SELECTION OF SUITABLE TECHNIQUE FOR STRENGTHENING AND REHABILITATION OF MASONRY WALLS

Final Year Project UG-2017

By

NUST BE-CE-17-212601 Muhammad Awais Rafi
NUST BE-CE-17-240630 Muhammad Shahzeb Khan
NUST BE-CE-17-212452 Muhammad ArsalanAbbas
NUST BE-CE-17-227913 Talha Ameen

NUST Institute of Civil Engineering (NICE)

School of Civil and Environmental Engineering (SCEE)

National University of Sciences and Technology Islamabad, Pakistan

(2021)

This is to certify that the

Final Year Project titled

“Selection of Suitable Technique for Strengthening and Rehabilitation of Masonry Walls.”

Submitted by

NUST BE-CE-17-212601 Muhammad Awais Rafi
NUST BE-CE-17-240630 Muhammad Shahzeb Khan
NUST BE-CE-17-212452 Muhammad Arsalan Abbas
NUST BE-CE-17-227913 Talha Ameen

has been accepted towards the requirements for
the undergraduate degree

in

CIVIL ENGINEERING

____

Dr Azam Khan
Designation (Lecturer)
NUST Institute of Civil Engineering
School of Civil and Environmental Engineering
National University of Sciences and Technology, Islamabad, Pakistan

COPYRIGHT NOTICE

DEDICATION

We dedicate our work to our beloved parents and honourable teachers who supported us to achieve quality education and accomplish our academic objectives with excellence and admiration.

ACKNOWLEDGEMENTS

“***In the name of Allah, the most beneficent and the most merciful***”

We are greatly obliged to our supervisors ***Dr Azam Khan and Lecturer Arslan Mushtaq*** for assisting us in understanding and completing this thesis. Their assistance and a continuous appraisal helped us to think out of the box to get more valuable and appropriate deductions from the academic work.

The accomplishment of this work is the result of the guidance and cooperation of many encouraging fellows and seniors. It is difficult to assess their help and support. In the end, we would like to express gratitude to our parents who always supported and encouraged us during our academic career. I am especially thankful to Zohaib Ahmad and Uzair Azhar for all their help and unwavering support throughout this endeavour.

Table of Contents:

Chapter 1

1. ABSTRACT

A multitude of methods was studied, which were used for the rehabilitation of typical masonry buildings which had been subjected to settlements. By studying different methods used for the rehabilitation of masonry buildings, a suitable method for our site had been selected, which had undergone settlement, and cracks were visible in the walls and slabs of the building. The main objective of our project was to achieve two goals, economy and strength, the strengthening of typical masonry wall bearing structures subjected to settlement induced cracks by using the most optimum and cost-effective rehabilitation methods. By comparing various methods which were applicable the best one for our site was selected. A relationship between the total covered area of brick masonry and the optimum required area of columns for effective rehabilitation was determined. The objective of selecting the most suitable method of rehabilitation design was the adoption of RCC frames for our case study. Part of our methodology was developing an empirical threshold between the total covered area and the required area of RCC columns for optimum rehabilitation design of wall bearing structures. To support the approach, the case study building was modelled in Etabs software.

2. INTRODUCTION:

Wall masonry structures are the ones which are built using bricks and mortar. Wall masonry structures are mostly residential buildings. Usually for the construction of a residential building, bricks are used up to a height of 3 floors.

This type of construction is spread far and wide in our country since no extra/ scientific knowledge is required in the construction. One can easily hire masons and helpers, and they will work on our orders and the plan shared with them. In some construction, columns are provided for better support and to cater for the loads being applied.

Any person without the consultation of a certified engineer can have his/her house built. But the problems occur when certain criteria are not met before the commencement of the construction.

In our final year project, we have looked upon a case study of a residential, one storey house that was built without any consultation. The house is situated in Talagang, Chakwal in Punjab. Shortly afterwards the completion of its construction, one side of the house experienced settlement. All the walls on a side settled and imposed a great risk on the safety and stability of the building.

Preliminary inspection of the incident found out that the soil underneath the walls had settled that indirectly led to the settlement of the walls. Further study revealed that at the time of its construction, no soil tests were performed, neither the strata of the location were checked. The load from the walls resting on the unstiffened soil caused the soil to settle.

This caused a lot of tension and stress to the owner of the house and led to more money being spent on the restoration of the house to its original position.

For the project, the architectural plans of the house were acquired. These plans thoroughly explained all the details of the house including the beams, walls, and lintel details. These plans were examined by us and used throughout the project for convenience.

A modelling software known as ETABs was primarily used, in which the whole house was 3D modelled.

Normally for such settled houses, columns are introduced at specific points throughout the walls. These can be interior as well as exterior ones. Columns used in our case study were of different sizes and orientations.

For the settled side of the house, the columns used were of long in nature having deep foundations. This was done so that the load of the column does not occur on the soft strata, instead, it is moved down to the hard strata. This ensures that even if the soil was not properly condensed, proper construction can take place in which the loads are transmitted to deeper depths unto the hard strata.

3. PROBLEM STATEMENT:

This has become a very alarming problem nowadays and continues to spread in our societies. The problem is that inexperienced people without the consultation of proper engineers and architects start their own projects. This at one end leads to money and time saving for the owners. But in hindsight, this ultimately leads to more troubles later.

Without knowing the ins and outs of the whole construction work, the product will for a time be good but once the fault/ problem starts, it will become a total mess later. It is a common practice in Pakistan that engineers are not consulted for the construction of residential buildings. This results in a number of problems regarding the site conditions and stability of the structure later. In our case study, a single-story brick wall bearing residential building has been subjected to settlement. This has caused cracking in the building to the extent that it has affected its structural integrity.

4. OBJECTIVE:

This research aims to study of different type of methods which are used for the rehabilitation of typical masonry buildings which have subjected to settlements. By studying different methods used for the rehabilitation of masonry building a suitable method for our site will be selected which have undergone settlement and cracks are visible in walls and slabs of the building. The main objective of our FYP was to achieve two goals which have been described below:

- Strengthening of typical masonry wall bearing structures subjected to settlement induced cracks using most optimum rehabilitation methods. For this, we will study various methods which are capable of rehabilitation of masonry building. By comparing various methods which are suitable and the best one for our site was selected.
- To develop a relationship between the total covered area of brick masonry and the optimum required area of columns for effective rehabilitation.

5. SCOPE OF STUDY:

This paper is intended to provide information on the strengthening of typical masonry wall bearing structures subjected to settlement induced cracks using the most optimum rehabilitation methods and compare various methods which are suitable and the best one for our site was selected which was using reinforced concrete columns.
After selecting the most suitable method the structure was analysed on ETABS.

Chapter 2

6. LITERATURE REVIEW:

We looked several research papers and following were found relative to our fyp.

6.1. *Rehabilitation and strengthening of old masonry buildings.*

By: H. Meireles; R. Bento
Date Published: March 2013

The strengthening of old masonry buildings is an important issue since these buildings constitute the historical centres of many cities and thus deserve attention from the state authorities for preservation purposes. When strengthening an old building, one must focus first on understanding how it is working, assessing its performance for gravity and seismic loads. Then, the problems and/or pathologies must be encountered and only then one can start prescribing the necessary solutions for the rehabilitation or strengthening.

The ageing of the masonry and in particular its desegregation depends a great deal on the way the masonry is protected by coating; the cracking or the loss of these coatings, expose the masonry to the action of the atmospheric agents being especially relevant to the action of the wind transporting sands and dust that give rise to erosion. The foundation settlements are usually associated with the construction of additional floors and/or the execution of excavations in the adjacent areas of the building and have has a result in the decompression and dragging of the soil. The changes in the groundwater flows are also important.

On the other hand, the structural system of the building may be assessed and improved whenever necessary. One reason for improving the structural system of a given building may be, for instance, the objective of changing its use or merely an adaptation to nowadays usages and facilities. For instance, the introduction of toilets, the introduction of elevators, air conditioning, the widening up of rooms, etc. Moreover, one can think of improving the structural system for earthquake resisting purposes. It is then very important to understand very well the original behaviour of the structure.

6.2. *Local interventions for structural improvement:*

a) ***Injections in Crack:***

The injections in cracks, internal or at the face, of a masonry wall, are a solution of strengthening that is irreversible. They are, however, used frequently because they preserve the original aspect of the exterior of the wall. It is particularly indicated for the rehabilitation of the masonry that has internal cracks connected between them. For this solution, a cementitious based grout is used or a hydraulic based grout or others such as organic resins-based grout. This solution is based on the injection in holes previously made with injection tubes and spread throughout the wall, to fill with the grout the internal cracks. For the external cracks, the coating should be removed previously, and the injection tubes may be used also.

b) ***Strengthening roof diaphragms with plywood***

To stiffen and strengthen the roof diaphragm (which may be originally made only by a single layer of boards nailed to the joists), one can adopt an intervention that is compatible with the original timber structure, by adding multilayer spruce plywood panels, which are lighter and easier to apply to an inclined plane in comparison to a reinforced concrete slab, although providing a significant stiffness increase.

One example of intervention [Magenes et al., 2012], Fig. 7, consists of adding 3 layers of plywood, each 21 mm thick, glued with polyurethane glue and connected to the purlins by means of chemically anchored, 10 mm diameter threaded steel bars. After having drilled and cleaned the hole, a two [9] component epoxy mixture is inserted in the hole and then the bar is introduced and rotated to distribute the resin. Bars were placed at a constant spacing of 30 cm and penetrated the purlins to connect the upper plank layers with the roof structure.

c) ***Transversal anchorage in wall:***

The application of transversal anchorage in walls aims to connect better the two layers of the wall avoiding their separation from the interior core, as can be seen in Fig. 8. The interior core is usually constituted by the rubble of low quality. The application of such technique may include, or not, binding material such as grout (cement, lime).

d) ***Strengthening masonry column with jacketing:***

In similarity with the case of strengthening the masonry walls with reinforced cement coating, the masonry piers can be strengthened with reinforced concrete as an outside layer. The steels rods are placed in the perimeter of the pier and then the concrete is poured covering the steel rods. The rods should be anchored to the base foundation of the pier.

e) ***Repair of damaged wood elements***

These are repair techniques and not strengthening solutions. The reduced existence of pieces of natural wood of considerable dimension nowadays makes it difficult to substitute complete pieces of damaged wood with natural wood elements. In this way, one can find several substitutes for wood.

The damaged wood elements may be replaced by glued laminated wood, for instance. The damaged wood elements can be replaced also with epoxy resin mortar and this mortar has similar mechanical characteristics to the wood to be reconstructed.

6.3. *Global interventions for structural improvement*

a) ***Strengthening of masonry walls with reinforced cement coating:***

In this case one places thin layers of coatings of cement reinforced with steel (or glass fibre or plastic meshes, see section d)) on masonry walls. The coating increases the strength and ductility of the walls. It can be placed on the outside or on the inside or both, depending on the most accessible areas. To enable the behaviour of both elements (existing and new) to work together one places steel connectors on the wall. It is thought that a wall of rubble (stone) masonry with 0.60 m of thickness reinforced with two layers of cement coating with steel meshes and with 0.10 m thickness in total, may have increased its strength in compression and shear of 3 to 6 times its original strength,atleast.

a) b)

Fig. 10 a) Masonry wall from the inside with steel mesh, b) spraying of the cement grout into the wall [fotos by Appleton, 2011]

b) ***Strengthening of masonry walls with polypropylene meshing:***

Polypropylene meshing uses common polypropylene packaging straps (PP - bands) to form a mesh, which is used to encase masonry walls, preventing both collapse and the escape of debris during earthquakes. PP -bands are used for packaging all over the world and are therefore cheap and readily available while the retrofitting technique itself is simple enough to be suitable for local builders. PP - meshing has been applied in Nepal, Pakistan and more recently in China. This method is most readily applicable in terms of low -cost upgrading of traditional structures to limit damage caused by normal earthquakes and give occupants a good chance of escape in a once -in -a - lifetime large earthquake. Non -engineered masonry is widespread throughout the developing world and replacement of all such dwellings is both unfeasible and undesirable, given that they are often the embodiment of local culture and tradition. It is therefore often more feasible to consider low-cost retrofitting.

c) ***Strengthening of floors and improving the connection floor/wall***

Traditional masonry buildings have timber floors, and they are typically flexible. The increase of the in -plane stiffness of floors is an evident and most effective method of improving the seismic behaviour of old masonry structures. This is mainly because the increase of in -plane stiffness of floors enables the structure behaves like a box, i.e., enables the horizontal forces to be redistributed between the different vertical structural elements, and then the horizontal forces of failing walls can be redistributed to the adjacent remaining walls. A significant role in the stability of the entire building is assigned to the floors.

d) ***Strengthening with composite materials (CFRP and GFRP):***

It is possible to strengthen with composite materials such as carbon or glass fibres reinforced polymers piers and spandrels within walls and/or columns of masonry. But the application of such method on masonry is still scarcely found. The strengthening improves flexural behaviour or tension and compression through increasing the confinement for instance in columns. The Carbon Fibre Reinforced Polymer (CFRP) or Glass Fibre Reinforced Polymer (GFRP) layers of material are glued with epoxy resin to the cleaned surface of masonry.

e) ***The use of horizontal tie rods :***

Tie -rods in steel can be used in several applications of old masonry buildings. For instance, they can avoid or at least decrease the probability of out -of -plane failure. Tie -rods can be also used in arches to absorb horizontal impulses.

Fig. 22 Tying of masonry vaults with tie-rods in steel (Santos, 2003)

Findings

This Paper provided us with multiple techniques that could be used for rehabilitation and strengthening of masonry buildings.

- Strengthening of masonry walls with reinforced cement coating
- Strengthening of masonry walls with polypropylene meshing
- Strengthening of floors and improving the connection floor/wall
- Strengthening with composite materials (CFRP and GFRP)
- Use of horizontal tie rods.
- Strengthening with RC & steel frames

The method which was most compatible for our building was providing RCC frames.

6.4. "*LCA-based study on structural retrofit options for masonry buildings*"

By: Loredana Napolano & Costantino Menna & Domenico Asprone & Andrea Prota & Gaetano Manfredi

Date Published :9th October 2014.

This paper provides a systematic approach and environmental data to drive the selection and identification of structural retrofit options for existing buildings, in terms of sustainability performance. The final aim of this work is also to provide researchers and practitioners, with a better understanding of the sustainability aspects of retrofit operations. In fact, the environmental impacts of the retrofit options here investigated can be used for future research/practical activities, to monitor and control the environmental impact of structural retrofit operations of existing masonry buildings.

In the present study, the environmental impact of different technological options for typical retrofit operations on masonry structures has been assessed. Four different structural options have been examined by means of LCA a: local replacement damaged mortar, mortar injection, steel chain installation, and application of grid-reinforced mortar. In all the retrofit options, it clearly appears that the recycling of building materials generates environmental benefits in all the categories. In particular, the recycling of building materials involves environmental benefits due to avoided impact of virgin material production. In the LRDM and MI retrofit options, the use of light mortar as a possible scenario (construction phase) is responsible for the major environmental impact in all LCA categories. When the LRDM and MI option comparison is done, the results show that the LRDM option is the major responsible for the environmental impact in all the categories. In the SCI retrofit option, the investigated scenarios presented similar environmental profiles, with the E scenario (cold steel chain elongation) that determines an impact that is only 3 % larger than the impact of the D scenario for all the categories.

In the GRM retrofit option, the use of the steel-reinforced grid with any recycling at the end of life produces the highest environmental impact in all LCA categories. On the contrary, when the reinforced grid is re-used in other structural engineering applications, steel GRM option presents the lowest environmental impact. Finally, the authors want to emphasize that the retrofit options and related scenarios presented in this paper and the corresponding environmental results can be used both in future research activities and in retrofit design stages to assess the environmental performance of retrofit strategies applied to existing buildings. This means that different retrofit alternatives can be considered and compared in a specific case, by considering the constraint of providing the same (minimum) requested structural performance. Indeed, an LCA-based comparative study can be then conducted on a real case considering the outcomes of this study, i.e., multiplying the obtained environmental impacts by the amount/extension of materials needed for the considered retrofit technique, possibly identifying the option characterized by the lowest impact.

Findings:

1. Different technological options for typical retrofit operations on masonry structures has been assessed. Four different structural options have been examined by means of LCA.
2. Local replacement damaged mortar (LRDM), mortar injection (MI), steel chain installation (SCI), and application of grid-reinforced mortar (GRI).

6.5. *"Case Study of Detailed Settlement Analysis of an Old Residential Building within Lahore Fort, Pakistan"*

By: Ehtisham Mehmood, Khawaja Adeel Tariq, Safeer Ullah Khan, and Ammar Raza
Date Published: 1st September 2018

This study deals with settlement analysis of a single story old residential building constructed inside the Lahore fort, Pakistan. It was constructed on non-engineering fill, and it exhibited major differential settlement. The building started to exhibit cracking and was rendered unserviceable in 2009. The building must be demolished for the new proposed structure. Crack mapping was performed to get an idea about the prevailing structural condition of the building.

Precise levelling was carried out to determine the exact amount of differential settlement in various parts of the building and its surrounding area. Soil investigation was carried out to determine the depth of the non-engineering fill and any other factors that contributed to the excessive settlement of the building. The engineering properties of the associated soil samples were determined. Finite element analysis was carried out using computer aided software to suggest different foundation solutions for the site. A cost analysis was also carried out for the decided remedy.

The historic site is very sensitive for new building construction. The situation becomes critical when excavation must do adjacent to building of historical nature. The 6m replacement can be achieved by first constructing soldier piles/ diaphragm wall with tie back anchors along the perimeter of the building to a sufficient depth. Instrumentation and other measures must be used to measure the response of the adjacent historic building to vibration, settlement, etc. during construction [16]. It is recommended to use a strip foundation for better and more uniform distribution of the building loads.

Findings:

- The walls of the building were liable to cracks due to settlement.
- The solution proposed was to replace 6m soil and constructing soldier piles or diaphragm wall with tie back anchors along the perimeter of building to sufficient depth.

Many other research papers were studied and these three were most relevant to our study of fyp and by using these papers we were able to decide the best optimum method for rehabilitation of our site building which was using reinforced cement concrete columns. The reason for selecting RCC columns was that there was a hard soil under the soft strata. These reinforced columns were decided to be placed at a depth to hard ground under soft strata of the building so that settlement is catered, and no more settlement occur in building.

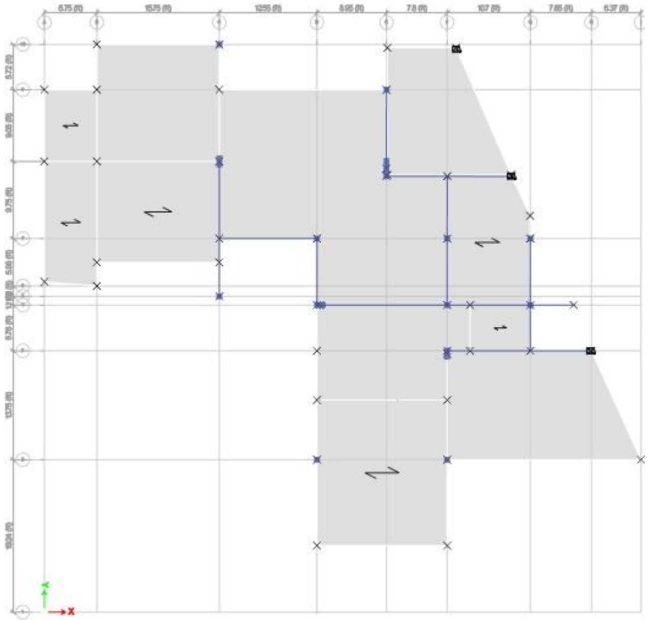
7. METHODOLOGY:

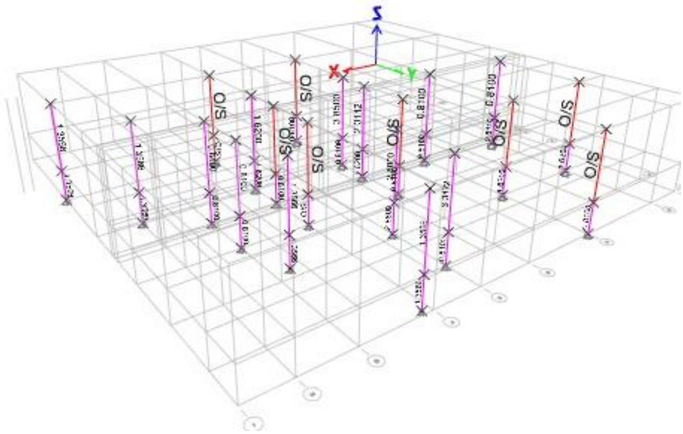
The objective of selecting the most suitable method of rehabilitation design of RCC frames for our case study, the methodology adopted had two distinct parts. The first part was the hit and trial method to achieve the most sustainable rehabilitation design with optimum number of columns and beams and the most suitable positioning of these columns and beams. The second part of our methodology was Developing an empirical threshold between the total covered area and the required area of RCC columns for optimum rehabilitation design of wall bearing structures.

To follow up with this methodology, the case study building was modelled in ETABS software. Various models were designed in ETABS for the most optimum position and number of columns and beams. The models are mentioned as follows.

7.1. Model-1:

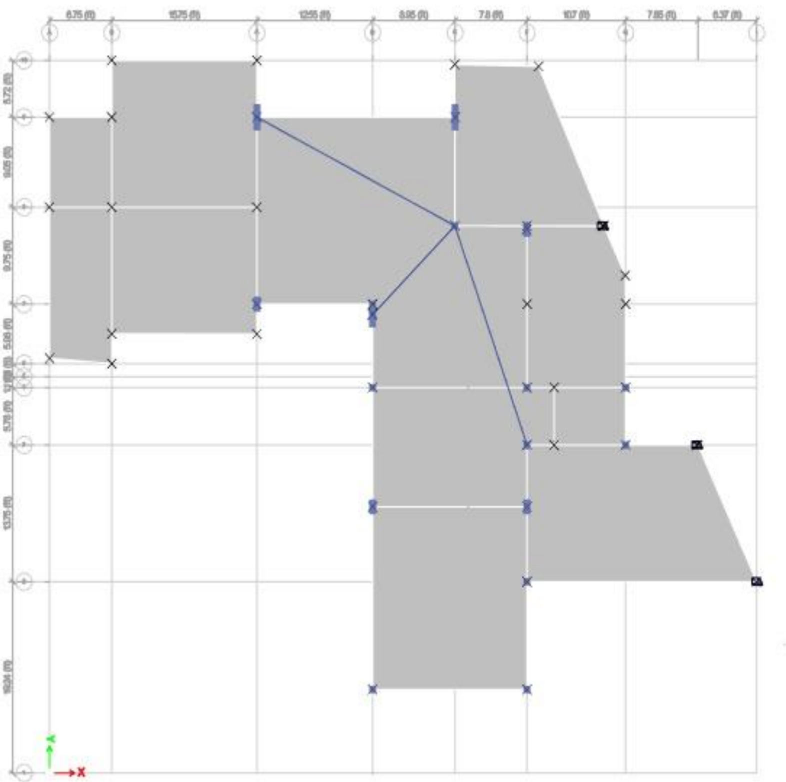
The total number of columns used in this model was 17. In this model, the number of columns 1,2,3 and 4 was 10, 3, 1, and 3, respectively.

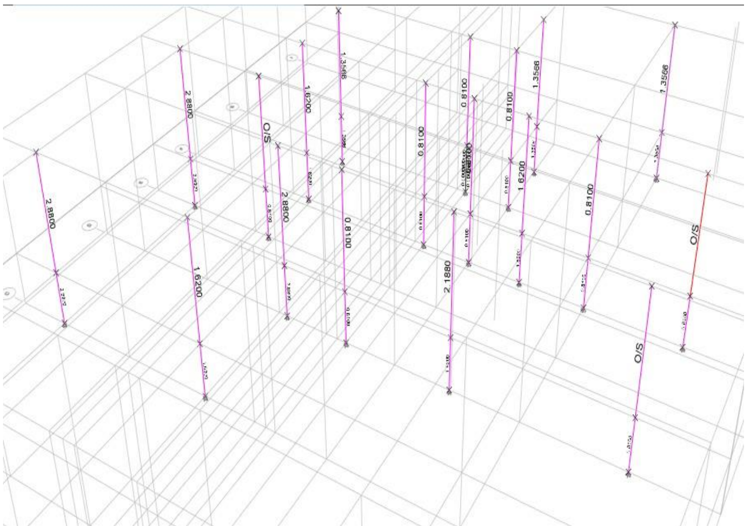




7.2. **Model-2:**

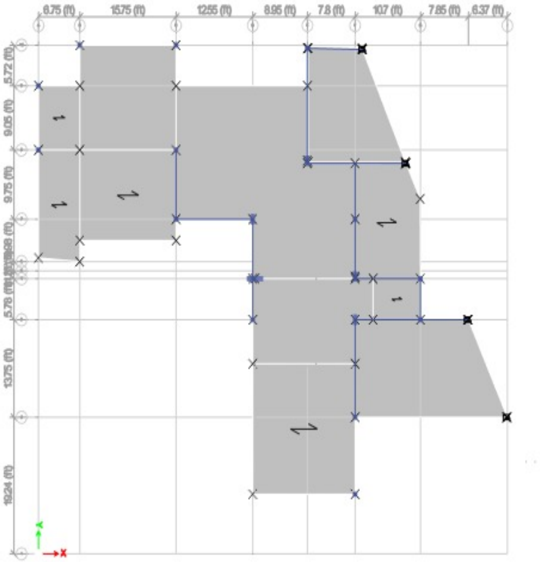
The total number of columns used in this model was 19. In this model, the number of columns 1,2,3 and 4 was 9, 4, 3, and 3, respectively.

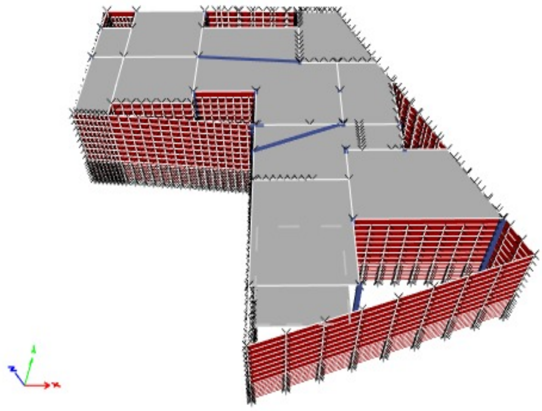


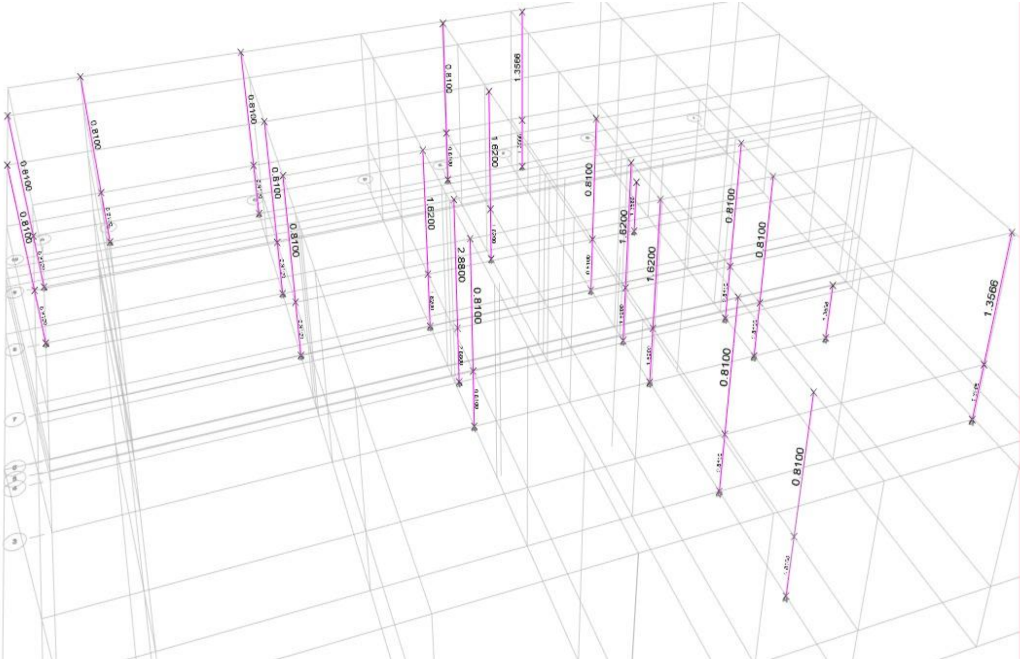


7.3. Model-3:

The total number of columns used in this model was 21. In this model, the number of columns 1,2,3 and 4 was 12, 1, 4, and 4, respectively.

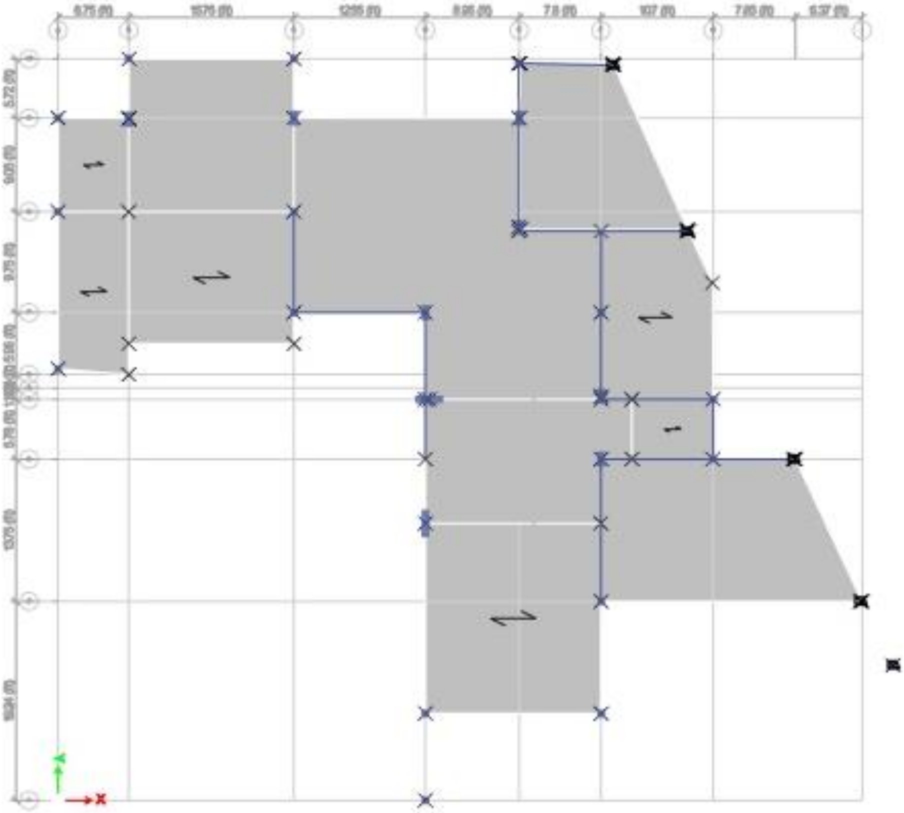


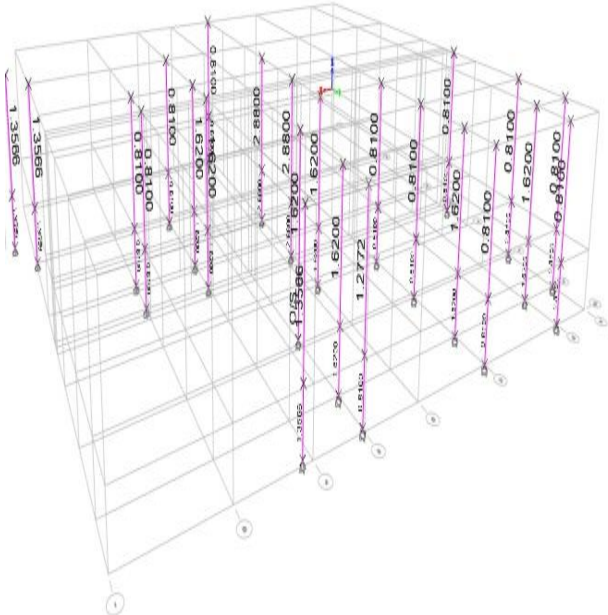




7.4. Model-4:

The total number of columns used in this model was 28. In this model, the number of columns 1,2,3 and 4 was 14, 7, 2, and 5, respectively.

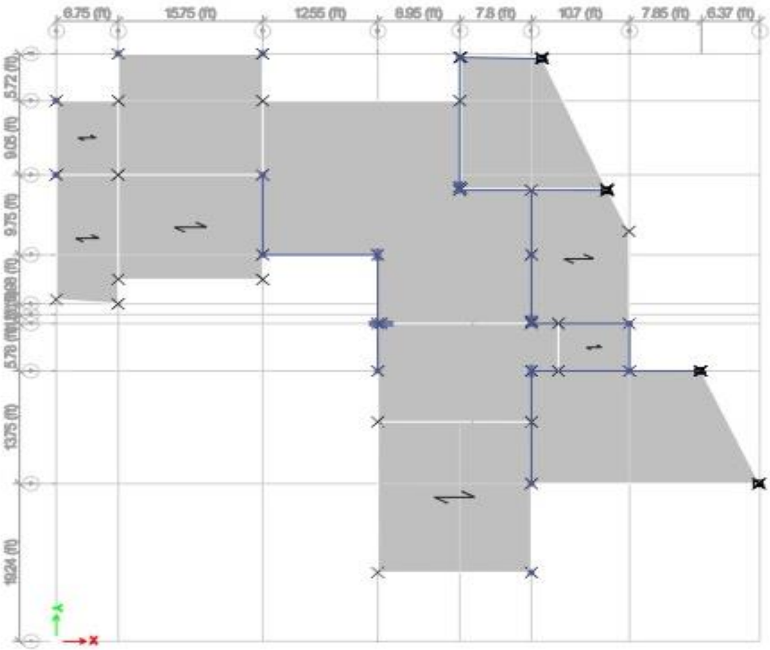




The model-3 was found to have the most optimum number of columns, hence different orientations of model-3 were designed in the next stage.

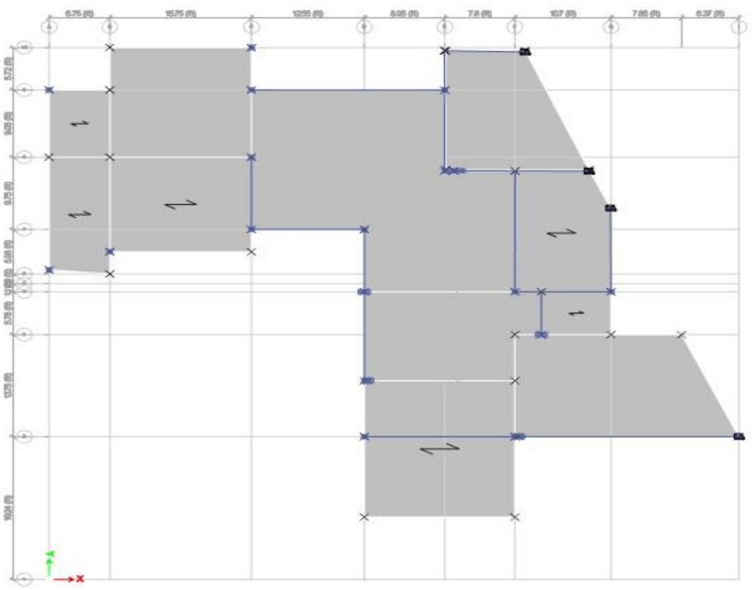
- **Model-3 Orientation 1:**

Maximum column spacing in this orientation was 25 feet.



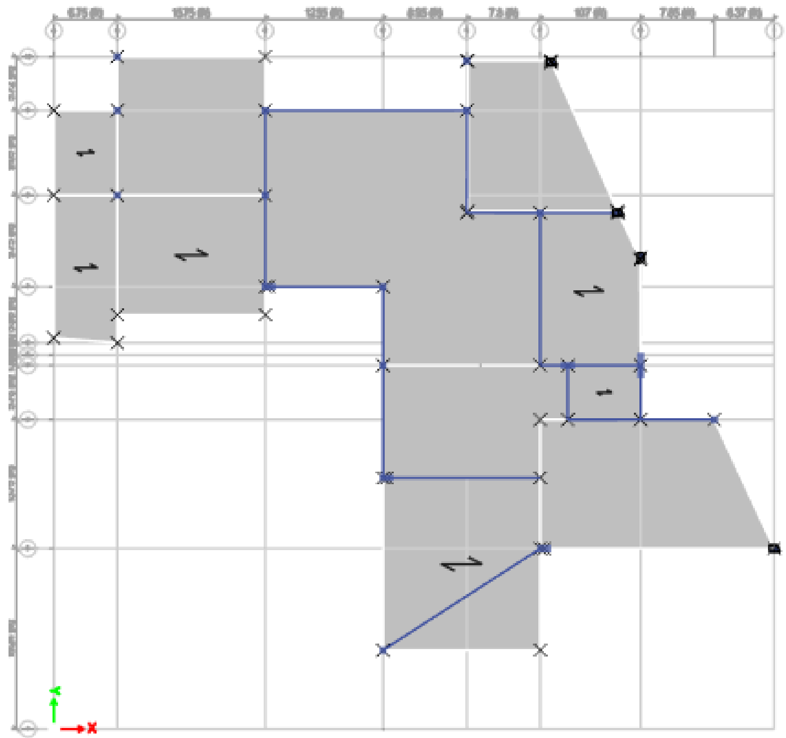
7.5. **Model-3 Orientation 2:**

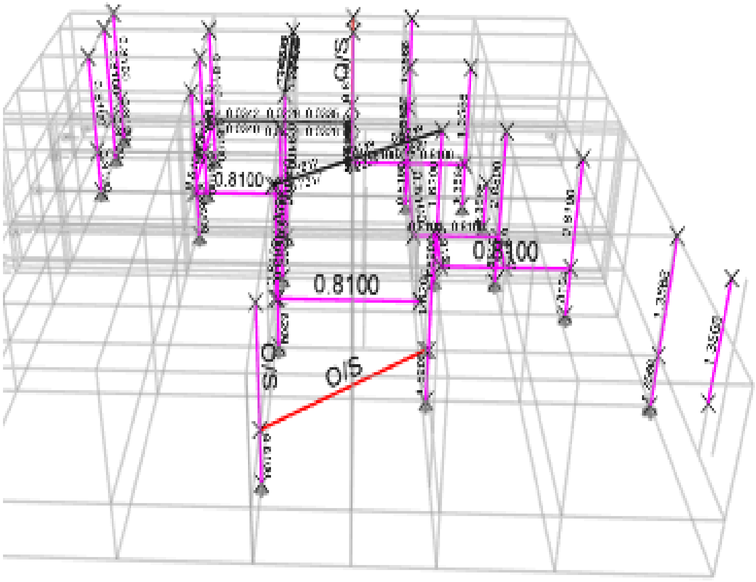
Maximum column spacing in this orientation was 35 feet.



7.6. Model-3 Orientation-3:

Maximum column spacing in this orientation was also 35 feet, but the number of beams was increased as shown in the model.




0.8100
0.8100
0.8100
S/O
O/S
O/S
1.3500

Chapter 4

8. ETABS:

ETABS is a 3D modelling software for any kind of structural analysis and design. Using this program, we could perform both steel structure and RC Structure. Here are some important advantages of ETABS software for 3D modelling which made it the most adequate software for our final year project.

ETABS Software, abbreviated for "Extended Three-dimensional Analysis of Building Systems" is a 3D integrated software that is used for structural analysis and design purposes in areas like civil engineering. It integrates every small aspect of engineering designing while also involving the production of schematic sketches. As many of us know how difficult it is when it comes to carefully lay out a structure on a piece of paper with every nuance being taken care of and that's where ETABS is useful.

ETABS provides a wide range of tools that an engineer can use depending on the choice of structure that has to be designed. Immensely popular nowadays and highly productive, ETABS is really an easy-to-use software. It even supports the creation and modelling of complex designs and offers graphic displays, comprehensive designing techniques, linear and non-linear analytical power, visualization tools and reports. Along with STAAD Pro and ProtaStructure, ETABS is one of the most powerful software tools for structural analysis. 3D modelling, visualization, and automatic code-based learning are some of the unique features of this software. ETABS also supports several analytical models like response spectrum analysis, time-history analysis, and line direct integration time-history analysis.

1. ETABS allows user for Graphic input and modification for the sake of easy and quick model creation for any type of structure.
2. Creation of 3D model with the utilization of plan views and elevations, 3D model of any kind of complex structure can be created easily.
3. With the help of similar storey concept creation of a 3D model is very easy and quick. If the storeys are similar, then the model generation time can be reduced multiple time through a similar storey concept.
4. Editing the model is very easy. Moving any object from one position to other, combining two or more objects using merge command, making the similar object using Mirror command and make a copy of any object in the same level of different story level.
5. Drawing of an object with most accuracy using snap command consisting of the end, perpendicular and middle or some other options.
6. The creation of an object is very quick for any type of object like a beam, column, slab, wall etc. with one click of the mouse.
7. Easy navigation through multiple viewing of windows. This feature allows you to create or edit your model very easily with a real-time view.
8. Create your model and editing has been easy through 3D view with a different type of zoom option as well as panning command for moving the whole model easily without any rotation.
9. Different view option of the 3D model including a plan view, any side elevation view, and customization view created by the modeller.

10. Graphical insertion of the sectional dimension of any kind of shape and material through section designer. Almost all types of shape of various members are available in this program.
11. The geometry of model copying and pasting feature from and to spreadsheets.
12. The exporting capability of the model geometry to .dxf files can be used in different working aspects.
13. Automatic consideration of self-weight of material has made it easy to consider the self-weight of various members even if sizes change
14. Automatic creation of Earthquake and Wind load saves lots of time to calculate them manually and assign them in the 3D Model.
15. Load combination as per your defined building code is also automated; you do not need to define them individually which save lots of time.
16. Very easy importing of model geometry as well as the design of Reinforced Concrete structures as per Greek code with the integration of STEREOSTATIKA.
17. For the design of Reinforced Concrete structures as per Greek and masonry structure as per Eurocode 6 also Reinforced Concrete jackets as per to Greek Code and pushover analysis has been made easy to perform by automatically creating plastic hinges.
18. For the 3D design of structural components like bridges, dams, tanks and building structures this program has integration with SAP2000.

Compared to the other structural engineering software packages available in the market,

ETABS has several additional advantages:

1. Built-in drawing utilities: To aid the engineers in modelling, ETABS comes with a built-in feature for drawing and drafting. Some other packages also have this feature, but the quality is much better in ETABS.
2. Extensive reports: ETABS generates detailed and comprehensive reports for every project or task you perform, be it calculation of stresses, deformation or failure analysis, and design summary.
3. Design of concrete and steel frames: Among all the materials available to build structures, concrete and steel are by far utilized the most in terms of volume. ETABS has specialized modules that deal with concrete and steel frames to optimize your calculations and offer capacity checks for frame elements.

8. ETABS MODELLING:

The models were initiated in ETABS, and the components were defined for the model. The codes used were (ACI 3.18-14)

8.1. DEFINING GRID AND STORY DATA:

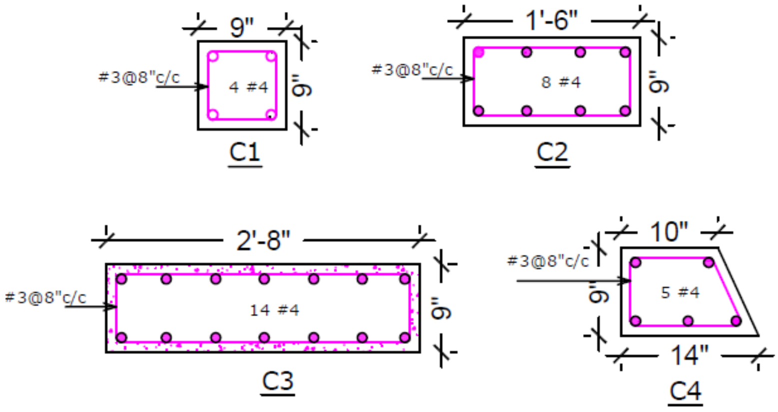
By using architectural plan, we have defined grid. And we have assigned all the floors which were taken from architectural plans.

8.2. DEFINING MATERIAL:

We have defined 4 types of materials. These were Concrete Fc 4000psi, Concrete Fc 3000psi, Steel Gr60, Steel Gr50 for walls we have assigned Masonry of 3000psi. All these materials were assigned as we are using hit and trial method and we will be taking the material accordingly. We modify our material property. The properties of material are selected by ETABS automatically and Unit weight of concrete is takes as 150 lb/ft^2 and the unit weight of Steel is taken as 480 lb/ft^2.

8.3. DEFINING COLUMNS.

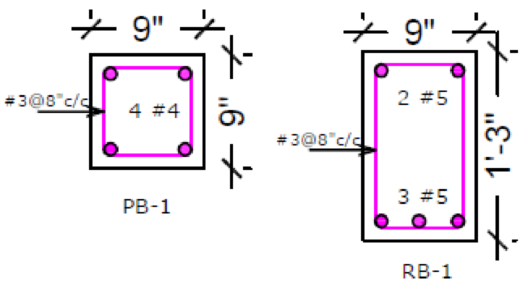
We have given 4 types of columns. The cross-section of these columns was provided along with the architectural plans of the building. We used 4000 psi concrete as the material for the columns. We modify our stiffness value using ACi 318-19, the moment of inertia taken is of 0.7Ig as they are weak in tension than in compression. Then we modify our rebar. Referring to the code we have selected 1.5" cover and we change reinforcement configuration as rectangular and circular accordingly. The cross-section of the columns is provided as follows.



X-SECTIONAL DETAILS OF COLUMNS

8.4. DEFINING BEAMS:

We have selected rectangular beam of 2 types. The cross-section of the beams is attached below. Again, we change our stiffness modifier using ACI 319-19 we select moment of inertia to be 0.35Ig. The Beam is assumed to be unsuitable for torsion, so the value has a factor of 0.01. The cover given was of 2" for both top and bottom bars.



X-SECTIONAL DETAILS OF BEAMS

8.5. DEFINING SLAB:

We have selected a 6" shell thin slab as we assume shear stresses to be 0. The stiffness modifiers are taken from code. Modifying stiffness modifiers from ACI 318-19 we have taken moment of inertia to be 0.25Ig.

8.6. DEFINING LOADS:

Firstly, we assigned our load patterns. ETABS calculates Dead load automatically. Then we have calculated super imposed deal load. All the loads are accommodated including Floor load taken as 36psf, masonry wall of 9" as 990 psf.. For live load all the live loads were taken from the code ASCE 7-16.

After Defining all the components, we assigned all the component properties on the ETABS.

8.7. ASSIGNING FRAMES.

In frame we have all the beams and columns. Firstly, we place our columns. We have all the gridlines we need to map our columns accordingly placing rectangular corner columns and interior columns. Then we place our beams between our columns.

8.8. ASSIGNING SLABS.

After setting up our frame we place our slabs on our frames. We took slabs of 6”.

Chapter 5

9. RESULTS AND DISCUSSION:

Based upon the ETABS models with the various number of columns, we conclude that for masonry residential single-story house which was our case study in this final year project, for a house of 2500 sq ft covered area, we require a minimum of 21 columns with a cumulative area of 16.25 sq ft.

Analyzing the models in ETABs helped us in determining a single model which had a specific arrangement of columns. This model stood out above the rest and easily sustained the loading conditions applied on the columns.

As you can see, there is not a single column that is over-stressed or appears to be buckled. So, this model is very much acceptable.

For each of the model we made, the number, size and positions of columns were changed. This helped us to gather a bunch of data based on these points. Some models failed as there were fewer columns and the load were not supported.

Economic factors were kept in mind as an excessive increase in our costs would have rendered our project incomplete. So, we needed to keep the cost point in check too. Having a greater number of columns was also not acceptable as they were taking more space than required and there is a direct increase in the cost of the project.

During construction, time and time are the main components that need to be in check throughout the project. So, there should be no negotiations on these two points. An increase in the time and cost affect all the parties involved and becomes a nuisance for everyone.

As the covered area in our case was 2500 square feet, so the empirical relation we have developed is in correspondence to the same. The relation is and will become a criterion for construction. One can use this relation to find out how many columns he/she needs to provide for proper load distribution.

Chapter 6

10. RECOMMENDATIONS

So, in a nutshell, to effectively rehabilitate a settled masonry residential house of 2500 sq ft covered area:

1. The minimum area of RCC columns required is 16.25 sq ft.
2. The maximum spacing that can be provided in these columns is 25 ft.

There are 2 different approaches used in the ETABs models, one explains the number of columns required in the building. While the other tells us about the maximum spacing that can be provided between the columns for smooth functioning.

11. REFERENCES

- Nanni, A., Tumialan, J., G.: Fibre-Reinforced Composites for Strengthening of Masonry Structures, SEI Journal of IABSE, Vol. 13, No. 4, 2003..
- Penazzi, D., Valluzi, M. R., Saisi, A., Binda, L., and Modena, C. (2001). Repair and Strengthening of Historic Masonry Buildings in Seismic Areas, Archi2000 Session 5: Architectural Heritage in Seismic Areas, Paris, France: UNESCO (7 p).
- ElGawady, M. and Lestuzzi P.M.B. (2004). A review of conventional seismic retrofitting techniques for URM. *The 13th International Brick and Block Masonry Conference*, Amsterdam.
- Costa, Alexandre A., Arêde, A., Costa, Aníbal, Guedes, J. and Bruno Silva, (2010a), Experimental testing, numerical modeling, and seismic strengthening of traditional stone masonry: comprehensive study
- masonry walls and strengthening solutions. *Earthquake Engineering and Structural Dynamics*. Wiley (published online 20 Sep. 2010).
- Bob, C., Bob, L., Florea, V., Gruin, A.: New Techniques for Rehabilitation of Masonry Structures, IABSE Symposium: Structures and Extreme Events, Lisbon, 2005.
- Dan, S., Bob, C., Enuica, C., Bob, L., Badea, C., Gruin, A.: Modern Solutions for Strengthening of Structural Elements, IABSE Congress: Creating and Renewing Urban Structures, Chicago, 2008.
- Drysdale, R., Hamid, A. and Baker, L., "Masonry Structures: Behavior and Design", Prentice-Hall Inc., Inglewood Cliffs, New Jersey , 1993.
- Kahn, L. F. ,"Repair and Strengthening of Masonry ", Proceedings 2nd Seminar on Repair and Retrofit of Structures, pp. 247, Ann Arbor, May 1981.
- Hutchison, D. L, Yong, P. M. F. and McKenzie, G. H. F. , " Laboratory Testing of a Variety of Strengthening Solutions for Brick wall Panels" , Proceedings WCEE, San Francisco, Vol. 1
- Meier, U. and Kaiser , H. ," Strengthening of Structures with CFRP Laminates ", Advanced Composites Materials in Civil Engineering Structures , ASCE Proceedings of the Specially Conference , 1991, pp. 205-211.