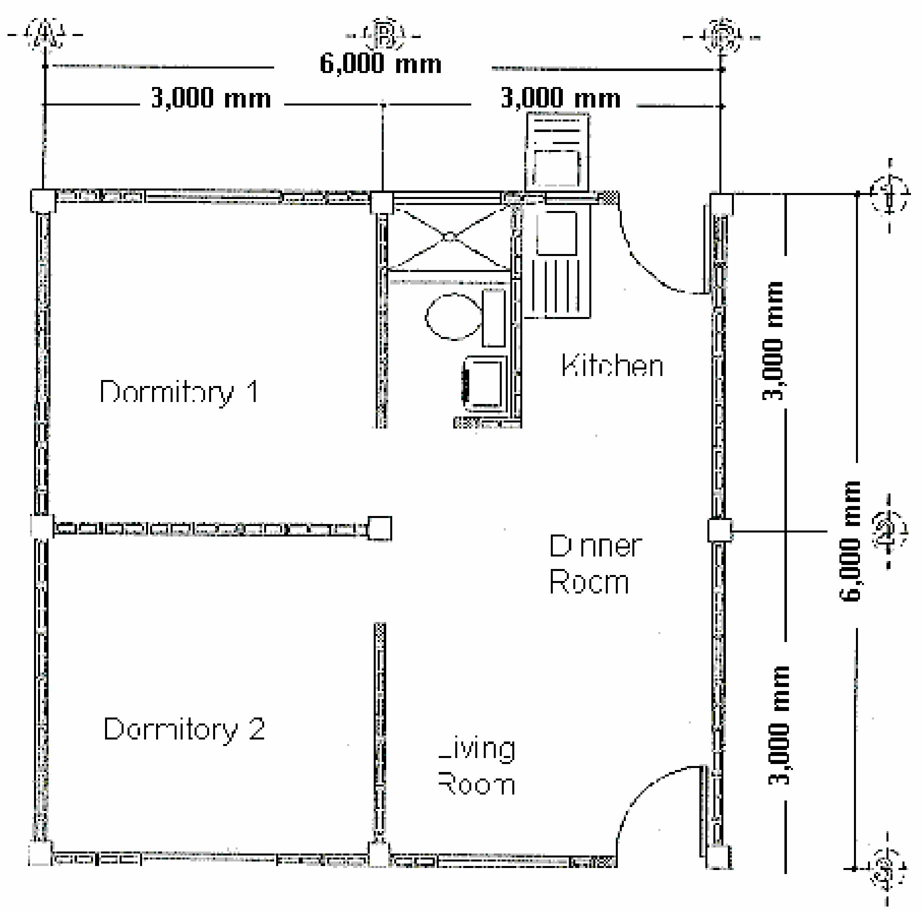


Figure No. 1: UST plan

Structural features

It was stated that every house should be earthquake resistant designed regardless of the structural system or design selected by the constructors. Twelve main design patterns were identified. Most of them were done either by a traditional reinforced concrete structure or a steel frame one. A few of non-traditional systems such as the masonry or the wood fibre shear walls types were also implemented. The overall description of the design patterns is presented in Table No. 1.

Houses constructed with a reinforced concrete or a steel frame structure used masonry infill to form walls of 60 mm in width. Without exception, walls were built after the construction of the structural system, with a very poor confinement to the frames and low strength materials. For such reasons, the contribution of walls to the seismic resistance was neglected.

Table No. 1: Structural patterns in UST project

Structural System	*Characteristics of Vertical Elements*	*Characteristics Of Beams*	*Pattern Type*
Reinforced Concrete Frames	9 Columns per house	Weak, embedded in the slab. Loaded on the short axes.	C1
		Weak, embedded in the slab. Loaded on the long axes.	C2
		Loaded on the short axes.	C3
		Loaded on the long axes.	C4
		Precasted in both directions.	C5
	6 Columns per house	Strong, 6,000-mm length, loaded on the short axes.	C6
RC Box	Shear walls casted in situ	None. A precast slab is placed in site over the walls.	C7
Steel Frames	9 Square Tube Columns per house	"G" form and loaded in both directions.	S8
Steel & Reinforced Concrete Frames	9 Square Tube Columns per house	Reinforced Concrete, embedded in the slab and loaded on the long axes.	S9
		Reinforced Concrete, loaded on the short axes.	S10
Masonry	Shear walls	Weak embedded in the slab. Loaded on the short axes.	M11
Wood Fibre	Shear walls made of wood fibre shells on a steel frame	None. A reinforced concrete slab is casted over a steel shell.	W12

The masonry house of UST project

Materials and design specifications

The masonry house of UST project is shown in Photograph No. 1. It was constructed with the following materials:

a) Blocks of 5 MPa in strength (compressive stress resistance) as drawn in Figure No. 2
b) Portland cement mortar of 21 MPa in strength
c) Corrugated steel bars of 420 MPa in strength, 8 mm of diameter for vertical reinforcement, and non-corrugated steel bars of 5.5 mm for horizontal reinforcement. The vertical bars were placed at the corner of walls embedded in the block with mortar, while the horizontal bars were spaced every three blocks (every 600-mm along the height)
d) Reinforced concrete of 21 MPa in strength, for the roof slab of 150 mm in thickness.

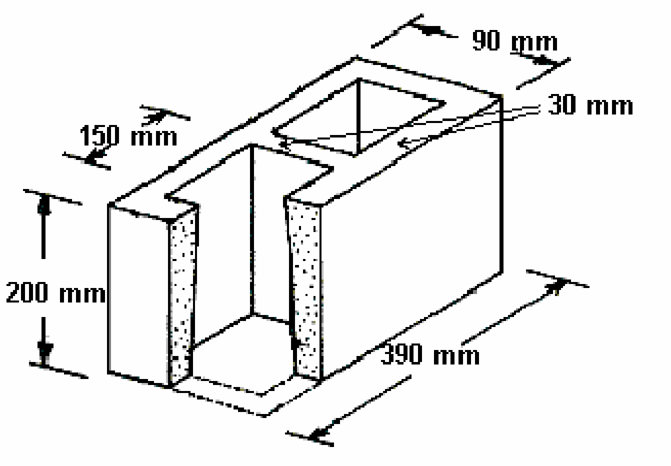
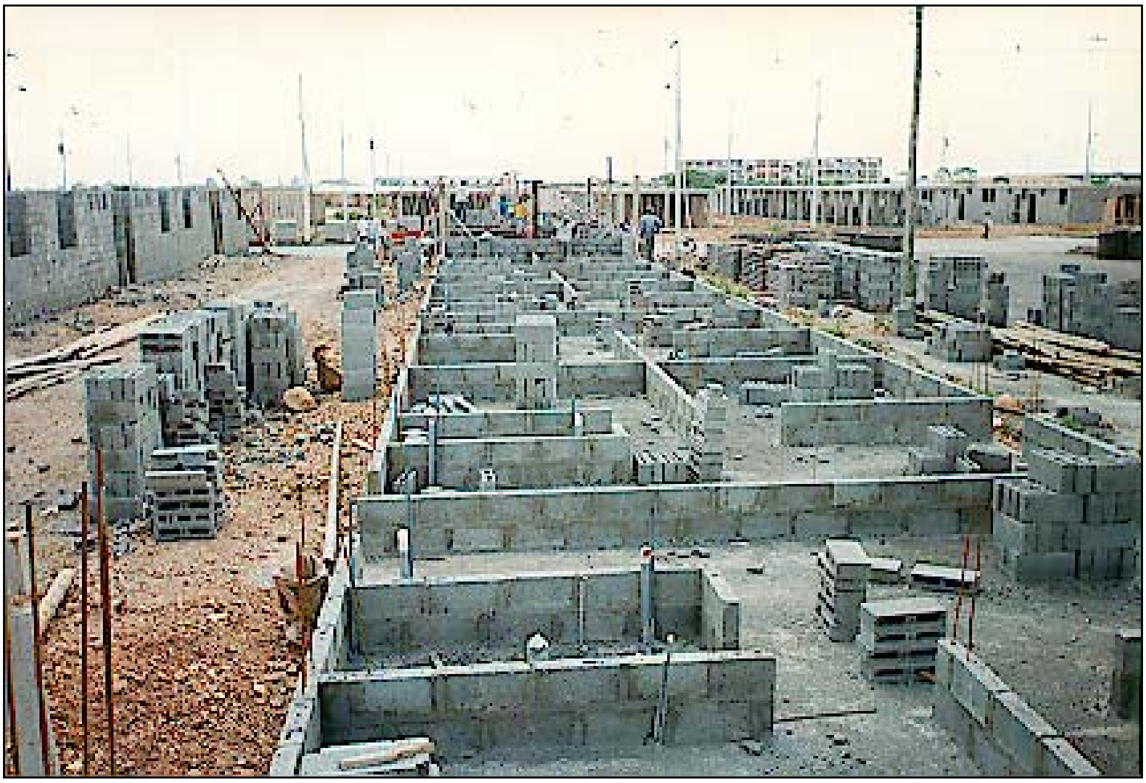


Figure No. 2: Block dimensions



Photograph No. 1: Masonry houses constructed in the UST project.

Structural behaviour

The masonry house has been studied using a static lateral force calculated with a seismic coefficient of 0.186 (as specified by the Ecuadorian National Construction Code) and the vertical loads due to the construction of a second floor. Applied vertical loads and seismic horizontal forces are presented in Table No. 2.

A tridimensional shell element was analysed to check the structural performance, obtain the working stresses and improve the house's design. Their owners will rapidly expand houses at UST to a second floor. That's why the FUNDACYT research project [1] wanted to know whether they are secure or not, and if so, how much seismic resistance supports the masonry type in comparison with others.

Table No. 2: Vertical loads and horizontal forces applied to the masonry house

Item	*Specific Weight (MPa/mm x 10^{-7})*	*Dead Load (MPa x 10^{-5})*	*Live Load (MPa x 10^{-5})*	*Seismic Force (N)*
Walls	150	-	-	-
RC Slab	240	-	200	368.7
Roof	-	65	90	297.6

Results from the analysis are presented in Table No. 3, for every critical element not satisfying the specified allowable stresses. Critical elements are shown in Figure No. 3. It was assumed a workmanship factor [5] equal to 0.5.

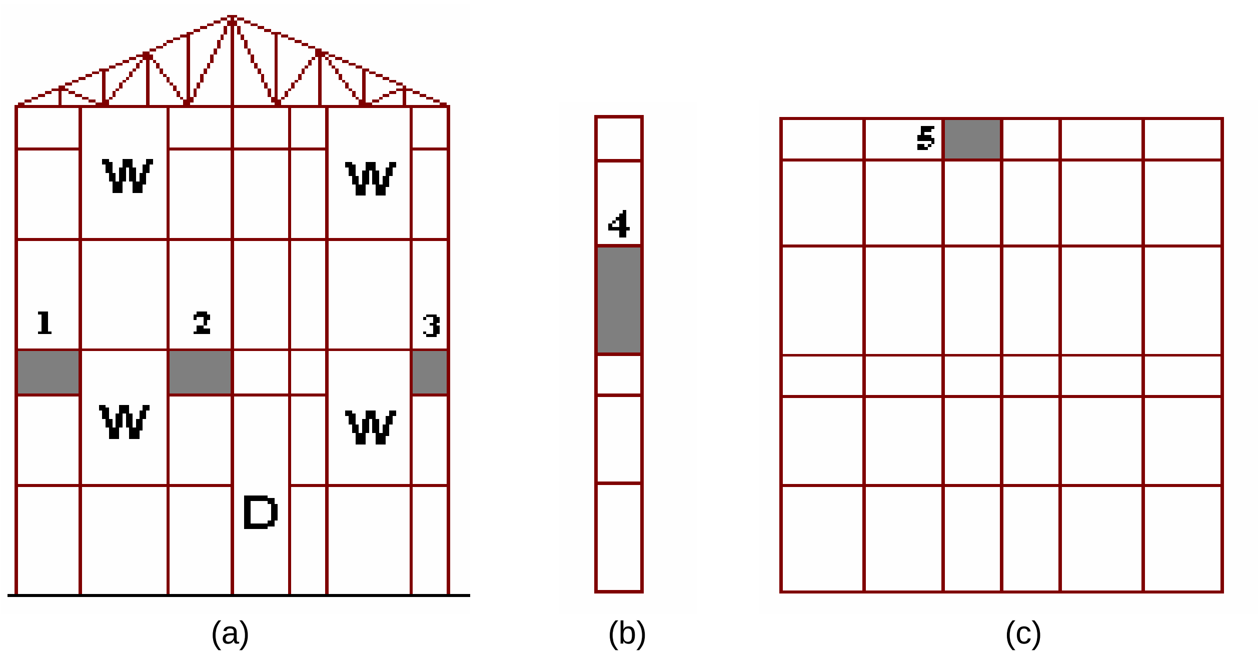


Figure No. 3: Critical elements at UST masonry house obtained from the shell analysed to study the structural behaviour.

It was found that:[4]

(a) Three critical elements located at the front similar to others at the back wall will experience severe local damage due to the lack of a heading beam.
(b) Internal wall at the bathroom needs reinforcement.
(c) At the lateral walls a critical element is located at the top of the second floor. This is because the model does not consider a connection between roof and walls. The roof should restrain the walls.

In conclusion, few elements will experience severe damage during an ultimate design earthquake. The structure will reach inelastic behaviour but will not collapse [4]. This is considered normal.

To reduce damage in critical elements and to improve the original design in order to keep the structure within the elastic range some countermeasures are recommended [4].

Table No. 3: Results from tridimensional shell analysis

Type Of Element	Stress Type[3,6]	Allowable Stress [3,6] (KPa)	Working Stress at element (In KPa)				
			No. 1	No. 2	No. 3	No. 4	No. 5
Without reinforcement	Axial (fa)	144.1	515.0	258.6		166.2	31.0
	Compressive (fbr)	521.9	296.5	142.7		102.0	22.8
	Shearing (fv)	117.2	71.0	157.2		84.1	57.2
	Bending (ft)	86.2	51.0	1,420		19.3	222.7
	Combo (+ -fa+ft)	57.9	-464.0	1161		185.5	191.7
Reinforced	Compressive (Fa)	144.1	121.3	37.9	83.4		9.0
	Bending (Ft)	661.9	21.4	75.8	22.1		345.4
	Combo (fa/Fa + ft/Ft)	1	0.9	0.4	0.6		0.6
	Steel stress	165,474.2	-7340,2	-0.7	-4,195		27,000
	Bounding stress	689.5	410.2	199.9	312.3		467.5
	Shearing stress	217.2	66.2	137.2	102.0		20.7

Improving the original design

To improve the original design the following is necessary:

a) Increase the diameter of vertical bars up to 10 mm at the front and back facades
b) Place one 8 mm bar at the bathroom wall to reinforce that area
c) Place a 900x200 mm beam reinforced with two 8 mm bars at the head of the windows and doors in the front and back facades to prevent the failure of panels 1, 2, and 3, which are subjected to large bending stresses.

These specifications done to improve the seismic performance of the UST masonry house are shown in Figure No. 4.

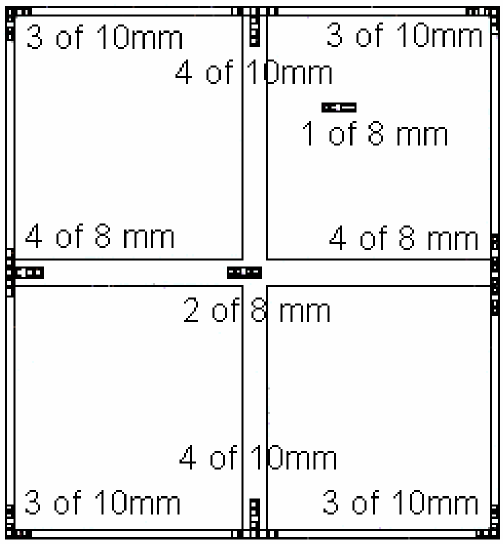


Figure No. 4: A plan of the improved design for a masonry house

A comparative study for the various types of structures built by UST

Outline of the evaluation

In situ data collection was done from eight companies to gather information from their structural systems. This sample consisted of 5,287 houses (44% of the universe) being a representative sample of almost every kind of pattern implemented. See Table No. 4.

Based upon the collected data, various types of analysis were done to study the structural behaviour, direct costs, social benefits and so on. For a better understanding of the complexity of such an evaluation having various degrees of freedom, many indicators have been developed. The evaluation is to be performed considering the following five aspects: construction and management quality, structural performance, financial and direct costs, environmental impact and the social benefits and cultural preferences.

Table No. 4: Structural systems investigated

Pattern Type	C1	C3	C4	C6	S8	S9	M11	W12	TOTAL
No. Of houses	300	500	870	1,600	1,200	200	500	117	5,287

Indicator's Marks

Usually the indicator's marks will correspond to a scale of five grades as follows: excellent (E), good (G), normal (N), poor (P) and bad (B).

Construction and management quality

The construction quality was found to have an incidence over the structural safety and the management quality, a large impact over the people preferences (here defined as cultural preferences) and no significant influence in the direct costs. These conclusions are stated by the comparison of the Construction quality indicator (shown in Table No. 5) with others.

It was observed that the Management quality had an impact over the construction period, and the financial and direct costs, in addition to other effects described in the remarks of Table No. 6, where the Management quality indicator is presented.

Table No. 5: Construction quality indicator (obtained in site and estimated subjectively).

<table>
<tr><th>Pattern Type</th><th>Indicator Value</th><th>Remarks</th></tr>
<tr><td>C1</td><td>N</td><td>Traditional construction techniques were applied with normal results</td></tr>
<tr><td>C3</td><td>G</td><td rowspan="2">Good results were obtained from the use of steel forms, which provided a better casting and finishing of RC elements.</td></tr>
<tr><td>C4</td><td>G</td></tr>
<tr><td>C6</td><td>N</td><td>Traditional construction techniques were applied with normal results</td></tr>
<tr><td>S8</td><td>P</td><td>Very poor bounding of blocks from wall to the steel structure</td></tr>
<tr><td>S9</td><td>B</td><td>Bad casting of the reinforced concrete slab over steel columns</td></tr>
<tr><td>M11</td><td>N</td><td rowspan="2">These non-traditional structural system involve techniques of which workers weren't enough trained. Quality may improve easily in future.</td></tr>
<tr><td>W12</td><td>N</td></tr>
</table>

Table No. 6: Management quality indicator (obtained in site and estimated subjectively).

Pattern Type	*Indicator Value*	*Remarks*
C1	G	Small things such as a good workmanship organisation, enough stock of materials, reuse of form works, etc., make the difference.
C3	G	
C4	N	Blocking of walls was a critical activity. A shortage of blocks, equipment and workmanship produced normal results.
C6	N	
S8	G	Usage of steel structures makes management easier for the many
S9	N	Mixed systems were built with normal results.
M11	G	Companies involved were big, with good management performance.
W12	G	

Structural performance

Using the same analytical process used with the masonry house, an analytical model was prepared for every pattern considering the expansion of the building to two stories and providing an input seismic force according to the Ecuadorian code. From the structural analysis and objective criterion, the Structural performance indicator shown in Table No. 7 was estimated.

Table No. 7: Structural performance indicator

Pattern Type	*Indicator Value*	*Remarks*
C1	P	Beams do not satisfy code requirements in two story buildings.
C3	E	Satisfy code requirements. This is a very much secure design.
C4	G	Satisfy code requirements.
C6	N	Merely satisfy code requirements in two story buildings.
S8	P	This is a flexible structure, having a poor control of drifts. It is expected a severe damage in the walls made with weak blocks even during moderate earthquakes.
S9	B	Out of code requirements. There is a lack of shear resistance due to a bad connection of the RC slab with the steel columns.
M11	N	Merely satisfy code requirements in two story buildings.
W12	G	Satisfy code requirements.

Financial and Direct costs

Direct costs listed below in Table No. 8 have been calculated for a single house, including the construction costs of partition walls, structural elements and others. Where estimated in ecuadorian sucres (ECS) at a change rate of 3.500 ECS per US dollar.

Table No. 8: Construction's direct cost (indirect costs had not been estimated).

Pattern Type	C1	C3	C4	C6	S8	S9	M11	W12
Direct cost in miles of Ecuadorian sucres	7,489	7,389	7,932	7,736	7,790	7,469	7,843	9,707

The Direct cost indicator presented in Table No. 9, resulted from a subjectively estimation done the comparison of the direct cost information and other indicators here defined.

Table No. 9: Direct cost indicator

Pattern Type	*Indicator Value*	*Remarks*
C1	G	This house cost 6% less than C4 and almost the same as C3. A little saving of money for a good cost through a large lost of safety.
C3	E	Excellent cost with an excellent seismic performance. This proves that it is not effective to save money on the structure. Other factors such as management are much more important to such a purpose.
C4	P	Constructor expended little more money than necessary. Good quality of construction with normal management became expensive.
C6	N	Normal construction quality and normal management lead to a normal cost.
S8	N	
S9	G	Little saving of money through the greatest lost of seismic safety.
M11	N	Normal prices for a non-traditional system is not enough for the many. People expect from new systems a good save of money.
W12	B	A high cost new technology to low cost housing is a bad business

The construction period listed in Table No. 10 was obtained in site by objective observation. Such information was used for the estimation of the Financial costs indicator presented in Table No. 11.

Table No. 10: Construction period (measured in days per house).

Pattern Type	C1	C3	C4	C6	S8	S9	M11	W12
Construction's Period	5,3	4,6	8,8	6,7	2,1	3,3	2,1	1,8

Table No. 11: Financial costs indicator (Estimated subjectively from the construction period, which is the main factor that determines financial costs).

Pattern Type	*Indicator Value*	*Remarks*
C1	N	5 days per house seems to be the normal time to construct a RC house.
C3	N	
C4	B	Too much time. This also explains why C4 has not a good direct cost
C6	P	Needed little more time
S8	G	2 or 3 days per house is a good construction period. These projects had reduced financial costs to nearly half of the RC costs. Among them, W12 is the one that can get the best value of this indicator in the future.
S9	G	
M11	G	
W12	G	

Environmental impact

Sources of pollution are cement industries, stone and sand mines, etc. The use of wood causes deforestation. Some construction systems produce less environmental impact than others do, as shown in Table No. 12.

Table No. 12: Environmental impact indicator (Estimated subjectively).

Pattern Type	*Indicator Value*	*Remarks*
C1- C9	N	The R. C construction produces a normal environmental impact.
S8	G	Steel construction cause less environmental impact
S9-M11	N	Similar to RC construction systems
W12	E	This is a “clean construction”.

Social benefits and cultural preferences

Social affairs are very much important. In a country with a 10% of unemployed people, governmental projects should look forward to stimulating the construction of projects with high social benefits, measured in terms of workmanship occupancy (see Tables No. 13 and No. 14). The cultural preferences are to be carefully taken into account by constructors to do a good business. As a statement of fact, people think that a RC house improves the economical status much better than others do [2]. (refer to Table No. 15)

Table No. 13: Workmanship indicator (men per house and per day).

Pattern Type	C1	C3	C4	C6	S8	S9	M11	W12
Workmanship indicator	39	38	29	32	13	36	47	14

Table No. 14: Social benefits (Estimated from workmanship indicator and others) [2]

Pattern Type	*Indicator Value*	*Remarks*
C1	G	Much workmanship was involved in these projects for a good direct cost. This is considered a good social benefit. Everyone won.
C3	G	
C4	N	In RC projects, it seems that those companies that involved less than the optimum number of workers didn’t reached the best direct cost.
C6	N	
S8	P	Few people involved means a project of a minor social benefit.
S9	N	Mixed systems involved as much people as RC
M11	E	Social benefits are the best. The highest labour force is required
W12	P	Few people involved means a project of a minor social benefit.

Table No. 15: Cultural preferences (Estimated from people interviews) [2]

Pattern Type	*Indicator Value*	*Remarks*
C1	G	People can recognise a house that is below the security standards.
C3	E	A Reinforced concrete house with a good structure and high construction quality is largely preferred. People use to pay extra money to be able to get one of these houses.
C4	E	
C6	G	People don’t like to have 6 columns instead of 9 in their houses.
S8	N	Steel structures are accepted but not preferred by people
S9	P	People can recognised a house that is below the security standards, and if it is made of steel instead of RC is much less accepted
M11	P	People missed the columns. They feel insecure
W12	B	People think that are very insecure and very cheap.

Main conclusions

1. People prefer RC houses. Acceptance of masonry construction needs to be supported by an educational campaign and to prove a very good structural behaviour on existing buildings to be well accepted. Therefore, it is very important to improve the seismic design of the UST masonry house in case of construction of new projects.

2. Masonry construction costs are similar to the cost of most of the traditional systems made with RC or Steel. Costs can be improved in future by means of training. Under a free market (UST had a fix price for any kind of house) masonry shouldn't be the best choice. To construct a RC house in Ecuador is the best business.

3. Subsidies may be given to the constructors instead of to the beneficiaries to make them prefer masonry instead of any other system. It is a priority of the Nation to reduce unemployment obtaining the highest social benefits from the low cost housing projects.

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