Structural assessment and rehabilitation of historic buildings in Galveston, Texas

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Abstract

The city of Galveston is located by the coast on the Galveston Island in Texas. Due to its strategic location, the city served as the main port for the Texas Navy during the Texas Revolution, and later served as the capital of the Republic of Texas.

The city of Galveston is one of the major tourist attractions in the state due to its historical districts, which host buildings constructed in Greek, Gothic and Victorian styles. However, this important collection of the 19th century buildings is under serious risk due to hurricanes, which have killed thousands of people and caused tremendous damage in the Gulf of Mexico. The most recent devastating hurricane in the region was Ike, which struck in September 2008.

This study aims to explore the structural performance of the historical residential buildings in the city of Galveston and propose appropriate structural strengthening methods to increase their structural performance in a probable hurricane while keeping their historical values. Available information has been gathered about structural systems and connections between the structural members. A typical mathematical model that represents the structural systems and conditions of a Victorian style residential building has been developed. As the final step of the study the model has been analyzed under dead loads and wind loads with alternative strengthening approaches. The results obtained from these analyses would be helpful to assess the present structural performance of the buildings and understand how much strengthening they require. The results are also used to compare the performances of the existing structural systems and the improved structural systems. And finally, as preserving the original quality of the historical buildings is crucial in conservation, the least destructive methods to the originality of the building are identified.
Keywords: cultural heritage in Galveston, historical timber buildings, structural assessment of historical timber buildings, wind analysis of historical timber buildings.

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1 Introduction

The city of Galveston is located by the coast on the Galveston Island in Texas. The island is oriented northeast-southwest, with the Gulf of Mexico on the east and south, West Bay on the west, and Galveston Bay on the north. Forming a natural harbor and a port for trading, Galveston Bay offered economic and commercial advantages, which exponentially increased after Texas won its independence in 1836. Despite its flat, sandy and narrow land, the island became an important destination and the port of entry for thousands of European immigrants. In addition, the slave trade supplied labor to cotton planters and urban slaveholders [1].

The period from 1870 to 1900 defined the architectural characteristics of the land. Galveston became a city of expanding commercial and shipping center. However, the hurricane of September 8, 1900, which is still known as the deadliest natural disaster in North America, devastated the island by killing over six thousand people and destroying about one-third of the buildings [2].

Hurricanes striking the United States bordering the Gulf of Mexico are known to have caused severe damage. Among them all, Ike is the last devastating hurricane that hit the Galveston area. Ike made a landfall over the north end of Galveston Island as a Category 2 hurricane with 110 mph maximum wind speed on September 13, 2008. It caused total damage of $29.5 billion in the United States and killed 195 people [3].

Galveston has not fully recovered from the effects of the devastating hurricanes. The community, which comprises of people who have not abandoned the city, is still vulnerable and socially exposed to hazards. The social aspect of vulnerability could be improved by resilient design, which would be based on providing sound structures against hurricanes for the residents.

There are also economic vulnerabilities that trouble Galveston Island. After the hurricanes, the economy, which is primarily based on shipping and tourism have been adversely affected. The community has been in serious need for the revival of the components of these items to support the economy.

The tourism industry of Galveston is based on leisure travel, conventions, and tourism. The city has an invaluable cultural asset, which is particularly due to its popularity among European immigrants in the 19th century. The majority of the cultural heritage is located at the East End Historic District, Silk Stocking National Historic District, Lost Bayou Historic District and Strand/Mechanic Historic District (Figure 1) [4, 5].

This study aims to explore the structural performance of the historic residential buildings in the city of Galveston. It also explores the efficiency of strengthening the connections to increase the performance of historical timber buildings in a probable hurricane while keeping their cultural values. A model similar to the plan scheme and layout of a 19th century historical building has been developed based on available data about materials, structural systems and connections between the structural members. Analyses have been conducted on the mathematical model with alternative strengthening approaches regarding the

Figure 1: 19th century house in Galveston.

connections between the structural members. The results obtained from these analyses would be helpful to assess the present structural performance of the buildings and understand how much strengthening they require. The results would also be used to compare the performances of the existing structural systems and the improved structural systems. And finally, as preserving the original quality of the historical buildings is crucial in conservation, the least destructive methods to the originality of the building have been identified.

2 History and architecture of the city of Galveston

The first European settlements on Galveston Island, which was named after the Count of Gálvez, Bernardo de Gálvez y Madrid, were constructed in the early decades of the 19th century. Upon the successful independence from Spain, Congress of Mexico established the Port of Galveston in 1825. Due to its strategic location, the city played an important role as the main port for Texas Navy during the Texas Revolution and then served as the capital of the Republic of Texas [5]. In 1838, a city plan with very precise grid pattern was developed. The narrow lots, which were probably the result of scarce land, shaped the architectural characteristics of the city. After the Civil War, mansions were built for the wealthier residents; however, a big fire in 1885 destroyed forty blocks with around 500 houses. Therefore, a big portion of the historical asset that represented the city's past was ruined. After this fire, an important portion of the houses was replaced within a year. This process brought a more uniform look to the city [2].

Galveston remained as one of the largest ports in the United States until it was devastated by the great hurricane in 1900. After this big disaster, the city showed its resiliency in a more radical way by building 17 feet high and 4-mile long sea wall, which was extended for another six and a half miles. The construction was completed in July 1904; but this process necessitated a significant change in the structure of the island. The elevation of the island was raised in a process that lasted seven years. The grading of the island started at the highest point, which is the sea wall, and sloped towards the downtown area including the Old Central Carver Park, which is now one of the historic districts. The lower level of many structures was partially filled, especially where houses were set on raised basements or masonry piers. This explains the half buried foundations that can be seen on some of the larger structures [2, 6, 7].

In September 2008, the region was devastated one more time with Hurricane Ike. As a result of the change in topography, the Old Central Carver district in downtown area sustained a great damage due to flooding that saturated the infrastructure and buildings. The majority of the region housed the working class occupying the housings for low to moderate-income residents. Historically, the houses located near the port were home to the minority working class. The study that was carried out by the University of Texas at San Antonio in 2009 showed that more than 40% of the housings in the north side of the town have historical features and should be preserved [6].

Galveston hosts one of the most important collections of the 19th century architecture. An important number in its building stock represent the Greek revival, Gothic, Romantic, Clayton Era, and Victorian architecture. Even though the architectural styles show great variety, it is possible to categorize the building types according to their plan schemes and layouts. The most commonly encountered building types could be listed as: Shotgun cottage (commissary house), front or side gabled house, gulf coast cottage, southern town house, I-house, Italianate house and L-plan Victorian cottage [2].

Galveston's architectural preservation and revitalization efforts over several decades have earned national recognition [7]. Especially after Houston took the lead in the port commerce after the big disaster and Galveston was no longer dominated by port activities and wholesale trade, the city's survival has depended on preservation. Many buildings, especially dwellings have experienced multiple rehabilitations since 1970s [2, 6].

3 Strengthening of historic timber buildings against wind loads

Wood structures are generally not exposed to large inertia forces as they are light weight [8]. They are capable of carrying higher loads for short periods of time and they can have excessive deformations due to their ductile nature. Wind loads can produce bending stress in wall studs. Adequate braces are required for stability reasons as timber buildings are most susceptible to wind damage due to strong storms or hurricanes [9, 10].

To determine the wind pressure on a structure, the wind speed must be determined. The wind speed can basically be calculated according to the codes and regulations that provide the map of wind speed across the country. Besides the location of the building, the wind speed also depends on the size of the building. To calculate the total wind pressure, the positive and negative pressures on the windward and leeward sides should be added together [9].

Strengthening of any building starts with a detailed understanding of structural behavior. However, this may not be an easy process as the properties of wood are variable. The species of the tree, natural imperfections combined with the construction quality and connection and fastener details make it more difficult to achieve a reliable structural assessment [8].

Assessment of structural performance of historic wood buildings is even more difficult due to unknown material and mechanical properties, complexity of the structural layout and connection details. There are other factors that would affect the structural performance of the building, such as decay, termites, change of service, temperature and humidity, condition of bearing members and connections and duration of loads that the structure has been exposed to. A detailed investigation about these issues is one of most important steps of strengthening of historic wood structures [11].

A careful inspection for the structure is necessary before making any decisions about the type of strengthening required. If deterioration were limited to one member, replacing that member would be efficient. Local strengthening can be preferred if the damage is also local. However, since detailed inspections require stripping the structure, the process would be both costly and difficult even before starting the procedure [8, 11]. Considering that the structure has historic values, it should be preferred to keep the structure as close as possible to its original characteristics. Moderate interventions might be better means for strengthening, as they would provide improvement to a certain degree while preserving the original characteristics [12].

In the process of replacing a member, directing the loads temporarily to other structural members while disconnecting the defective member and assembling the new member are the two main concerns. Even if it is limited to only one structural member, the process might present problematic issues. Adding straps, steel ties or plates, on the other hand, can considerably improve the behavior and preserve the historic quality in a more practical and manageable way. Diagonal members can be added in the openings, or simple braces can be added to create rigid connections and improve behavior [8].

4 Structural analysis of a historic timber building in Galveston

4.1 Definition of the analysis process

In this part of the study a frame of a two-story historical timber house has been modeled by using the SAP2000 software. The model has been developed according to the drawings and surveys of a 19^{th} century building, which is currently under restoration. The purpose of the analyses is to propose methods to improve the resistance of historic timber buildings against wind loads while preserving their historical value as much as possible. Linear analyses considering dead load and wind load have been performed on the model.

There are various ways to strengthen historic buildings. Many of these methods would provide the desired strength in terms of behavior; however, one of the key points is to preserve the original members of the building. In many cases, provided that it guarantees the desired behavior and strength, adding new members to the system or reinforcing the connections is a more preferable approach than replacing the structural members in a historical building.

In this study, one frame has been selected to show the effects of connections and support conditions on the behavior of structural systems. Based on the same plan scheme, five different configurations related to column-and-beam-connections and the support conditions have been considered. Two sets of analyses, first one under dead loads and second one under wind loads, have been performed on each configuration. The properties of the configurations related to support conditions and column and beam connections are given as the following:

Configuration 1:	All supports are fixed. All column and beam connections are rigid.
Configuration 2:	All supports are hinged. All column and beam connections are rigid.
Configuration 3:	All supports are fixed. The column and beam connections at the outer bays are released forming weak points at both levels. The connections at the inner bays are still rigid.
Configuration 4:	All supports are fixed. The column and beam connections ate the inner bays are released forming weak points at both levels. The connections at the outer bays are still rigid.
Configuration 5:	All supports are fixed. All column and beam connections are released.

As the building is currently under restoration due to a fire it has experienced in the recent years, the structural members were all visible. The column dimensions were measured as 20 cm x 20 cm and the beam dimensions were measured as 10 cm x 20 cm. The dead weight due to secondary structural members such as joists and studs have been included in the calculations. The unit weight for the wood members has been taken as 8 kN/m^3 (specified as 50 lb/ft^3 in the restoration documents) and Modulus of Elasticity has been taken as 11 031 612 kN/m^2 (specified as 1,600,000 lb/in^2 in the restoration documents). The loads have been taken as 4 kN/m^2 and 2 kN/m^2 at the floor and roof level, respectively.

Representative wind loads has been applied on the frame as well. Using the software developed by Ochshorn at Cornell University [13], and considering the tributary area of the frame, the wind pressure that a Category 5 hurricane with 240 km/h (150 mph) speed would create has been applied on the frame as a combination of windward and leeward pressure.

4.2 Results of the analyses

The analysis results provide significant findings about the effects of connection details and support conditions. In this study, only the displacement values in the horizontal and vertical loads have been given as the displacements values give important clues about the probable behavior of the system.

Figures 2–5 display the horizontal displacements in the given configurations. Table 1 shows the maximum displacement and moment values. The vertical displacements are due to the dead loads, and the horizontal displacements are due to the wind loads. The most critical displacement values are detected at the upper corner of the frame system; hence the table lists only the most critical values in each setup.

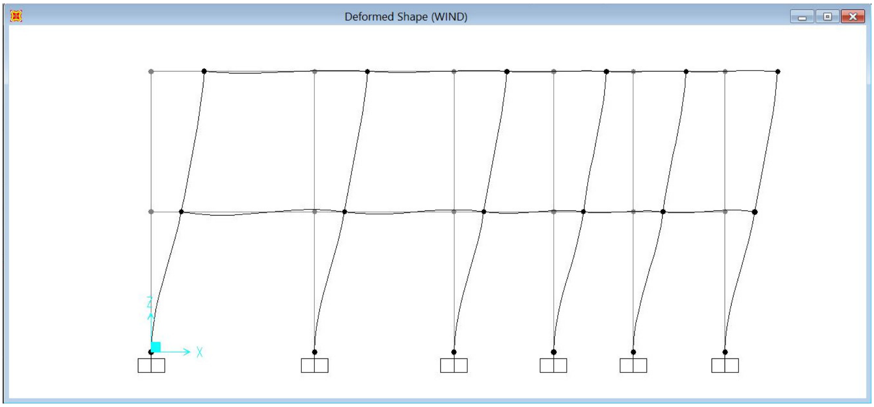

Figure 2: Horizontal displacements in Configuration 1.

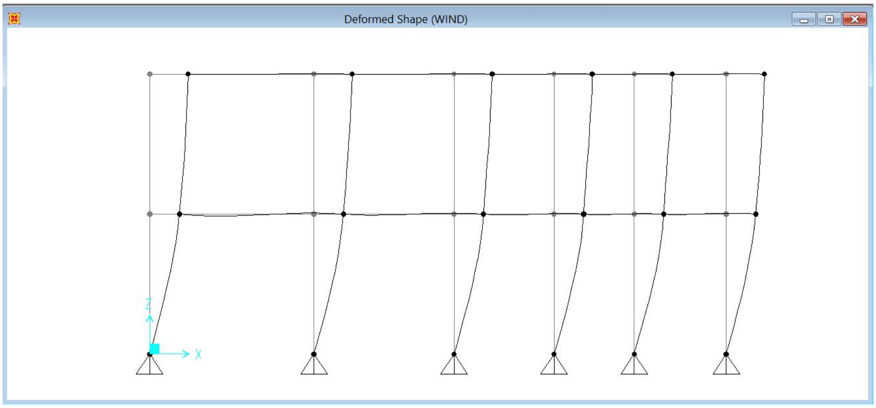

Figure 3: Horizontal displacements in Configuration 2.

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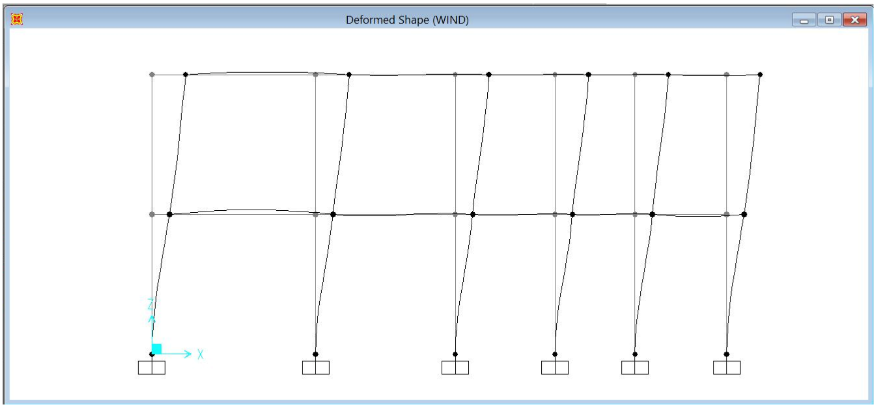

Figure 4: Horizontal displacements in Configuration 3.

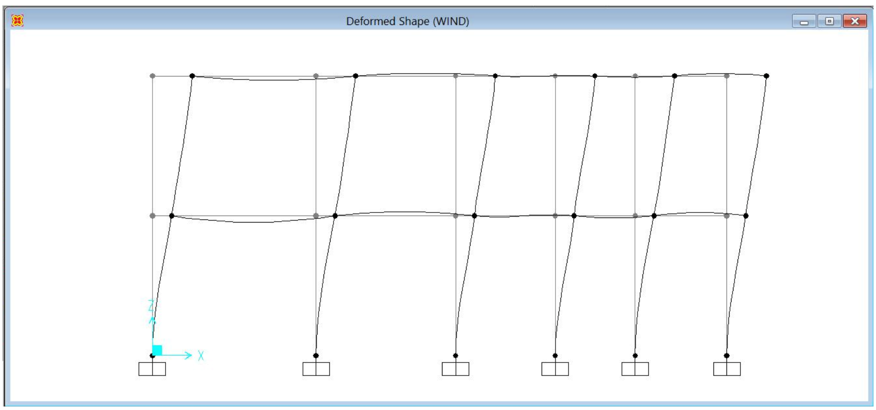

Figure 5: Horizontal displacements in Configuration 4.

Table 1: Displacements and moments.

Model	Displacements		Moments	
	Vertical Load (mm)	Horizontal Load (mm)	Vertical Load (mm)	Horizontal Load (mm)
Configuration 1	0.47	33.08	1.40	11.96
Configuration 2	0.81	95.00	1.27	30.95
Configuration 3	1.65	41.50	0.19	5.14
Configuration 4	0.78	55.00	2.05	10.30
Configuration 5	0	222.04	0	47.72

The table also lists the most critical moment values for each configuration. The most critical bending moment values are obtained at the beam and column connection point at the top of the ground floor column. Interpretations of these results are given in the next section with possible suggestions to improve the behavior of historical timber structures.

5 Conclusions

According to the outputs obtained from the analyses, the maximum vertical displacements have been observed in Configuration 3, which has the weak points at column and beam connections at the outer bays. Still, this value is only 1.65 mm and does not indicate any risks. The maximum displacement in the horizontal direction, however, is observed in Configuration 5, where all the beam column connections are released. The displacements are seen as excessive and they are not within the acceptable limits. If the connections are not treated, the building is likely to collapse during a strong wind. The released connections could be taken as the basis for the typical behavior of historic timber structures with no straps or braces between the columns and the beams.

The most efficient configuration in terms of both vertical and horizontal loads is where all the supports are fixed and the column and beam connections are rigid, which is Configuration 1. The horizontal displacements look excessive with a value of 33.08 mm; however considering the ductile behavior of timber, this value could be considered to be within acceptable limits. Besides, it is still a great improvement when compared to the 222.04 mm displacement where all the connections are released Thus, this difference shows us how important the condition of a beam and column connection is.

When Configuration 1 and Configuration 2 are compared, the difference is seen at both the vertical and horizontal displacements. The vertical displacement increases from 0.47 mm to 0.81 mm and horizontal displacement increases from 33.08 mm to 95 mm. Both the vertical and horizontal displacements in Configuration 2 are the second biggest values in their categories. The reason for these big displacement values is the hinged supports at the base of the column. Even though all the column and beam connections are rigid, the structure still shows a weak resistance, especially against horizontal forces, when the columns do not have fixed supports.

When Configuration 3 and Configuration 4 are compared, we see that the rigid connections at the outer bays and released connections at the inner bays provide better resistance against wind forces than the rigid connections at the inner bays and released connections at the outer bays would. So, if there is a limit for interrupting the structure, the modifications related to the connections should be realized on the outer bays rather than inner bays.

The best way of creating rigid connections in a timber system is to insert diagonal members. However, inserting diagonal members within a frame may not be strictly necessary to improve the behavior. It will also damage the original appearance of the building by blocking the openings on the façade. Instead, a bracing from the beam to the column by means of a steel strap would provide enough improvement for lateral load resistance while interrupting the façade arrangement much less than a diagonal member would. Additionally, the condition of the column supports should be considered and rigid connections for those should be provided when possible.

When moment values are considered, it is possible to come up with a similar conclusion. The biggest moment values are obtained at Configuration 5 where all the column and beam connections are released. The second biggest values are seen when the column supports are hinged instead of fixed. The connections should be improved by providing rigid connections at the base of the columns. The connections between the columns and the foundations have to be reinforced and modified to create fixed supports.

The historic timber dwellings in Galveston constitute the very significant part of Galveston culture. The island is prone to strong winds and floods; therefore these structures are susceptible to damage. It is very important to preserve the historical structures with minimum interruption to their original characters. Providing the structure with bracings and reinforcing their connections with foundations are among the most efficient and least destructive ways to improve their behavior.

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