Proposed Oobleck Tuned Liquid Damper (OTLCD) In Nineteen-Storey Hotel and Casino Building in Angeles City, Pampanga

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***Abstract*: The province of Pampanga is located in a region that is earthquake-prone as it is surrounded by faults, notably the West Valley Fault System. Along with this, the location of the locale, Nineteen Storey Hotel and Casino Building in Angeles City, Pampanga, is a high-risk earthquake zone as identified by the Hazard Mapping. This study aims to evaluate and compare the performance of Oobleck Tuned Liquid Column Damper (OTCLD), traditional damping liquids in TCLD, and without TCLD by performing simulations on a scaled model miniature of the locale. The data collected was based on accelerometer readings and trial-and-error experiments. The results revealed that a 2:1 cornstarch-to-water ratio was the right mixture in providing stable and efficient Oobleck. Also, the use of hot water for stabilization was discovered, which improves the settlement and consistency of the mixture. Furthermore, the earthquake simulation showed that buildings with TLCDs have lower peak acceleration than without TLCDs, especially the proposed Oobleck TLCD, which provided the lowest peak acceleration across all levels of intensity of the shake table input. Moreover, the threshold activation of Oobleck has been found at level 2 of the shake table, at which the damping efficiency is at its highest, and its difference with the water-based TLCD is noticeable. Therefore, this study concludes that the proposed Oobleck TLCD at the locale was deemed more effective than using traditional damping fluids, which has the potential to be a ground-breaking discovery in structural applications.**

***Keywords*: Tuned Liquid Damper, Oobleck, Damping Efficiency, Shake Table, Intensity Level.**

1. Introduction

The 2030 Agenda for Sustainable Development offers a common road map for peace and prosperity for people and the planet, both now and in the future. It was endorsed by all United Nations Member States in 2015. Essentially, it is centered around the seventeen (17) Sustainable Development Goals (SDGs) shown in Figure 1, which represent a pressing need for action from both developed and developing nations in an international collaboration [1]. The sole focus of SDG 9, a part of the 2023 agenda, is to build a functioning and structurally resilient infrastructure as a basis for a successful community. As an ever-changing world, the future demands challenges; in turn, industries and infrastructure should be upgraded accordingly. With this, innovative sustainable technologies, and assuring equal and universal access to information and financial markets should be promoted. It is expected that these measures will bring prosperity, more job opportunities, and stable and thriving societies all over the globe.

Fig.1. Sustainable Development Goal

According to Volcano Discovery, as of the end of the year 2024 ranking, the Philippines is ranked eighth out of 195 nations with the most recorded earthquakes in 2024, with 17,708 earthquakes. And ranked fifth (6) among the nations with the highest seismic activity, ranking alongside Chile, Taiwan, and Japan, after an earthquake of magnitude 7.1 was reported on Basilan Island, Philippines. [2]

An earthquake is a natural disaster that induces global disruption. Both high magnitude and smaller magnitude earthquakes that hit unprepared locations can lead to significant outcomes, along with many affected persons. Earthquakes cannot be predicted in terms of exact timing; Seismologists, Geologists, and Environmental Scientists can only estimate the magnitude and intensity based on historical data. Since technology nowadays cannot provide precise predictions of time, location, or magnitude of an earthquake, enhanced public awareness of the said estimations helps individuals and governments to better prepare for the potential disaster effects. [3]

Controlling the seismic vibration is highly important because earthquakes occur randomly. As earthquakes can never be precisely predicted, proactive structural design and retrofitting approaches are required in order to minimize possible damage. Base isolation and vibration control technologies, which include dampers, become an important part of one approach. Damaging vibrations during an earthquake are prevented by such technologies, thus enabling buildings to absorb and disperse seismic energy. [4]

Tuned liquid dampers (TLDs) are innovative devices that are designed to reduce vibrations in structures, especially for high-rise buildings exposed to dynamic loads like wind loads or seismic activity. These dampers work by using the inertia of a liquid mass, which is systematically placed within a tank, to neutralize oscillations by resisting force or intensity from structural movements, as shown in Figure 2. The fundamental principle beyond TLDs pertains to their ability such as to tune and adjust the natural occurrence of the fluid sloshing motion and align with the structure's intense frequency, thereby enhancing overall stability and comfort for occupants as shown in Figure 2. [5]

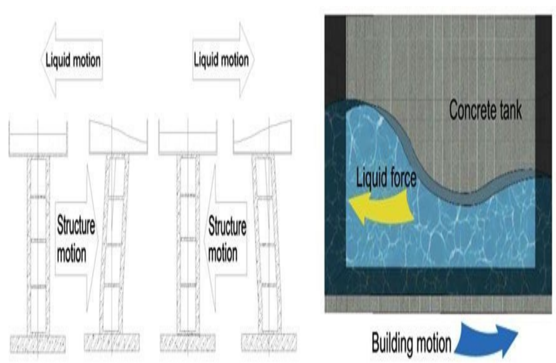

Fig.2. Mechanism of a building equipped with a TLD and a schematic of liquid inside a TLD tank

Most of the TLCD research that has been done focuses on increasing the damping force by using the utilization of pressure losses through valves, orifices, or viscous liquids [6]. The mixture of starch and water, Oobleck, is a non-toxic, inexpensive demonstration of a non-Newtonian fluid. The particularly interesting thing about Oobleck is the uncertainty around its status as a liquid or solid. It exhibits peculiar behavior because of its viscosity. Viscosity is simply how much layers of a fluid resist moving past one another under shear pressures or stress. When the shear force is applied, it gets more viscous and takes on the characteristics of a solid. It behaves like a fluid when the force is removed. [7]

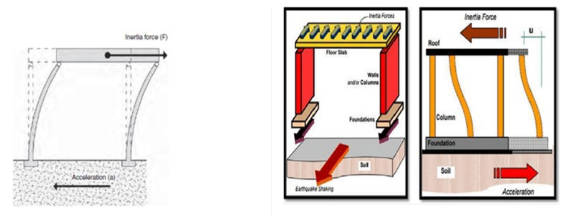

Fig.3. Effect of Inertial Force in the building during an earthquake

2. Methods

A. Methodological Framework

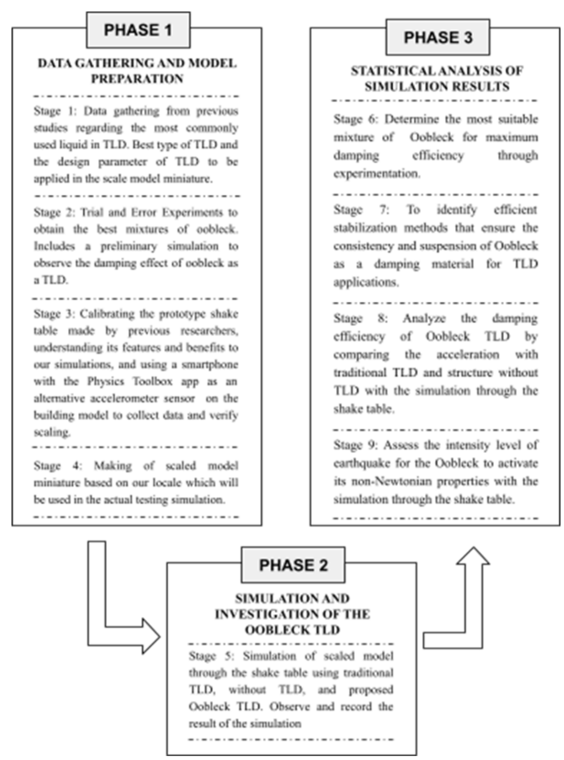

Fig.4. Methodological Framework

Earthquakes create seismic waves that shake the ground violently. The ground shaking can cause buildings to vibrate and sway, significantly stressing the structure [8]. Inertial force, as defined in Newton's First Law of Motion, which is produced during an earthquake, is the inertial response of the building's roof to remain at rest while its ground is already moving. In effect, as shown in Figure 3, the columns will move along the motion of the inertia force, which produces internal stresses inside the columns as they are forced to bend due to this movement [9]. When a building experiences an earthquake, the base of the building moves along with the ground shaking, but the roof or top part of the building moves differently than the base of the structure which can result in the stresses of weak walls or joints in the building, putting it in a tendency to be damaged or collapse [10].

B. Research Design

The study uses an experimental design research approach to test the ideas through controlled experiments where an independent variable is changed or manipulated to measure how it affects the dependent variable. In this research, the oobleck serves as the independent variable, where we measure the building's seismic responses and effects as our dependent variable when subjected to an earthquake, but reinforced with oobleck damping liquid. This is based on a similar study, where the use of a scaled rectangular TLD and its properties were evaluated through an experimental study using high-speed videos and software trackers that extracted data from the investigation [11]. Related to the current study, experimental research was conducted through scaled models and data collection and reading through electronic devices that were placed on the modified shaking table. The following data measured through actual experiments, was determined whether the proposed oobleck damper fluid significantly attenuates the seismic effects in a scaled model building of the Nineteen-Storey Hotel and Casino Building in Angeles City, Pampanga.

C. Research Locale

The study was conducted at the Widus Hotel and Casino Expansion, located at 5400 Manuel A. Roxas Highway, Clark Freeport Zone. The building is a 4-star hotel featuring a modern casino hotel where it is set on landscaped grounds. Additionally, the hotel mirrors a modern architectural design of two towers that cater to about 237 contemporary rooms and suites. The building dimensions are 72m long and 18.5m wide, and the storey height per storey is 3.5m. The number of storeys the building has is nineteen (19), one reason why it is the researchers' choice of locale, as the study demands high-rise buildings to test the efficiency of the proposed damping liquid. This location is also an area prone to seismic activity due to its geological context, and not only a major commercial hub. According to the HazardHunterPH seismic hazard assessment obtained from their website, the building is approximately 28.8 km south of the nearest active fault. Though it is safe in ground rupture, the data says it is prone to ground shaking, having intensity VIII, which is based on the PHIVOLCS Earthquake Intensity Scale (PEIS), this intensity is considered very destructive, where people can't stand even outdoors, and many well-built structures are damaged noticeably. [12] The integration of an OTLD provides an innovative approach for improving the structural resilience of high-rise buildings against dynamic forces. Due to the Widus Hotel and Casino's architectural prominence within Angeles City, the Widus Hotel and Casino is an ideal study. Through the implementation of the OTLD, the research aims to evaluate its effectiveness in natural events such as earthquakes. The study locale was chosen to utilize the hotel for certain purposes, particularly in testing miniature models on shake tables. Even though the study does not directly analyze the structural damping of the hotel itself, the hotel characteristics still provide a pertinent context for evaluating the effectiveness of OTLD in mitigating seismic loads. By constructing a scaled-down model of the hotel for experiments, the researchers aim to leverage its unique structural features to effectively assess OTLD performance under simulated earthquake conditions. The study locale has been chosen to further understand and explore the earthquake resilience of the buildings in relation to having tuned oobleck dampers to dissipate and mitigate seismic loads, enhancing not only the structural integrity but also the overall safety of the people the hotel is catering to.

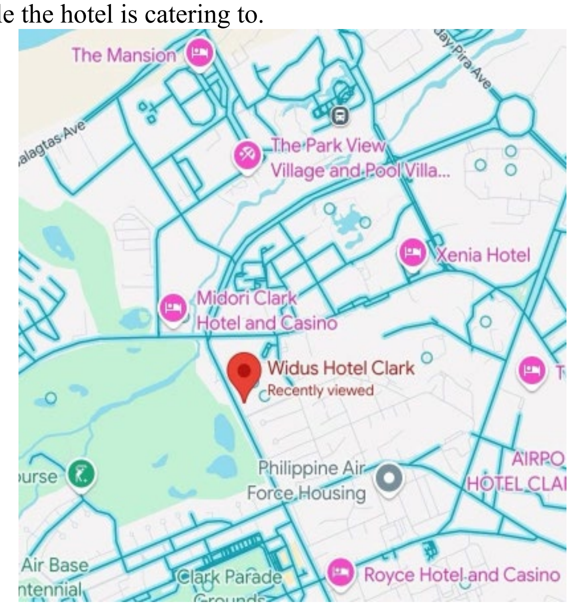

Fig.5. Vicinity Map of Widus Hotel and Casino Extension

D. Data Collection

The study aims to provide an extensive knowledge of the TLD's impact by combining experimental and observational data.

A precise data collection process, which involves experimentation, observation, and gathering information such as the process of using the shake table from previous studies and the use of smartphones as an alternative accelerometer sensor, is implemented to achieve this study. In addition, the primary data collection methods analyze the behavior of the Oobleck TLD in different levels of shaking, including conducting experiments as well as observing.

1) Data Gathering from Previously Conducted Studies

The researchers sought studies about the different kinds of liquids used in Tuned Liquid Dampers. The researchers have seen that the commonly used liquids in TLD are water, magnetic fluids, silicone oil, and other viscous fluids. The commonly used liquids mentioned, water is the most common of all, and 4 related literatures used it as their agent, while the magnetic fluid has 2 studies used, and only 1 study used silicone oil. Water has been chosen to compare its effectiveness with Oobleck. Also, the researchers looked for studies about different types of TLDs and what is the best type of TLD to be applied in the structure. In this search for studies, the common TLDs used were Tuned Sloshing Damper (TSD), which has different shapes of tanks, such as rectangular, cylindrical, and spherical. Another type of TLD is the Tuned Liquid Column Damper (TLCD), which has a U-shaped tank. Based on research, the TLCD is the best to use in a structure owing to its U-Shaped tank and its orifice, which adds to the effectiveness of the fluid. Since the scaled model miniature that the researchers will make is a column type, the TLCD is a perfect fit for the miniature to be made.

For the design parameters of TLCD that will be used in the actual testing, the researchers used data from previous studies. For the height of TLCD, it is computed to be 10% of the building height with a 28% allowance, in the equation,

$$H = 1.28[\frac{1}{10}(H_{building})]. [13] \quad (1)$$

In calculating the width of the columns of TLCD, it can be solved by taking up 20% of the building's width, in the equation,

$$W = \frac{1}{5}(W_{building}). [13] \quad (2)$$

The height of the orifice is calculated by getting 10% of the building's width, represented by:

$$D_o = 0.10(W_{building}). [14] \quad (3)$$

Lastly, with the diameter of the orifice, it is recommended to take half the height of the orifice, that

$$d_o = 0.50(D_o). [14] \quad (4)$$

2) Achieving the Proper Mixture of Oobleck

The researchers employed a trial-and-error approach for determining the proper mixture of Oobleck that can effectively activate during the seismic events. The primary objective of formulating the proper mixture of Oobleck is to enhance the responsiveness when it is integrated into the TLD system of the nineteen-storey hotel and casino building. To obtain this data, different ratios of water and cornstarch are tested carefully to find the adequate consistency that will maximize the fluid's unique properties. Additionally, the researchers tried to experiment with other additives that would be added to the Oobleck's mixture, including vinegar, baking soda, flour, and gelatin. Unfortunately, these additives were not enough to achieve the optimal mixture of oobleck. The researchers were doing a trial-and-error experimentation in finding out an alternative way to obtain a minimal to no settlement of the oobleck. During this process, boiling water was used instead of lukewarm water. As a result, it was found out that boiling water is a good alternative to reduce the settlement of oobleck. By experimentation and data collection, researchers aim to determine the most effective Oobleck mixture for application in the Proposed Oobleck TLD system. Exploring the variations of the mixture will contribute well to the development of an efficient and stable damper that can be used in a nineteen-storey hotel and casino building.

3) The Use of Prototype Shake Table Made by the Previous Researchers

Initially, the researchers gathered information from the literature from the previous researcher about their prototype shake table, which gives details about the procedure and steps on how to operate the shake table. The shake table is an important apparatus to artificially produce the effect of an earthquake. The shake table will be used to execute different earthquake loading conditions to facilitate the evaluation of acceleration in the building model effectively. This, in turn, makes it easier to assess the acceleration of the nineteen-storey hotel and casino structure model that has been constructed. To measure acceleration during the simulation, a smartphone attached to the building model was used as an alternative accelerometer sensor, utilizing the Physics Toolbox app. The researchers prepared a letter of request sent to the previous researchers and the adviser that contained permission to use the prototype shake table.

4) Data Gathering through Comparison of Scaled Model Miniature with Oobleck TLD, Traditional TLD, and Without TLD

The researchers assembled a Scaled Model Miniature made of steel bars, and it will be used in the actual testing simulation. And the researcher used a 1m:1.5cm scale to reduce the size of the proposed building. The scaled model miniature will be installed on the motorized shake table to perform the actual testing and simulation. Using a motorized shake table and a smartphone with the physics toolbox app, the researchers will compare the data obtained from Oobleck TLD, Traditional TLD, and without TLD. This study will highlight the advantages of Oobleck TLD compared to Traditional TLD and without TLD. The data to be adopted in determining the effectiveness was acceleration from a smartphone that was fixed on the top of the building. The researchers will observe the acquisition of data and record the actual testing and simulation to obtain the results in the comparison of the scaled model miniature with Oobleck TLD, Traditional TLD, and without TLD.

E. Data Analysis and Procedure

The present research combined both experimental testing and comparative evaluation in the data analysis to evaluate how effective Oobleck works as a Tuned Liquid Damper (TLD) in minimizing lateral acceleration movement under an earthquake-simulating condition. Each objective was evaluated through a set of experiments, comparisons, and an intensive study of data obtained from the shake table tests, which were properly carried out for each of the objectives.

1) Optimize Cornstarch-Water Ratio

To improve the damping efficiency of Oobleck, researchers conduct experiments to find the appropriate ratio of cornstarch to water for use in structures that have been exposed to earthquakes. The goal is to formulate Oobleck such that it can readily activate in an earthquake to provide the required damping while fitted in the TLD system of a nineteen-storey hotel and casino building. The appropriate cornstarch and water ratio is also important in making sure that the blend has the right combination of viscosity for optimal energy dissipation.

In the experiment, the efficacy of different cornstarch to water mixtures was examined by varying the compositional ratios: 0.5:1, 0.75:1, 1:1, 1.5:1, 2:1, and 2.5:1. Each sample is kept in jars and is prepared through careful measurement of the amount of cornstarch and water to ensure a consistent form of Oobleck. In this regard, finding an optimal viscosity that will help enhance the distinct characteristics of Oobleck, such that it will aid in counteracting lateral movements during earthquakes, yet provide a timely response to earthquake forces.

The results for each combination are assessed concerning their viscosity, performance in damping, and similar attributes after the researchers conducted a number of experiments. This involves an experimental process where the proportions are adjusted according to the findings of the ratios, finding the best cornstarch-water blend aimed at enhancing the properties of the fluid. This ideal mixture is then performed within the TLD system, so that Oobleck would minimize lateral acceleration and also improve the safety of the building structure in the event of an earthquake. Upon testing the ratios, the researchers identified a problem, that oobleck settles quickly. Fortunately, the researcher found an alternative solution; the water used in the mixture was hot to achieve the desired consistency and performance of the Oobleck as a damping material.

2) Identify the Efficient Stabilization Method

In some of the recent studies, researchers have sought to modify Oobleck, a mixture of cornstarch and water, in a way to improve its stabilization and suspension properties. Since Oobleck is non-Newtonian, in normal situations it functions as a liquid, but when a stress is applied in a horizontal manner, it becomes solid. The material is a good possibility for use in Tuned Mass Dampers (TLDs) that help to reduce the effect of earthquakes. The main aim of this research is to design an improved fluid consisting of Oobleck that can be applied in tall structures such as high-rise buildings without a significant increase in the cost of production.

The fundamental properties of Oobleck arise from the correct proportion of cornstarch and water, where the cornstarch particles are suspended in the water. However, over time, the cornstarch particles can begin to settle out of the mixture, compromising the fluid's effectiveness as a damping material. The researchers initially sought to find affordable additives to improve Oobleck's stability, but these attempts did not yield successful results. Consequently, the researchers tested to address this issue of whether the temperature of the water, specifically using hot water, could be a factor in improving the consistency of Oobleck, which could lead to better performance in seismic conditions.

The study aimed at identifying an effective method for stabilizing Oobleck without the additional incorporation of other ingredients. Several tests carried out on hot water mixed with it were directed towards finding the extent to which such a mixture could affect fluid thickness, stability, and damper properties. The results prove that hot water would generally improve the overall performance of Oobleck; it stabilizes as well as increases damping. This affirms that hot water alone has a simple, cheap, and effective option to be applied for Oobleck in advanced seismic applications.

The findings from this study are promising for the future use of Oobleck in TLD systems, particularly in structures located in earthquake-prone regions. The researchers are able to create a material that can be economically feasible for large-scale use in buildings and other infrastructure by using the most efficient stabilization method to improve the stability and suspension of Oobleck as a damping liquid.

3) Evaluate Oobleck Tuned Liquid Column Damper Effectiveness

The researchers explored the potential of using Oobleck as a Tuned Liquid Damper (TLD) to reduce predominantly horizontal movement of a building structure during an earthquake. For this purpose, the shake table, which had been constructed by other researchers to carry out earthquake simulations, was employed. This is important equipment for creating forces that mimic an earthquake and for testing the performance of various damping materials under such conditions. For instance, the researchers, before proceeding with their simulation, reviewed the relevant shake table literature in depth, and this assisted in the preparation of their tested methodology. A smartphone was used as an alternative accelerometer sensor on the building model to record acceleration data during the simulations. The collection of data was facilitated further, as well as the monitoring of the building's response in real time.

The first step involved designing a scaled model of a nineteen-storey hotel and casino structure and the tuned liquid column damper, whose main purpose is to evaluate how the structure would react to seismic forces in practice. This model is then set on the motorized shake table, where the different intensity level conditions are programmed. Intensity and duration of the shake table are varied to simulate more realistic seismic activities. The effectiveness of the Oobleck TLD system is subsequently assessed in two contrary environments: one with a traditional TLD system and the other with no TLD system at all. One of the earthquake tests used traditional TLD, Oobleck TLD, and No TLD configurations, ensuring that the three conditions were tested in the same earthquake simulation for comparison purposes. The accelerations of the building, as well as its general stability, are monitored and recorded throughout the shake test with the help of a smartphone with the physics toolbox app, serving as an alternative accelerometer sensor installed in the scaled model building.

4) Determine Activation Threshold

In this phase of the study, the researchers aimed to identify the threshold magnitude of seismic force required to trigger the Oobleck, activating its non-Newtonian properties. In order to evaluate this, the shake table is utilized by the researchers in order to reproduce the effect of different earthquake-induced forces.

The shake table simulates earthquake forces by adjusting the duration and level of the shaking to replicate the characteristics of an earthquake of a specific magnitude. Using these parameters, researchers measure the level of simulated seismic force. Apart from this, the researchers resume applying Oobleck fluids to lower shaking levels and continue to increase the simulated quakes for the first noticeable change in the behavior of the fluid. In these tests, the smartphone with the physics toolbox app will serve as an alternative accelerometer sensor, measuring the peak acceleration of the building model. In order to find the activation threshold of the Oobleck, peak acceleration will be the basis since the mass is constant across all building models, comparing their acceleration will be the method to determine the threshold level on the basis of the shake table input. The researchers will compare the peak acceleration of the buildings with water-based TLCD and Oobleck TLCD in terms of the damping efficiency. Damping efficiency can be computed using the formula,

$$DE = \frac{\textit{Peak Acceleration of Bldg. with TLCD} - \textit{Peak Acceleration of Bldg. without TLCD}}{\textit{Peak Acceleration of Bldg. without TLCD}} \times 100\%. \quad (5)$$

Then, the difference in damping efficiency between the buildings with water-based TLCD and Oobleck TLCD across all levels will be compared, and the level at which there is the highest difference in their damping efficiency will indicate the activation threshold of the Oobleck. At this level, the non-Newtonian properties of Oobleck are fully attained. This data in real-time also enables the researchers to keep track of changes in Oobleck when its non-Newtonian behaviors are triggered at varying levels of seismic stress.

A major step in the process is measuring the specific threshold at which Oobleck behaves in a state of shear-thickening. If Oobleck is subjected to forces greater than a certain level, the material becomes more resistant to flow or thickens, effectively increasing its stiffness in opposing lateral movement of a structure. The results obtained from the shake table experiments are quantitatively assessed to find out the threshold earthquake response acceleration or force that is necessary to turn on the non-Newtonian effect of Oobleck. This threshold information is essential for the development of Oobleck-based TLD systems that can be safely installed in regions where earthquakes are frequent so that the material will perform the necessary damping function when the seismic forces exceed working stresses. By means of this testing and analysis, the researchers not only determine the parameters necessary for the activation of Oobleck but also enhance its limits as a possible and creative seismic mitigation material.

F. Ethical Considerations

As this study employs, research ethics will be taken into consideration. Given this ethical aspect and to avoid any foreseeable problems in the conduct of this study, permission to conduct such will be secured from the project engineer of Nineteen-Storey Widus Hotel and Casino Building, the locale of the study.

The management will be well-informed by the researcher about the purpose of the study and their contribution to it. Consent from the administration will be obtained, and appropriate permission will also be ensured for the usage of the given data or structural plans of the building being modelled.

In addition, the management will be given the assurance that all information that will be gathered from them will be treated with care and confidentiality and shall only be used for the study.

3. Results and Discussions

This chapter shows the collected data collected using the methodology in Chapter 2. Also, the results and discussions are in accordance with the research objectives.

A. Design of Building Miniature and Tuned Liquid Column Damper

Fig.6. Miniature Dimension

The locale of this study is located at the Widus Hotel and Casino Expansion, located at 5400 Manuel A. Roxas Highway, Clark Freeport Zone, Angeles City, Pampanga. The building has a dimension of 72m long and 18.5m wide, and a 3.5m storey height per floor with a total of 19 floors. The Researchers utilized a 1m:1.5cm scale to reduce the size of the building, ensuring it would fit into the motorized shake table. The final result of the scaled-down building suggests that its length should be 108cm, while its width is 27.75cm, and the height of the building is 99.75cm, with a 5.25cm per storey as shown in Figure 6. Scaling down the building model is a fundamental requirement in shake table experiments to precisely simulate the structural and dynamic responses of the actual structure, while also addressing the spatial and operational constraints of the shake table. Accurate scaling allows the miniature model to effectively reflect the seismic behavior of the full-scale building, offering critical insights into its performance and potential failure patterns during earthquake events [15].

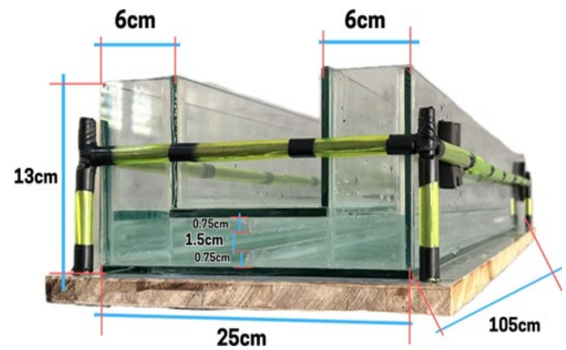

Fig.7. Dimensions of Tuned Liquid Column Damper (TLCD)

After scaling down the building model, the next step is building the TLCD that will confine the damping liquids for testing. From the scaled-down dimension, it has a total height of 99.75cm, a width of

27.75 cm, and a length of 108cm. The design of TLCD, which is shown in Figure 7, will follow the formulas presented in Chapter 2 of this research. The height of TLCD will be computed based on the formula:

$$H = 1.28[\frac{1}{10}(H_{building})] \ [13]. \quad (1)$$

Also, the width of the columns will be solved using the equation,

$$W = \frac{1}{5}(W_{building}) \ [13]. \quad (2)$$

The orifice's height is governed by the equation,

$$D_o = 0.10(W_{building}), \quad (3)$$

and the opening of the orifice is equal to

$$d_o = 0.50(D_o) \ [14]. \quad (4)$$

Using the aforementioned formulas, the results will yield to the following:

$H = 13cm.$, $W = 6cm.$, $D_o = 3cm.$, and $d_o = 1.50cm.$

B. The most desirable ratio of cornstarch and water in maximizing the damping efficiency of Oobleck TLD against seismic events.

Table 1. The cornstarch-to-water ratios compared in the study

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RATIO (C.S. TO WATER)	MIXABILITY	VISCOSITY	SLOSHING EFFECT	SETTLEMENT	REMARKS
0.5:1	Very fast	Very low	Very High	Very Low	Too much fluid, very low iscosity, and very high sloshing. The least performance in the damping effectiveness.
0.75:1	Fast	Low	High	Very Low	Mixable even without hot water, but lacks viscosity, and has high sloshing. Poor performance as a fluid damper is expected.
1:1	Fast	Moderate	High	Low	mproved mixability, especially with the help of hot water, but still suboptimal due to the high sloshing effect
1.5:1	Moderate	Moderate	High	Low	Improved overall consistency; however, it still has a high sloshing effect.
2:1	Moderate	Moderate	Moderate	Moderate	Hot water makes this thick ratio surprisingly easy to mix; it retains effective damping performance properties even when it cools. Most optimal or balanced, and stable consistency of all ratios.
2.5:1	Slow	High	Low	High	Almost close to being solid, no sloshing effect, but hard to mix even with hot water, and has high settlement issues.

The study objective is to determine the best and effective cornstarch-to-water ratio for creating oobleck as a liquid damper. Six ratios were tested, including 0.5:1, 0.75:1, 1:1, 1.5:1, 2:1, and 2.5:1, to evaluate their behavior and consistency [16,17]. Through observation and comparative testing, it was found that the 2:1 ratio, two parts cornstarch to one part water, exhibited the most desirable fluid damper properties. Among all mixtures, the 2:1 ratio produced the most optimal sloshing effect as the researchers subjected the following mixtures of different ratios to shaking motion, which is essential for energy dissipation in damping applications. Additionally, when hot water was introduced to the trial ratios, 2:1 showed a more consistent mixture among others. This ratio turned out to be the most suitable mixture for analysis and application in the study.

The further objective was to analyze the physical traits of each ratio in terms of viscosity, mixability, and settlement behavior [13]. In this, a 2:1 mixture ratio showed the most optimal viscosity, which allowed the oobleck to transition easily between solid to liquid states under applied force, such as shaking motion whenever cornstarch particles settle. It also mixed faster and more uniformly compared to the other ratios, making it easier to prepare and reproduce. One more thing, the settlement behavior of the 2:1 ratio was observed to be in moderation with particles settling over time. The following findings supported the decision to choose the 2:1 cornstarch-to-water ratio as the standard formulation for the experimental phase in the study. Refer to the table for actual findings.

Table 1 above shows a comparison of different cornstarch to water ratios based on standard characteristics for an effective liquid damper. Initially, the deciding factor of more effective fluid dampers is with greater thickness or viscosity, which perform better than the most common dampening liquid, which is water [13]. However, in an oobleck mixture, the researchers encountered altering factors among the ratios such as mixability, sloshing effect, and settlement of cornstarch, but then the researchers through trial and error came up with the most stable ratio of 2:1 which is the right proportion of an oobleck based on one of the related literatures [18]. Through comparative analysis of all the ratios, the 2:1 mixture proved that it is the most effective in producing stable and efficient oobleck. Based on the results above, it showed moderation among all factors mentioned, having the best consistency and proper ratio, making it ideal for damping purposes. The consistency was moderately thick but still manageable, especially when mixed with warm water. The researchers proposed the use of warm water during preparation to help improve mixability for all ratios. This combination of properties further supported the 2:1 ratio to be the most suitable choice for the study.

In more specific comparison, the other ratios, ranging from 0.5:1 to 1:1, showed fewer desirable results. Lower ratios, such as 0.5:1 and 1:1, were too watery, with very high sloshing and low viscosity. Although the 1.5:1 ratio showed improved consistency, it still lacked the stability in a factor of sloshing effect, in which the flow of fluid is crucial in damping performance. Some mixtures became easier to handle with the help of warm water, which served as a solution to the initial problem about settlement and mixability, but their behavior under force, like shaking motion, was still not as optimal as the chosen ratio.

C. Efficient stabilization methods that ensure the consistency and suspension of Oobleck as a damping material for TLD applications.

The application of hot water in making an Oobleck prevents settlement or sedimentation and improves the mixture's consistency. Applying heat promotes better suspension of cornstarch granules, resulting in a smoother and more homogeneous mixture [19]. Studies have shown that using hot water during the mixing process effectively reduces settling issues. In contrast, larger particles tend to settle at the bottom when cold water is used for mixing, resulting in an uneven texture that detracts from both visual appearance and structural performance. On the other hand, hot water provides a uniform distribution of particles throughout the mixture [20]. In this objective, results after various experiments showed that the application of hot water stabilizes the Oobleck mixture significantly and produces a more uniform consistency, leading to increased viscosity and more pronounced behavior. The most efficient approach not only for achieving the desirable consistency but also to enhance the overall performance of Oobleck as a damping liquid is by heating water to be used. The hot water variant showed better viscosity and more consistent behavior compared to mixtures prepared with room temperature water, ambient temperature water, or cold water. Increased heat energy was referred to as this improvement since it enhanced the dispersion of cornstarch particles in the suspension and reduced the occurrence of clumps and inconsistencies of Oobleck. During testing, visual and tactile tests confirmed the uniform blend consistency of the hot water-based Oobleck. With the mixture being more responsive to applied forces, the damping performance of Oobleck improved. Results suggest that hot water alone is a feasible and efficient way to stabilize Oobleck, making it even more appropriate for seismic damping applications such as Tuned Liquid Dampers (TLDs).

D. Oobleck Tuned Liquid Damper (OTLD) in reducing the earthquake-induced acceleration of the building.

Table.2. Acceleration Produced by Different Shake Table Intensities

Shake Table Intensity	**Acceleration**
Level 1	2. 7523 m/s ^2
Level 2	4. 3326 m/s^2
Level 3	7. 8319 m/s^2
Level 4	8. 7478 m/s^2

Table 2 shows the measured accelerations recorded from four intensity levels on the shake table. As can be observed, a higher level of shaking intensity means a higher acceleration is produced. It demonstrates the direct relationship between the shake table input and the simulated ground motion induced in the structure.

At level 1, the recorded acceleration is 2.7523 m/s^2 then progressively increased to 8.7478 m/s^2 at level 4, which is the maximum input for the shake table. Higher intensity levels simulate stronger earthquake forces or seismic ground motion, as a result, the structure would be induced to higher inertial forces, which can lead to structural damage if no countermeasures are applied. Newton's Second Law of Motion (F = ma) states that an object's inertia causes it to resist changes in motion. Various floors of a building experience various inertial forces when an earthquake-induced acceleration acts on them. This results in base shear, which is the lateral force applied at the foundation level. The structure's mass and peak ground acceleration (PGA) determine how much base shear occurs [21].

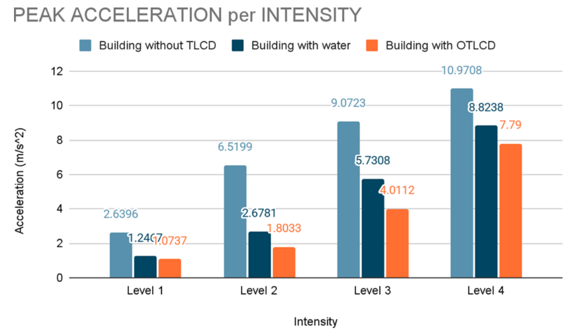

Fig.8. Peak Accelerations of Miniature Buildings Tested on a Varying Shake Table Intensities

Figure 8 presents the peak acceleration experienced by three building models subjected to four different shake table intensities. The models are: (1) a building without a tuned liquid column damper (TLCD), (2) a building with water-based TLCD, and (3) a building with Oobleck-based TLCD.

As the intensity of shaking increases from Level 1 to Level 4, an upward trend in peak acceleration can be observed, in which a building without any damper records the highest peak accelerations in all levels. Meanwhile, the buildings with TLCD exhibit reduced response acceleration, especially the Oobleck-based TLCD, which shows the lowest peak acceleration. In multi-degree-of-freedom structures, the TLCD successfully reduces seismic-induced vibrations, especially when adjusted to the inherent frequency of the structure. This passive damping technique provides a workable way to increase the seismic resistance of a structure. [14]

Table 3
Damping Efficiency of Water-Based TLCD vs Oobleck TLCD

Intensity Level	**Water-Based TLCD** (m/s^2)	**Damping Efficiency (%)**	**Oobleck TLCD** (m/s^2)	**Damping Efficiency (%)**
Level 1	1.2407	53	1.0737	59.32
Level 2	2.6781	58.92	1.8033	72.34
Level 3	5.7308	36.83	4.0112	55.79
Level 4	8.8238	19.57	7.79	28.99

Delving deeper into the data of the simulation, the following results are observed. As explained in the figure above, different levels of intensity also give a different acceleration induced in the building. These different intensities of shaking are synonymous with the different magnitudes of an earthquake that a building can experience, from lower to higher magnitude.

From these, looking at the building with no TLCD, when it is subjected to different intensities, we can see that there is a spike in the acceleration in the higher intensities from Level 2 to Level 4. However, the peak accelerations experienced by the building without TLCD are significantly higher than the acceleration given by the shake table input, which indicates that the building with no damper, particularly a high-storey structure, has an amplified acceleration because the buildings sway, which creates extra acceleration aside from the acceleration given by the earthquake itself. In contrast, the buildings with TLCD show promising results since the peak acceleration of the structure was reduced significantly in comparison to the building without a damper. It can also be seen from the results that reduced peak acceleration is lower than the acceleration induced by the shake table, which demonstrates the role of dampers in minimizing the seismic force experienced by the structure. To highlight, the Oobleck TLCD showed the lowest peak acceleration, even lower than the water-based TLCD, which suggests that a non-Newtonian fluid like Oobleck has the potential to be highly effective in damping systems. Due to the Oobleck's properties, which include high viscosity when exposed to high forces. High-viscosity fluid dampers are effective in seismic reduction because they efficiently absorb and dissipate earthquake energy, significantly reducing structural vibrations. By converting kinetic energy into heat through fluid shear, these dampers minimize inter-story drift and enhance overall building stability during seismic events. [22]

E. Threshold level of the shake table required to activate Oobleck.

Table 5 demonstrates the damping efficiency of Water-based TLCD and Oobleck TLCD across all levels of shaking intensities from Level 1 to Level 4. Damping efficiency refers to the effectiveness of a damper in reducing the induced acceleration of a building, in this case, the peak acceleration felt by the structure. With the data gathered, it is calculated by the formula for damping efficiency,

$$DE = \frac{\text{Peak Acceleration of Bldg. with TLCD} - \text{Peak Acceleration of Bldg. without TLCD}}{\text{Peak Acceleration of Bldg. without TLCD}} \times 100\%.$$

At intensity level 1, both dampers showed exemplary damping efficiency, with the Oobleck TLCD showing a slightly higher efficiency (59.32%) than water-based TLCD (53%). When the intensity was increased, the Oobleck TLCD still consistently outperformed the water-based TLCD in reducing the peak acceleration experienced by the building. It is worth noting that at level 2, Oobleck TLCD achieved its highest damping efficiency at 72.34%, as compared to 58.92% of water-based TLCD. The results determine that the significant increase in the damping efficiency of the Oobleck TLCD, where the gap between the results from water-based and Oobleck TLCD is noticeable, may indicate the threshold at which the non-Newtonian properties of Oobleck have fully activated. Oobleck's properties at low stress, Oobleck's particles slide smoothly due to lubrication forces, keeping it fluid. When stress increases, these forces collapse, and friction between particles causes them to lock together, making the mixture behave like a solid due to abrupt force or impact. [23]

At higher intensities, like levels 3 and 4, it is observed that both dampers declined in their damping efficiency. However, despite this, the Oobleck TLCD still maintained its excellent damping efficiency which registers 55.79% at level 3 and 28.99% at level 4, surpassing the performance of water-based TLCD, which performed at 36.83% at level 3 and 19.57% at level 4. These results suggest that Oobleck TLCD is more effective than a traditional TLCD at damping the structure against seismic energy induced by the earthquakes.

4. Conclusions and Recommendations

A. Conclusion

This research was initiated with the primary intent of studying the performance of Oobleck, considered as a non-Newtonian fluid made from cornstarch and water, and whether it could act as a damping material in Tuned Liquid Damper (TLD) systems for the control of seismic motion in high-rise buildings. This study has been conducted in order to find the best ratio for the mixture, to find an effective stabilization method, and finally to measure the performance of Oobleck as a seismic acceleration reduction solution concerning conventional water TLDs.

The results of the research can lead to the following conclusions:

- Several cornstarch-to-water ratios were tested, and the 2:1 ratio was found to be the most effective in terms of stability, viscosity, and damping performance. Noticeable sloshing was noted compared with other ratios, and it maintained better suspension.
- The experiment performed indicates that hot water is indeed a significant agent in stabilizing an Oobleck mixture. Furthermore, hot water helped the mixing, settled the particles, and was beneficial to the consistency of the fluid, which made hot water an effective option for stabilizing Oobleck.
- The shake table simulations confirmed that the building with the Oobleck-based TLCD achieved lower peak accelerations compared with the water-

based TLCD and the structure with no damper.

- Oobleck TLCD performed maximum damping efficiency for all intensity levels, while its peak efficiency reached at intensity level 2 is 72.34%. It was again seen performing better than a conventional TLCD even at high intensity levels when damping efficiency is generally known to decrease, thus proving further that Oobleck is efficient in reducing earthquake-induced vibrations.
- The research findings concluded that Oobleck, especially an optimized 2:1 mixture with hot water, should be regarded as a very competent and low-cost damping medium, being non-Newtonian and therefore in principle very useful for seismic protection systems, especially for tall buildings in zones of seismicity.
- Thus, the study concludes that Oobleck is not only a viable but a superior alternative to conventional damping fluids in TLCD systems, providing enhanced damping efficiency, better performance under seismic conditions, and potential for real-world structural applications.

B. Recommendations

Upon accomplishing the study, the researchers have recommendations to provide further improvements for future studies related to this study.

- Explore potential admixtures that can better the overall properties of the oobleck damper. The researchers have done several tests regarding this matter in which vinegar is the best among compared admixtures, however, it has properties that can contribute to maintenance issues, such as smell, etc. Future researchers can investigate further catalysts to contribute to the uniformity of the liquid damper.
- Since the researchers used a prototype shake table that can alter real-life data accuracy, future studies have the option to use an actual shake table provided by PHIVOLCS if available and possible. The researchers contacted several government agencies for this approach, but were unable to push through as it was too strict in terms of requirements and requests to higher-ups.
- The study does not include cost analysis, but future researchers can explore which is the best cost-effective fluid damper to be used in structures. This may be done by comparing oobleck damper and other mentioned fluids to compare them with the traditional damping liquid, which is water, and the best choice of a liquid damper.
- The study is limited to analyzing lateral movements only since the shake table can only provide the said movement. In this area, future researchers can study vertical loads or other possible loads a structure can experience, and test if oobleck dampers can produce better damping performance than other liquid dampers.
- The study used hot water to achieve the best ratio of oobleck damping liquid. For this, researchers can explore other possible ways to maintain oobleck consistency, as it performs best when hot water is used.
- The researchers have come up with a scaled model miniature of an actual building based on its storey height and outside dimensions, using steel bars. Further study from future researchers may replicate an actual scaled-down down including all necessary dimensions (outside and inside dimensions) to explore not just magnitude and acceleration induced in a building during an earthquake, but also the intensity it causes with or without oobleck damping liquid.
- Oobleck has properties that are at risk for fungal or bacterial growth. The researchers suggest studying ways to improve the Oobleck-tuned liquid column damper's longevity and ways to maintain the effectiveness and actual properties of the Oobleck damper.
- The researchers used a scaled model from an actual building that does not use tuned liquid dampers. For future researchers, look for established buildings that are using tuned liquid dampers and reference them to further study how actual tuned liquid dampers are installed.
- The used motorized shake table does not relate to an actual earthquake's intensity and magnitude. While the researchers have the recorded data for the shake table's acceleration for each level of intensity it's shaking, future studies can be about relating the shake table's four levels of intensities and its recorded acceleration data to an actual earthquake's real-life magnitude and intensity for greater accuracy. DOST PHIVOLCS has the data for recorded peak ground acceleration in the Philippines, which future researchers can request to correlate the actual data from what the shake table's acceleration can provide. The said recommendation for requesting data from the agency was not followed by researchers due to time constraints.

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