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IMPROVEMENT OF THE EARTHQUAKE RESISTANCE OF EXISTING ADOBE DWELLINGS IN CUZCO, PERU

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SUMMARY

The main objective of this study is to improve the earthquake resistance of existing two-storey adobe dwellings. In order to evaluate the efficiency of six strengthening alternatives for adobe houses, a same number of analytical models were studied under the effect of El Centro earthquake, using a three-dimensional dynamic FEM-program. Prior, a fieldwork in a local neighborhood of Cuzco, Peru had been made to achieve technical and social-economical information about the people and their houses. The six strengthening alternatives evaluated were: horizontal diaphragms; collar beams; vertical tension bars; additional interior walls; welded wire mesh and vertical diagonal stiffeners. The selected alternatives, (diaphragm, additional wall and mesh) have been made considering effectiveness, cost and applicability. Then they had been combined in one model, given as a result an average reduction of 35% of the element stresses compared to the unreinforced model. Besides the technical study, a social-economical survey was done to determine whether it is cost-effective for the government to invest in the improvement of two-storey adobe dwellings. For this calculation, statistics about damage of previous earthquakes, demographic data of Cuzco and information from the interviews was used to model the expected economical loss for the government when an earthquake occurs. To analyze this problem, a system dynamic calculating program was used. In order to convince and help people to reinforce their house, the government should invest in a reinforcement project. Calculations show that the government can invest US$ 104 in the weakest houses of and US$ 52 in stronger houses. Multiple possibilities for the investment in the reinforcements of houses have been found. Its applications will depend on local conditions and the attitude of the government towards a reinforcement project.

INTRODUCTION

Dwellings throughout Andean region, like Cuzco in Peru, are commonly built of unreinforced masonry, mainly with adobes bonded with mud mortar and straw. The reason for constructions of this kind of material is undeniably its low cost for rural and urban areas. However, this traditional construction

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material has a little resistance to earthquake-induced forces. The collapse of adobe constructions has been and still remains as one of the main cause of loss of human lives and of economical damage following strong earthquakes, especially in developing countries (Kuroiwa [1]). In Peru one of the most dramatic example is the1970 Huaraz earthquake, when due to the collapse of about 15,000 adobe houses, more than 50,000 people died.

According Giesecke [2], although many years of research have succeeded in developing improved construction techniques and the Adobe Code for Building Constructions has been adopted in Peru, these efforts are not directly applicable to existing adobe constructions, which represent a real seismic risk. The main purpose of this study deals with such existing two-storey adobe houses in Cuzco and how to improve its earthquake resistance.

Perhaps the most widely proposed method of strengthening adobe houses is the placement of bond beam in the upper perimeter of the wall; another method, among the others, consists in covering both faces of the walls with a welded wire mesh on which a thick mortar rendering is placed. In this regard an extensive experimental research using a shaking table has been done in Mexico by Meli [3].

In the poor suburbs of Cuzco, dwellings are mainly constructed of adobe and the people that live there, do not have the financial means to make substantial investments to improve their houses. Hence, the suggested strengthening alternatives must be low budget.

The project team studied first the characteristics of adobe two story dwellings by performing fieldwork in a local neighborhood called Wimpillay. Technical observations of the houses had been made and the social economic situation of the people who lives in adobe houses was evaluated. Detailed report on the research program can be found in the internal publication of DELFT-UNSAAC [4].

Then a technical study to the dynamic behavior of two-storey adobe buildings was carried out with the help of a three-dimensional dynamic FEM-program. Alternative reinforcements had been developed and analyzed. From the alternative reinforcements, a selection was made. The selected alternatives were detailed and the cost of the alternatives had been estimated.

Beside the technical study, a social-economical study had been made to determine whether it is cost effective for the government to invest in the improvement of two storey adobe dwellings. A statistics about damage of previous earthquakes, demographic data of Cuzco and information from the interviews was used to model the expected economical loss for the government when an earthquake occurs. A system dynamic calculating program was used to model this problem.

FIELDWORK ADOBE DWELLINGS

To find out more about the constructions several houses have been examined with permission of the inhabitants. To divide the houses into different types, the following criteria are used: Foundation depth, Small openings for doors and windows, Floor beams protected against the elements, Weight constructed roof, Reinforcement in corners and Collar beam.

Description of Type I houses

The characteristics of this type of constructions present serious constructive deficiencies such as little depth of foundations generally made of stones and mud and lack of protection of the adobe wall against humidity. The adobe walls lack proper joints of mortar between the adobe blocks. These constructions do not have a collar beam or any reinforcement at the corners of the walls. Its structural quality is low, since the walls present a high percentage of openings for windows and doors. The floors beams, generally wooden eucalyptus, don't have any chemical treatment that protects them against the elements. These beams deformed by using them as they still were humid. These deformations caused problems in the groove joint of the walls. The characteristic roof of the adobe houses, constructed with straw, mud and stone roofing tiles, adds an extra weight to the wall, creating additional stresses.

Description of Type II houses

The characteristic of this type of construction contains fewer constructive deficiencies than the previous type. In this case the depth of the foundation is more sufficient and the materials used are stones with mud or stones with cement. To avoid the filtration of humidity in the walls, the houses have a baseboard with cement mortar. The mortar deficiency in the vertical joints is also presented in this type of constructions. Contrary to type I, these houses contain fewer openings for windows and doors. These constructions don't have a collar beam or any reinforcement in the corners of the walls. The wood used in the medium level is not protected against the elements and the roof is designed in the same heavy construction as in type I.

Description of Type III houses

The constructions defined by type III are better constructed; the foundation is made of stones and mud or cement and is protected against infiltrations of humidity. To the joints of the adobe blocks has been paid more attention, as well as in the horizontal joints as in the vertical joints. The openings in the walls for windows and doors, is the same as in the previous type, but contrary to type II, on the top of the walls a collar beam is attached. The collar beam is a wooden, eucalyptus; beam (Ø 8" = 0.20 m).The wood used at the first floor level lacks treatment of protection against the elements. In this type, the same problem exists for the excessive weight of the roof of the houses, as described in the previous types.

Summary of the three different types

In Table 1 the three different types of houses, as described before, are compared shortly by the different criteria.

Table 1: Three different types of houses compared

	TYPE I	TYPE II	TYPE III
Foundation depth	-	+-	+
Small openings for doors and windows	-	-	+-
Floor beams protected	-	-	+-
Light constructed roof	-	-	-
Reinforcement in corners	-	-	-
Collar beam	-	-	+

Legend:

- Not included / badly constructed
+- Included, but not well enough constructed
+ Included in construction

TECHNICAL ANALYSIS

Methodology

In this part of the report, a technical analysis of adobe dwellings is performed. The dynamic behavior of adobe dwellings is studied. Several reinforcement models were implemented. A Finite Element Method-program was used to evaluate the different reinforcements models.

Static horizontal analysis of a type III house

In figure 1, relatively high stress locations are marked and identified for the static horizontal analysis. In figure 2 and actual type III house is depicted. In table 2, the marked locations are qualified and quantified.

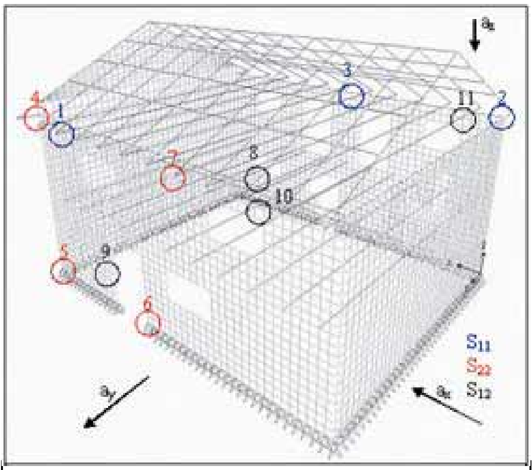

Figure 1: high stresses for static horizontal analysis of type III house

Figure 2: actual type III house

Table.2: high stress values for static horizontal analysis of type III house

Location	Shell number	Type of stress(*)	Stress (kN/m^2)		Description
			Positive face	Negative face	
1	5839	S_{11}	463	-374	Horizontal bending at the top corner
2	2246	S_{11}	-501	435	Horizontal bending at the top corner
3	4386	S_{11}	-288	256	Horizontal bending at the middle of the wall
4	3071	S_{22}	-353	325	Bending of top part of the wall
5	5840	S_{22}	-427	-421	Vertical compression at the base corner
6	5422	S_{22}	-387	-387	Vertical compression at the corner of door
7	2514	S_{22}	-85	-255	Compression and bending in the closet
8	4827	S_{12}	-76	175	Shear underneath window
9	5605	S_{12}	48	175	Shear next to door
10	5046	S_{12}	38	-85	Shear above window
11	3535	S_{12}	105	-120	Shear in upper corner of the wall

* Shear stresses are S_{12}, horizontal stresses S_{11} and vertical stresses S_{22}

Dynamic analysis of a type III house

In table 3, the maximum stresses dynamic analysis of type III house is resumed. The highest Eigen period is 0.7289 s.

Table.3: maximum stresses dynamic analysis of type III house

Location	Shell number	Type of stress	Stress (kN/m^2)		Description
			Positive face	Negative face	
1	5861	S_{11}	2350	2313	Horiz. bending at the top corner
2	5311	S_{11}	855	930	Horiz. bending at the middle of the wall
3	3571	S_{22}	1114	1086	Bending of top part of the wall
4	5363	S_{22}	239	58	Tension between door and window
5	5505	S_{12}	330	425	Shear next to window
6	4428	S_{12}	327	294	Shear next to window

Overall stresses in **Dynamic analysis of type I, II and III**
The average stresses of the three different types of houses are compared in table 4. This information will be used later on in the social-economical part. The information can be used for evaluation of the strength of the different houses.

Table 4: average stresses of dynamic analysis

Type of house	S_{11} (kN/m^2)		S_{22} (kN/m^2)		S_{12} (kN/m^2)	
	max	min	max	min	max	min
I	129	-144	30	-123	64	-70
II	199	-209	76	-168	111	-112
III	252	-267	90	-210	134	-135

Results
Stresses
To compare the different types of analysis, the maximum stresses of the same elements must be known. Therefore, the indicated elements used to evaluate the dynamic analysis are also evaluated in the static horizontal analysis. The results of the dynamic analysis are summarized and added to the results of the static analysis in table 5 and 6.

Table 5: maximum stresses static and dynamic analysis of type III house

Location	Shell number	Type of stress	Static stresses (kN/m^2)		Dynamic stresses (kN/m^2)	
			Positive face	Negative face	Positive face	Negative face
1	5861	S_{11}	-320	360	-2350	2313
2	5311	S_{11}	-227	223	-958	930
3	4893	S_{11}	160	-165	932	-882
4	3571	S_{22}	-353	326	-1095	1086
5	5363	S_{22}	-560	-182	-635	-594
6	3537	S_{22}	-214	167	-826	768
7	5505	S_{12}	-71	150	-286	425
8	4428	S_{12}	-121	147	-310	294
9	3572	S_{12}	163	-165	446	-521

Table.6: ratio between dynamic and static stresses

Location	Shell number	Type of stress	Ratio dynamic/static		Average ratio
			Positive face	Negative face	
1	5861	S_{11}	7.3	6.4	5.6
2	5311	S_{11}	4.2	4.2	
3	4893	S_{11}	5.8	5.3	
4	3571	S_{22}	3.1	3.3	3.2
5	5363	S_{22}	1.1	3.3	
6	3537	S_{22}	3.9	4.6	
7	5505	S_{12}	4.0	2.8	2.9
8	4428	S_{12}	2.6	2.0	
9	3572	S_{12}	2.7	3.2	

Stresses are formed by pure tension/compression and bending. The contribution of compression in type S22 and shear in type S12 is proportionally higher than its bending component. Due to relatively high horizontal displacements of the walls, bending contributes the most to the stresses. The horizontal deformations are high because the walls are less stiff in the plane perpendicular to the wall than in its plane direction. Therefore, the wall is more responsive to accelerations perpendicular to the wall, resulting in high horizontal stresses. This explains the fact that the ratio of the horizontal stress (S11) is considerably higher than the ratio of the stresses S22 and S12.

Displacements
The displacements for the two different types of analysis are summarized in table 7. As in the case of stresses, the displacements of the dynamic analysis are considerably higher than the displacements of the static analysis. In figure 3, an example is shown of the dynamic movements of three joints in the x-direction. Similar images could be shown for the y- and z-direction, because the nodes are accelerated in three directions.

Table 7: displacements static and dynamic analysis

		Static			Dynamic		
Wall	Joint	x (mm)	y (mm)	z (mm)	x (mm)	y (mm)	z (mm)
1	61	31.5	2.91	-2.47	86.5	3.11	-2.54
	21	22.5	2.59	-2.31	48.7	2.69	-2.30
	2999	12.5	1.44	-1.53	17.0	1.35	-1.48
2	234	13.9	2.10	-1.13	40.8	2.69	-1.26
	2228	8.87	1.22	-0.921	24.2	1.35	-0.993
3	1391	2.92	31.9	-2.95	3.13	102	-2.76
	1380	1.93	19.5	-2.43	1.84	50.4	-2.23
4	4603	3.49	37.2	-2.63	4.32	79.3	-2.55
	513	1.84	22.3	-1.90	1.80	37.4	-1.75

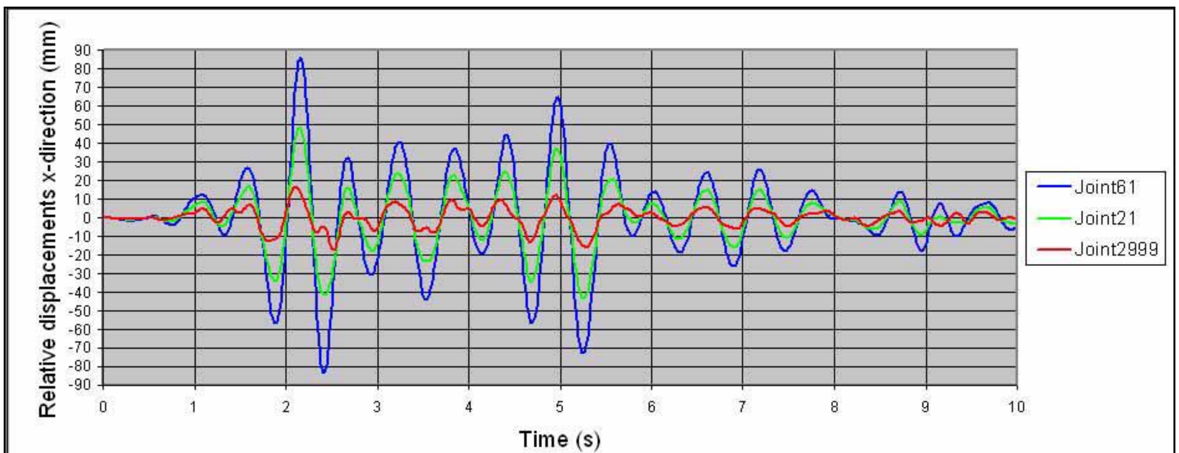

Figure 3: displacements of dynamic model

The joints in figure 3 are all situated in the same plane. The displacements are higher for joints that have a higher elevation. Similar remarks and figures can be made for the velocity and acceleration. The fact that higher accelerations occur at the top of the wall is one of the main reasons that the dynamic analysis results in higher stresses than the static analysis.

ALTERNATIVES FOR IMPROVING EXISTING BUILDINGS

The Universities of Cusco and Delf has been done a great deal of research in the field of seismic resistance and retrofitting of two-storey adobe houses in Cuzco (Kok [5], Rojas-Bravo [6]).

To reduce the risk of collapse of an adobe house, the stresses caused by an earthquake need to be decreased. In order to lower these stresses, alternatives for reinforcing the dwellings will be proposed and analyzed. The analysis will be done by using a three-dimensional dynamic FEM-program to establish the stresses in the houses with reinforcement implemented. The effectiveness of the reinforcement will be determined by comparing the stresses in the houses with reinforcement to the stresses in the houses without reinforcement.

To simplify the analysis, only one house will be used to model the different alternatives. The type III house has a basic plan. In order to simplify the modeling and straightforward the interpretations is the most appropriate house to implement the alternative reinforcements.

Alternative I: diaphragm
With the aim of make the house more rigid a diaphragm is introduced. The floor beams have to be properly connected to the walls. In this way, the walls will interact and the house will be more rigid. Between the connections of the beams and the walls, horizontal diagonal stiffeners will be placed (figure 4). The horizontal diagonal stiffeners are made of steel cables, so the cables are subjected to tension only. The horizontal diagonal stiffeners and floor beams form the diaphragm. The horizontal diagonal stiffeners will be attached to all intersected beams. The same method is used in the roof; the roof beams are connected to the walls and crossbeams will be applied. The out of plane deformation that generates horizontal tension and compression stresses will be reduced by the diaphragm because the beams are tied to the tension strings. Therefore, occurring deformations will generate tension in the cables reducing further deformation The maximum moments occurring in the corners and in the walls will lower, resulting

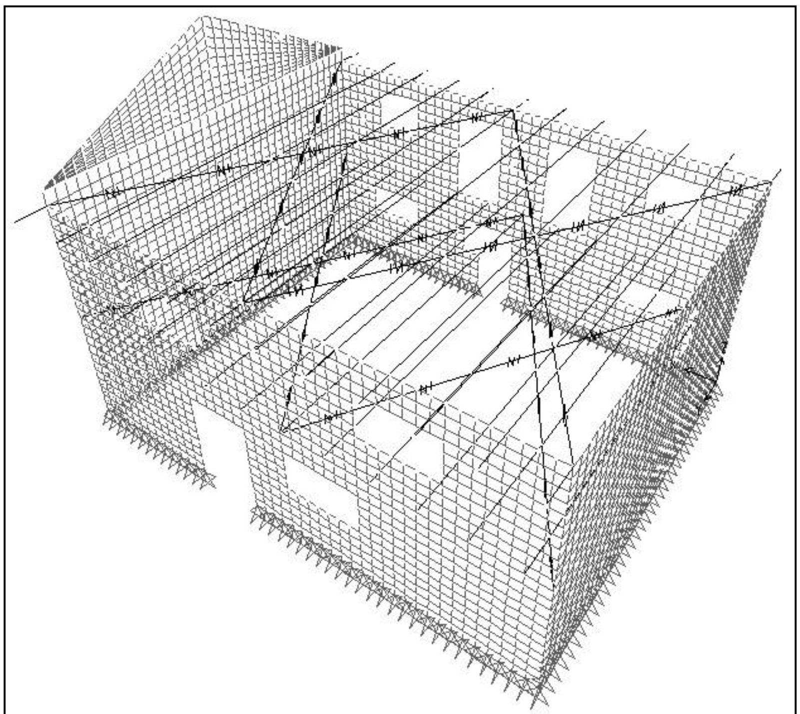

Figure 4: diaphragms in house

in smaller stresses. The diaphragm will transmit the most horizontal forces to the most rigid wall. This alternative will meanly decrease the horizontal bending stresses.

The connection between wall and beams is modeled as hinges, as well as the connections between beam and string.

The horizontal bending stresses in the walls are reduced considerably compared to the model with no reinforcements and no connections between beams and walls. In figure 5, the models with and without reinforcements are compared. As illustrated in the figure, the horizontal tension forces in the middle and at the corners of the longest wall have been reduced significantly. The axial forces that appear in the steel strings are quite large. Using a yield stress of 235 N/m2, a maximum force of 30 kN can be handled per string. Some of the occurring forces in the strings exceed the maximum applicable force, with a maximum value of 72.5 kN. When doubling the diameter to 1 inch, the strings become stiffer, inducing higher forces in the strings. It turned out that also these forces could not be transmitted by the strings. In order to deal with the forces, steel with a yield stress of 435 N/m2 should be used. Then the maximum force that can be applied to the string will be 56 kN. This is still not enough to handle 72.5 kN. It should be noted however, that the strings will yield but not break. In other words, the reduction of the horizontal tension stresses in the walls will be smaller if the maximum allowable force in the strings is exceeded.

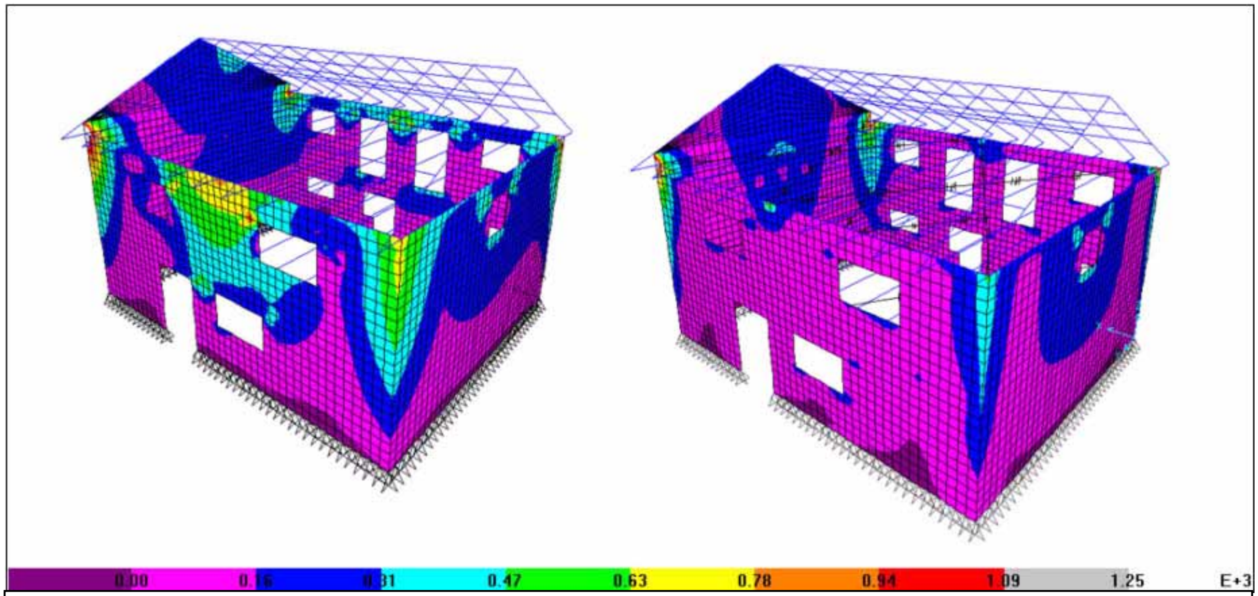

Figure 5: reduction of horizontal tension stresses with diaphragm, left unreinforced, right

Alternative II: collar beam

In this alternative, an additional collar beam is attached at the first floor level. The collar beam is connected externally of the wall, on both in and outside of the house. The collar beam will reduce the deformation caused by flexure because the collar beam will function as a tension tie. Besides that, it will distribute the shear forces along the wall, so shear stress concentrations should reduce.

The collar beam is assumed to have a rectangular cross-sectional area of 0.10 m·0.20 m. The Young's modulus of the wood is set to $2{\cdot}10^6$ kN/m2, the Poisson's influence is neglected. The collar beam will be connected to the floor beams and to the walls. The entire perimeter of the house will be covered by the collar beam.

The reduction of horizontal tension stresses is not as high as for alternative I, but still is significant. The collar beam does not have a substantial influence to the tension stresses. The shear stresses are considerably lowered by the application of the collar beam.

Alternative III: vertical tension bars
The implementation of vertical tension bars made of wood have no influence on the vertical tension stresses. The steel bars do change the stress pattern, but still no considerable reduction is detected. When a mesh is implemented, the stresses in the façade are reduced but at other locations in the walls, the stresses are increased. The results of this alternative reinforcement are unsatisfying.

Alternative IV: additional interior wall
Just like the diaphragm alternative, this alternative aims to decrease the stresses caused by flexion of the walls. If an additional interior wall will be placed, the displacements cause by bending in the middle of the wall is reduced. This results in lower stresses in the middle of the wall and at its corners.

The wall is modeled as any other wall in the models. The wall is made of adobe, 0.45 m thick and has no openings. The connections between the different walls are fully rigid. At the foundation, the wall is restrained by hinges. The wall does not interact with floor beams or roof beams.

The horizontal stresses caused by bending are reduced on the places where expected. In the middle of the long wall, the stress is reduced from 940 kN/m2 to 755 kN/m2. It should be noted that the stress in the reinforced model occurs very locally. As shown in figure 6, the stresses in the walls are significantly lower in the reinforced house in comparison to the original house. Only in the middle of the wall, at the connection with the new wall, a high stress concentration occurs.

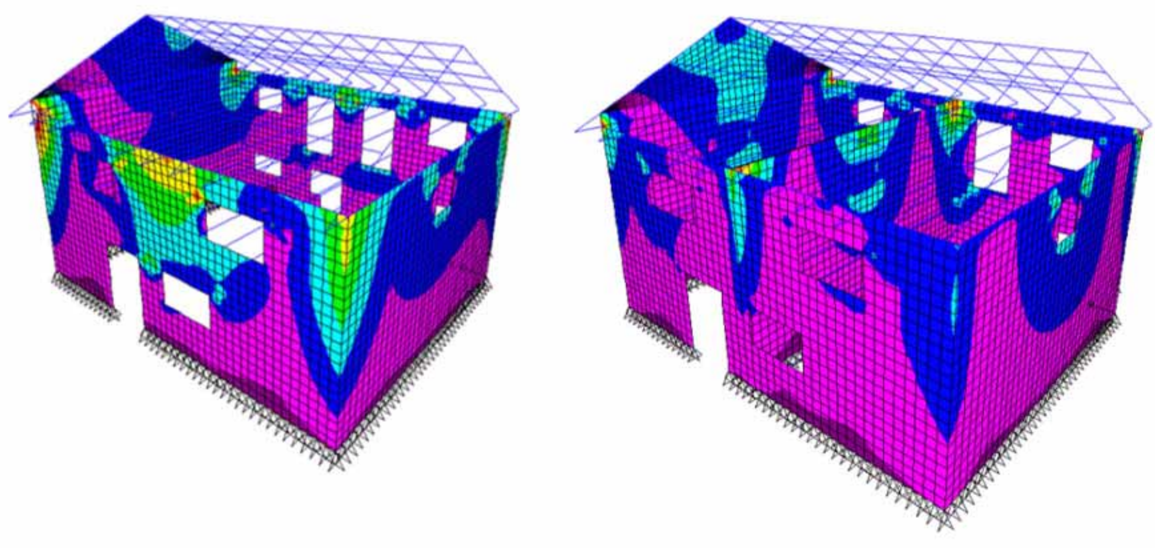

Figure 6: reduction of horizontal tension stresses with additional interior wall, left unreinforced, right reinforced, in kN/m^2

Alternative V: mesh

This alternative aims to reduce the horizontal tension stresses in the corners by covering the adobe blocks in the corners on both sides with a mesh. The mesh is made of steel wire and is meant to help the adobe by taking account for the tension stresses caused by bending moments.

Several meshes with different diameter of the wire were tested. The mesh with 1 mm diameter (¾ inch spaced) did not show any considerable reduction of stresses. Another mesh, with 2.5 mm diameter (½ inch spaced), did show a reduction of the tension stresses caused by bending in the corners. However, the horizontal bending stresses in the middle of the wall were more or less unaffected. By implementing a mesh to the wall, the in plane rigidity of the wall is increased. Therefore, higher shear stresses are attracted, resulting in higher peak values. The maximum allowable force in the wires is 91 kN/m1. This value is not exceeded by far. The used model does not model cracks. When cracks occur, the wire will take more tension stresses and keep the adobe blocks together. In this way, it will delay the collapse of the dwelling but this cannot be simulated in this model. The mesh with 1 mm diameter will also behave differently when cracking would be modeled.

Alternative VI: vertical diagonal stiffeners

To transmit the forces in the roof and in the floor induced by the accelerations of the earthquake, vertical diagonal stiffeners are introduced. These stiffeners connect the roof with the floor and the foundation. The stiffeners are made of steel cables, so only tension can be transmitted To attach the cables to the floor, a collar beam will be modeled at the level of the first floor. The stiffeners will reduce the shear stresses in the walls because the horizontal forces in the roof and floor are partly transmitted by the cables. The modeled collar beam will also contribute to the decrease of shear stresses.

The shear stresses are reduced as expected. The maximum force occurring in the 1-inch strings is 93.5 kN, the maximum allowable force of 119 kN is not exceeded, the shear stresses of the reinforced model is compared to the unreinforced model. The shear stresses have a considerably lower value in the reinforced model; especially critical areas near openings have lower shear stresses.

SELECTION OF ALTERNATIVES

For the selection of the alternatives, the effectiveness of the reinforcements must be evaluated. Besides the effectiveness, applicability and cost will be included in the selection. The results of the previous paragraphs will be summarized in table 8. The applicability of the alternatives is subdivided in labour-intensity, difficulty and acceptance. Acceptance is the willingness of people to implement the reinforcement. Exterior tension bars, for example, will rate low on this scale.

Table 8: evaluation of alternatives

Alternative	Effectiveness	Applicability			Cost
		Labor-intensity	Difficulty	Acceptance	
Diaphragm	++	-	-	+	-
Additional Wall	++	+	++	-	+
Mesh	-	-	+	+	0
Vertical diagonal stiffeners	0	+	--	--	0

Selected alternatives combined

In this paragraph, the selected alternatives are combined in one model. This model will be analyzed in the same way that other models have been analyzed. The maximum stresses will be compared to the unreinforced model in table 9 and table 10 in the same way as the effectiveness has been determined for the alternatives.

Table 9: Compared value of the stress of the combined model

Stress type	Unreinforced model	Combined alternatives positive stress	Combined alternatives negative stress
S_{11}	100%	53,0%	55,7%
S_{22}	100%	73,0%	69,2%
S_{12}	100%	60,7%	74,9%

Table 10: Number of elements that exceed maximum or minimum allowable stress

Stress type	Unreinforced model maximum stress	Combined alternatives maximum stress	Unreinforced model minimum stress	Combined alternatives minimum stress
S_{11}	29,71%	6,27%	1,08%	0,21%
S_{22}	5,37%	3,19%	0,13%	0,22%
S_{12}	83,16%	55,44%	83,04%	70,36%

In figure 7 and 8, the contour output plots of the combined alternatives are compared to the plots of the unreinforced model. It can be seen that both the horizontal tension stresses and the shear stresses are reduced significantly.

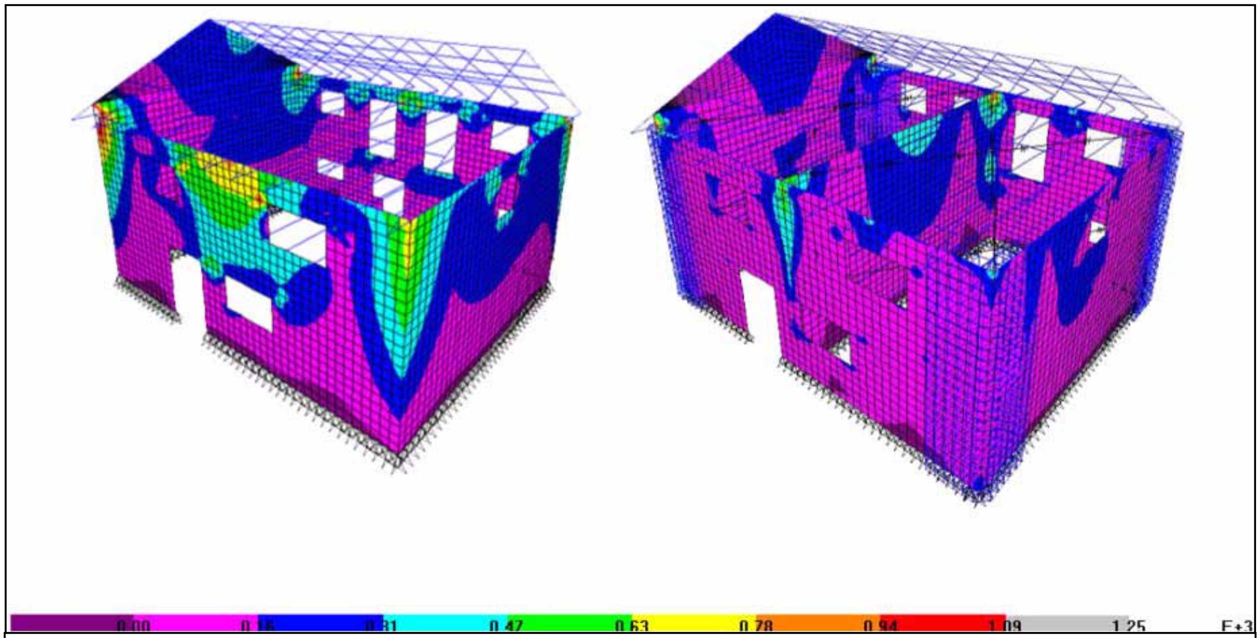

Figure 7: reduction of horizontal tension stresses for the combined alternatives, left unreinforced, right reinforced, in kN/m^2

The mesh, additional wall and diaphragm work together to reduce the horizontal tension stress as can be seen in figure 7. The high stresses that remained in the corners of the house with the diaphragm alternative are lowered by the application of the mesh. The wall induces some additional bending stresses in the middle of the wall because of refrained displacements.

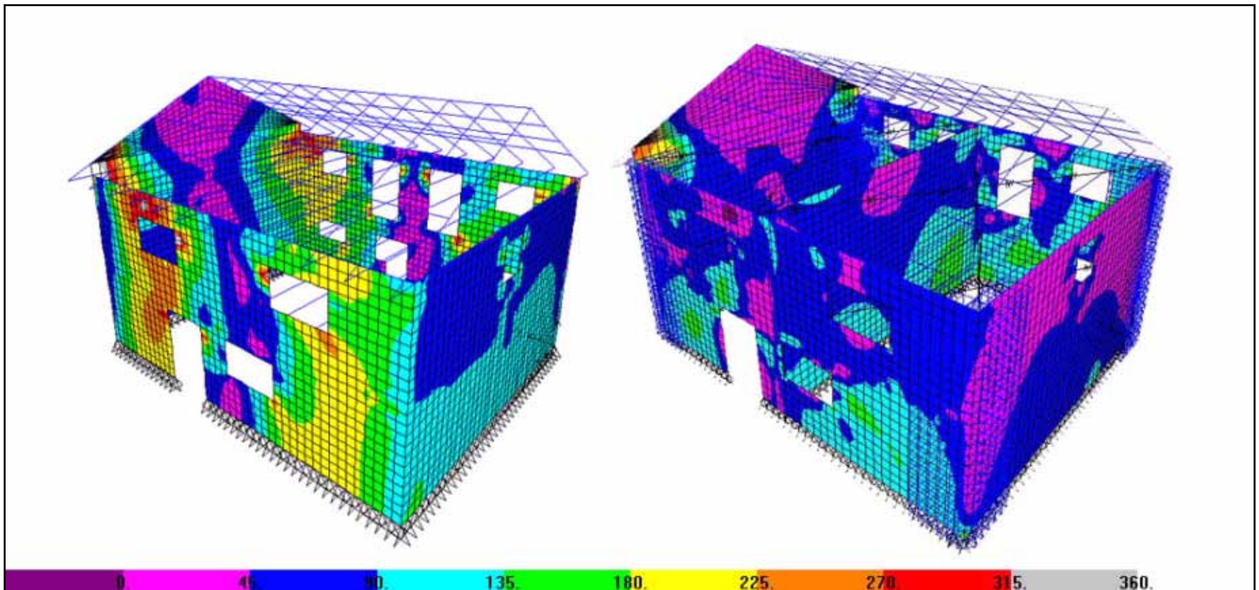

Figure 8: reduction of shear stresses for the combined alternatives, left unreinforced, right reinforced, in kN/m^2

In the used model, the connection of the diaphragm with the walls is situated at the same location as the additional wall. Therefore, the diaphragm and the additional wall do not act together optimally. The combination of these alternatives could be optimized by changing the location of the connection of the diaphragm and the walls. The total cost of the three alternatives combined is US$ 482. Applying several of the reinforcements instead of all of them is useful and therefore will be cheaper. The alternatives can be applied separately and do not need to be implemented simultaneously.

SOCIAL-ECONOMICAL ANALYSIS

This part of the research has been done to determine the influence of economical and social aspects as well as the economical loss of an earthquake for the government. Casualties, caused by an earthquake, will be an economical loss for the government and therefore it is beneficial to prevent adobe houses from collapsing. The quality of the construction of adobe houses will influence the economical loss for the government.

Reduction of economical loss

In order to evaluate the profitability of the investment, a system dynamic software package called Stella has been used to analyze the impact of reinforcement implementation. The relations between the factors and aspects that influence the economical loss for the government are illustrated in figure 9, 10 and 11.

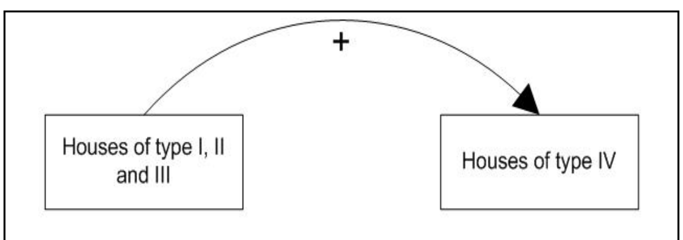

Figure 9: Relation between number of houses of different types

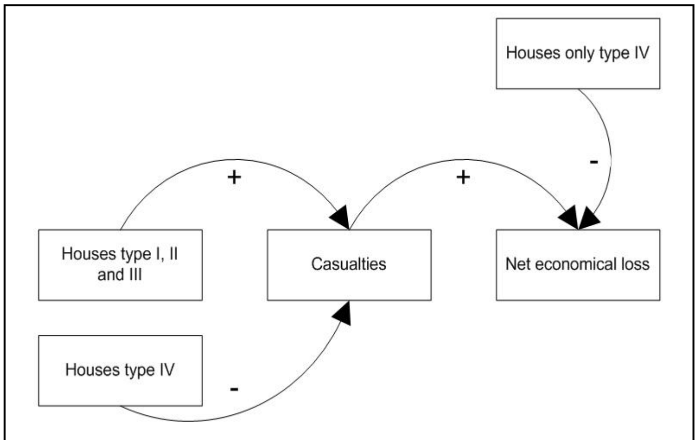

Figure 10: relations between houses of different types, casualties and net economical loss

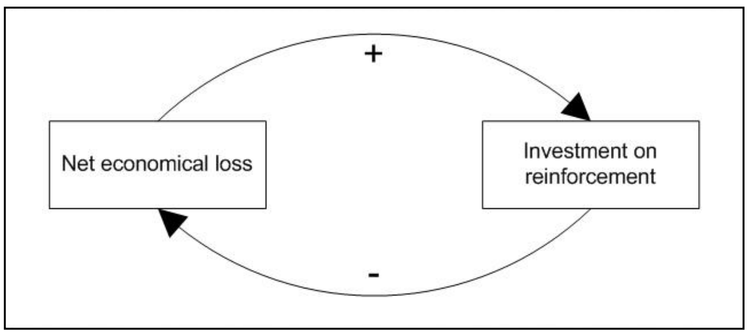

Figure 11: relation between net economical loss and investment on reinforcement

Results
According to the calculation, it would be affordable for the government to invest in the reinforcement of adobe houses. The investment which can be done is US$ 104 per house of type I and US$ 52 per house of type II and III. Besides the investment of the government, the contribution of the people must be known to determine the total allowable costs of reinforcement. A recommended costs contribution by the government and the owners is show in table 11

Table 11: recommended cost reinforcement

Type of house	Maximum investment government	Own contribution reinforcement	Total costs reinforcement
I	104	378	482
II	52	430	482
III	52	430	482

CONCLUSIONS

After modeling several reinforcement alternatives, a selection has been made. The selection criteria are composed of the effectiveness, cost and applicability. The selected alternatives are the diaphragm-alternative, additional wall-alternative and mesh-alternative. The different selected alternatives had been combined in one model, given as a result an average reduction of 35% of the element stresses compared to the unreinforced model. The total cost of the implemented reinforcements for the combined model is US$ 482. Instead of applying all three alternatives, the inhabitants could apply only two alternatives. In this case, a combination of the mesh-alternative with the diaphragm-alternative (US$ 398) or the mesh-alternative with the additional wall-alternative (US$ 224) would be recommended. According to social-economical analysis, casualties caused by an earthquake, will be an economical loss for the government and therefore it is beneficial to prevent adobe houses from collapsing. The quality of the construction of adobe houses will influence the economical loss for the government. According to the calculation, it would be attractive for the government to invest in the reinforcement of adobe houses. The investment which can be done is US$ 104 per house of type I and US$ 52 per house of type II and III. Besides the investment of the government, the people contribution for reinforcement reaches US$ 378 (Type I house) and US$ 430 (Type II and III house).

The present numerical model have to be improved to evaluate alternative reinforcements: test model with several earthquakes, include non-linear material behavior like cracking, verify used type of connections for roof and walls and including more adobe properties. Better results can be obtained also by modifying the house layout, as well as reducing the weight of the roof and the height and unsupported length of the walls.

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