# A TECHNICAL STUDY OF CONCRETE HOLLOW BLOCK SLAB SYSTEM OF A 2-STOREY RESIDENTIAL BUILDING SITUATED IN A SEISMIC ZONE 4, PARTICULARLY IN DAVAO CITY, PHILIPPINES

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**ABSTRACT**

*The concrete hollow block slab system is common in the Middle East and African regions. However, the commonality of these two regions is that they have lower seismicity and belong to seismic zone 4, unlike most regions in the Philippines. This study aims to develop an innovative concrete hollow-block slab system for a 2-story residential building model using the seismic zone 4 parameters and to ensure that the inter-story drift meets the minimum requirement of the National Structural Code of the Philippines (NSCP). The researcher made a structural model using STAAD.Pro, which was then utilized to study the effect of weight reduction on the slab and the development of a concrete hollow block product suitable for this kind of slab system. Analysis revealed that the introduction of an additional concrete rib beam in the structural model and the optimum concrete mix design of the CHB product could support the concrete hollow block slab system. The inter-story drift result was within the NSCP's minimum requirement.*

***Keywords:*** *CHB Slab system; NSCP; seismic zone 4, STAAD.Pro*

## INTRODUCTION

Several types of structural floor systems are designed and implemented globally, including post-tensioned slabs, hollow-core slabs, flat slabs, concrete hollow-block slabs, and conventional solid floor slab systems, which are widely used. Thus, the structural floor system plays a significant role in the cost of building structures [Nassar et al, 2020]. Obtaining innovative solutions gives the construction industry an advantage. Choosing the correct slab type for the structure will be crucial in the design phase, as the structural design engineer must always prioritize the building's safety over economic considerations [Ahmad et al, 2023]. The weight of the floor slab varies depending on the type of slab used in the building. Moreover, the total weight of a building plays a significant role in earthquake-resilient design, influencing its response to seismic forces. The forces generated during earthquakes are proportional to the building's weight. The basic principle is that heavy structures experience more inertial forces during ground shaking than lighter ones. Chopra further explained the method of analyzing structures that behave dynamically during an earthquake [Anil, 2020]. Furthermore, the concrete hollow block slab design reduces the structure's weight, potentially eliminating the need for remote tension bars while maintaining the strength of the concrete floor slab [Kyakula et al, N.A].

In the Philippines, the seismic zone was divided into two zones, with most belonging to seismic zone 4. Therefore, solid slabs and precast hollow-core slabs are already widely used in construction; hence, the guidelines for structural design are provided in the National Structural Code of the Philippines (NSCP, 2015 edition), Section 407 [Association of Structural Engineers of the Philippines,2015]. Other than this kind of floor slab system, only foreign best practices are available for reference. It will be challenging for the structural design engineer to use this kind of reference; otherwise, there must be a supporting academic or detailed research study on the concrete hollow-block slab system to serve as a reference. In Davao, a local manufacturing company produces precast reinforced concrete slabs with hollow cores along their longitudinal direction [Concretek.com, N.A]. However, concrete hollow-block slabs are not well known or readily available in the local market. Like solid concrete slabs, the concrete hollow block slab behaves primarily as a flexural member, and the design is like that of T-beams with an effective width equal to the spacing between ribs [6]. It would be a great challenge for our structural engineers to explore an innovative solution for floor slab systems that integrates concrete hollow blocks.

## METHODOLOGY

The analysis and design of a 2-storey residential building are performed using STAAD.Pro software in accordance with the NSCP 2015 edition, using standard sizes of 400mm x 200mm x 100mm for concrete hollow block products. Various load tests were performed on the developed concrete hollow block product.

### *A. Seismic capacity of the building using the CHB slab system*

To ensure the occupants' safety, the building's seismic capacity using the CHB slab system must be met.

*Structural Analysis.*

The 2-story residential buildings were analyzed in STAAD.Pro, and inter-story drift and soft-story adequacy were assessed. The following steps were applied to both the CHB slab and the conventional slab system for comparison:

a) ***Dead load calculations.***

This includes the self-weight of reinforced concrete ribs or solid slabs, concrete hollow blocks, floor finish, and miscellaneous items such as mechanical, electrical, and plumbing

b) ***Live load calculations.***

1.9 kPa was used, per the minimum live load requirement in the NSCP 2015 edition.

c) ***Seismic load calculations.***

Seismic parameters were based on the specific location provided in the scope of the study. The structure detailing requirements of the earthquake-resisting concrete frames were carried out under the UBC 1997 code:

1) Importance factor, 1
2) Soil Profile, Sd = 4
3) Zone factor, zone 4 = 0.4
4) R factor, SMRF = 8.5
5) Near source factor, Na = 1.2, Nv = 1.6
6) CT values = 0.0731

d) ***Load combinations.***

Minimum load combinations from the NSCP 2015 edition were applied.

1) 1.4DL
2) 1.2DL + 1.6LL + 0.5RL
3) 1.2DL + 0.5LL + 1.6RL
4) 1.42DL + 0.5LL + EQX
5) 1.42DL + 0.5LL – EQX
6) 1.42DL + 0.5LL + EQZ
7) 1.42DL + 0.5LL – EQZ
8) 1.12DL + EQX
9) 1.12DL – EQX
10) 1.12DL + EQZ
11) 1.12DL – EQZ

***e) Seismic analysis.***

The Equivalent Lateral Force (ELF) method was used in this structural analysis because it complies with the NSCP 2015 edition and STAAD.Pro will perform the three-dimensional static analysis.

### *B. Concrete Hollow Block Product Development*

The locally available concrete hollow blocks are not designed to support the load intended for this study and are only suitable for wall construction. The distance between the rib beams was in accordance with the concrete hollow blocks used in the study. The proposed dimension of the concrete hollow block was optimized in a mixed design and subjected to various load test methods.

#### *1. Optimum Mix Design.*

The proportion of fine aggregates together with the cement was defined experimentally. The following are the sizes of aggregates:

a) Fine aggregates: pass through a 4.8mm sieve.
b) Cement: standard available in the market.

***2. Load tests.***

The trial mix samples were cured for at least 28 days, and subjected to the type of test (compression and flexure). The developed optimal trial mix design for CHB was tested to a minimum live load of 1.9 kPa.

## RESULTS AND DISCUSSIONS

This chapter presents the findings and analysis of the data gathered from the structural analysis results of the 2-story building and the load test of the concrete hollow block product development for this study. Two identical structures were modelled and analysed for both the conventional solid-slab and CHB-slab systems. Both structural models were subjected to the same seismic zone 4 parameters per the NSCP 2015 standards, and their material quantities were compared.

### *C. Seismic Behavior of the Residential Building Using Concrete Hollow Block Slab System*

Doing things in an alternative way to what we are already comfortable with is a risk we need to face, regardless of whether it is an innovative approach. A conventional solid slab system is the easiest way to design and implement, but an innovative CHB slab system may be a risk, a risk that can be resolved. The NSCP laid out guidelines; as long as they are followed, the risk is mitigated. In determining the building's safety, complex analysis is required; however, software can reduce the complexity. The CHB slab system of a 2-storey residential building was modeled and analyzed in accordance with the seismic zone 4 parameters, aiming to comply with the NSCP code minimum requirements.

***1. Structural modeling using STAAD Pro software***

The 2-story residential building was modeled primarily in STAAD.Pro for both conventional solid slab and CHB slab systems. The final member sizes for the main columns and main beams were determined after completion of the structural analysis of the conventional solid slab system. All information from this model was used as the baseline for the CHB slab system. Additional concrete rib beams were introduced to the model to support the hollow concrete blocks product. The specifications for the concrete rib beams connected to the main beams were released in the analysis at both ends. This allows the concrete rib beams to transfer loads directly to the main concrete beams without creating moments at the joints.

The practical application of the release specification enables the fabrication of concrete rib beams, which can then be detached from the main structure. It could be installed separately in the building, together with the concrete hollow blocks product, in which the main beams are originally adequate to receive the conventional solid slab. This model narrows the gap between conventional solid slabs and CHB slab systems.

## 2. *Structural analysis using STAAD.Pro software*

This study aims to establish the minimum requirements of the NSCP 2015, in which the entire structure was analyzed, and the inter-story drift adequacy was checked using STAAD.Pro. The equivalent lateral force method was used for seismic load, and UBC 97 seismic parameters for Tigatto, Davao City, as shown in Table 1. The parameter values were taken from the National Structural Code of the Philippines 2015 and DOST Fault Finder, as shown in Figures 1, 2, and 3. Minimum load combinations required by the NSCP were also considered.

| Parameters | Value |
|---|---|
| Zone, 4 | 0.4 |
| Importance Factor (I) | 1 |
| Response Modification Factor (RWX) | 8.5 |
| Response Modification Factor (RWZ) | 8.5 |
| Soil Profile Type (Stiff Soil) | 4 |
| Near Source Factor (Na) | 1.2 |
| Near Source Factor (Nv) | 1.6 |
| CT Value for Concrete (CT) | 0.0731 |

*Table 1. Structural model for a conventional slab system.*

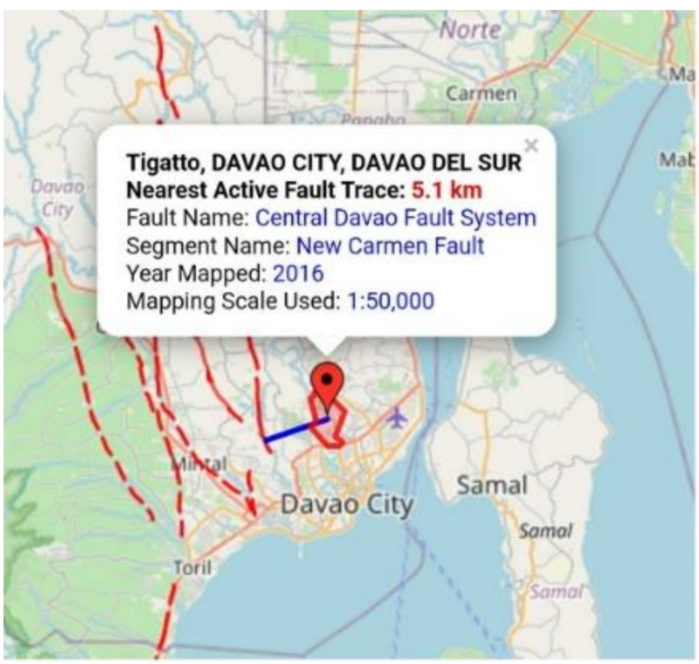


Table 208-5 Near-Source Factor $N_a$ [1]

| Seismic Source Type | Closest Distance To Known Seismic Source[2] | | |
|---|---|---|---|
| | ≤ 2 km | ≤ 5 km | ≥ 10 km |
| A | 1.5 | 1.2 | 1.0 |
| B | 1.3 | 1.0 | 1.0 |
| C | 1.0 | 1.0 | 1.0 |

Table 208-6 Near-Source Factor, $N_v$ [1]

| Seismic Source Type | Closest Distance To Known Seismic Source[2] | | | |
|---|---|---|---|---|
| | ≤ 2 km | 5 km | 10 km | ≥ 15 km |
| A | 2.0 | 1.6 | 1.2 | 1.0 |
| B | 1.6 | 1.2 | 1.0 | 1.0 |
| C | 1.0 | 1.0 | 1.0 | 1.0 |

*Figure 1. Nearest Source Factor: DOST Fault Finder (left), NSCP2015 (right).*

Table 208-1 - Seismic Importance Factors

| Occupancy Category [1] | | Seismic Importance Factor, $I$ | Seismic Importance [2] Factor, $I_p$ |
|---|---|---|---|
| I. | Essential Facilities [3] | 1.50 | 1.50 |
| II. | Hazardous Facilities | 1.25 | 1.50 |
| III. | Special Occupancy Structures | 1.00 | 1.00 |
| IV. | Standard Occupancy Structures | 1.00 | 1.00 |
| V. | Miscellaneous structures | 1.00 | 1.00 |

[1] *See Table 103-1 for occupancy category listing*

[2] *The limitation of $I_p$ for panel connections in Section 208.7.2.3 shall be **1.0** for the entire connector*

[3] *Structural observation requirements are given in Section 107.9*

[4] *For anchorage of machinery and equipment required for life-safety systems, the value of $I_p$ shall be taken as **1.5***

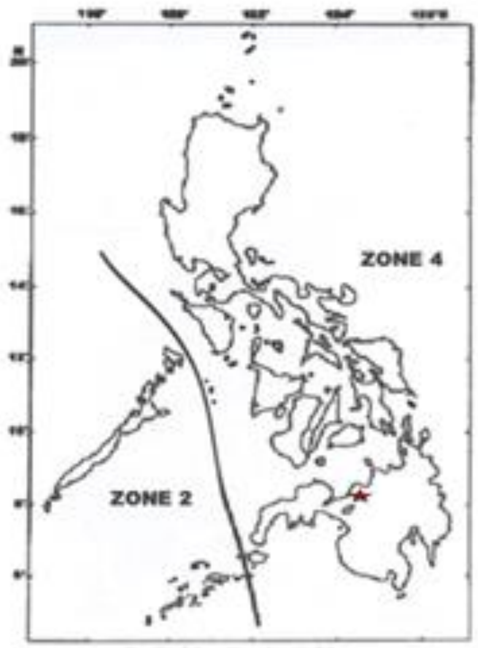


*Figure 2. Seismic Importance Factor (left), Seismic Zone (right), NSCP 2015.*

Table 208-11A Earthquake-Force-Resisting Structural Systems of Concrete

| Basic Seismic-Force Resisting System | $R$ | $\Omega_O$ | System Limitation and Building Height Limitation by Seismic Zone, m | |
|---|---|---|---|---|
| | | | Zone 2 | Zone 4 |
| ***A. Bearing Wall Systems*** | | | | |
| • Special reinforced concrete shear walls | 4.5 | 2.8 | NL | 50 |
| • Ordinary reinforced concrete shear walls | 4.5 | 2.8 | NL | NP |
| ***B. Building Frame Systems*** | | | | |
| • Special reinforced concrete shear walls or braced frames (shear walls) | 5.0 | 2.8 | NL | 75 |
| • Ordinary reinforced concrete shear walls or braced frames | 5.6 | 2.2 | NL | NP |
| • Intermediate precast shear walls or braced frames | 5.0 | 2.5 | NL | 10 |
| ***C. Moment-Resisting Frame Systems*** | | | | |
| • Special reinforced concrete moment frames | 8.5 | 2.8 | NL | NL |
| • Intermediate reinforced concrete moment frames | 5.5 | 2.8 | NL | NP |
| • Ordinary reinforced concrete moment frames | 3.5 | 2.8 | NL | NP |
| ***D. Dual Systems*** | | | | |
| • Special reinforced concrete shear walls | 8.5 | 2.8 | NL | NL |
| • Ordinary reinforced concrete shear walls | 6.5 | 2.8 | NL | NP |
| ***E. Dual System with Intermediate Moment Frames*** | | | | |
| • Special reinforced concrete shear walls | 6.5 | 2.8 | NL | 50 |
| • Ordinary reinforced concrete shear walls | 5.5 | 2.8 | NL | NP |
| • Shear wall frame interactive system with ordinary reinforced concrete moment frames and ordinary reinforced concrete shear walls | 4.2 | 2.8 | NP | NP |
| ***F. Cantilevered Column Building Systems*** | | | | |
| • Cantilevered column elements | 2.2 | 2.0 | NL | 10 |
| ***G. Shear Wall- Frame Interaction Systems*** | 5.5 | 2.8 | NL | 50 |

*Figure 3. Response Modification Factor, NSCP 2015.*

According to NSCP, the requirement for structural analysis, the maximum inelastic response displacements shall not exceed the inter-story drift limits. The stiffness of the lateral resisting elements, the column in this case, shall be adequate before proceeding with the reinforced concrete design. The conventional solid slab system was initially analyzed, as shown in Figure 4, to establish the study's baseline. Iteratively, an adequate inter-story drift was established through analysis in STAAD Pro software.

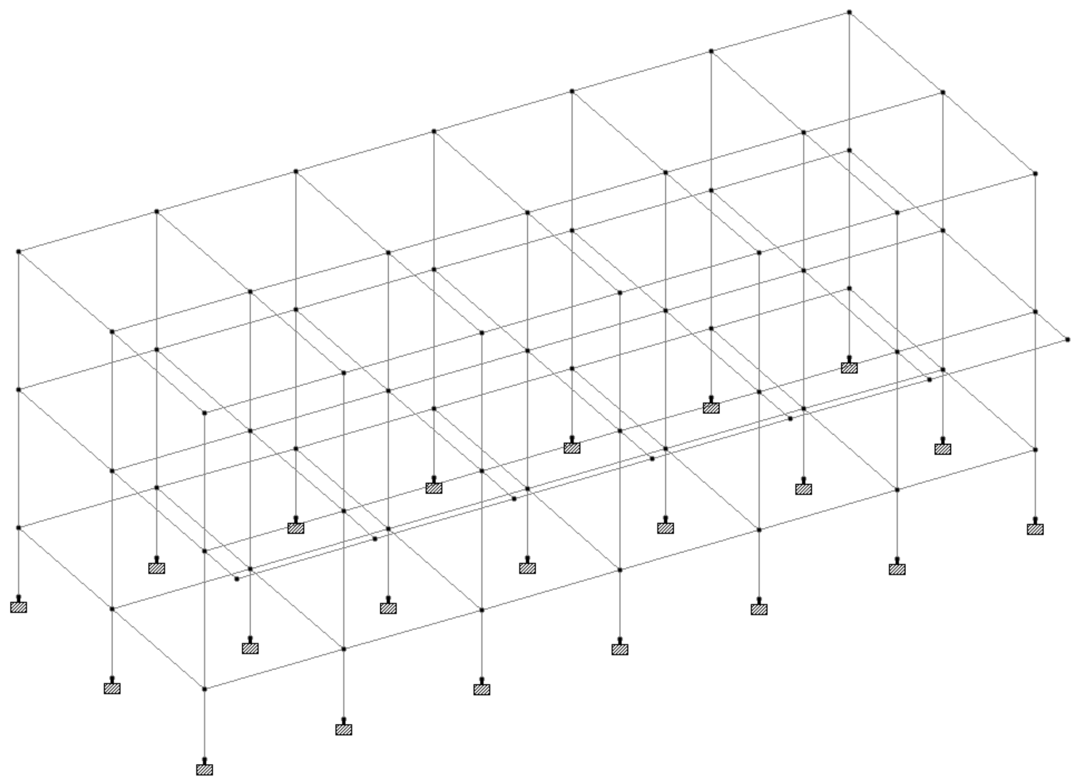

*Figure 4. Structural model for a conventional slab system.*

The same column and main beam member were used in the analysis for the CHB slab system, and a concrete rib beam was added to support the concrete hollow block products. The distance between the concrete rib beams was illustrated in Figure 5. The translation of the distance of the concrete rib beams in STAAD.Pro for the CHB slab system is illustrated in Figure 6.

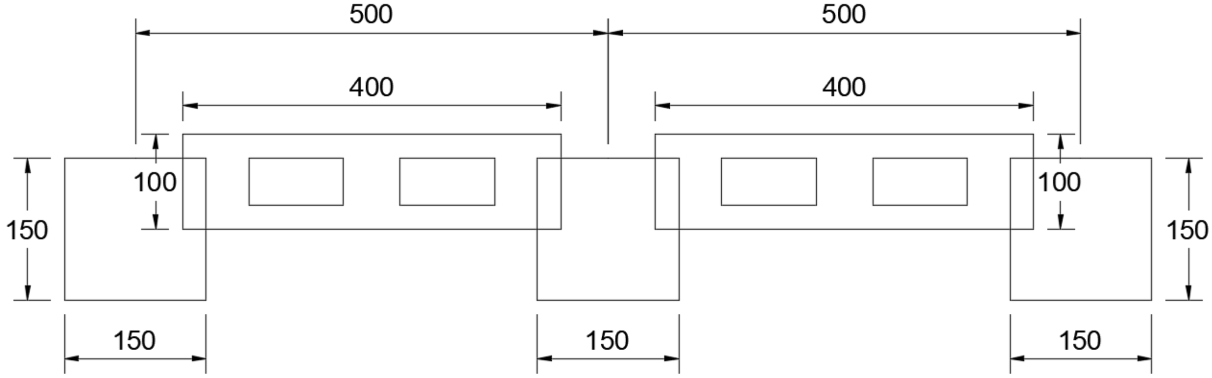


*Figure 5. Concrete rib and concrete hollow block typical section.*

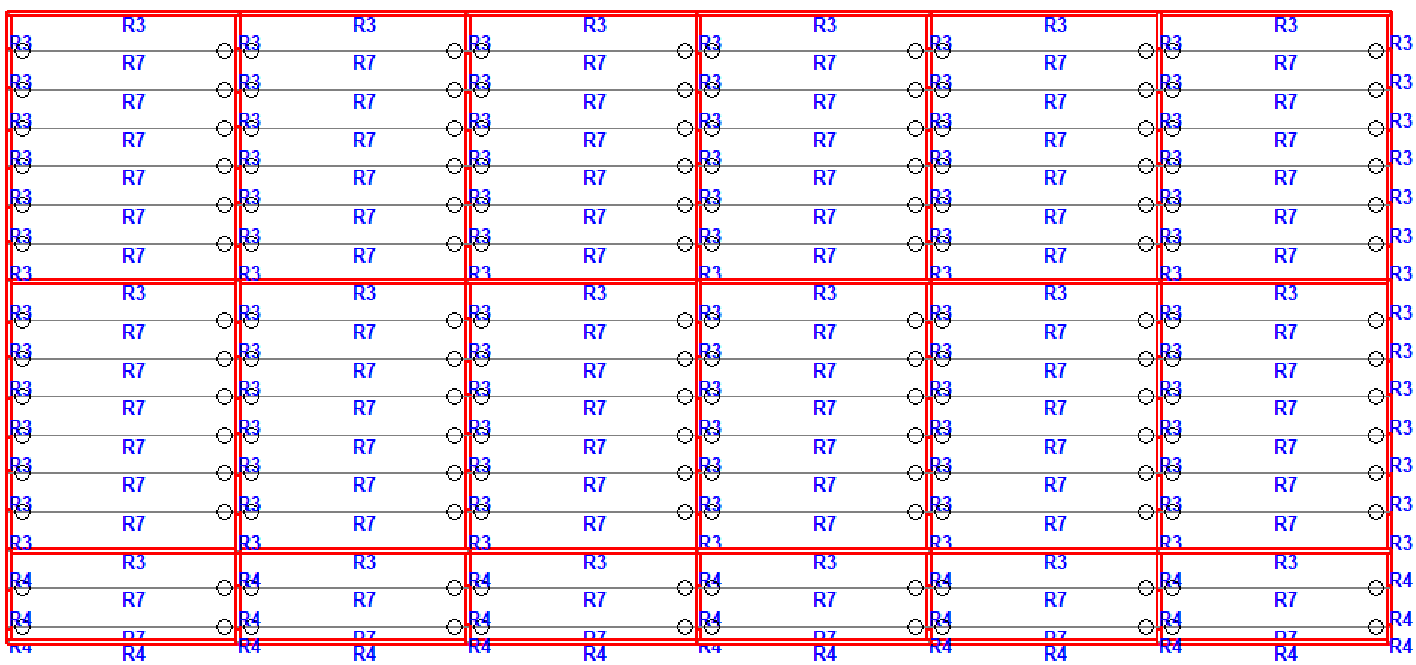

*Figure 6. The concrete hollow block slab system with a concrete rib.*

The entire structural model for the CHB slab system, as shown in Figure 7, was analyzed using STAAD.Pro. Accounting for the slab's hollow property, the floor load was adjusted, and the inter-story drift was checked for adequacy.

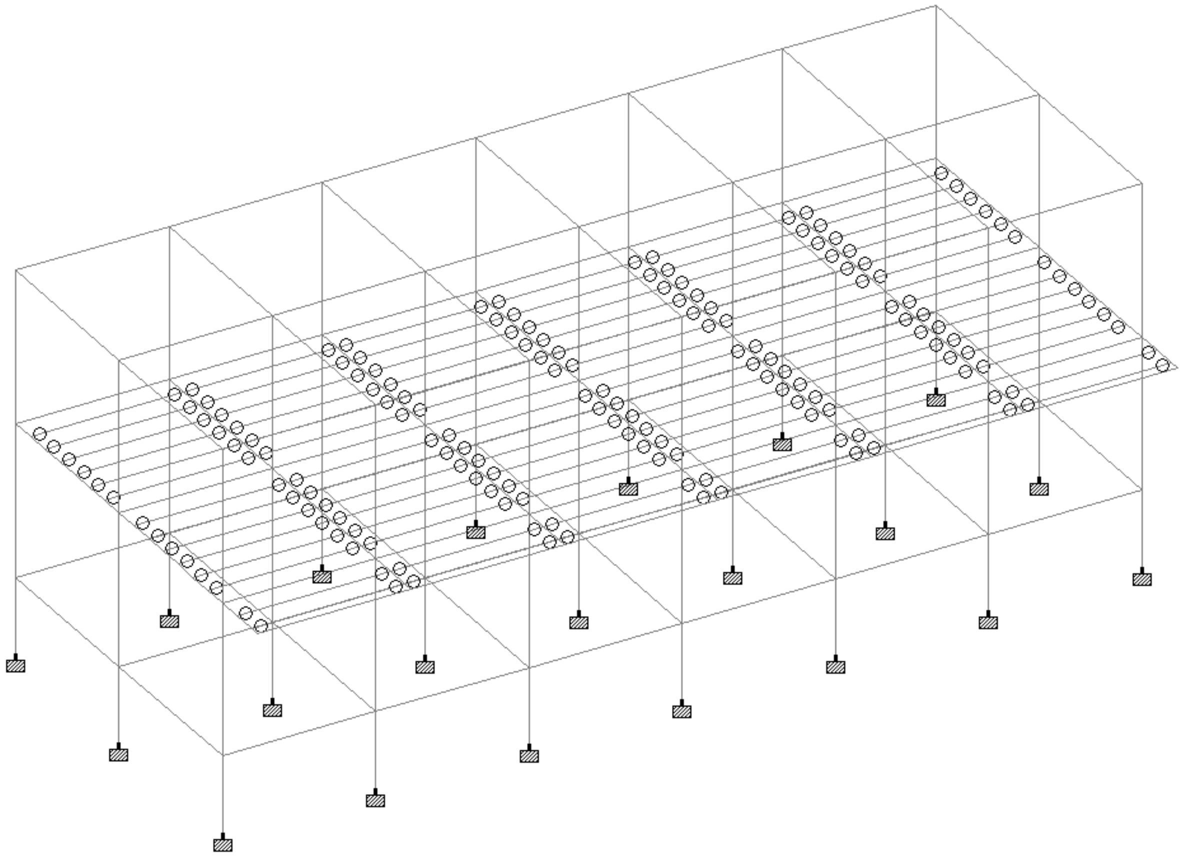

*Figure 7. Structural model for a CHB slab system.*

In the conventional slab system, the floor load was 4 kPa covering a two-way slab distribution. In the CHB slab system, on the other hand, the floor load was 3.4 kPa, applied to a one-way slab distributed over the concrete rib beams. The additional rib beams added in the CHB slab system were carried as self-weight in the analysis. Both results show the adequacy of the minimum code requirements, as shown in Figure 8. However, if we look closer at the inter-story drift values, the CHB slab system represents a more adequate system as compared to the conventional solid slab system. This is perhaps because it has less load weight acting as a lateral force when excited by the seismic forces.

| STORY | HEIGHT (METE) | LOAD | AVG. DISP(CM ) X | AVG. DISP(CM ) Z | DRIFT(CM ) X | DRIFT(CM ) Z | RATIO | STATUS |
|---|---|---|---|---|---|---|---|---|
| 2 | 4.50 | 16 | 1.1633 | 0.1033 | 1.1633 | 0.1033 L / | 387 | PASS |
| | | 17 | -1.1634 | 0.0892 | 1.1634 | 0.0892 L / | 387 | PASS |
| | | 18 | 0.0094 | 1.5788 | 0.0094 | 1.5788 L / | 285 | PASS |
| | | 19 | -0.0095 | -1.4010 | 0.0095 | 1.4010 L / | 321 | PASS |
| | | 20 | 1.1633 | 0.0600 | 1.1633 | 0.0600 L / | 387 | PASS |
| | | 21 | -1.1634 | 0.0606 | 1.1634 | 0.0606 L / | 387 | PASS |
| | | 22 | 0.0095 | 1.5502 | 0.0095 | 1.5502 L / | 290 | PASS |
| | | 23 | -0.0095 | -1.4296 | 0.0095 | 1.4296 L / | 315 | PASS |

(a)

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 2 | 4.50 | 16 | 0.9802 | 0.0291 | 0.9802 | 0.0291 L / | 459 | PASS |
| | | 17 | -0.9798 | 0.0244 | 0.9798 | 0.0244 L / | 459 | PASS |
| | | 18 | 0.0071 | 1.1764 | 0.0071 | 1.1764 L / | 382 | PASS |
| | | 19 | -0.0067 | -1.1270 | 0.0067 | 1.1270 L / | 399 | PASS |
| | | 20 | 0.9801 | 0.0170 | 0.9801 | 0.0170 L / | 459 | PASS |
| | | 21 | -0.9799 | 0.0164 | 0.9799 | 0.0164 L / | 459 | PASS |
| | | 22 | 0.0070 | 1.1684 | 0.0070 | 1.1684 L / | 385 | PASS |
| | | 23 | -0.0068 | -1.1350 | 0.0068 | 1.1350 L / | 396 | PASS |

(b)

*Figure 8. Inter-story drift: (a) conventional solid slab system (b) CHB slab system*

Additionally, both slab system models are analyzed as special moment-resisting frames; the only difference between the two is the slab's placement. An additional concrete rib beam was integrated into the CHB slab system. Further, it has been specified as released, as it was assumed to be installed as precast concrete. The conventional solid slab system, on the other hand, was analyzed as a two-way slab loading.

### *D. Development of Concrete Hollow Block Slab*

Due to the unavailability of the CHB product required to test the load capacity of a CHB slab system, a new product has been developed. The concrete hollow block plays a crucial role in the slab system, where it holds the minimum live load requirement of a residential building. The concrete hollow block product was developed for the CHB slab system, as shown in Figure 9.

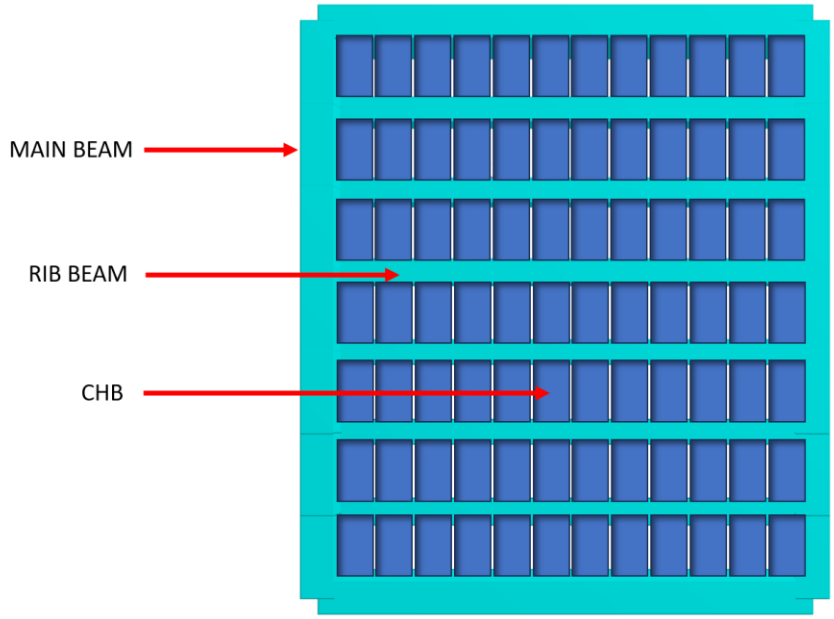


*Figure 9. Concrete slab system layout.*

1. **CHB Concrete Optimal Mix Design**

The concrete hollow block was prepared using an optimal mix design of 4 parts aggregates and 1 part cement, as shown in Figure 10. Normal mixing of concrete was followed.

Figure 10. Concrete mix design: 4 parts aggregates and 1 part cement.

A hollow block mold was prepared with dimensions of 100mm by 200mm by 400mm, with 2 holes measuring 50mm by 100mm, as shown in Figure 11.

*Figure 11. 100mm x 200mm x 400mm steel hollow block mold.*

The concrete was mixed and placed in a mold. The concrete was cured for a minimum of 28 days, see Figure 12.

*Figure 12. Casted concrete hollow block.*

Like ordinary concrete, the CHB was manufactured by mixing aggregate and cement, cast in a mold, and cured for a minimum of 28 days. The goal is to determine whether a hollow portion of the concrete block can sustain a load for residential buildings.

## 2. Testing of Concrete Hollow Block Slab

There are no available test procedures for this kind of product. One way of testing a concrete product is to simulate it in the actual scenario. Using the method from ACI 437.2, load testing for an existing concrete structure. A monotonic load test was conducted using a 40-kg bag of cement, piled to 7 stacks (280 kg total), and left for 30 minutes; see Figure 13. The load test simulated a load of 350% of an average person's weight (80 kilograms) with a foot stepping on a single CHB.

*Figure 13. Site Load test.*

Laboratory tests were also made using a Universal Testing Machine to determine the CHB's crushing point (see Figure 14). The CHB should sustain a minimum of 160% of the live load, which is 1.9kPa live load as per the code. The laboratory load test result must be greater than 160% of the live load (lab load test result > 1.6LL).

Where

LL = 1.9 kPa = 1,900 N/m2

Surface area = (0.2m x 0.4m) = 0.08m2

1 N = m (kg) x 9,81 m/s2

To get the minimum load m (kg)

$$m\ (kg) = 1.6 \times \frac{1900\ N/m2 \times 0.08\ m2}{9{,}81\ m/s2} = 24.8\ kg, \text{ hence} < 280kg \text{ (load test)}$$

*Figure 14. Laboratory test using UTM.*

Same with the actual site load test, the bottom of the UTM plate was elevated and supported at both ends only. This will simulate the CHB slab system, and the result will determine the maximum weight a CHB can carry. Four samples have been subjected to a laboratory load test to determine their point load. The lowest test result is 5.3 kN, corresponding to 66.25 kPa.

The result shows that the CHB can carry a load at up to 3,486% of the expected NSCP minimum live load requirement. The aggregate-to-cement ratio can be adjusted and retested to meet the optimum live load requirements. Given the satisfactory results from both site load testing and laboratory testing, a manufacturing company can use these results to create a product suitable for actual construction. Furthermore, when these products are available on the market, the structural designer will have the option to choose the innovative CHB slab system.

## CONCLUSION AND RECOMMENDATIONS

The study aimed to develop an innovative slab system design that is not popular here in the Philippines. The CHB slab system is popular only in countries with low seismic activity, and no one has tried it here in the Philippines because no studies or guidelines have been established. The study's focus on an innovative slab system, uncommon in the Philippines, aligns with the rising need for adaptable and efficient construction methods. By proposing the use of precast concrete rib beams and concrete hollow block products, this study underscores a practical approach to accelerating construction, reducing labor costs, and shortening project timelines, paving the way for new construction practices in the region.

### *E. Seismic Behavior of the CHB System*

It is the responsibility of the structural design engineer to ensure the building's design primarily protects its occupants' safety. The building design must comply with the minimum load requirements specified in the building code. This study holds value not only for structural engineers and builders in the Philippines but also for developers seeking innovative, efficient, and safe construction techniques that comply with the requirements of seismic zone 4.

The results of the inter-story drift in the analysis, using seismic zone 4 parameters, validate the safety and structural integrity of the CHB slab system in these regions. In the same manner, the concrete hollow block product passed the site load test and the laboratory load test. This work supports the goal of prioritizing occupant safety by adhering to NSCP codes. Therefore, using the CHB slab system addresses concerns about why structural design engineers in the Philippines are not opting for it. Furthermore, the residential developers and residents would likely feel safe with this kind of building's CHB slab system.

### *F. Availability of the Concrete Hollow Block Product*

The availability of the right concrete hollow block product ensures that the CHB slab system serves its intended purpose. The concrete mix formula for the CHB slab system differs from that for ordinary CHB for walls. The concrete hollow block product and the precast concrete rib beam could be made available in the local market. The installation of precast concrete rib beams and concrete hollow block products could shorten the construction timeline and save more money.

Moreover, this study demonstrates the potential to develop an innovative, cost-effective, and structurally viable concrete slab system for residential buildings. The satisfactory seismic behavior of a 2-story residential building using a CHB slab system provides a practical alternative to conventional solid concrete slab systems.

### *G. Recommendations*

The author of this study would like to recommend the following:

1) To conduct further study on higher storey buildings and commercial occupancy buildings; hence, this study is intended only to apply to up to 2-story residential buildings. The results may vary depending on the minimum live load and importance value of the building as indicated in the NSCP.

2) To conduct training or seminars for structural engineers for a better understanding of this innovative CHB slab system.

3) To a manufacturer who wishes to produce concrete hollow blocks, to find the most economical concrete mix that can sustain the minimum live load requirement of the building, and is subject to load testing and laboratory testing. The same applies to the pre-cast concrete rib, which must undergo load testing. Other than concrete mix design, the integration of other alternative materials in the CHB production may apply.

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