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Evaluation Of Concrete Hollow Block (CHB) Masonry Infilled Walls as A Structural Member of the 4-Storey DJGHS BLDG Using Strut-And-Tie Model Considering Nonlinear Analysis

Darianne A. Manalo [1], Malonzo O. Ocampo [1], Lovelyn M. Daquiz [1], Aljohn A. David [1], Hazel Mae M. Macapagal [1], Mary Grace E. Pangan [1], Christian Samuel S. Sanchez [1], Gilmark Repulda [2], Charles G. Lim [2]

[1]*Student, Department of Civil Engineering, College of Engineering and Architecture, Don Honorio Ventura State University, Pampanga, Philippines.*

[2]*Faculty, Department of Civil Engineering, College of Engineering and Architecture, Don Honorio Ventura State University, Pampanga, Philippines.*

Corresponding Author: manalodarianne7@gmail.com

Abstract: - This paper focused on the effectiveness of Concrete Hollow Block (CHB) masonry infilled walls as a structural member by applying Strut-and-Tie Method (STM) using Pushover Analysis and Non-Linear Response History Analysis on the performance behavior of seismic activity in a low-rise building considering in-plane strength, rigidity, ductility, and stiffness. Concrete Hollow Block (CHB) infill walls are the most commonly used partition walls in construction in the Philippines. Though it is considered nonstructural and is not included in design models, by analysis, infill walls can help reduce the damage from seismic activity. This study aims to consider the Concrete Hollow Block (CHB) masonry infill wall as a structural member in analysis and determine its influence on the stability of the structure. Pushover analysis was used to determine the behavior of the structure during seismic activities, and four factors were considered. Stiffness gives an 8.62307% difference using the strut and tie method while 19.9928406 %, 19.46441%, and 19.66178% difference for rigidity considering three structural performance levels: immediate occupancy, life safety, and collapse prevention, and 18.1274404%, 15.4238879%, and 13.9694582% considering in-plane strength. Ductility, however, shows the same result using the two design methods. The result proved that the strut and tie approach have a substantial effect on resisting elastic deformation and deflection and reducing the impact of lateral force, making the structure more stable.

Key Words: — ***Academic Competencies, Civil Engineering.***

I. INTRODUCTION

An earthquake is a natural ground-shaking catastrophic event associated with causing significant damage to people. This event causes the destruction of property, loss of financial resources, traumatic injuries to people, illness, or even death.

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The Philippines lies on the east of the Pacific Ocean, making the Philippines a high-risk country susceptible to earthquakes. The Philippines is susceptible to natural disasters like earthquakes. The Philippine Institute of Volcanology and Seismology (PHIVOLCS) records an average of 20 earthquakes per day and almost 100–150 earthquakes each year (Ong et al., 2021). It is necessary to prepare an earthquake disaster mitigation plan and to start as soon as possible (JICA et al., 2004). In response to disaster mitigation, evacuation centers are chosen by the LGU, where people can shelter during post-earthquake events. Evacuation centers (ECs) are significant to every community as they serve as an immediate evacuation where residents are out of danger. With that, ECs must be well-developed and structurally integrated. According to the City of Mexico LGU, ECs have mostly covered courts or school buildings. The researcher's case study building is the 4-story building in Don Jesus Gonzales High School, a senior high school building mandated by the LGU as an EC for the residents of Brgy. Pandacaqui. This structure is enclosed in Concrete Hollow Blocks (CHB) non-load bearing masonry infilled wall, which influenced the in-plane seismic performance of a reinforced-concrete frame. Past research and previous earthquakes propose that these walls interrelate with the frame throughout the seismic activity. Although CHB masonry walls are reinforced with steel bars vertically and horizontally, CHB walls are weak against lateral loads. It is integrated through the infilling frame. Hence, during seismic activities, the frame detaches from the CHB masonry walls, initiating compressive contact stresses stuck between the walls and frame, resulting in diagonal cracks on opposite corners (Mendoza et al., 2011). As stated by the Philippines Institute of Volcanology and Seismology (PHIVOLCS), the Southeast Care Fault will produce no less than 7.2 magnitude earthquakes that might happen sometime within this period as it approximately moves every 400-500 years, and the last movement of this fault was recorded during 1658. With that, there is a high risk for a structure enclosed in CHB masonry walls to collapse under seismic loads easily.

This study aims to analyze the performance behavior of the school building through the annexation of masonry-infilled walls as load-bearing structural members considered in the structure analysis. In conventional structural analysis, masonry-infilled walls are not included as they typically do not carry loads. It only serves as a partition or for other architectural reasons, resulting in a bare frame analysis of the buildings. However, using the Strut-and-Tie Model (STM), these non-structural members can be treated as structural members included in the analysis using the forces acted by these walls. A tool for ensuring the security of concrete components as they are being designed is called the Strut-and-Tie Model (STM). This design approach accounts for all load effects using a truss analogy and traces the flow of forces to predict the structural capacity confidently. It is extensively utilized in designing and computing the D-regions where strain distribution is assumed to be nonlinear and where plane sections do not remain plane since STM will provide better and higher precision data than any previous design approaches. Modeling the wall-frame interaction, including CHB masonry-infilled walls in structural analysis, results in more complex data or procedures. Hence, engineers exclude the effects of this wall and focus on presenting or analyzing the reinforced concrete frame as a bare frame model. Prior knowledge about the flow of stresses is required to develop STM to trace the flow of forces. Thus, the Finite Element Model (FEM) was performed to feign the lateral load-deformation performance and failure pattern of the masonry walls based on micro-modeling of CHB masonry infilled walls to develop the flow of forces in STM resulting in the in-plane strength of masonry infilled walls (Singhal, 2017). Lastly, a nonlinear response history analysis was conducted to analyze the performance behavior of the structure under seismic loads.

1.1 Literature Review

One of the most hazardous nations in the world is the Philippines. Its location on the "Pacific Ring of Fire" makes it susceptible to earthquakes brought on by tectonic plate movement. There are many types of natural disasters, with earthquakes ranking as one of the deadliest and most horrifying. Earthquakes are sometimes regarded as the most dangerous and terrifying natural disasters. Its intensity can range from hardly perceptible to extremely violent, capable of obliterating entire cities (Ongy et al., 2020). Even though they are uncommon, large destructive earthquakes often happen accidentally. There was a considerable loss of life and property when these earthquakes occurred close to populous areas. PHIVOLCS has issued a warning to Metro Manila over the potential for "The Big One," which could result in earthquakes of high to 7.2 magnitudes and be categorized as "Very Destructive" based on the length of the Southeast Care Faults (Baylon et al., 2021).

Bohol, Philippines, was severely damaged by a 7.2-magnitude earthquake that rocked the area on October 15, 2013 (Cummins et al., 2016). A damage assessment was completed for the 2013 Bohol, Philippines, earthquake with a magnitude of 7.2. The strong ground shaking that resulted from this incident caused damage to over 70,000 buildings. The Bohol earthquake tested the structural integrity of buildings and infrastructure. Fifty-eight thousand houses received some damage, while 15,000 were destroyed. According to a post-event survey on the building's earthquake performance, the wood with a light frame is the most resilient against earthquakes as it returned a lower risk of surpassing damage states. Contained masonry and hollow concrete blocks with wood or light metal function similarly, despite the fact that various structures need maintenance and have minute flaws. Concrete Hollow Blocks perform poorly, as seen by the countless structures that have collapsed but can still be repaired, claim Naguit et al. (2016). A magnitude 7.8 earthquake with an epicenter around 100 kilometers north of Manila struck the Philippines on July 16,

1990. It was one of the costliest natural disasters ever to affect the Philippines. As a result, more than 1,600 people passed away. There was significant damage to bridges, roads, embankments, and naturally occurring slopes in around 20,000 square kilometers. The main areas where weak structures and associated damage were observed were Baguio and Agoo (Tokimatsu et al., 1991). A better understanding of the building will help lessen any possible damage caused by earthquakes, which can occur at any time. It can lessen the risk of earthquakes by promoting safer building techniques, increasing readiness levels, and enhancing the country's infrastructure.

Concrete Hollow Block (CHB) is widely used as a non-load-bearing material for structural elements that are assumed to be completely independent of the primary structural system of an infrastructure (Dolores et al., 2020). It is the main material used in the construction industry. According to Lugsay et al. (2020), the typical mixture includes Portland cement, water, gravel, and sand. Low-rise buildings typically use CHB walls as non-structural components frequently overlooked in frame analysis. When there is seismic activity, it is considered that they do not carry any lateral stresses. As a result, the frame behavior cannot simply be that of a bare frame but must instead be that of a CHB in-filled frame. Low-rise reinforced concrete frames (RCF) may occasionally have concrete hollow block (CHB) walls that function as external, interior, and partition walls. 'Masonry infill' refers to using the frame to fill a masonry wall. Research from the past and earthquakes indicate that when there is seismic activity, the walls, and frame interact. During the earthquakes in 2001 in Bhuj and 1985 in Mexico City, the performance of the masonry walls was examined. The investigations concluded that the contribution of the infill walls could not be disregarded, particularly in areas with high and moderate seismicity. The interaction between the frame and the infill might significantly boost the frame's strength and stiffness (Mendoza et al., 2011).

July 16, 1990, the Luzon Earthquake was a crucial lesson in the structural ramifications of ignoring the CHB walls, such as the soft story collapses that caused hotel structures in Baguio City to fall. The examination of the wall-frame interaction is easier when CHB walls are taken into account. Structural engineers and designers often need to pay more attention to this. Compared to the traditional bare frame technique, modeling CHB walls as infill compression struts in the seismic analysis might dramatically change the behavior of the frame by boosting its stiffness and strength. Failure to take CHB properties into account in the frame analysis may result in property damage and negatively influence public health (Mendoza et al., 2011). A study was carried out in 2013 to comprehend the effect of infill walls on the seismic performance of RCF. El Centro, Parkfield, and San Fernando are three different ground motions under which the two 4-story RC constructions were tested with and without infill walls. It was determined that the walls' contribution to the structures' seismic performance needed to be considered. The researchers also found that adding infill walls decreases the structure's ductility and improves its stiffness (Jalaeefara & Zargarb, 2020).

Investigations have been done into the behavior of infill walls during seismic events. The structure experiences lateral and inter-story displacements with horizontal excitation. A differential in-plane horizontal displacement field parallel to the mortar bed joints is simultaneously applied to each infill wall. Studies of reinforced concrete (RC) column failures after earthquakes show that RC frame constructions frequently experience RC column failures. This occurred when weak RC frames were positioned around sturdy infill walls. Assuming that these infills will not participate in resisting any load, either lateral or axial, masonry is employed to fill the spans between the horizontal and vertical resisting sections of the building frames. As a result, an infill wall considerably improves the frame structure's strength and rigidity. Numerous analyses have shown that the frame that does not account for infill has considerably less strength and stiffness than the infilled frame. As a result of their ignorance, numerous multi-story structures susceptible to seismic loads that act out of the plane failed. Materials used in masonry are regarded as fragile. As a result, it is known as a non-structural element. It promotes sensitivity to seismic and lateral loadings and increases rigidity and stiffness. As a result, the equivalent diagonal strut technique is employed to calculate the overall structure's stiffness. Changes in the material used to fill the spaces between columns and beams can be seen to affect the results. When there is infill present, displacement is more effectively controlled. In terms of the increase in mass and rigidity, solid concrete blocks function more effectively in limiting displacement than brick infill or bare frames. The drifts are greatest for all infilled frames at the bottom of the structure's level. As we travel higher, the drifts for the naked frame gradually rise in value until they surpass those of the infilled structure. The best performance in lowering drift values comes from solid blocks. The elasticity modulus of the infill affects the building's rigidity. Base shear will rise with structure stiffness, and the presence of infills makes the frame even stiffer. The ductility of the frame is lost as a result of the solid blocks' extreme increase in stiffness (Patel & Jamani, 2017).

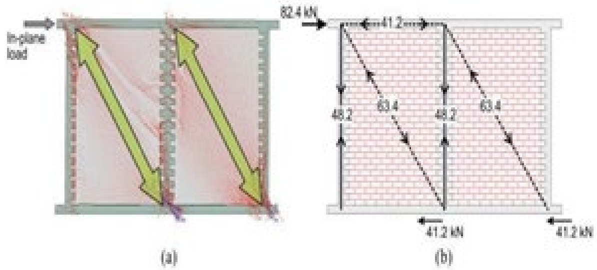


Fig.1.1 Strut and Tie in Masonry Infilled Walls

Note. (A) Principal Stress Vector Plots. (B) Strut-and-Tie Model. From "Strut-and-Tie Model for predicting the shear capacity of confined masonry walls with and without openings" by Singhal, V. et al, 2017.

The Strut-and-Tie Model (STM) is a tool used to ensure the safety of concrete components during design. In order to forecast the structural capacity securely, this design approach accounts for all load effects using a truss analogy and traces the flow of forces. The strut-and-tie model will produce better and more accurate data than conventional design methods. It is widely used in designing and computing the D-regions where strain distribution is thought to be nonlinear and in which plane sections do not remain plane. The designer or engineer must recognize the system of internal forces and its balance with the applied loads externally when designing a brick wall by including strut and tie. According to Nielson and Hoang's study, the strut and tie model's capacity data can unquestionably offer a conventional structural design solution compared to other approaches because it is based on the lower bound theory of plasticity. According to the lower bound hypothesis of plasticity, a load large enough to find a stress distribution that matches the yield surface stresses and maintains both internal and external equilibrium will not cause the structure to collapse. The strut and tie model aims to replicate or test how a structure will behave at its absolute limit stage.

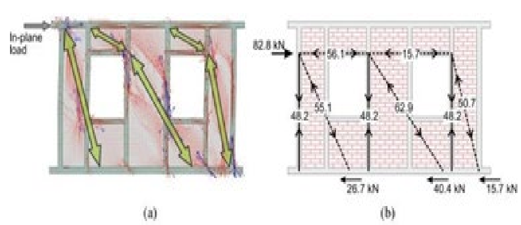


Fig.1.2. Strut and Tie-on Infill Wall Panel with Openings

Note. (A) Principal Stress Vector Plots. (B) Strut-and-Tie Model. From "Strut-and-Tie Model for predicting the shear capacity of confined masonry walls with and without openings" by Singhal, V. et al., 2017.

Due to the intricacy of the stress distribution, which can only be represented by utilizing the most precise finite element analysis, strut, and tie modeling is quite difficult on masonry walls with openings. The strut-and-tie model is practical for design applications because it requires less work to construct and compute than other models.

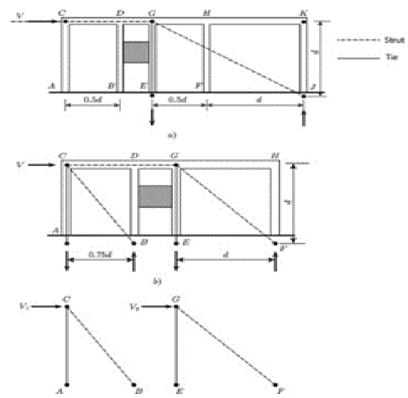


Fig.1.3 Strut-and-Tie with wall openings

Note. A) h/L ratio greater than 2.0 are disregarded in STM. (B) h/L ratio less than 2.0 are considered in STM. From Brzev, S. et al, 2016.

If the height-to-length ratio is less than 2.0, which corresponds to a minimum angle of 25 degrees, a reinforced masonry wall panel with openings was considered in a strut and tie model. The member must be ignored if the ratio is equal to or more than 2.0. The analysis can be carried out by computing the overturning moment at the base of the wall and using the internal forces from the node equilibrium equation. It is possible to evenly transfer lateral stresses along the tributary panel's length connected to the strut-and-tie model's node in a limited masonry wall panel with apertures. Various design forces such as shear, axial, and bending moment can be calculated in each constrained masonry wall panel. Shear forces in a strut can be identified as a horizontal force component. The panel's vertical component considers seismic loading and the vertical force brought on by gravity loads. The total of the tributary axial loads from two neighboring vertical struts can be used to calculate the axial load. On the other hand, it is possible to calculate the bending moment as the sum of the shear force acting on the wall's top and the wall panel's height.

1.2 Finite Element Model (FEM)

Problems involving shear loads are commonly solved using numerical techniques like the finite element method and geometric modeling, which examine the D-region's stress and strain distribution. The nonlinear strain distribution in the D-region causes the plane section to deviate from its plane state. Applying the continuum mechanics approach while considering the compatibility, equilibrium state, and stress-strain connection into account is crucial. In order to solve partial differential equations and equilibrium equations involving stress, displacement, and strain, as well as a combination of the three, one must follow the principle of minimum total potential energy or virtual work. This is accomplished by using the finite element method, or FEM.

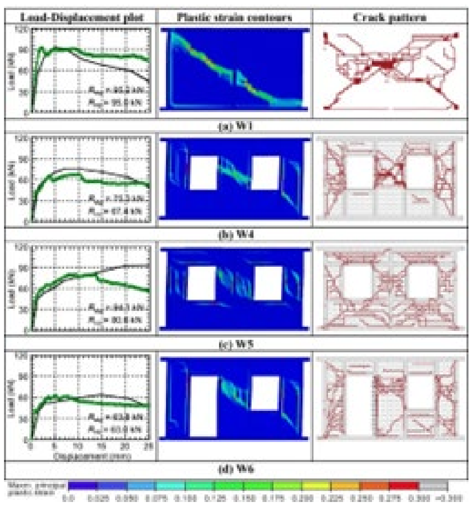


Fig.1.4 Finite Element Model

Note. Comparison of the load-displacement curve and crack patterns from experiments and Finite Element simulation. From “Strut-and-Tie Model for predicting the shear capacity of confined masonry walls with and without openings” by Singhal, V. et al., 2017.

Figure 1.1 compares the load-deformation caused by monotonically rising loads and matching envelope values computed during the cyclic in-plane testing of restricted masonry wall specimens. Valid data between experimental and analytical results were discovered prior to any significant cracking, and later due to the opening and closing of cracks, load-deformation behavior was noticed and governed. There were some differences between solid walls and walls with apertures regarding strength and post-peak behavior. Strength predictions from finite element analysis Rfe were close to the experimental values Rexp in solid walls. However, walls with openings showed a greater loss in strength when compared to experimental load-deformation curves; this disparity may be caused by a significant concentration of stresses in the corners of wall apertures that were poorly structured. Equivalent plastic strain contour plots matched the observed cracking patterns; for example, finite element analysis of the W4 wall with window holes revealed significant plastic strains in the middle pier, whereas, on the W5 wall, the plastic strains are more evenly distributed. Additionally, the solid wall W1 experienced a critical diagonal crack that ran the whole height and length of the wall. The findings suggest that the finite element model can accurately forecast the post- and pre-peak behavior of a constrained masonry wall. This model helps develop the strut and tie framework of masonry walls by determining the stress flow.

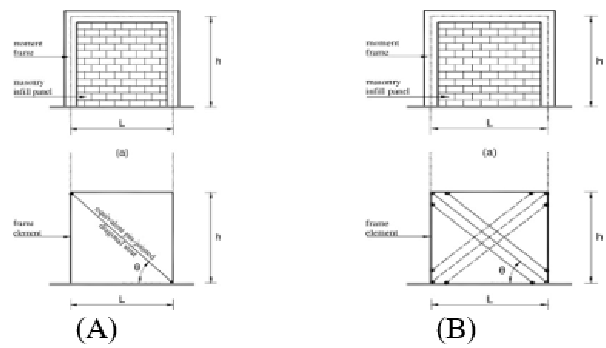


Fig.1.5 Macro-Modeling of walls

Note. Equivalent strut model for masonry infilled walls. From Asteris, P.G., 2008

There are two types of finite element methods: macro models and micro models. The modeling technique that focuses on the behavior of a specific structural component or member with excellent detail that tries to find and encompass all potential modes of failure is shown in Figure 1.2-B. In contrast, Figure 1.2-A focuses on a structure's overall behavior or capacity without modeling or including all possible nodes of local failure. According to a macro model, the shearing pressures and bending moments in the frame members cannot be duplicated by using a single diagonal strut to link the two loaded corners (Reflak & Faijfar, 1991; Saneinejad & Hobbs, 1995; Buonopane & White, 1999). After that, macro- models were put out. However, they often relied on several diagonal struts. Each infill panel in the model provided by Chrysostomou (1991) has six compression-only inclined struts, with three parallel struts used in each parallel direction and an off-diagonal strut for important points along the frame members.

1.3 Pushover Analysis

The reaction of the structure and the response of an equivalent single degree of freedom system (SDOF) are assumed to be related in static pushover analysis. Since there is only one mode controlling the time history response, the shape of the mode must remain constant throughout. This is comparable to the assumptions and predictions of the maximum seismic response of multi-degree of freedom (MDOF), which holds regardless of the degree of deformation. The goal displacement's magnitude must be established to carry out this study. The target displacement, or roof displacement, refers to the estimated overall displacement a structure is anticipated to endure. When applying inelastic spectral demand information to an inelastic system, displacement demands must be gathered. The R factor, or the ratio between elastic strength demand and yield strength, is needed to do this. The target displacement and load patterns where deformation is anticipated to occur are among the numerous factors under this type of research that will significantly impact the accuracy of seismic design predictions.

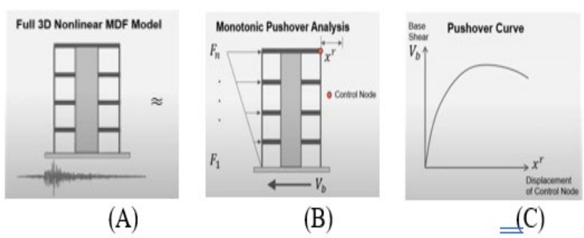


Fig.1.6 Basic Idea of Pushover Analysis

Note. (A) A ground motion structure in x- and y-direction. (B) Monolithically increasing lateral load pattern F1 … Fn to push the structure in x- or y-direction. (C) Develop the base shear, Vb, and target displacement, xr relationship. From "Part 2: Pushover Analysis Procedures - Basic Concept" by Najam, F. (http://structurespro.info/). CC BY.

As seen in Figure 1.6, the nonlinear multiple degrees of freedom model were subjected to a ground motion in a specific direction during a pushover analysis procedure. It serves as a visual depiction of the story forces, F1 to Fn, or dynamic loading applied to the structure. Starting from a small or lower amplitude and increasing monotonically, these forces will push the building into the horizontal or x direction. During this process, base shear, or the sum of the continuously increasing forces, and the roof displacement, or xr, was measured, and this process will continue until the building or structure is damaged. The pushover curve defines the target or roof displacement before applying loads to the structure. This loading will maintain the structure's linear elastic and seismic performance at a certain roof displacement.

Additionally, pushover analysis evaluates a structural system's performance by calculating the deformation requirements and strengths under earthquake designs. The static inelastic analysis is used to perform it, and the results are compared to the capabilities that are accessible at the level of structural performance. It is based on an evaluation that assesses key performance indicators, such as inter-story drift, elemental deformations, and connection forces. Additionally, data and information are expected to be provided on a variety of response characteristics, such as the actual demand force on brittle elements under axial force demands that are visible on columns, force demands on brace connections, moment demands on beam-to-column connections, shear force demands in deep RC beams, and unreinforced masonry wall piers, among others. It can calculate the effects of strength failure in one member or element on the entire behavior of the structure and potential inelastic deformations brought on by the dissipation of energy by ground vibrations. In addition, it can locate all crucial areas other than strength discontinuities where deformation is anticipated to happen. It makes inter-story drift estimates highlighting strength and stiffness discontinuities that are advantageous for damage mitigation. It checks the suitability of load routes that consider all connections and elements, whether structural or non-structural, which contribute to the structural system's foundation, stiffness, and considerable strength. Because of its simplicity and the availability of dependable engineering software, such as STAAD, Pushover analysis has been adopted.

1.4 Nonlinear Response History Analysis (NLRHA)

Among all nonlinear approaches, nonlinear response history analysis is regarded as the most trustworthy analysis technique (Alemdar et al., 2013). This analysis aims to determine how well or how the structure will respond to a specific seismic load. This analysis's selection of an acceleration record is crucial. This algorithm requires inputs of ground motion records in order to produce a valid output. Ground motion is included so that a representation of ground hazard or shaking can be provided for a specific construction at the same level. Ground motions must be supported by data from physics-based models, which has drawbacks such as a dearth of recordings, particularly for large earthquakes, or another source from previously recorded earthquake events with a nearly identical magnitude. Because seismic loads are applied directly to a structure, nonlinear response time history analysis best describes a structure's behavior (Li, 1996). Calculations of the system's internal forces, maximum values of displacement, and plastic deformation for each unit of time.

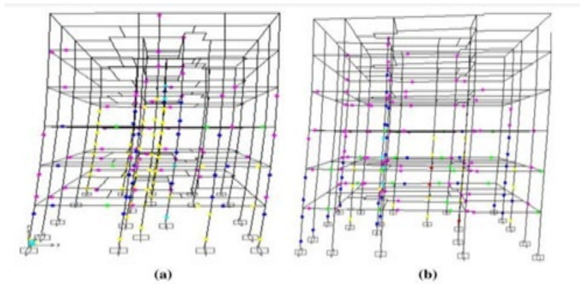


Fig.1.7 Pushover Analysis of RC building collapsed during Van (Turkey) Earthquake

Note. The plastic hinges occurred through (A) x-direction and (B) y-direction. From Bayraktar, A. et al, 2013.

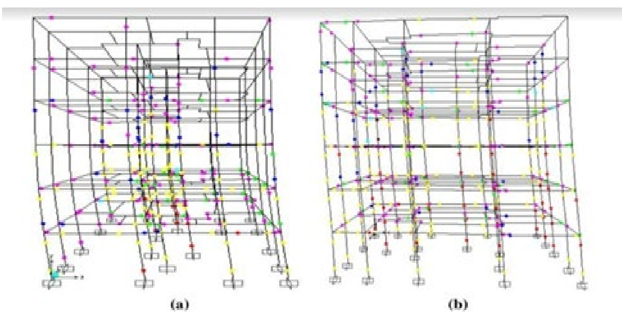


Fig.1.8 Time History Analysis of RC building collapsed during Van (Turkey) Earthquake

Note. The plastic hinges occurred through (A) x-direction an (B) y-direction. From Bayraktar, A. et al, 2013.

In their study, Bayraktar et al. compare the outcomes of static pushover analysis and nonlinear analysis used to evaluate a reinforced concrete building that collapsed during the Van earthquake in Turkey. The results are depicted in Figures 1.4 and 1.5. The building they selected for their case building analysis was ultimately destroyed in October 2011 due to the severe damage it had sustained. Turkish Earthquake Code of 2007 (TEC-2007) was the code that was considered when evaluating seismic performance. The findings demonstrate a significant difference between the values from the two analyses. Comparing static pushover analysis to NLRHA, which depicts a distinct performance level of a structure, reveals a reduced damage ratio. The average discrepancy between the two analyses is about 50%. Nonlinear time history analysis in the x direction reveals no damage in 53 columns, minimal damage in 21 columns, and marked damage in 10 columns. In terms of beams, 30 had no damage, 37 had minimal damage, seven had marked damage, 45 had advanced damage, and 1 out of 120 had collapsed. In contrast, in the pushover analysis, no damage was recorded in 72 columns, minimum damage in 21, and damage was indicated in 5 columns. Regarding beams, 11 out of 120 had advanced damage, 26 had minimal damage, and 83 had no harm.

In addition, results from nonlinear time history analysis through the y direction show that 1 out of 120 beams collapsed, 10 received marked damage, 45 experienced advanced damage, and 37 had no damage at all. In terms of damage to columns, there was none in 41, minimal damage in 3 of them, marked damage in 9 of them, advanced damage in 36 of them, and collapse in 6 of the 126 columns. According to pushover study results, 76 beams had no harm, 28 had minimal damage, 3 had notable damage, and 13 out of 120 had advanced damage. Out of 126 columns, four collapsed. Eighty-eight had no damage recorded, 5 had minimal damage, 16 had marked damage, 13 had advanced damage, and 16 had no damage. The structural system of the residential building needs to meet the performance level required by TEC-2007, according to the data gathered through nonlinear time history analysis and pushover analysis. Abnormalities, inadequate reinforcing, and detailing, poorer-quality concrete, poor construction, etc. may impact the building's seismic performance.

1.5 General Problem

The conventional structural analysis treats CHB masonry infilled walls as non- structural members as it typically has a non-load bearing capacity which can mostly be seen in typical buildings in the Philippines. However, the behavior of CHB masonry infilled walls considering the in-plane strength, rigidity, and stiffness, has a substantial effect during seismic activities. Higher in-plane rigidity of the masonry wall provides additional stiffness to the frames that will reduce the seismic vibration, which will change the behavior of the wall and the forces in the frame. According to the Field Report of EEFIT on the Luzon Earthquake in 1990, several cases were observed in Baguio where structures had substantially been damaged and collapsed. Most failures were traced to the modification of the structural frame due to infill walls. Moreover, excluding CHB walls in the structural analysis has resulted in unintended soft-story failures. (Mendoza, et al., 2011).

The researcher’s case study building is a senior high school that serves as an evacuation center for the Pandacaqui Municipality of the City of Mexico residents. It is located less than 33km near the care fault. The evacuation center must be earthquake-resilient to mitigate the damages of this catastrophe to the community. With that, the researchers aim to assess the maximum capacity of the structure with the inclusion of CHB masonry infilled walls in the structure analysis based on the factors of stiffness, rigidity, and in-plane strength.

1.6 Objectives of the Study

1.6.1 General Objectives of the Study

This research study aims to determine the effectiveness of including the Concrete Hollow Blocks (CHB) Non-Load Bearing masonry infilled walls by applying the Strut- and-Tie Model approach that will distribute the loads along the walls resulting in an additional strength to fully maximize the capacity of the structure to resist seismic loads that will help in analyzing the structural integrity of the existing 4-storey building in Don Jesus Gonzales High School.

1.6.2 Specific Objective of the Study

- To analyze and determine the influence of CHB Non-Load Bearing masonry infilled walls on the performance behavior factors considering in-plane strength, rigidity, and stiffness to the structural stability of 4-storey building in Don Jesus Gonzales High School during seismic activities using Nonlinear Pushover Analysis.
- To determine the deformation of the structure by using the Finite-Element model (FEM) micro-modeling of CHB masonry infilled walls for the application of Strut- and-Tie Model (STM) in the inclusion of CHB Non-Load Bearing masonry walls.
- To compare and evaluate the results of the analysis of CHB Non-Load Bearing masonry infilled walls between the conventional frame analysis and with the inclusion of masonry walls based on the Nonlinear Response History Analysis (NLRHA).

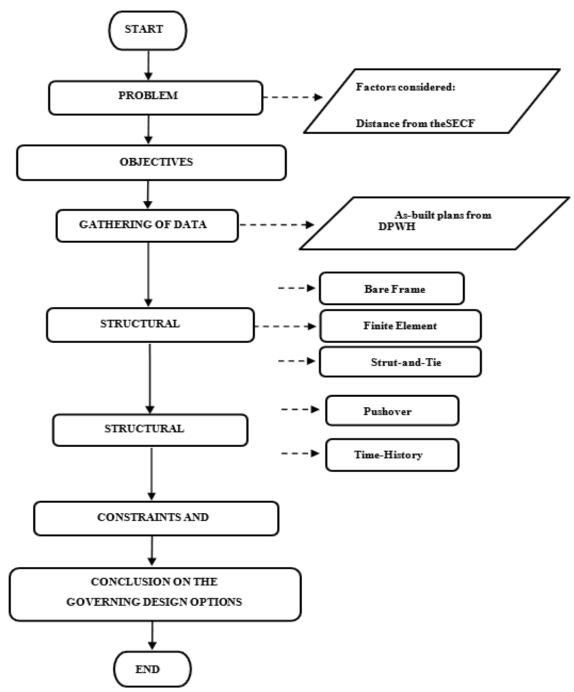
1.7 Significance of the Study

As the community and the public are the most affected when seismic activities occur, the structural design of structures is needed to give attention to and develop. Innovations and inventions are needed for a much stronger design of buildings to reduce the casualties that earthquakes and aftershocks may cause. For this, the researchers aim to provide additional data and information regarding using the Strut-and-Tie Model to Non- Load bearing CHB masonry infilled walls in mitigating the effects of seismic activities on the structure.

This study was conducted to assess the factors such as the in-plane strength, rigidity, and stiffness of the CHB masonry infilled walls of the structures for the overall stability of the structures, as it was included for the assessment and design for the structural frame of the structure.

The study will analyze the condition of the existing 4-story building in Don Jesus Gonzales High School, along with its structural integrity. Thus, the researchers' study was significantly beneficial to the occupants and residents of Brgy. Pandacaqui to have an affirmation of the overall strength of the school for seismic activities.

1.8 Conceptual Framework



II. Methodology

Electronic technology and internet led to the inclination of the research study's methodology was detailed in this chapter by the researchers. This study's chapter describes the research methodology, which covers the research design, data collection techniques, data analysis, various software programs, presentations, and interpretation of the data and plans offered. This chapter aims to bolster the accuracy and dependability of the data and knowledge that the researchers have collected. Design Flow-Charts.

This project is conducted with the help and support of different data from various sources or legitimate departments working in government. However, problem identification is the first step in the project before data gathering. Earthquake is the main focus or basis of the problem since the Philippines and the City of Mexico, to be exact, are at risk when it comes to seismic activities. The designers established a parameter in choosing the case study building, which consists of its distance from the Southeast of the Care Fault and should be located in Tarlac City. Once the problem was known, conceptualization or formation of objectives was done.

The main objective of this study is to determine the effects of incorporating Concrete Hollow Blocks (CHB) Non-Load Bearing masonry infill walls in the structural analysis of Don Jesus Gonzales High School using the Strut-and-Tie Model approach by showing the significance of the response it performs in case study buildings. Data gathering was also conducted where DPWH provided an As-built Plan of Don Jesus Gonzales High School, and the city planning from the LGU of Mexico, Pampanga, provided the geotechnical report of that specific location.

With all the data and information collected, structural modeling was incorporated where three (3) models were created, namely: (1) the Bare Frame Model or the Conventional Model, (2) the Finite Element Model, and (3) the inclusion of CHB masonry infilled walls using Strut and Tie Approach. The bare Frame Model and the Strut and Tie Approach was modeled using STAAD and Seism build. The two models will go through two types of analysis, including the Pushover Analysis and Time-History Analysis. Under Pushover Analysis, inputs from the conventional modeling and including CHB masonry infilled walls should follow the ASCE 41-17 Code Requirements. Outputs from this analysis would be the structure's response and capacity, which includes the contributing factors such as stiffness, rigidity, ductility, and in-plane strength between the inclusion of CHB and without the inclusion of CHB walls.

On the other hand, for the time-history analysis, using STAAD and inputs of 11 ground motions from the Peer Ground Motion Database and Spectral Matching using STAAD and Seism match. A load-displacement curve can be obtained from this analysis. Once the two analyses are performed, results were compared. In addition, constraints and trade-offs was discussed and analyzed in this study. Accurate and valid interpretations was provided given all the data from the two analyses of the Bare Frame Model and utilization of the Strut- and-Tie Approach and from the Finite Element Model. Conclusions and recommendations will also be presented for future references, researchers, and another beneficiary's Mathematical model
Let S is the system.

III. Results and Discussion

This chapter shows the results of the Pushover Analysis, Finite Element and Nonlinear Time History Analysis (NLRHA) procedure with the 11 ground motions using Seismobuild and Structural Analysis and Design (STAAD). These analyses were incorporated into the bare frame model and model considering the CHB masonry infilled walls or the Strut and tie approach. It provides the different contributing factors of the CHB Masonry infilled walls such as stiffness, rigidity, in-plane strength, and ductility. Moreover, it presents the results and discussion of the critical section of the structure which can affect the overall stability of the existing structure. The comparison between the responses and effects between the bare frame model and utilizing strut and tie approach into the structure are also provided in this chapter.

IV. Conclusion and Recommendation

4.1 Conclusion

Considering masonry infilled walls as a structural member, using the strut and tie method substantially affects the structure compared to traditional design. Four different factors were considered, and researchers concluded that the results differ from the two design methods. For stiffness, the study gives an 8.62307 % difference using the strut and tie method, 19.9928406 %, 19.46441%, and 19.66178% difference for rigidity considering three structural performance levels: immediate occupancy, life safety, and collapse prevention, and 18.1274404%, 15.4238879%, and 13.9694582% considering in-plane strength. On the other hand, ductility shows the same result using the two design methods. Non-Linear Response History Analysis (NLRHA) was performed to determine the displacement and drift difference of the structure. The result in the two methods implies that a higher story resulted in a higher displacement than a lower story. Applying the strut and tie approach gives a good result compared to the bare frame method or the traditional design. Storey drifts, on the other hand, show a higher value on the upper part of the structure using the strut and tie model. The study shows a good result using the strut and tie approach, making the structure more able to resist lateral force due to seismic activities, elastic deformation, and deflection.

4.2 Recommendations

In light of the evidence discussed throughout the report and the conclusions above, the researchers recommend the following to improve the traditional design for future researchers and for structural engineers.

- Application of the same study to steel design structures.
- Differentiate concrete and steel structures with the application of strut and tie approach considering the same factors.
- Application of the same study to high-rise structures with five floors and above.

References

[1]. American Society of Civil Engineers, & Engineers, A. S. C. (2010). Minimum Design Loads for Buildings and Other Structures: ASCE Standard 7-10. American Society of Civil Engineers.

[2]. American Society of Civil Engineers. (2000). Prestandard and Commentary for the Seismic Rehabilitation of Buildings. Federal Emergency Management Agency.

[3]. Association of Structural Engineers of the Philippines, Inc. (2016). National Structural Code of the Philippines 2015 (7th ed., Vol. 1).

[4]. Attari, N. E., Chemrouk, M., & Amziane, S. (2013). Pushover Analysis of a Seismic Strengthening of an Existing Building Reinforced Concrete Structure. Advanced Materials Research, 641–642, 583–590.

[5]. Baylon, M.B., Lictaoa, C.S., Castillo, I.J.C., Dungog, C.K.P. & Jerusalem, L.R. (2021). Seismic vulnerability assessment of Sta. Lucia high school in Pasig City Philippines using rapid visual assessment and fragility curves. International Research Journal of Science, Technology, Education, and Management, 1(2), 119-135.

[6]. Bhanu, K.C., Ganesan, N., & Indira, P.V. (2020). A Review on Strut and Tie Methods.

[7]. IOP Conference Series: Materials Science and Engineering, 936.

[8]. Brodsky, A., Yankelevsky, D. Z., & Rabinovitch, O. (2021). Shearing of infill masonry walls under lateral and vertical loading. Journal of Building Engineering, 38, 102147.

[9]. Brzev, S., & Pérez Gavilán, J. (2016). Application of Strut-and-Tie Model for seismic design of confined masonry shear walls. Brick and Block Masonry, 2257–2264.

[10]. Carlos Ignacio, P. L., Acierto, D. I. A., Camba, C. P. P., Gomez, R. V. L., & Ozaeta,

[11]. M. I. M. (2020). A Comparative Study of Concrete Hollow Blocks with and without Rice Husk Powder as Partial Replacement to Cement. Journal of Physics: Conference Series, 1529(3), 032045.

[12]. Çavdar, Z., & Bayraktar, A. (2013). Pushover and nonlinear time history analysis evaluation of a RC building collapsed during the Van (Turkey) earthquake on October 23, 2011. Natural Hazards, 70(1), 657–673.

[13]. Çavdar, Z., & Bayraktar, A. (2013). Pushover and nonlinear time history analysis evaluation of a RC building collapsed during the Van (Turkey) earthquake on October 23, 2011. Natural Hazards, 70(1), 657–673.

[14]. Dolores, A. J. S., Lasco, J. D., Bertiz, T. M., & Lamar, K. M. (2020). Compressive Strength and Bulk Density of Concrete Hollow Blocks (CHB) Infused with Low- density Polyethylene (LDPE) Pellets. Civil Engineering Journal, 6(10), 1932– 1943.

[15]. Earthquake Hazards Program | U.S. Geological Survey. (n.d.). USGS.

[16]. Fajfar, P. (2000). A Nonlinear Analysis Method for Performance-Based Seismic Design.

[17]. Earthquake Spectra, 16(3), 573–592.

[18]. Finite Element Mesh Refinement Definition and Techniques. (n.d.-b).

[19]. Ipong, L. G., Ongy, E. E., & Bales, M. C. (2020). Impact of magnitude 6.5 earthquake on the lives and livelihoods of affected communities: The case of barangay lake Danao, Ormoc city, Leyte, Philippines. International Journal of Disaster Risk Reduction, 46, 101520.

[20]. Jalaeefar, A., & Zargar, A. (2020). Effect of infill walls on behavior of reinforced concrete special moment frames under seismic sequences. Structures, 28, 766– 773.

[21]. Japan International Cooperation Agency. (2004). Earthquake Impact Reduction Study Volume1.PDF.

[22]. Manshi, M. (2022, May 23). STAAD Software for Civil Engineering Students: Complete Guide.

[23]. Martino, R., Spacone, E., & Kingsley, G. (2000). Nonlinear Pushover Analysis of RC Structures. Advanced Technology in Structural Engineering.

[24]. Mendoza, R. et al., (2011). Investigation of the Influenced of Chb Walls in the Seismic Performance of Low-Rise Reinforced Concrete Frames Using the Equivalent Strut Theory and Sap2000. ResearchGate.

[25]. Mendoza, R. et al., (2011). Modeling of Chb Masonry for Seismic Analysis of Low-Rise Reinforced Concrete Frames: Effects of Chb Masonry Properties. ResearchGate.

[26]. Naguit, M., Cummins, P. R., Bautista, B. C., Edwards, M., Ryu, H., & Jakab, M. (2015). Earthquake Performance of Structures in the Philippines: A Post-event Assessment of the M7.2 October 2013 Bohol Earthquake. AGU Fall Meeting Abstracts, 2015.

[27]. Naguit, Muriel & Cummins, Phil & Edwards, Mark & Ghasemi, Hadi & Ryu, Hyeuk & Bautista, Bartolome. (2016). Earthquake Scenario-based Assessment for

Empirical Seismic Fragility Functions: A Case Study of the Mw7.1 Bohol Philippines Earthquake.

[28]. Najam, F., [Understanding Structures with Fawad Najam]. (2022). Part 2: Pushover Analysis Procedures - Basic Concept [Video]. YouTube.

[29]. Ong, A. et al., (2021). Factors affecting intention to prepare for mitigation of "the big one" earthquake in the Philippines: Integrating protection motivation theory and extended theory of planned behavior. International Journal of Disaster Risk Reduction, 63, 102467.

[30]. Ozturkoglu, O., Ucar, T., & Yesilce, Y. (2017). Effect of masonry infill walls with openings on nonlinear response of reinforced concrete frames. Earthquakes and Structures, 12(3), 333–347.

[31]. Patel, Y., & Jamani, A. (2017). Performance and Analysis of Masonry Infill in R.C. Frame Structure. Academia.

[32]. Peruch, M., Spacone, E., & Camata, G. (2019). Nonlinear analysis of masonry structures using fiber-section line elements. Earthquake Engineering &Amp; Structural Dynamics, 48(12), 1345–1364.

[33]. Petropoulos, G. (2022, July). Finite Element Method: What Is Its Role In Engineering?

[34]. Philippines.; Philippines. Department of Public Works, Transportation, and Communications. Publisher. (2016). The National Building Code of the Philippines (7th ed., Vol. 1).

[35]. Raka, E., Spacone, E., Sepe, V., & Camata, G. (2015). Advanced frame element for seismic analysis of masonry structures: model formulation and validation.

[36]. Earthquake Engineering &Amp; Structural Dynamics, 44(14), 2489–2506.

[37]. Saatcioglu, M., & Humar, J. (2003). Dynamic analysis of buildings for earthquake- resistant design. Canadian Journal of Civil Engineering, 30(2), 338–359.

[38]. Singhal, V. & Rai, D.C. (2016). [PDF] Strut-and-Tie Model for Predicting the Shear Capacity of Confined Masonry Walls with and Without Openings | Semantic Scholar.

[39]. Tokimatsu, Kohji; Kuwayama, Shinichi; Midorikawa, Saburoh; Abe, Akio; and Tamura, Shuji, "Preliminary Report on the Geotechnical Aspects of the Philippine Earthquake of July 16, 1990" (1991). International Conferences on Recent Advances in Geotechnical Earthquake Engineering and Soil Dynamics.11.

[40]. Wah, B. (2008). The Finite Element Method.

[41]. Allison, C. (2020, September 23). Meshing in FEA: Introduction to meshing. OnScale.