Building Rehabilitation of a Military Colonial Architecture: Miraflores Gunpowder Storage Building

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Abstract *— This article purpose is to show an investigation of the structural capacity for rehabilitation of an old clay brick masonry building. The structure past and historical value included in the literature exploration was to consider preview modification of the building system. The description of element's geometry composition informs a hypothetical structural behavior. The assumed properties material and applied load data were considering available values on codes of the American Society of Civil Engineers 2010 (ASCE 7-10) and American Concrete institute (ACI 2016). The description of the actual building conditions informs the elements deterioration. Additionally, for the purpose of locating the steel rebar, a non-destructive test was conducted. Three dimensional analysis for wind and seismic load were implemented using Etabs software. Eventually, some recommendations for the building rehabilitation were made considering investigations findings. Finally, an architectural proposal was considered to accommodate with no structural elements modifications.*

Key Terms *— Clay Brick Masonry, Code's Material Properties, Etabs, Rehabilitation.*

BUILDING HISTORY

During the 18th century, San Juan city fortifications were built as part of the defense master plan designed by Thomas O'Daly. The plan included five powerhouses; San Gerónimo 1768, Santa Barbara 1766-1776, Miraflores 1776, Santa Elena 1783 and San Sebastián 1791. These structures were built to keep and store the thousands of pounds of gunpowder and other military material required by the well-fortified "Plaza de San Juan" [1]. Due to the growth of the city and for security reason some of the powder houses needed to be closed. Nowadays, Santa Barbara is inside of El Morro Fort; San Gerónimo is preserved as a historic building; San Sebastian was demolished on 1923; Santa Elena and Miraflores are abandoned buildings.

40 years later after the Spanish-American war that ended in 1898, some changes started to impact Miraflores Zone. After serving as a powder house, for more than a century, it was converted to be a chapel in 1940, as show figure 1. But before that, the structure was also part of the Quarantine Station 1899 of Isla Grande Naval Base.

The Naval Base closed in 1971, and in 1982 with a special permit, the Institute of Puerto Rican Culture used the structure to accommodate San Juan Children's Choir and "Ballet de San Juan" headquarters. The actual owner of the building is the Government of Puerto Rico, but as part of the facilities of a special District the responsibilities are in the Convention Center District Authority. The CCDA is responsible for developing, managing and supervising all the district facilities. As part of the development plan of Isla Grande, Miraflores natural and physical environment would be restored; a gastronomic program for this structure is proposed.

Figure 1
Miraflores Gunpowder Magazine - January 24, 1980
Eastern Façade, Castillo Photography

STRUCTURAL DESCRIPTION

As described in the nomination form of the National Register of Historic Places Inventory of the building from 1980, this structure has undergone many changes. The building consists of a rectangular floor plan (50'4" x 189'1") surrounded by a wall (8'5" high) for protection [1]. Central space is covered by a thick barrel vault and reinforced by thick buttresses. On the outside, there are two sentry boxes, one at each opposite corner of the rectangular plan; is has three window openings and half dome as a roof. The structure has seven buttresses providing the same number of bays. The principal building material is clay brick masonry, with plastered walls [1]. The inside consists of a big open space, just like a contemporary storage building.

Some visible changes start in 1940 when the space or hall between the outer walls and the main building was covered with a slanting reinforced concrete slab and straight barrel clay roofing tiles on the outside. Those modifications include a bell-tower on the northeastern corner and eighteen large wooden doors at the inner wall for which lunettes were opened on the barrel vault. To accommodate the chapel program, space was divided for a small and large chapel, bathrooms and sacristy. Divisions are made using reinforced concrete walls.

ASSESSMENT: PHASE ONE

To consider a proposed use for the structure is important to have an up-to-date condition survey. Following the standards of the Historic American Building Survey Guide to Field Documentation (HABS), on–site work begins [2]. The building required cleanup on the surroundings for taking pictures and measurements purpose. A measurement tape of 100 feet was helpful to measure interior spaces, wall openings, and corridors and beam size. Also for the very high ceiling, the laser measure completed the drawing dimensions. It was possible to carry out a visual inspection of every space of the structure.

Structure Elements

To complete a full map of the structure, elements, materials and connection were identified. Table 1 shows the building spaces, element and materials and figure 2 shows its location on floor plan view.

Table 1
Spaces, Element and Materials

#	Space	Description
1	Surround Hall	Clay brick thick wall with a concrete layer, openings to exterior 10% with iron fence, 50% open and 40% walled up with concrete brick.
2	Main Space (or Chapel)	Clay brick thick wall and ceiling. Broken wood door and evidence of air condition system installation.
3	Sacristy Space	Wood panel covering reinforced concrete walls, Clay brick thick walls
4	Bathrooms	Height ceiling and complete bathroom features
5	Small Chapel	Evidence of air condition system installation, Clay brick thick walls
6	Building Roof	Inverted beam, assumed connection with buttresses, evident roof treatment, deteriorated drainage system.
7	Sentry boxes	At the building front 90% missing, at the back some problems with vegetation that are peeling off the concrete coating, the ceiling (half dome) has several cracks.

*visual assessment summary.

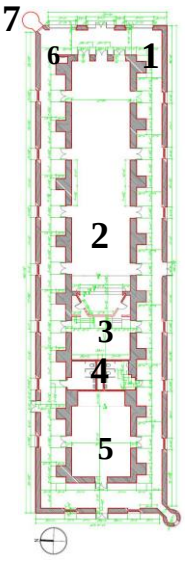

Figure 2
Miraflores Gunpowder Magazine's As-Built Plan View, Not to Scale

ASSESSMENT: PHASE TWO

Reviewing as-built plans and on-site observation of current structural conditions indicate damage and deterioration of the structure. Those results could be assumed as consequences of lack of building maintenance and its abandonment situation. The findings are discussed as follows.

The first thing that attracts attention are the massive clay brick walls. External and internal walls are constructed predominantly in solid clay brick masonry and their measures are 22.25 and 28 inches respectively. It's important to make clear that the initial purpose of the exterior wall was to protect the main structure, the one who support the barrel vault. That's why the interior walls are thicker than the exterior. That's is a common military construction typology for Spanish gunpowder magazines in Puerto Rico. Added partition walls are of reinforced concrete and wood panels. The exterior walls have 21 opening, from floor to ceiling, 13 are open and 8 are bricked up. The interior walls have 18 openings to accommodate wood framed doors. Walls reach eight (8) feet high. Figure 3 shows that walls are covered with a thick layer of concrete coating from 0.25 to 0.50 of an inch. It is assumed that the coating is to protect the brick integrity and avoid mortar lost.

Figure 3
Section Area of an Exterior Wall Missing Concrete Cover

Above the outer wall there is a rectangular concrete beam, 19" x 8", which it is at the bottom where the slope of the roof rests that covers the corridor that surround the structure. Figure 4 shows the slab visible corrosion damage in the steel rebar at the northwest side of the ceiling. From the visual observation is concluded that the rebar doesn't have the required concrete cover for protection. But no rebar has more than 10% loss of its diameter. Other parts of the ceiling have visible deterioration presented by paint peeling assumed to be caused by moisture. At the top of the slab, the roof, is covered by Spanish clay tiles that are broken, missing or deteriorated. Those conditions could conduct to leakage through the concrete slab causing corrosion in the steel rebar.

Figure 4
Sloping Ceiling and Roof Covered My Spanish Clay Tiles

The inner wall also reaches 8 feet high and at that point starts the barrel vault curvature. That central space reaches a maximum height of 17 feet with 22 feet and 10 inches wide as interior measurements. Brick concrete coating loss are the most visible evidence of deterioration. There's no visual substantial damage to the curvature of the main roof. Pointing to a unit pattern, the exposed area shows a longitudinal configuration of the brickwork. This type of construction needs to be considered since there are studies that conclude that cases with concentrated and lateral loads, there is a

considerable increase in the load capacity of the structure [3]. Describing the geometry, it could be interpreted as a longitudinally extended arch or a laying half cylinder. Figure 5 shows that the doors opening, at the main space, are defined by lunettes, described as a half-moon shaped space recessed void. This architectural gesture doesn't compromise the load behavior of the structure.

Figure 5
Barrel Vault Missing Concrete Cover

There is asphalt roof system waterproofing treatment at the exterior side of the barrel vault which is the main roof. There is evidence of lack of maintenance provoking obstruction, by dirt and vegetation that grow up through time, in the roof drainage. Figure 6 shows 8 inverted beam crossing the top of the barrel vault and resting in the buttresses; this connection cannot be seen. Each inverted beam is also connected with each other by a small longitudinal beam. That extra reinforcement element will be considered in addition to increase the load resistance capacity of the roof, as a military structure.

About the mechanical system inside the building, there is some evidence of an air conditioning system. The small chapel space has remains of old air ducts that still hangs from the ceiling. In fact, many wood door transoms have a rectangular hole assumed to be used for that purpose. That means the ceiling height help to accommodate any needs as air ducts or electricity features as lighting.

Figure 6
Barrel Vault Roof with Inverted Beam

The only sentry box that is still in place has an evident problem with the settlement. Figure 7 shows that the half dome roof has cracks that cross the ceiling. The exposure of the base is evidence of erosion. It is assumed that the problem could be caused by unequal compression of its foundation. For purpose of this investigation, the structure foundation will not be considered.

Figure 7
Substantial Crack inside the Half Dome of the Sentry Box

The other sentry box is 90% lost and the remaining pieces can be seen on the side wall and base, or floor. The entrance space was bricked up to avoid unwanted visitors. Near that is the bell tower that is constructed of reinforced concrete. It rests in an extension of the interior wall above and in the first buttress of that side. Figure 8 shows those remain elements in the actual condition of deterioration.

All 16 buttresses, 8 at each side of the building, area in perfect condition. Those elements have a rectangular base of 52 x 45 inches and rise to 17 feet high. Don't have visual deterioration, damage or alterations. The floor of the entire structure is in the same condition.

The building structure has plenty space around it to accommodate parking spaces, service area, mechanical equipment and take advantage of the landscape, extending the program outside it.

Figure 8
Missing Sentry Box

STRUCTURAL EVALUATION

The goal of the structural analysis is to determine that the building could be rehabilitated to hold a new use. Actual owner, Puerto Rico Convention Center, want to development a gastronomic use. The following studies will show if the structure has adequacy to the requirement needed to hold a restaurant program.

Considerations, Assumptions and Testing

Old clay bricks are difficult to characterize, due to the wide diversity of raw materials, manufacturing processes and conservation states [4]. Clay brick masonry have an attractive appearance and positive properties such as high compressive strength, durability and excellent fire, weather, thermal and insulation resistance. The historical investigation record of the structure demonstrate that the initial construction process starts circa 1768 (18th century), so at its 248-year old structure the durability is unquestionable.

Assumed clay brick properties are in accordance with ASCE 7-10, Chapter C3: Dead Loads, Soil Loads, and Hydrostatic pressure [5]. On table C3-2 Minimum Densities for dead loads from Materials it specifies conditions for Clay as follows.

For a clay property selection that is in accordance with the studied structure was considered initially constructions condition, in other words without the concrete coating. Table 2 shows the different types of clay that was considered. To be conservative damp clay density was selected because Puerto Rico has a very humid climate. Another mechanical property data that would be necessary is the Poisson's ratio which was assumed to be 0.2.

Table 2
Clay Density – ASCE 7-10

Material	Density (lb/ft^3)
Clay, dry	63
Clay, damp	**110**
Clay and gravel, dry	100

Another material property that was considered for the investigation was the concrete compressive strength. The ACI 562-16, Standard Code Requirements for Assessment, Repair, and Rehabilitation of Existing Concrete Structures and Commentary have standard data for a specific period of time [6]. On table 6.3.1a: Default compressive strength of structural concrete, psi, we can find an assumed concrete compression strength. In this specific case, the historical documentation reads that the concrete additions of the structure were from 1940. Therefore, the corresponding period is 1920-1940. According to the code for footing are *1500 psi* and for beams, slabs, columns, and wall would be *2000 psi* [6].

In addition, and recommended of ACI 562-16 was used a non-destructive testing to document the rebar's location in the concrete slab and beams [6]

[7]. The equipment used with a rebar detection system was the *Profometer 5*$^{+}$ that utilizes non-destructive pulse-induction method. Testing areas were made on the concrete wall inside the sacristy space, the small chapel space and at the bathrooms. Figure 9 shows the scan result of the sloping roof ceiling. Figure 10 shows result of the concrete beam at the top of the exterior clay brick wall that support the lowest side of the slopping roof. Figure 11 and figure 12 shows the inverted longitudinal beam and the curvedly beam at the top of the barrel vault roof. Finally, figure 13 shows one side wall of the bell tower. The result of the scan shows that all concrete element was reinforced using steel rebar. The walls at the interior, main space's partitions, are of reinforced concrete but don't have major structural purpose for the existing building. That means that are free for modification including new space configuration.

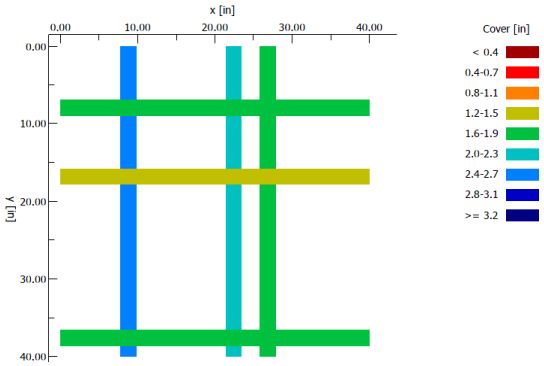

Figure 9
Sloping Roof Slab

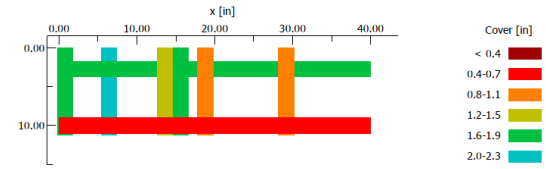

Figure 10
Rectangular Concrete Beam to Support Sloping Roof

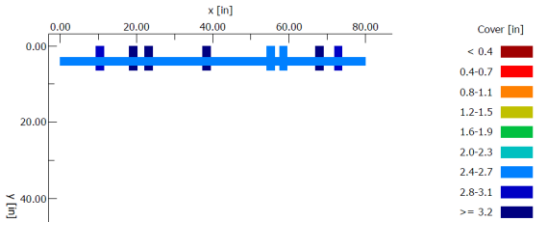

Figure 11
Inverted Longitudinal Roof Beam

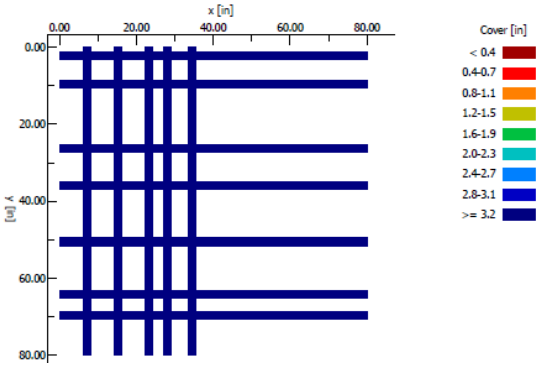

Figure 12
Inverted Cross Roof Beam

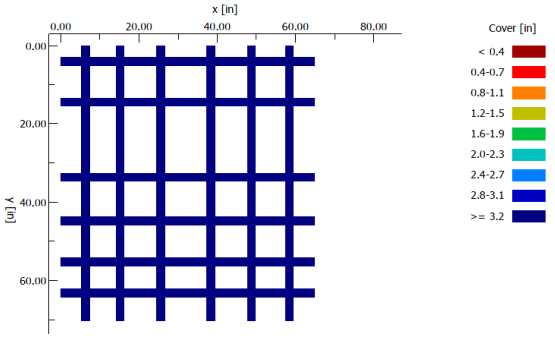

Figure 13
Bell Tower Rebar Location

The position of the scanner equipment, on the element, need to be mentioned for a proper reading of the rebar location graphics. For the inverted longitudinal and cross beam at the roof, obviously, scan reading was taken from the upper side. The rectangular beam was taken from the side and for the sloping slab was taken from the ceiling. Finally, one of the lateral walls of the bell tower was scanned.

Structural Modeling

As-built plans were made using AutoCad application which makes easier the construction of the 3D model and using it as a base. The structure was modeled using an engineering software product named Etabs 2015, version 15.2.2. Transferring all information collected in the digital model was the same thing as making a 3d free body diagram. It is necessary to understand or at least have an idea of the structure behavior. For example, the junction between the curved concrete beam and the clay brick buttress cannot be seen. The connection

between those two elements was assumed and interpreted in the model as a semi-rigid beam to column connection to establish the linking. The interior and exterior wall, the sentry box, the barrel vault, the buttresses, the reinforced concrete beam and roof were modeled with their respective measurements. Using the data collected in the investigation and previously discussed assumptions the specific properties was added to the modeled structure. Figure 14 shows the building model.

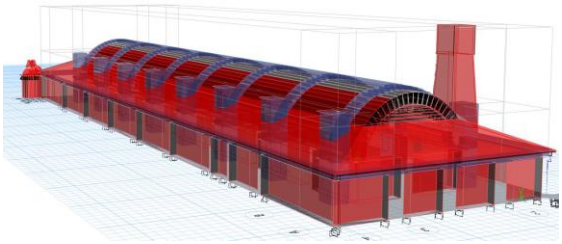

Figure 14
Structure Model on Etabs: Front Facade

After adding material properties, it is time to add corresponding live and dead loads to conduct wind and seismic analysis. The structure will hold a restaurant program and for that case, ASCE 7-10 establish a minimum uniformly distrusted live load of 100 lb/ft^2 [5]. That program doesn't affect the structure for being only one story height. In addition, the live load for the pitched and curved roof was 20 lb/ft^2. Also, to conduct structural analyses was considered load combination of self-weight, dead load, live, wind and seismic load according to ASCE 7-10 [5].

Analysis Result

The historical performance of the structure based on visual observation demonstrate a very strong stability. The analysis performed on the modeled structure reflect that hypothesis. The software Etabs presented the automatically generated seismic load analysis according to ASCE 7-10. Some data that determined the result are:

- Multiple direction
- Structure height above base: 32.8 ft (tower bell height).
- Long-period transition period= 8sec.
- Response modification factor, R=8
- Location souce by USGS Lat./Log Lattitude:18.449509 Longitude: -66.093923
- Roof angle: 6.75º

The calculated base shear was 425.552 kips (425,000 lb.) for x and y direction with a used period of 0.384 sec. As shows on figure 15, for both direction, was calculated a seismic force at 8 ft. above base 22.56 kips (22,560 lb.) and at 32.79 ft. (bell tower) a 349.14 kips (349,140 lb.).

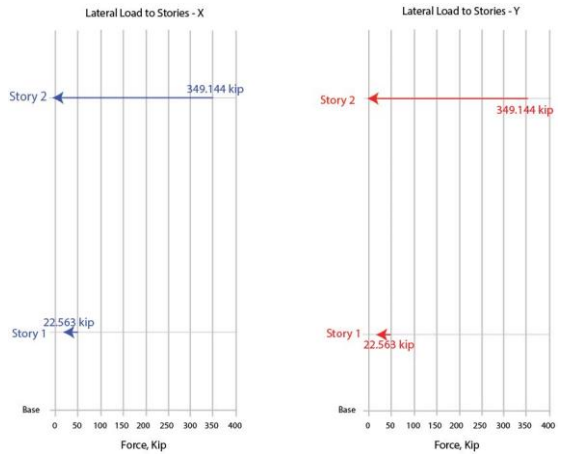

Figure 15
Story Forced Calculated by Etabs

Reading the result obtained, the building generates an enormous force and moment at the base for seismic reaction. That behavior was expected corresponding massively of the majority of the studied elements. Figure 16 shows the direct force per unit length acting on the elements. Predominant colors are green and cyan with the corresponding value from 0.00 to 0.24, respectively.

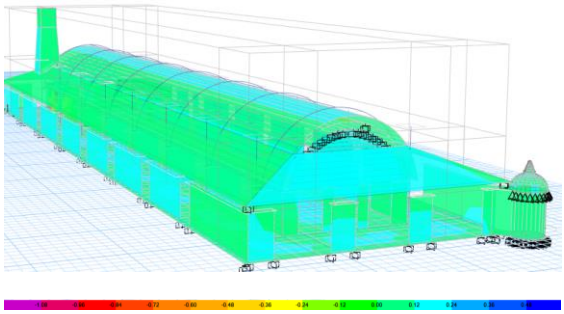

Figure 16
Direct Force per Unit Length by Etabs

On the wind load analysis, some data that determined the result are:

- Exposure from: frame and shell objects
- Exposure category: C
- Solid/Gross area ratio: 0.7 (maximum value)
- Gradient height: 900
- Emperical exponent: 9.5
- Topographic factor, K_{zt}=1
- Gus effect factor, G=1

The analysis result was a wind applied force of 12.59 kips (12,590 lb.) and 19.69 kips (19,690 lb.) at top story as maximum x and y direction respectively. The structure had a maximum displacement of 0.00764 of an inch and a minimum of 0 of an inch at the base. No significant drift of 0.000031 and a shear force of 52 kips (52,000 lb.).

Figure 17 shows the maximum principal force per unit length acting in the element. The predominant color for clay brick element is fuchsia purple wish value range is from 0.00 to 0.42. On the top surface of the reinforced concrete roof the range are variable.

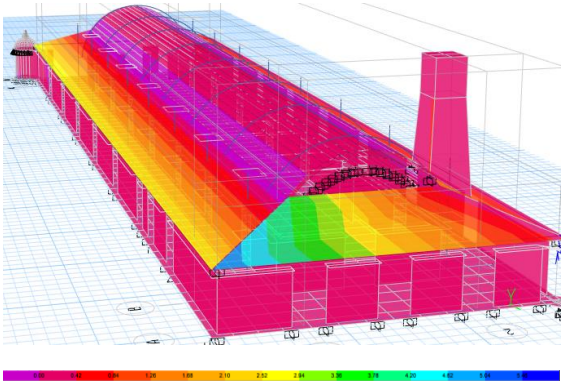

Figure 17
Maximum Forces per Unit Length Graphic by Etabs

BUILDING REHABILITATION

The rehabilitation of the architectural heritage results in the need to improve existing structure to accommodate new uses. Also to preserve, protect, and maintain the history and culture of the place. Puerto Rico has a stable tourism industry around the island. The proposed restaurant program will use the elegance of an old structure to promote the culture and its cuisine.

Structural Restoration

The walls will continue being protected with the concrete coating. A Repair will be needed to the interior and exterior wall, especially in areas that the coating is missing. Also, will need cover old small perforations. The barrel vault ceiling will also need the concrete coating in the missing area. The mechanical and electrical system for the main space will be anchored to the side wall and some time to the ceiling to accommodate lightings feature.

The concrete sloping slab roof will need repair in the area that the reinforcement protection cover is missing. The affected area is small compared to the entire building roof. Reference [8] recommend a few steps described as follows;

- Remove all unsound concrete
- Undercut the exposed corroded bars to provide clearance for under-bar cleaning and full bar embedment
- The clear space behind the reinforced steel should be greater than ¼ inch, plus the dimension of the maximum-sized aggregate in the repair material.
- The damage bar will require a gap from ¾ to 1 inch to inspect and cleaning (wire brushing or water-blasting).
- Place the repair material and encapsulate the bar with it. Reference [9] recommend types of coating for reinforcement.

The visual inspection of the area of corrosion determinates that the bar doesn't have lost more than the 10 % of its diameter. In that case, rebar will not require extra additional reinforcement [8]. Reference [9] recommend several materials for crack repair on concrete slabs.

The existing sentry box will need repair on its foundation to avoid interior and exterior cracking. To recommend a proper repair method will be necessary a detailed investigation about the existing soil and foundation. As a preliminary proposal is recommendable a helical pier repair method. The

technic has some advantage like ideal for compression force, little to no vibration, immediate load transfer upon installation, installed torque correlates to capacity, and can support 50,000 pounds per pile. This alternative only consists in screwed a pile into the ground until the desired bearing capacity is achieved [10].

Architectonic Proposal

For the other side of the building, the proposal will be an imitation of the old sentry box. The material will be reinforced concrete, steel and glass for the opening. The intention is to create a small space with an own character that its contemporary material imposed on the old structure. This architectonical gesture could be used as a privileged space of the corridor lounge or just to expose the restaurant menu.

Figure 18 shows the plan view of the main space down the barrel vault that will accommodate the dining room with a capacity of 30 round tables of 4 feet diameter. At the end will be a 16 feet bar space with direct access to the kitchen area. For the confection of food, a full equipped kitchen will be accommodated in a space of 450 square feet.

The existing bathroom are in compliance with the International Building Code 2009 requirement in a relation between occupant load and plumbing features. The space designated for storage room has a size of 730 square feet and also could accommodate a small office for the administrative purpose. The remaining space is the corridor that surrounds the main spaces. For that area is proposed to be a lounge space designed to be a public space for relaxing, drinking with a group of friend or just to have an informal meeting. In addition, the building space could be used for a big event if the outdoor is included as part of the spatial sequence.

Basically, the proposed restaurant program was accommodated in the building space in one manner to avoid structural modifications. The consideration made the rehabilitation more feasible focusing just in repair what it's already damaged.

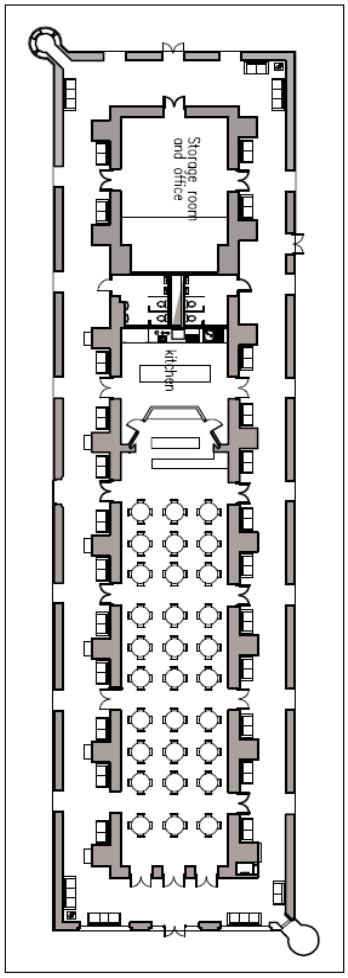

Figure 18
Building Plan with Restaurant Furniture

COST ESTIMATE

Table 3 shows the cost estimate breakdown repairs in a preliminary concept. The part that are considered are the ones necessary to start using the building with the proposed restaurant program. In some cases, for a single project are necessary to consider a few steps. For example, the sloping roof repairmen are necessary to consider the followings; the steel reinforcement concrete cover and protection, the removal of the old clay Spanish tiles, crack repairmen material and procedures, concrete roof waterproofing treatment, new Spanish clay tiles, transportation, installation and labor. The table cost values are based from data of a variety of construction companies that estimates the labor by square feet.

Table 3
Repair and Proposed Modification Cost

Repair	Quantity	Cost
Reinforced concrete sloping roof repair	500 ft^2	$700.00
Spanish clay tile replacement and roof treatment	5160 ft^2	$200,000.00
Concrete coating at the ceiling of the barrel vault	8,000 ft^2	$15,000.00
Construction of ramp for handicap accessibility	1 / 24 ft.	$3,000.00
Electrical, Mechanical and water plumbing installation and repair	9450 ft^2	$60,000.00
Doors and iron fences	39 units	$20,000.00
Sentry Box cracks and settlement repair	35 ft^2	$15,000.00
Construction of a sentry box with steel, concrete and glass	35 ft^2	$25,000.00
	Total	**$338,700.00**

CONCLUSION AND FUTURE STUDIES

The material properties data of this case study was assumed by codes standard data, investigation report, and companies testing documentation. To conduct a more accurate investigation it would be recommendable to explore more with laboratories testing exercise with material extracted from the structure. A full investigation can be based on the composition of the clay brick and its direct relation with its raw material, size, geometry and compression capacity. Also would be necessary to conduct some destructive testing to corroborate some connections like the inverted beam at the barrel vault roof with the buttresses. To confirm the behavior of the foundations, it will be necessary to investigate with the proper equipment the condition of the entire building foundation. At last, the structure could have a simple investigation in comparing brick cover material, as concrete coating versus the original lime covering.

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