Comparative Analysis of Fiber Reinforced Polymers (FRP) On the Behavior of Reinforced Concrete Beam-Column Joint by Simulation Approach Using Ansys Workbench R22

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Abstract: - When earthquake strikes, exterior beam-column joints are considered to be the most vulnerable structural component in reinforced concrete structures. In this paper, three types of FRP composites namely carbon FRP, glass FRP (synthetic fibers), and hemp FRP (natural fibers) have been tested to compare their effectivity against each other in retrofitting beam-column joints. Ten simulated samples, which includes one control (unwrapped) specimen, and three retrofitted (wrapped) specimens of each type of FRP composites wrapped at L/3, L/4 and L/5 were modeled and tested using non-linear finite element analysis in Ansys Workbench R22 in order to evaluate the parameters which are deformation, equivalent stresses, equivalent elastic strain and strain energy. Numerical results shown significant improvements on all parameters in beam-column joint when wrapped by FRP composites. Among the four parameters, only deformations of the three FRP composites has significant difference and it is used to determine the most effective one which is the carbon fiber reinforced polymer (CFRP).

Key Words: — *Beam Column Joint, Finite-Element Method, Fiber-Reinforced Polymers, Cyclic Behavior.*

I. Introduction

The Philippines is bounded by five active faults: The Western Philippine Fault, the Eastern Philippine Fault, the South of Mindanao Fault, the Central Philippine Fault, and the Marikina/Valley Fault. Due to the movements of these faults, ground movement occurs that is why the Philippines is prone to natural calamities especially or particularly to earthquakes. Earthquakes are the most catastrophic natural calamities in recorded history, and they are one of the potential causes of death and infrastructure damage in seismically vulnerable regions. (Abbas et al., 2021).

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These calamities killed hundreds of thousands of people and destroyed property worth billions of pesos. Earthquake can damage both horizontal and vertical structures particularly the reinforced concrete structures. Many RC frameworks were created with the intention of supporting just gravity loads. They are neither strong or ductile enough to demonstrate a global failure mechanism brought on by cyclic loading circumstances. Due to insufficient transverse reinforcement and "strong column/weak beam" design, these structures typically have non-ductile reinforcement at the beam column joint areas (Naveeena & Ranjitham, 2016). Considering the damage to Reinforced concrete structures, in reinforced concrete structures, beam-column joints are considered as one of the most critical elements. Large lateral deformations caused by RC beam-column junction damage or failure could cause the structure to collapse or fail. In Addition, according to Attari et al. (2019), in frame constructions that suffer from significant inelastic deformations during earthquakes, 1 2 beam-column joints are typically recognized as crucial region. Whereas, when earthquake strikes, the stability of the beam-column joints has a significant impact on the energy dissipation and ductility capabilities of these structures.

Fig.1. Damage on top of first storey columns after Moro Gulf Earthquake

Source: Phivolcs

In order to lessen or prevent the damage, one of the solutions is to strengthen the beam-column joints using Fiber-Reinforced Polymers. Due to its unique properties and simplicity of use, one of the well-known repairing, strengthening and renovating material is the fiber reinforced polymer. According to Shen et.al (2021), Fiber-reinforced polymer is commonly used for the retrofitting, improving, restoration and strengthening of reinforced concrete structural elements such as beams, columns, and beam-column joints. When it comes to the properties, aside from the high strength to weight ratio, the fiber reinforced polymer shows different properties such as stiffness, damping property, corrosion, fire and impact resistance and high durability (Rajak, 2019).

To show the effectiveness of FRP as a strengthening material, the study conducted by (Shen et al., 2021), showed that after reinforcing joints using FRP sheets and the suggested strengthening strategies, the seismic performance of joints was greatly enhanced upon subjecting it under cyclic loading.

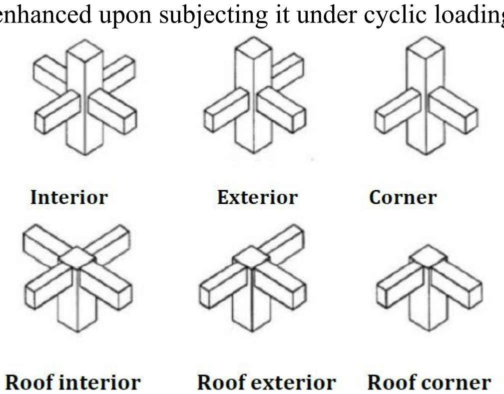


Fig.2. Different types of Beam-Column Joints Source: Source: Naveeena, 2017

II. Review of Related Literature

2.1 Effects Of Earthquake To Beam-Column Joints

In the history of mankind, the most devastating natural disaster is the earthquake and it serves as a potential cause of death to people and it affects and damage the different established infrastructures (Abbas et.al., 2021). According to Elmasry (2017), Earthquakes may occur in anywhere and anytime and the effects of the ground shaking on the structures especially concrete structures varies and ranges from mild to severe responses depending on the design of the structure. Zainal et.al., (2021) added that tremors created and done by an earthquake can damage the reinforced concrete structures.

Fig.3. Damage done by Earthquake to Horizontal and Vertical Structures

Source: Bob et.al (2013), CNN (n.d.), Photo Friday (n.d.)

Since earthquake mostly affects the infrastructures, the crucial part of the frame or structure is the beam-column connections. According to Hamid (2018), The critical and crucial part of the reinforced concrete frame structures which gives resistance against seismic loads in plastic region is the beam-column joints. With relation to the claim of Hamid, according to Attari et.al (2019), during earthquake, in frame structures which are experiencing deformations, reinforced concrete beam-column joints are considered as critical regions. As a support to the claim, Zainal et.al (2021) stated that one of the reasons why reinforced concrete beam-column joints are considered critical is that the loads acting in the columns and beams connected with each other are transferred in the connections or joints. Additionally, during earthquake, joints experience the highest damage due to different loadings and forces subjected to it such as compressive forces, tensile and shear forces.

Since beam-column joints are considered as the most critical region in a frame structure particularly in a reinforced concrete structure, if the joints fail, the whole structure will fail. Shen et.al (2021) stated that, the failure of beam-column joints may lead to the collapses of the whole structure or building since the beam-column joint is the critical region of a reinforced concrete structure which is prone to inelastic deformations and shear stresses. According to Gajalakshmi (2016), failure in shear mechanism and bond which are brittle in nature governed the failure of beam-column connections. Attari et.al., (2019) stated that during the movement of the surface of the earth, the ductility capacity of certain structures including the energy dissipation capacity are depending on the beam-column joints' stability. The ductility capacity of a structure is very important. To explain further, Chidambaram et.al., (2012) stated that ductility responds inelastically during earthquake which makes it as an essential property of structures and it serves as the ability of the structural members and the structure itself to deform inelastically without decreasing too much in strength and stiffness. Since some properties are dependent on the stability of beam-column joints, it is true now that if the joints fail, the whole structure will fail.

Somma (2012) explained and enumerated the possible challenges and failure that beam-column joints may experience during earthquake and it includes beam failure especially when the beam creates plastic hinges, Joint failure that may occur when the beam-column connection fails in shear without the yielding of the beam, also, Beam-joint failure may take place especially when the shear failure of the joint was preceded by the yielding of the beam and lastly, joint-beam failure may occur when one of the resistant contributions of beam-column connection loses after the beam. In Addition, Hamid (2018) mentioned the following most important causes for the beam-column joints' failure under any unanticipated loading and it includes inadequately spliced reinforcement for the column above the beam-column connection, absence of reinforcement in the joint particularly transverse reinforcement and insufficient development length for the reinforcement of the beam.

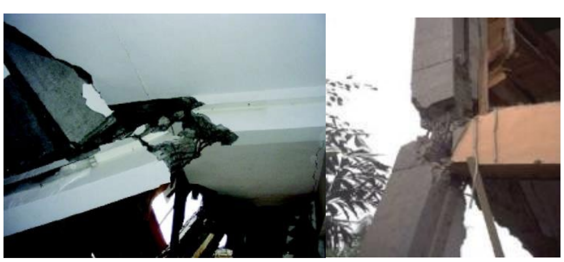


Fig.4. Beam and Joint Failure during Earthquake Source: Research Gate – Patnaik et.al (2012)

Since earthquake affects the beam-column joints, Under the shaking or movement caused by an earthquake, the beam-column joints are subjected to moments occurring in similar directions either clockwise or counter-clockwise. With these moments, in a beam- column joint, the top bars are tensioned or pulled in one direction while the bars at the bottom are pulled in the opposite direction (Suryakanta, 2017). In addition, Suryakanta (2017) stated that if in the said joint, the strength of the concrete is low and if the reinforced concrete column does not have enough wide dimension, insufficient grip in the steel done by concrete may occur and with this situation, the steel bar inside the beam- column joint may slip and it may lead the beam to lose its capacity to carry load. Similar to the claim of Suryakanta (2017), Hamid (2018) also stated that the beam connected to a column through a joint experienced the moment in the direction directly proportional to the direction of the loading. In addition, according to Elmasry (2017), columns will create moments approaching the yield moment while flexural strength at the joint will develop in the beam.

2.2 Different Types of Fiber Reinforced Polymer and Its Application

The development and use of fiber reinforced polymer coincides with the upgrading construction sector. With that, with the modernization of construction industry, the introduction and application of fiber reinforced polymer also arises. One of the well- known strengthening materials for structural components such as beams, columns and beam-column joints is the fiber reinforced polymer or FRP in short. According to Attari et al. (2019), the development of composite materials made fiber-reinforced polymer an option for enhancing, repairing, and bolstering various reinforced concrete structural elements considering the properties such as strength-to-weight ratios and stiffness-to- weight ratios. With relation to the previous claim, fiber-reinforced polymer is commonly used for the retrofitting, and strengthening of reinforced concrete structural elements such as beams, columns and beam-column joints (Shen et. al., 2016).

Fiber reinforced polymer is another substance that is utilized to strengthen other materials besides reinforced concrete. In addition to reinforced concrete, fiber reinforced polymer is utilized to fortify a variety of materials. According to Guades (2016), FRP is mostly applied and used for the rehabilitation, performance improvement and strengthening of the structures built with the use of materials such as concrete, steel and wood. In addition, Guades (2016) further said that due to the cheap cycle cost and straightforward deployment, Fiber-reinforced polymer is especially important for replacing infrastructure composed of conventional and traditional materials.

Due to its distinct physical characteristics and ease of usage, fiber reinforced polymer is employed as reinforcing and retrofitting materials. The use of FRP is commonly utilized as strengthening techniques in accordance to its advantages to light weight, resistance in corrosion and high tensile strength (Shen et.al, 2021). The advantages of fiber reinforced polymers, according to Guades (2016), includes chemical and environmental resistance, high specific strength, light weight, high durability, and low maintenance requirements. The properties of a certain Fiber reinforced polymer depend on the composite material used. According to Naser (2019), Fiber reinforced polymers are under to a class of materials known as composites. In Addition, Masuelli (2013) said that fiber reinforced polymer are composites used in different engineering applications which includes the bridges and building infrastructures. Composite materials are made up of two or more than two materials which possess different characteristics and properties from each other (Abbood et.al, 2020). Abbood et. al (2020) also added that fiber-reinforced polymer is designed from different fibers. Rajak (2019) added that, Composites are consisting of fibers and these fibers especially their orientation and arrangement determines the different properties and structural behavior of the composite material.

Since composites are made up of fibers, there are two types of fibers used as FRP, The Natural fibers and Synthetic Fibers. Rajak (2019) claims that natural fibers include palm, banana, coir, luffa, cotton, abaca, and others; these fibers are accessible in nature and are cheap to buy. In addition, these fiber materials show different properties such as biodegradability, high strength, specific stiffness and low cost.

To further explain the types of fibers used particularly the synthetic fibers, Rajak (2019) stated that synthetic fibers are produced by chemical synthesis and also known as human made fibers. In addition, Rajak (2019) also mentioned that Carbon, aramid, and glass fibers are found beneath the synthetic fibers.

Explaining the two types of synthetic fibers, the glass fiber and carbon fibers, Rajak (2019) stated that glass fibers are widely used synthetic fibers compare to other types due to its strength and durability. Similar to this Guades (2016), the most dominant fiber used as fiber reinforced polymer in the industry is the glass fiber due to its combined properties mainly low cost and high strength which are ideal for many structural situations., In addition, when it comes to reinforced concrete, glass fiber-reinforced polymers exhibit increase in ductility and shear strength (Attari et.al, 2016). With relation to the characteristics, another noteworthy characteristic of glass fiber includes transparency, stability, chemical resistance, hardness, strength, stiffness, and flexibility (Paglicawan, 2021). Also, the physical and mechanical properties of glass fiber also known as fiber glass has a density of 2.5g/cm3, it has a young modulus of 70 GPa. 3% of elongation and it has a tensile strength of 2400 MPA (Abirami et al., 2020). When it comes to cost, according to (Abbood, 2020), compare to other types of Fiber reinforced polymer, GFRP have relative low cost. In terms of drawbacks in performance, Glass Fiber-reinforced polymer (GFRP) also shows weakness in thermal stability, alkali and heat resistance (Shen et.al, 2021). Additionally, another drawback of Glass fiber- reinforced polymer is the low resistant to alkaline especially when with long term strength due to stress rupture (Abbood, 2020).

On the other hand, the other type of fiber-reinforced polymer under synthetic fibers is the Carbon fiber-reinforced polymer (CFRP). According to Masuelli (2013), Carbon fiber-reinforced polymers is a very strong FRP containing carbon fiber. In addition to that, Guades (2016) stated that, carbon fibers are high performance fibers which are essential and suitable for carrying primary loads applications or ideal for applications involving the carrying of heavy weights. When it comes to properties and characteristics, a carbon fiber has a low density, low conductivity, high elastic modulus, and a high fatigue strength, (Abbood, 2020). The physical and mechanical properties of carbon fiber have a density of 1.4g/cm3, it has a young modulus of 230.0 GPa. 1.4 - 1.8% of elongation and it has a tensile strength of 40000 MPA (Abirami et al., 2020). Comparatively speaking, when it comes to the cost, carbon fiber reinforced polymer is more expensive compare to glass fiber-reinforced polymer and other types of fibers. According to Guades (2016), the price of the carbon material per kilogram is relatively high compare to glass fiber reinforcement since carbon fiber shows excellent structural performance compare to other types.

In the Philippines, there are infrastructures which uses carbon fiber as fiber reinforced polymer. For example, the Corazon Locsin Montelibano Memorial Regional Hospital in Bacolod City has been renovated using carbon fiber composite, The De La Salle University Building in Taft, Manila and also The Malacanang Guest House in Manila.

Meanwhile, the other type of fiber composite material used as reinforced polymer is the natural fibers. Alshgari (2022) stated that due to easier process, environmentally friendly and capability to potentially save energy, natural fibers can serve as a replacement to synthetic fibers such as glass fibers. However, just like synthetic fibers, natural fibers do also have weaknesses and drawbacks and one of the drawbacks is its hydrophilic nature which causing them to be vulnerable when involved with moisture (Sinha et.al, 2020). Majority of natural fibers came from plants; however, some came from animals, (Barba et al., 2020). To further explain, Barba (2020) stated that there are also categories for natural fibers, and it includes bast fibers like banana, kenaf, and jute, as well as fruit fibers like coconut and palm oil, cotton, coir, and kapok, which also fall under seed fibers. Additionally, under natural fibers are the stalk fibers such as wood, bamboo and grass and lastly, leaf fibers are also under natural fibers and this includes sisal, pineapple, piassava and of course, the abaca fiber.

Among the different natural fibers, abaca fiber is the most popular type of natural fiber. Barba et.al (2020) stated that among the composite fiber materials available in the market, abaca fiber serves as contender in the development and usage natural fiber composites. Abaca plant with a scientific name of Musa Texitilis is known as manila hemp and it is similar to banana tree and belongs to the Musaceae family. Additionally, abaca fibers are known as one of the strongest natural fibers available in the market and it cost less than the synthetic fibers (Barba et.al, 2020). The physical and mechanical properties of abaca fiber also known as hemp has a density of 1.47 g/cm3, it has a young modulus of 70 GPa. 2.0 – 38% of elongation and it has a tensile strength of 690 MPa (Abirami et.al, 2020).

In order to bond the fiber reinforced polymer composite in the beam-column joint, epoxy resin is used. According to Mugahedamran (2018), the resin serves as both a matrix and an interaction agent in a variety of FRP composites. Thermosetting and thermoplastic polymers make up the majority of resins. Since the choice has an impact on the mechanical properties of composites, the choice of resins during the production process is crucial. FRPs are also composite materials made of a matrix and fibers. The components that bear the applied loads are fibers, and the matrix ensures their uniformity, repeated application of applied loads to the fibers, and protection from the outside environment (Masauelli 2013).

Any of the fundamental adhesive elements or dried end products made from epoxy resins are known as epoxy. RC elements typically have a small amount of a compound (1%–3%) added to the surface of the strengthening region (Mugahedamran 2018). Epoxies can be divided into two categories: glycidyl epoxy and non-glycidyl epoxy. Glycidyl epoxy resins go by the names glycidyl ether, glycidyl ester, or glycidyl amine, whereas non-glycidyl epoxy resins fall under the cycloaliphatic or aliphatic resin categories.

In addition, Mugahedamran (2018) a coating, sealing resin, and bonding agent for moistening out mechanical fabrics, epoxy is effectively used. The thin-film cure capabilities of epoxy are exceptional, and it outperforms polyester resin in terms of micro cracking resistance. Additionally, epoxy offers tensile protraction at failure of 3.5% to 4.5%.

When applying epoxy, the room temperature and adhesive concentration need to be closely watched. In addition to boosting flexural and compressive strengths, increasing interlaminar shear and impact strength, and increasing damage tolerance, epoxy offers good fiber bonding (matrix to fiber).

2.3 The Aesthetics of Retrofitting by Wrapping Method using Fiber- reinforced Polymers (FRP)

Fiber-reinforced polymers (FRP) serves as an essential material in the construction industry both in internal reinforcement but more on external reinforcement and the FRP system can be applied on regular and irregular geometric surface (Antoniou, 2022). Additionally, these FRP materials whether in form of sheets, laminates, bars or stings and even wraps, serves as a steel reinforcement's replacement both in transverse and longitudinal direction in order to increase the shear capacity and flexure capacity of the structural member where the FRP material is applied.

When it comes to the application, according to Antoniou (2022), the fiber- reinforced polymer material is wrapped on the structural member with dry method or wet method together with the help of epoxy resin when it comes to sealing of the substrate. With the proper and strictly considering the fiber direction, the FRP fabric is rolled carefully with a plastic roller. After the application, for the final surface, the surface is sealed with epoxy coating or cementitious coating, sometimes like the resin applied on the sheet. Also, Antoniou (2022) added that fire-resistant boards or mortars can be applied on the finishing or outer surface due to the poor resistance of the fiber-reinforced polymers system to fire in order to improve the resistance in terms of high temperatures.

2.4 Life Span of each Fiber-reinforced Polymers and the Retrofitted Structures

The materials used in building are critical to the performance and durability of any project. Since FRP studies are still on-going there is still no actual data that shows the service life of a structure retrofitted by a fiber-reinforced polymer. But according to FRP in Construction article, a structure retrofitted by a FRP may last up to 75 years with little or no maintenance, lowering overall construction costs and producing more long-term economies of scale.

2.5 The ANSYS Workbench R22-Simulation Integration Platform

In the early part of 1940s, the finite element method was introduced as a mathematical procedure or technique which is used in solving equations specifically partial differential equations even though portion of the system of equations must be solved manually. With the development of technology, in the 1960s, computers which can solve large systems of equations arises which made possible for the application of finite element method to problems especially in engineering related problems and practices (Thompson et.al, 2017).

A mathematical technique known as Finite Element method is used in solving and setting up different systems of equations both integral and differential. In addition, under the branch of engineering, finite element method is used when dividing a system with a behavior which may not be anticipated with the use of equations especially equations which are in closed forms into small elements or pieces and the system has a known or approximated solution (Thompson et.al, 2017). In addition, Thompson et.al, (2017) explained that a system of geometry represented by nodes known as series of number of points in a space is required by the finite element method. Each node is consisting of different set of degrees of freedom (DOFs) mainly displacements, temperature and other engineering quantities which are interconnected nm by mathematical interactions defined by elements which are also combined with each other to set the equations which will portray the system that must be analyzed. As a support to the claim of Thompson (2017), Lee (2018) stated that dividing the structural body into several small pieces and simple bodies in terms of geometry is the main idea of the finite element method. Additionally, the small bodies are known as elements which has corresponding established equations which will be solved simultaneously (Lee, 2018). One of the software which uses finite element modelling is the ANSYS.

According to Thompson (2017), to be able to shorten the time period of work and to save money with the use of finite element program in terms of calculations, the program ANSYS was developed and coded in the last quarter of 1970 by Dr. John Swanson, an employee in Westinghouse Astronuclear Labs located in Pittsburgh.

Additionally, according to Lee (2018), Dr. Swanson holds some degrees in mechanical engineering both B.S and M.S and also, a Ph.D. when it comes to applied mechanics. The original version of ANSYS is consisting of 40 elements about the various types of beams, bricks, dampers etc. ANSYS is a software used in modelling particularly finite element modelling for mechanical problems such as heat transfer, electro-magnetic, static, dynamic and linear or non-linear structural analysis which requires numerical solving (Stolarski et.al., 2018). Similar to the claim of Lee (2018), ANSYS serves as an implementation software in different classifications of problems such as fluid, mechanical, and structural problems which needs simulation using finite element method.

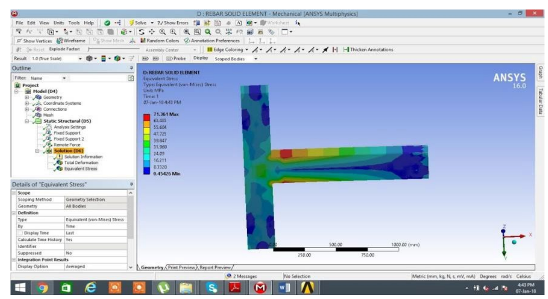


Fig.5. Modelling the Beam-column Joints using ANSYS Software

Source: Prashant Patil (2020)

In ANSYS, Step by step procedure for structural simulations, different equations used in structural system, and variety of quantities which also included in each node as set of degree of freedom including stresses, strains, displacements and other important quantities in civil engineering are presented (Lee, 2018). In today's time, the program ANSYS especially its products are widely used in different fields of engineering including electronics, aerospace, marine, construction, material industries and many more (Thompson, 2017).

According to Stolarski (2018), ANSYS can be used using two methods, the Command file approach which has advantage that the whole analysis may be portray in smaller text files yet more elevated learning curve for many users and the other method is the GUI or the graphical user interface. Lee (2018) explained the use of the GUI (Graphical User Interface). The GUI or the workbench GUI serves as the entrance or gateway to different applications particularly workbench applications and some are the Design Modeler, Design exploration, Project schematic and engineering data (Lee, 2018). Additionally, under the project schematic is the system for static structural analysis is created. According to özgün (2021), the different quantities such as forces, stresses, strains and displacements caused by the applied loads acting on a structure or structural components are being determined in a static structural analysis. Lee (2018) added that a static structural analysis includes six distinct steps in order to present a static structural analysis namely engineering data, geometry, modal, setup, solution and results.

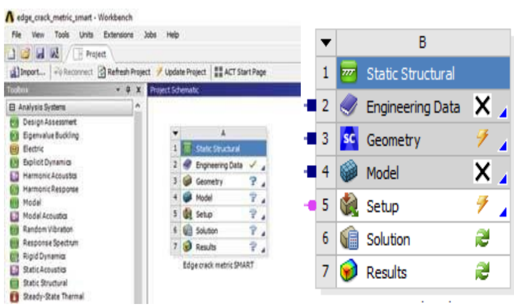


Fig.6. The six steps in Static Structural Analysis Source: Digital Engineering – Tony Abbey and CraigSneddon (2021)

To further explain the process, Lee (2018) mentioned the purpose of each cell. Starting with the first step which is prepare all the engineering data which is about specifying the different properties of the material being analyzed such as Poisson's ratio, young modulus and etc. The second step is about creating a geometric model either 2D or 3D using CAD software or the CAD applications in the workbench namely DesignModeler and SpaceClaim which are designed to create the required specific model to be used in the simulation using ANSYS. The third step in static structural analysis is the model which is about dividing the model particularly the geometric model into finite element model. Lee (2018) also added that in dividing the geometric model, it can be viewed as establishing or solving the governing equations. Since the real-life model of an object or component is hard or very much complicated to establish, in ANSYS, under the model process, the geometric model is being divided into elements. For the next step, it is about setting up the various load conditions needed in the analyzation process. In ANSYS (Workbench), the applied conditions are called environment conditions. For the fifth step, by clicking the solve in the mechanical GUI, the solving process on the finite element model or mesh can be done. For the last step under the static structural analysis, after solving the problem and doing the numerical solutions, it is time to view the results and the results can be animated.

2.6 Simulated Model of Beam-Column Joint

The part of the column that is framed into by the deepest beam which is within that depth is known as the beam-column joint. In a structure which composed of moment resisting frames, these are often categorized based on geometric configuration and classify as corner joints, interior joints, and exterior joints (Saravanan, 2019).

An external beam-column joint has a beam terminating on one face of the column, whereas an internal beam-column joint has two beams on either side of the column or when beams enclose a column's four vertical sides, with regard to the plane of loading. Moreover, when two adjacent vertical sides of a column are framed by each other in a beam, the connection is referred to as a corner joint or knee or L-joints (Saravanan, 2019).

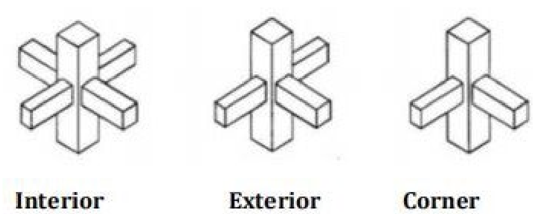


Fig.7. Different Types of Beam-Column Joints Source: Naveeena, 2017

Saravanan (2019) also stated that beam-column joints are also classified according to its anticipated deformation and loading conditions, namely, Type 1 and Type 2 which are based on ACI-ASCE committee recommendation. Type 1 joints are designed solely for strength, without taking particular ductility needs into account. These are used in structural frames that are made to withstand normal wind loads and gravity. On the other hand, type 2 joints are made to maintain their strength even when deformation reverses into the inelastic range. This category applies to joints in framed structures made to withstand lateral loads from earthquake, blast, and cyclonic winds.

According to Naveeena et al. (2017), T-connections or external beam column joints in reinforced concrete frames have come to be known as weaker parts when subjected to cyclic lateral loads. Several damages in this particular area may lead into deterioration and collapse of the entire frame. The initial intent of many RC frames was to support just gravity loads. They are unable to demonstrate a global failure mechanism brought on by cyclic loading circumstances due to its lack of ductility and strength.

The overall cyclic behavior of RC structures, in particular, depends critically on the hierarchy of strengths around beam-column joints. Therefore, preventing early failure of these joints is a crucial element in contemporary seismic design to enable the framing members to operate at their maximum capacity (Pohoryles et al., 2019).

A study from Vijaya et al. (2014) considered exterior joint in the analysis of beam column joint. Their study takes into account the joint detail, material properties, and the loading conditions. The test is consisting of two types of specimens, which are control or unstrengthened specimen and retrofitted or strengthened specimen. Column and beam's dimension details and reinforcement details must take into account for the model. For retrofitted specimen, different wrapping length and arrangement of FRP composites must also be considered.

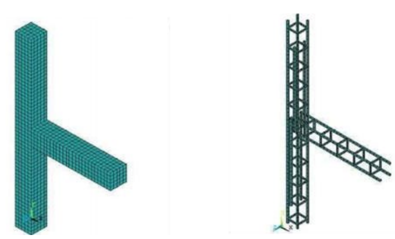


Fig.8. Typical View of ANSYS Model and its Details Source: Vijaya et al., 2014

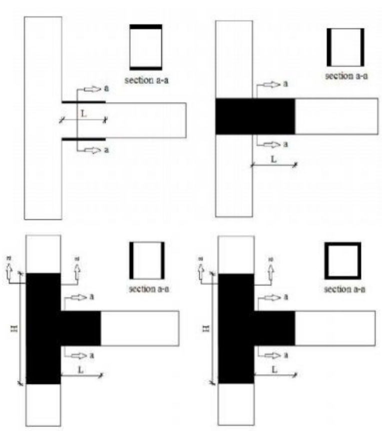


Fig.9. Different Wrapping Arrangements of FRP Composites Source: Vijaya et al., 2014

2.7 The Finite Element Method using ANSYS

Aside from conducting actual experimental study to assess the behavior of beam- column joint under given loading condition, simulation of the test can also be an option by applying the concept of Finite Element Analysis (FEA) using available software such as ANSYS. According to Brush (2019), calculations, models, and simulations are used in finite element analysis (FEA) to forecast and comprehend how an object might react under various physical conditions. The finite element method (FEM), a numerical methodology, is used in FEA. It splits an object's structure into a number of components, or elements, and then links the elements at points known as nodes.

A related study from Naveeena et al. (2017) used SOLID65 for 3-D modelling of solid comprising with and without reinforcing bar (rebar) for the element properties. In applications using concrete, the element's solid capacity can be used to simulate the behavior of the concrete, while the rebar capability can simulate the behavior of the reinforcing bars. Discrete modeling is used to simulate concrete reinforcement by assuming a 100 percent connection between steel and concrete.

At each node, the beam column has six degrees of freedom. These consist of rotations about the x, y, and z axes as well as translations in these directions. Applications involving massive rotation, huge strain nonlinearity, and linearity are all well-suited to this element. For the laminated composites, SHELL 91 was used in modelling for the reason of its efficiency against SHELL 99 with fewer than three layers of an element model. It can be applied to thick sandwich constructions or layered applications of a structural shell concept. Applications may have up to 100 distinct layers when the sandwich option is disabled. (Naveeena et al., 2017).

In modelling RC beam-column joints, material properties and element used in the modelling of the concrete and reinforcing steels must be considered. Mass density, Modulus of Elasticity, Poisson's ratio and elements used is required for both concrete and steel. Compressive strength of concrete as well as the yield stress and tangent modulus of the reinforcing steel is also a requirement (Saravanan et al., 2019). On the other hand, material properties and element used in modelling fiber reinforced polymer (FRP) must be specified also such as its Young's modulus, major Poisson's ratio, tensile strength, shear modulus and thickness of laminate (Vijaya, 2014).

The simulated test was carried out by the control model or the joint without FRP wrapping and the retrofitted model or the joint with FRP and the boundary and loading conditions are identical for both specimen models. The column ends were fixed at both the bottom and top of the column to demonstrate the test conditions. To make it happen, the nodes' translations are given constant values of 0 (Vijaya, 2014).

After modelling the geometrical structure of the beam-column joint using ANSYS, the joint will be analyzed first without FRP wrapping as a control specimen. All degrees of freedom at the column's bottom are restricted then the beam

will be subjected to a cyclic load of up to 30KN (Naveeena et al., 2017)

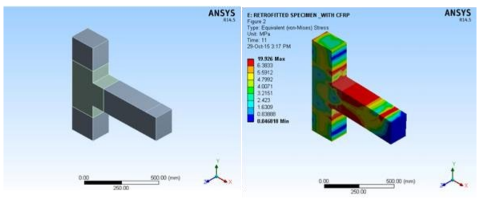


Fig.10. Exterior Beam-Column Joint Model and its Equivalent Stresses for Concrete without FRP Wrapping

Source: Naveeena, 2017

For the retrofitted specimen, loading and boundary conditions remains the same as the control specimen. The beam is subjected to a cyclic load of up to 60 KN. FRP's wrapping is 1.5 mm thick, has a Poisson's ratio of 0.22, and a modulus of elasticity of 230000 MPa. And it has 300 mm of wrapping on all sides (Naveeena et al., 2017).

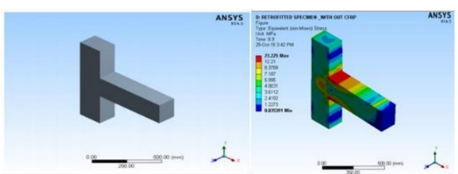


Fig.11. Exterior Beam-Column Joint Model and its equivalent stresses for concrete with FRP wrapping

Source: Naveeena, 2017

After the simulation process, the numerical findings are interpreted both with and without FRP wrapping. Using ANSYS, the recorded data from the deflection behavior and load carrying capacity are used to study their behavior during the investigation. The ultimate strength of the strengthened and unstrongened beam-column joints is tested. It comes out that The specimen with the retrofit has a 30% higher load carrying capability, load deformation characteristic and ductility also significantly improves than the specimen without the strengthening (Naveeena et al., 2017).

2.8 Deformation, Equivalent Stress, Elastic Strain and Strain Energy

In the static structural section of ANSYS Workbench R22, which uses finite element analysis, some of its major numerical results are in terms of deformation, equivalent stresses, equivalent elastic strain and strain energy. An article from Designing Buildings: The Construction Wiki (2022) states that when a load causes an excessive deflection, the component may fail especially when an intense tremor hits simultaneously with gravity loads. It could lead into stress and strain concentration at localized areas and break at some point. Moreover, excessive deformation can also lead into joint separation which results in severe loss of load bearing capability and structural failure. In order to lessen the deflection experienced of an element/structure under the load condition, rigidity or stiffness is increased which can be obtain by strengthening its section.

In design, stress is also a parameter to consider in design to prevent failure. In numerical result produced by ANSYS Workbench, equivalent stress is express in terms of equivalent (Von Mises) stress. According to Sound E.Y. (2023), Von Mises stress is a measurement of the material's total stresses at any particular place. It assists engineers in determining the amount of stress that an object or structure can sustain before failing. This means that a high equivalent Von Mises stress indicates that the material/structure is more prone to plastic deformation and failure.

Furthermore, elastic strain is also included on the results to be considered. According to Callister et al. (2013), elastic strain is the degree of distortion that a material may experience while still having the ability to revert to its initial shape when the load has been removed. When a material is stressed up to its elastic limit, it exhibits an elastic deformation and returns to its original shape. It only shows that, the greater the elastic strain of such a material, the greater the stress it can endure without incurring permanent or plastic deformation.

On the other hand, strain energy can also have a positive and negative implication on beam-column junction. A study from Gavin (2015) indicates that strain energy is a type of potential energy that is created by stress and deformation of elastic solids. Lower strain energy constitutes with the stiffness and resistant of the joint in terms of deformation, hence, the serviceability of the joint improves. In addition to this, lower strain energy can also mean that the joint is less prone to fatigue and failure over time. For such fragile material like concrete, high amount of stress energy can lead into cracking and failure.

III. Objectives of the Study

3.1 General Objective

This research aimed to compare and investigate the effectivity of different types of Fiber-Reinforced Polymers (FRP) on the performance of beam-column joint under a given actual load conditions.

3.2 Specific Objectives

Specifically, the research study aimed to:

- Identify the properties of Chosen FRP Composites, configuration of beam-column joints and loading conditions in the simulated Specimen
- Determine the optimal wrapping length of Fiber-reinforced Polymer (FRP) in the simulated specimen.
- Investigate the effect of the FRP composites on cyclic behavior of beam-column joints through simulation using ANSYS Workbench R22
- Identify the most effective type of FRP by performing comparative analysis in terms of quality to enhance the performance of beam-column joint.

3.3 Statement of the Problem

The purpose of this study was to compare and investigate the effectivity of different types of Fiber-Reinforced Polymers (FRP) on the performance of beam-column joint in terms of the four parameters namely the deformation, strain energy, equivalent stress, and elastic stress.

The study answers the following:

- What are the different properties of the chosen FRP, the configuration of beam-column joints and loading conditions in the simulated specimen?
- What is the optimal length of FRP in terms of different parameters in the simulated specimen?
- What is the effect of FRP composites on cyclic behavior of beam-column joints through simulation approach using ANSYS Workbench R22?
- What is the most effective type of FRP by comparative analysis in terms of quality to enhance the performance of beam-column joint?

Specifically, this sought to answer the following questions:

H0: There is no significant difference between the three types of fiber reinforced polymer (carbon, e-glass, and hemp) in terms of the four parameters namely the deformation, strain energy, equivalent stress and elastic strain.

H1: There is a significant difference between the three types of fiber reinforced polymer (carbon, e-glass, and hemp) in terms of the four parameters namely the deformation, strain energy, equivalent stress and elastic strain.

IV. Methodology

4.1 Phase 1 – The Engineering Data

Before proceeding to the actual modelling using ANSYS, properties of such involve material is a requirement. In this study, the focus of the simulation test is the beam-column joint which consists of concrete, steel reinforcement and strengthening agent which is fiber reinforced polymer (FRP) composites.

Since beam-column joint is a contact region between a column and a beam, it exhibits a non-linear behavior when load is applied. There is no linear relation between the column load, lateral force due to earthquake and gravity loads on the beam to its corresponding displacements. To perform non-linear analysis, researchers used the default non-linear concrete and steel in ANSYS Workbench as a material in simulating both control and retrofitted samples.

For the carbon and glass fiber reinforced polymer, the researchers conducted data gathering to come up in a specific type of carbon and glass respectively which was used in actual simulation and wrapping of retrofitted specimen. Some of its mechanical properties need to be considered are yield and tensile strength, density, specific gravity, modulus of elasticity and its strain at break (Amran et al., 2018). Since Hemp FRP is a kind of natural FRP that the researchers introduced, all of its mechanical properties will be gathered since it is not readily available in ANSYS Workbench R22 under engineering data of composite materials unlike the other two which are carbon and glass FRP.

In order to have a reference in modelling beam-column joints, the researchers requested a copy of mid-rise building's structural plan with high category of occupancy and level of importance when it comes to earthquake. Furthermore, the researchers used STAAD. R8i SS6 to model the actual structural plan of the requested mid-rise building where the loading configuration applied in the sample beam-column joint was extracted.

To extract the significant data such as the dimension and location of the most critical beam-column joint, the structural plan of the obtained mid-rise building will be then simulated in STAAD. R8i SS6 given these following steps:

- From the reference structural plan, each level will be modelled by the use of nodes. Connecting the nodes will result into creation of beams and columns of the structure.
- After the entire structure has been drawn, the dimension of each beams, girders and column will be set and assigned. Supports at the foot of structure will also be assigned to hold it.
- When the modelling of the entire structural plan has been finished, loads carried by the structure will now be computed and applied to the structural elements such as slabs, beams and girders. Slabs will be classified either one way or two-way. Note that all the loadings were all based on the typical values from an excerpt of NSCP 2015.
- Earthquake loads will be automatically calculated by providing the seismic information of the location where the mid-rise building built.
- After setting up all the loads acting on the structure, load combinations based on NSCP 2015 will be set up considering dead load, live load and earthquake load.
- On the post-processing section of STAAD. R8i SS6, loadings, shear and moment will be readily available and this will be the basis on determining the most critical beam-column joint and its carried lateral, axial and gravity loads.

4.2 Phase 2 – Modelling of Beam-Column Joint

After the completion of data gathering in material properties and the extractions of loadings in STAAD. R8i SS6, modelling of simulated control and retrofitted beam- column joint took place in ANSYS Workbench R22. The simulation and entire analysis of beam-column joint was performed in "static structural" which uses Finite Element Method (FEM) in analysis.

To start of the project, main materials such as concrete and steel was selected in general non-linear materials in engineering data. For carbon and glass FRP, the typical and most available one was selected. Moreover, hemp FRP was not readily available in engineering data of materials in ANSYS, thus, the researchers added it as a new material using the gathered material properties for hemp composites such as its density, modulus of elasticity and Poisson's ratio or strain at break.

Upon modelling the sample beam-column joint, the researchers created a total of ten (10) specimen consisting of one (1) control sample, and three (3) sets of retrofitted samples wrapped by carbon FRP, glass FRP and hemp FRP. On each set, three different wrapping lengths were considered based on the critical region in beam and column which are L/3, L/4 and L/5 to further investigate the effect of wrapping length on its offered additional strength.

4.3 Phase 3 – Simulation Under Loading Conditions and Numerical Analysis of Test Result

In this phase, all ten specimens (both control and retrofitted) were completed and ready to be tested. To prevent the sample to move upon application of loadings, boundary conditions were set on every samples. The top and bottom of the column was not permitted to move and displacements were set into zero in all directions (x, y and z- direction) but the end of the beam was set as free by the researchers to investigate more clearly the effect of FRP in terms of deflection caused by the loadings. All simulated samples were subjected into similar loadings (lateral load, column load and gravity loads) came from actual forces experienced by the most critical beam-column joint in the entire structure modelled from STAAD.R8i SS6. For this instance, analytical values of deflection, equivalent stresses, equivalent strain and strain energy experienced by the beam-column joint were calculated by ANSYS Workbench R22.

For the type of FRP which failed to enhance or induced significant effect to the performance of the simulated beam-column joint, researchers recommended to further improve the design specification or conduct further study regarding to that type of FRP.

To further explain and show how the simulation ran using ANSYS software, the following steps are given by:

- Engineering Data. All materials that will be used in the simulation will be selected under this section. Materials which are not readily available in the software can be inputted manually by inputting its mechanical property such as density, modulus of elasticity and Poisson's ratio.
- Geometry. In this section, modelling the geometric configuration of the simulated beam column joint took place as well as the detailing of reinforcement bars. For retrofitted specimen, a surface which represents the FRP composites will be apply on the desired region and length.

- Model. Lastly, after modelling the simulated control and retrofitted specimens, materials for the solid (concrete), reinforcements (structural steel) and surfaces (composites) will be assigned. Then, transforming the model into its equivalent mesh will allow the software to perform Finite Element Analysis (FEA). Boundary conditions will also be applied to hold the specimen in place before subjecting into loading conditions afterwards. This section also covered the setup, solution and result section of ANSYS Workbench. After performing the test, numerical results such as total deformation, equivalent stress, equivalent elastic strain and strain energy will be readily available in this section.

4.4 Phase 4 – Statistical Analysis

At this point, results were already available and ready to make a comparative analysis for each of the samples. Parameters to be considered in here is the comparison of each composite of FRP in terms of deflection, equivalent stresses, equivalent strain and strain energy to come up with the most efficient type of FRP relative to its offered additional strength. Having said this, the table below determines the variables to be used in statistical analysis**.**

The independent variables are the different types of FRP which are the Carbon Fiber Reinforced Polymer, Glass Fiber Reinforced Polymer and Hemp Fiber reinforced polymer. On the other hand, the dependent variables are the four parameters namely deformation, equivalent stress, equivalent elastic strain and strain energy.

Using the tables, researchers conducted a statistical test to compare the types of FRPs and the chosen wrapping lengths in terms of their deformation, equivalent stress, equivalent elastic strain and strain energy.

The researchers get the percentage difference to determine if there were any differences between the independent variables and dependent variables. Meanwhile, one- way Anova was used to determine which of the group were significantly different to one another. Finally, the researchers used TukeyHSD test to determine which group specifically made a significant difference. In TukeyHSD, the independent variables were paired up and compared while in ANOVA the independent variables were treated as a group and compared to one another in terms of the dependent variable.

V. RESULTS AND DISCUSSION

5.1 Engineering Data

5.1.1 Material Properties of Chosen FRP

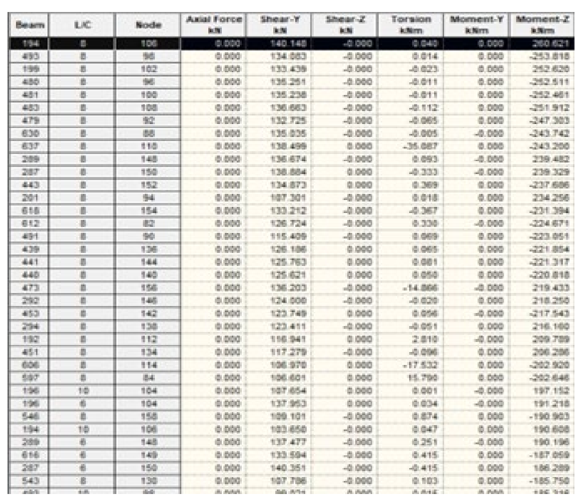
Table.1. The Different Properties of the Composite Materials (FRP) used in the Simulation using ANSYS Workbench R22

COMPOSITE MATERIAL (FRP)	DENSITY G/CC	MODULUS OF ELASTICITY, GPA	POISSON'S RATIO
Carbon FRP	1.8	290	0.2 – 0.4
E – Glass FRP	2.6	73	0.22
Hemp FRP	1.5	41	0.034

The researchers chose the variant of carbon FRP with intermediate strength of 290 GPa rather than the other type where their modulus of elasticity is 230GPa and 400 GPa. For glass FRP, the researchers selected E-glass or electrical glass FRP since it is the most common type and it is known on its good strength and stiffness and when it comes to cost, it is much cheaper compare to other types of glass fiber (Abdulqader et.al.,2014). Finally, mechanical properties of hemp or abaca FRP were gathered and inputted to engineering data section of ANSYS Workbench since it is not readily available. Upon inputting its density, modulus of elasticity and Poisson's ratio, the system automatically calculated the other important properties such as its bulk modulus and shear modulus.

5.2 Engineering Data from STAAD

The researchers used the structural plan of 3-storey DHVSU College of Engineering and Architecture Extension building as the reference mid-rise structure which is considered as a mid-rise structure with high category of occupancy and level of importance in earthquake.



Beam	L/C	Node	Axial Force kN	Shear-Y kN	Shear-Z kN	Torsion kNm	Moment-Y kNm	Moment-Z kNm
194	8	106	0.000	140.148	-0.000	0.040	0.000	260.621
493	8	98	0.000	134.083	-0.000	0.014	0.000	-253.818
199	8	102	0.000	133.439	-0.000	-0.023	0.000	252.620
480	8	96	0.000	135.251	-0.000	-0.011	0.000	-252.511
481	8	100	0.000	135.238	-0.000	-0.011	0.000	-252.461
483	8	108	0.000	136.663	-0.000	-0.112	0.000	-251.912
479	8	92	0.000	132.725	-0.000	-0.065	0.000	-247.393
630	8	88	0.000	135.035	-0.000	-0.005	-0.000	-243.742
637	8	110	0.000	138.499	0.000	-35.087	0.000	-243.200
289	8	148	0.000	136.674	-0.000	0.093	-0.000	239.482
287	8	150	0.000	138.884	0.000	-0.333	-0.000	239.329
443	8	152	0.000	134.873	0.000	0.369	0.000	-237.686
201	8	94	0.000	107.301	-0.000	0.018	0.000	234.256
618	8	154	0.000	133.212	-0.000	-0.367	0.000	-231.394
612	8	82	0.000	126.724	-0.000	0.330	-0.000	-224.671
491	8	90	0.000	115.409	-0.000	0.069	0.000	-223.051
439	8	136	0.000	126.186	0.000	0.065	0.000	-221.854
441	8	144	0.000	125.763	0.000	0.081	0.000	-221.317
440	8	140	0.000	125.621	0.000	0.050	0.000	-220.818
473	8	156	0.000	136.203	-0.000	-14.866	-0.000	219.433
292	8	146	0.000	124.000	-0.000	-0.020	0.000	218.250
453	8	142	0.000	123.749	0.000	0.056	-0.000	-217.543
294	8	138	0.000	123.411	-0.000	-0.051	0.000	216.160
192	8	112	0.000	116.941	0.000	2.810	-0.000	209.789
451	8	134	0.000	117.279	-0.000	-0.096	0.000	206.286
606	8	114	0.000	106.970	0.000	-17.532	0.000	-202.920
597	8	84	0.000	106.601	0.000	15.790	0.000	-202.646
196	10	104	0.000	107.654	0.000	0.001	-0.000	197.152
196	6	104	0.000	137.953	0.000	0.034	-0.000	191.218
546	8	158	0.000	109.101	-0.000	0.874	0.000	-190.903
194	10	106	0.000	103.650	-0.000	0.047	0.000	190.608
289	6	148	0.000	137.477	-0.000	0.251	-0.000	190.196
616	6	149	0.000	133.594	-0.000	0.415	0.000	-187.059
287	6	150	0.000	140.351	-0.000	-0.415	0.000	186.289
543	8	130	0.000	107.786	-0.000	0.103	0.000	-185.750
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Fig.12. Summary of Maximum Internal Forces Obtained from STAAD R8i SS6

After the simulation of the reference structural framing plan, the researchers selected the most critical external-beam column joint using the governing combination of gravity loads (dead and live loads) and lateral load (earthquake loads) acting in the structure.

Geometry of beam and column intersecting at that most critical external joint and also the detailing of steel reinforcement was listed and used to simulate its geometry under geometry section in ANSYS static structural.

Table.2. Details/Geometry for the Beam/Girder and Columns from the Structural Plan of CEA Extension Building

DETAILS FOR BEAM/GIRDER							
MARK	DIMENSION		MAIN REINFORCEMENT BARS				SPACING OF 12 mm DIAMETER BARS
	Width (mm)	Depth (mm)	At Support		At Midspan		
			Top bar	Bottom bar	Top bar	Bottom bar	
2G-1	300	500	4-25 mm	3-25 mm	3-25 mm	4-25 mm	2 at 50 mm, 6 at100 mm Rest at 200 mm O.C

DETAILS FOR COLUMN					
MARK	DIMENSION		STEEL REINFORCEMENT		SPACING OF 12 MM DIAMETER BARS
	Width mm	Depth mm	Main bars	ties	
2ND Floor to 3rd floor	450	450	12-20 mm dia	12 mm dia.	2 at 50 mm, 6 at100 mm Rest at 200 mm O.C
Ground floor to 2nd floor	450	450	12-20 mm dia	12 mm dia.	2 at 50 mm, 6 at100 mm Rest at 200 mm O.C

Considering the most critical beam-column joint, the researchers gathered the column axial load, lateral load acting at the joint as well as the gravity loads acting uniformly at the beam surface. Values were rounded up for optimum design. These loadings were used in the actual simulation test of all the ten specimens in ANSYS Workbench.

Table.3. Loading Conditions obtained from STAAD R8i SS6

LOADING CONDITIONS	
Column Axial Load	500 KN
Lateral Load due to earthquake	14.178 kN
Beam Pressure	70 kPa

5.3 Geometry and Modelling in ANSYS Workbench

Using the resulting geometry of the most critical beam-column joint and the acting loadings from the governing loading combination of the simulated structural plan of DHVSU CEA Extension Building in STAAD. R8i SS6, the simulated geometry has been executed in Geometry section of ANSYS Workbench. As default, the geometry of concrete and detailing of steel reinforcements for control and all retrofitted beam-column joint specimens are identical. For retrofitted samples (wrapped by FRP), only the wrapping lengths were altered.

Moreover, the researchers set up a boundary conditions to hold the simulated specimen in place and prevent it from moving when loadings were applied. Displacements on both top and bottom column were restricted in all directions but rotations were permitted. On the other hand, there is no boundary condition applied at the beam-end to further investigate the effects of FRP in terms of deflection.

Table.4. Different Boundary Conditions Considered

BOUNDARY CONDITIONS - DISPLACEMENT			
LOCATION	X - DIRECTION	Y - DIRECTION	Z - DIRECTION
Top – end column	0 mm	0 mm	0 mm
Bottom – end column	0 mm	0 mm	0 mm
Beam - end	Free	Free	Free

To complete the modelling process, all the extracted loads from STAAD. R8i SS6 has been applied to all the simulated specimen.

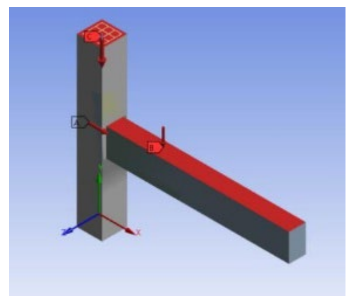


Fig.13. Model of the Control Beam-Column Joints with the Applied Loads

5.4 Summary of Numerical Results from ANSYS Workbench R22

Table.5. Summary of Obtained Results from ANSYS Workbench 322 – Different Types of FRP

SUMMARY OF OBTAINED RESULTS FROM ANSYS WORKBENCH R22 DIFFERENT TYPES OF FRP					
FRP	WRAPPING LENGTH	DEFORMATION (mm)	EQUIVALENT STRESS (MPa)	ELASTIC STRAIN (m/m)	STRAIN ENERGY (J)
Control		8.4063	40.261	3.91E-04	2.70010
Carbon	L/3	3.7042	35.650	4.01E-04	0.80011
	L/4	3.6960	35.257	4.60E-04	0.71723
	L/5	3.7167	38.992	4.69E-04	0.73504
E-Glass	L/3	3.6990	35.837	4.01E-04	0.77627
	L/4	3.6972	34.974	4.60E-04	0.70698
	L/5	3.7015	39.245	4.68E-04	0.71530
Hemp	L/3	3.7651	35.721	4.04E-04	0.79983
	L/4	3.7507	35.775	4.64E-04	0.72950
	L/5	3.7602	39.085	4.71E-04	0.73843

Graphical Representation of the Results for the Beam-Column Joints Obtained from ANSYS workbench R22 - Different Types of FRP

By comparing the 3 wrapping lengths (L/3, L/4, and L/5) in each FRP particularly in Carbon, E-glass and Hemp FRP, it shows that in Carbon FRP, the obtained value of deformation in millimeters with the wrapping length of L/4 is 3.6960 and it is the smallest value of deformation compare to L/3 with 3.7042 and L/5 with 3.7167 mm. Similar to the results obtained in terms of E-Glass FRP where in the wrapping length L/4 having a value of 3.6972 mm is the smallest value compare to other wrapping lengths L/5 having 3.7015 and L/3 having 3.6990 mm deformation value. Also, with the results obtained for Hemp FRP, between the three wrapping lengths, L/4 having 3.7507 mm is the smallest value compare to L/5 having 3.7602 mm and L/3 having 3.7651 mm. and, among the three (3) retrofitted specimens or the beam-column joints wrapped with FRP, Hemp FRP produces the largest value of deformation while E-glass FRP produces the smallest value. With the results obtained, the figure shows that the wrapping Length L/4 is the optimum length in terms of deformation.

On the other hand, by comparing all the results obtained from the retrofitted beam-column joints versus the control beam column joints, the deformation obtained for control beam is 8.4063 mm which is larger compare to the deformation obtained from the beam-column joints retrofitted with Carbon FRP, E-Glass FRP and Hemp FRP. With that, it can be concluded that in terms of deformation, beam-column joints with FRP produces smaller value of deformation compare to beam-column joints without any FRP Applied

The different wrapping lengths in each fiber-reinforced polymers produces almost the same pattern but varies in terms of equivalent stress. In Carbon FRP, between the Wrapping lengths, L/4 produces the smallest value of equivalent stress. The wrapping length L/4 has 35.257 MPa stress which is smaller compare to L/3 having 35.650 MPa and L/5 having 38.992 MPa. In terms of E-glass FRP, same with the Carbon FRP, L/4 produces the smallest value of equivalent stress since it has 34.974 MPa compare to L/3 which has 35.837 MPa and L/5 which has 39.245 MPa. Meanwhile, under Hemp FRP, although L/4 do not produce the smallest value of stress, it is a lot smaller compare to the wrapping length L/5 which has 39.085 MPa and the value of L/3 and L/4 do not differ that much since L/3 has a value of 35.721 MPa and L/4 which has 35.775.

On the other hand, comparing the equivalent stress produced by the retrofitted beam-column joints with the control beam column joints, the control specimen produces 40.261 MPa which is a lot larger compare to any wrapping lengths of all the specimen retrofitted with fiber-reinforced polymers.

In all Carbon FRP, E-glass FRP and Hemp FRP, L/3 produces the smallest elastic strain while the L/5 produces the largest elastic strain. Under the carbon FRP, L/3 produces 4.01E-04 while L/4 and L/5 produces 4.60E-04 AND 4.69E-04 respectively. In terms of E-glass FRP, the wrapping length L/3 has 4.01E-04 elastic strain while L/4 has 4.60E-04 and L/5 having an equivalent elastic strain of 4.68E-04 m/m. Lastly, under the Hemp FRP, L/3 produces 4.04E-04 while an elastic strain of 4.64E-04 is produced by L/4 wrapping length and a 4.71E-04 elastic strain produced by L/5.

The elastic strain produced by the retrofitted specimens are larger compare to the control specimen which only produces 3.91E-04 which is better since the larger the elastic strain produced, the better capacity to withstand deformation and prevent or avoid plastic deformation and even failure.

Same pattern of results for all the FRP are obtained wherein L/4 produces the smallest strain energy compare to L/3 and L/5. In Carbon FRP, L/4 produces 0.71723 which is the smallest strain energy value compare to the L/3 which has 0.80011 and L/5 which has 0.73504 J. under the E-glass FRP, the wrapping length L/4 also produces the smallest value having 0.70698 compare to L/3 having 0.77627 and L/5 having 0.71530. lastly, in terms of Hemp FRP, L/4 produces 0.72950 J which is smaller compare to the 0.79983 J produced by the wrapping length L/3 and 0.73843 J produced by L/5 wrapping length.

Comparing the results of all the retrofitted specimens to the control beam-column joints, Control beam-column joints produces 2.70010 J of strain energy which is larger compare to the values of strain energies produced by different wrapping lengths in different FRP.

In terms of deformation by comparing the 3 fiber-reinforced polymers in each wrapping length. Based on the graph 1, under the wrapping length of L/3, Hemp FRP produces the largest value of deformation having a value of 3.7651 mm compare to carbon FRP which has 3.7042 mm and the smallest value was produced by E-glass fiber which only has 3.6990 mm. In terms of L/4, E-Glass FRP also produces the smallest value having 3.6972 mm while Hemp FRP produces the highest value having 3.7507 mm. lastly, under the wrapping length of L/5, Same with the results in L/3 and L/4, E-glass FRP has the smallest value of deformation having 3.7015 mm compare to the Carbon FRP having 3.7167 and Hemp FRP having 3.7602.

The wrapping length L/4 produces the lowest or smallest value of deformation. With that, the wrapping length L/4 serves as the optimal length in terms of deformation. Focusing on L/4, Carbon FRP Produces the smallest value having 3.6960 mm. with that, it can be concluded that Carbon FRP is the most effective FRP among the three chosen FRP in terms of deformation.

In both L/3 and L/5 wrapping lengths, carbon FRP have produced the smallest value of equivalent stress compare to other FRP such as that under the L/3, Carbon FRP produces 35.650 MPa which is smaller compare to E-glass FRP having 35.837 MPa and Hemp FRP having 35.721 MPa. Also, under the wrapping length of L/5, Carbon fiber has 38.992 MPa which is the smallest compare to E-glass and Hemp both having more than 39 MPa. Meanwhile, under the wrapping length of L/4, E-glass FRP produces the smallest value of equivalent stress having 34. 974 MPa compare to Carbon FRP which has 35.257 MPa and Hemp FRP which has 35.775 MPa.

L/4 produces the lowest value of equivalent stress and in L/4, E-glass serves as the most effective FRP since it produces the smallest value of stress which is 34.974 MPa.

In terms of equivalent elastic strain. Based on graph 1, the wrapping length which produces the largest value of elastic strain considering all types of considered FRP is the L/5 while the wrapping length which produces the smallest elastic strain is the L/3. Under L/3 both carbon FRP and E-glass FRP produces 4.01E-04 m/m while Hemp FRP has 4.04E-04. Same with the wrapping length of L/4, both Carbon FRP and E-glass FRP have produced 4.60E-04 m/m while the Hemp produces 4.64E-04 m/m. Lastly, in the L/5 wrapping length, between the 3 FRPs, hemp FRP produces the largest value of elastic strain which is 4.71E-04 m/m

The goal is to produce the largest value of elastic strain, in the figure and based from the obtained results, L/5 produces the largest value. Meanwhile, even though that L/4 did not produce the largest value, still, the results do not differ that much in the results obtained from the wrapping length L/5. With that, L/4 can still serve as the optimal wrapping length and E-Glass FRP still, produces the smallest value similar to the carbon

The different strain energy obtained by each FRP and wrapping length. Under the wrapping length of L/3, Carbon FRP produces the largest value of Strain energy having 0.80011 Joules compare to the 0.77627 J and 0.79983 J produced by the E-glass FRP and Hemp FRP respectively.

Meanwhile under the wrapping length of L/4, Hemp FRP produces the largest value of strain energy having 0.72950 J compared to Carbon FRP having 0.71723 J and E-glass having 0.70698 J which is the lowest value in the wrapping length of L/4. Lastly, under the wrapping length of L/5, Hemp FRP also produces the largest strain energy having 0.73843 compare to Carbon FRP and E-Glass FRP.

On the other hand, under the wrapping length of L/4, E-Glass FRP produces the smallest value of strain energy.

5.5 Statistical Analysis

The following tables are presented below to determine which wrapping length to be used by the researchers.

Table.6. Percentage Difference for Different Types of Wrapping lengths – Deformation

PERCENTAGE DIFFERENCE FOR DIFFERENT TYPES WRAPPING LENGTHS (DEFORMATION)			
WRAPPING LENGTH	FRP	DEFORMATION (mm)	% DIFFERENCE
Control		8.4063	0.00
L/3	Carbon	3.7042	-55.94
	E-Glass	3.6990	-56.00
	Hemp	3.7651	-55.21
L/4	Carbon	3.6960	-56.03
	E-Glass	3.6972	-56.02
	Hemp	3.7507	-55.38
L/5	Carbon	3.7167	-55.79
	E-Glass	3.7015	-55.97
	Hemp	3.7602	-55.27

The table shows the percent difference in deformation for different chosen wrapping lengths. For the Carbon FRP with a wrapping length of L/3, it decreased 55.94 percent deformation from the Control Group. On the other hand, Carbon FRP with a wrapping length of L/4 decreased by 56.03 percent deformation. This implies that when the beam-column joint is wrapped by L/4 Carbon FRP it will be decreased by 56.03 percent which is 0.09 percent higher than the L/3 Carbon FRP. Meanwhile, when the beam-column joint is wrapped by L/5 Carbon FRP there will be a decreased of 55.79 percent in terms of its deformation. Therefore, L/4 wrapping length in terms of deformation of Carbon FRP governs.

On the other hand, L/3 E-Glass decreases 56 percent from the control group while E-Glass with L/4 wrapping length decreases 56.02 percent and E-Glass with L/5 wrapping length decreases by 55.97. Hence, L/4 wrapping length in terms of deformation in E-Glass FRP governs. Meanwhile, L/3 Hemp FRP decreases 55.21 percent from the control group while Hemp with L/4 wrapping length decreases 55.38 percent and

Hemp with L/5 wrapping length decreases by 55.27. Thus, L/4 wrapping length in terms of deformation in Hemp FRP governs.

In general, L/4 wrapping length governs in all of the types of FRPs in terms of deformation.

Table.7. Percentage Difference for Different Types of Wrapping lengths – Equivalent Stress

PERCENTAGE DIFFERENCE FOR DIFFERENT TYPES WRAPPING LENGTHS (EQUIVALENT STRESS)			
WRAPPING LENGTH	FRP	EQUIVALENT STRESS (MPa)	% DIFFERENCE
Control		40.261	0.00
L/3	Carbon	35.650	-11.45
	E-Glass	35.837	-10.99
	Hemp	35.721	-11.28
L/4	Carbon	35.257	-12.43
	E-Glass	34.974	-13.13
	Hemp	35.775	-11.14
L/5	Carbon	38.992	-3.15
	E-Glass	39.245	-2.52
	Hemp	39.085	-2.92

The table displays the percentage difference in equivalent stress for various wrapping lengths. For the Carbon FRP with a wrapping length of L/3, it decreased 11.45 percent equivalent stress from the Control Group. Carbon FRP with a wrapping length of L/4, on the other hand, reduced equivalent stress by 12.43 percent. This means that when the beam-column joint is wrapped in L/4 Carbon FRP, the equivalent stress is reduced by 56.03 percent, which is 0.98 percent higher than when wrapped in L/3 Carbon FRP. When wrapped in L/5 Carbon FRP, the equivalent stress is reduced by 3.15 percent. Therefore, L/4 wrapping length in terms of equivalent stress of Carbon FRP governs.

On the other hand, L/3 E-Glass decreases 12.43 percent from the control group while E-Glass with L/4 wrapping length decreases 13.13 percent and E-Glass with L/5 wrapping length decreases by 11.14. Hence, L/4 wrapping length in terms of equivalent stress in E-Glass FRP governs.

Meanwhile, L/3 Hemp FRP decreases 3.15 percent from the control group while Hemp with L/4 wrapping length decreases 2.52 percent and Hemp with L/5 wrapping length decreases by 2.92. Thus, L/4 wrapping length in terms of equivalent stress in Hemp FRP governs.

In general, L/4 wrapping length governs in all the types of FRPs in terms of equivalent stress.

Table.8. Percentage Difference for Different Types of Wrapping lengths– Equivalent Elastic Strain

PERCENTAGE DIFFERENCE FOR DIFFERENT TYPES WRAPPING LENGTHS (EQUIVALENT ELASTIC STRAIN)			
WRAPPING LENGTH	FRP	EQUIVALENT ELASTIC STRAIN (m/m)	% DIFFERENCE
Control		3.91E-04	0.00
L/3	Carbon	4.01E-04	2.71
	E-Glass	4.01E-04	2.55
	Hemp	4.04E-04	3.29
L/4	Carbon	4.60E-04	17.68
	E-Glass	4.60E-04	17.68
	Hemp	4.64E-04	18.76
L/5	Carbon	4.69E-04	19.98
	E-Glass	4.68E-04	19.80
	Hemp	4.71E-04	20.58

The table displays the percentage difference in elastic strain for various wrapping lengths. For the Carbon FRP with a wrapping length of L/3, it increased 2.71 percent elastic strain from the Control Group. Carbon FRP with a wrapping length of L/4 increased elastic strain by 17.68 percent.

This means that when the beam-column joint is wrapped in L/4 Carbon FRP, the elastic strain is increased by 17.68 percent, which is 14.97 percent higher than when wrapped in L/3 Carbon FRP. When wrapped in L/5 Carbon FRP, the elastic strain is increased by 19.98 percent. Therefore, L/5 wrapping length in terms of elastic strain of Carbon FRP governs.

On the other hand, L/3 E-Glass increases 2.55 percent from the control group while E-Glass with L/4 wrapping length decreases 17.68 percent and E-Glass with L/5 wrapping length decreases by 19.8. Hence, L/5 wrapping length in terms of elastic strain in E-Glass FRP governs.

Meanwhile, L/3 Hemp FRP decreases 3.29 percent from the control group while Hemp with L/4 wrapping length decreases 18.76 percent and Hemp with L/5 wrapping length decreases by 20.58. Thus, L/5 wrapping length in terms of elastic strain in Hemp FRP governs.

In general, L/5 wrapping length governs in all the types of FRPs in terms of elastic strain. From previous result of equivalent stress and considering Hooke's Law, the higher the stress experienced, the higher the elastic strain it will have.

Whereas, L/5 has the lowest percent deformation then certainly in elastic strain L/5 will governs.

Table.9. Percentage Difference for Different Types of Wrapping lengths – Strain Energy

PERCENTAGE DIFFERENCE FOR DIFFERENT TYPES WRAPPING LENGTHS (STRAIN ENERGY)			
WRAPPING LENGTH	FRP	STRAIN ENERGY (J)	% DIFFERENCE
Control		2.70010	0.00
L/3	Carbon	0.80011	-70.37
	E-Glass	0.77627	-71.25
	Hemp	0.79983	-70.38
L/4	Carbon	0.71723	-73.44
	E-Glass	0.70698	-73.82
	Hemp	0.72950	-72.98
L/5	Carbon	0.73504	-72.78
	E-Glass	0.71530	-73.51
	Hemp	0.73843	-72.65

The table displays the percentage difference in strain energy for various wrapping lengths. For the Carbon FRP with a wrapping length of L/3, it decreased 70.37 percent equivalent strain energy from the Control Group. Carbon FRP with a wrapping length of L/4, on the other hand, reduced equivalent strain energy by 73.44 percent. This means that when the beam-column joint is wrapped in L/4 Carbon FRP, the strain energy is reduced by 3.07 percent higher than L/3 Carbon FRP. When wrapped in L/5 Carbon FRP, the equivalent stress is reduced by 72.78 percent. Therefore, L/4 wrapping length in terms of strain energy of Carbon FRP governs.

On the other hand, L/3 E-Glass decreases 71.25 percent from the control group while E-Glass with L/4 wrapping length decreases 73.82 percent and E-Glass with L/5 wrapping length decreases by 73.51. Hence, L/4 wrapping length in terms of strain energy in E-Glass FRP governs.

Meanwhile, L/3 Hemp FRP decreases 70.38 percent from the control group while Hemp with L/4 wrapping length decreases 72.98 percent and Hemp with L/5 wrapping length decreases by 72.65. Thus, L/4 wrapping length in terms of strain energy in Hemp FRP governs.

In general, L/4 wrapping length governs in all of the types of FRPs in terms of strain energy.

For an overall conclusion, since L/4 showed positive results consistently in terms of different properties. Therefore, L/4 is the wrapping length to be considered in comparing the different types of FRPs.

5.6 Percentage Difference of the Three (3) Types of FRPs

The table shows the percent difference in deformation for different types of fiber reinforced polymers with a wrapping length of L/4. For the Carbon FRP, it decreased 56.03 percent deformation from the Control Group.

Table.10. Percentage Difference for Different Types of Fiber Reinforced Polymers – Deformation

PERCENTAGE DIFFERENCE FOR DIFFERENT TYPES OF FIBER REINFORCED POLYMERS (DEFORMATION)			
FRP	WRAPPING LENGTH	DEFORMATION (mm)	% DIFFERENCE
Control		8.4063	0.00
Carbon	L/4	3.6960	-56.03
E-Glass	L/4	3.6972	-56.02
Hemp	L/4	3.7507	-55.38

Hence, this indicates that upon wrapping Carbon FRP it will decrease the deformation of the beam-column joint. On the other hand, E-Glass decreased by 56.02 percent deformation. This implies that when the beam-column joint is wrapped by an E-Glass FRP it will be decreased by 56.02 percent which 0.01 percent higher than the Carbon FRP. Meanwhile, when the beam-column joint is wrapped by Hemp FRP there will be a decreased of 55.38 percent in terms of its deformation. In general, the most effective FRP among the three in terms of deformation is the E-Glass FRP since it has the highest reduced percentage.

Table.11. Percentage Difference for Different Types of Fiber Reinforced Polymers – Equivalent Stress

PERCENTAGE DIFFERENCE FOR DIFFERENT TYPES OF FIBER REINFORCED POLYMERS (EQUIVALENT STRESS)			
FRP	WRAPPING LENGTH	EQUIVALENT STRESS (MPa)	% DIFFERENCE
Control		40.261	0.00
Carbon	L/4	35.257	-12.43
E-Glass	L/4	34.974	-13.13
Hemp	L/4	35.775	-11.14

The table depicts the percent difference in equivalent stress for chosen fiber reinforced polymers. Carbon FRP reduced equivalent stress by 12.43 percent compared to the Control Group. As a result, wrapping Carbon FRP will minimize the equivalent stress of the beam-column joint. E-Glass, on the other hand, reduced equivalent stress by 13.13 percent. This means that when the beam-column junction is covered with E-Glass FRP, the percentage is reduced by 13.13 percent, which is 0.13 percent lesser than the Carbon FRP.

Meanwhile, when the beam-column joint is wrapped by Hemp FRP there will be a decreased of 11.14 percent in terms of its equivalent stress. In general, the most effective FRP among the three in terms of equivalent stress is the Carbon FRP since it has the highest reduced percentage while the lowest reduced percentage is the Hemp FRP.

Table.12. Percentage Difference for Different Types of Fiber Reinforced Polymers – Equivalent Elastic Strain

PERCENTAGE DIFFERENCE FOR DIFFERENT TYPES OF FIBER REINFORCED POLYMERS (EQUIVALENT ELASTIC STRAIN)			
FRP	WRAPPING LENGTH	EQUIVALENT ELASTIC STRAIN (m/m)	% DIFFERENCE
Control		3.91E-04	0.00
Carbon	L/4	4.60E-04	17.68
E-Glass	L/4	4.60E-04	17.68
Hemp	L/4	4.64E-04	18.76

The table shows the percent difference in equivalent elastic strain for different types of fiber reinforced polymers. For the Carbon FRP, it increases 17.68 percent equivalent stress from the Control Group. Hence, this indicates that upon wrapping Carbon FRP it will increase the equivalent stress of the beam-column joint. On the other hand, E-Glass increased by 17.68 percent equivalent elastic strain. Meanwhile, when the beam-column joint is wrapped by Hemp FRP there will be an increase of 18.76 percent in terms of its equivalent elastic strain. In general, the most effective FRP among the three in terms of equivalent elastic strain is the Hemp FRP since it has the highest increased percentage while the lowest increased percentage is the E-Glass FRP

Table.13. Percentage Difference for Different Types of Fiber Reinforced Polymers – Strain Energy

PERCENTAGE DIFFERENCE FOR DIFFERENT TYPES OF FIBER REINFORCED POLYMERS (STRAIN ENERGY)			
FRP	WRAPPING LENGTH	STRAIN ENERGY (J)	% DIFFERENCE
Control		2.70010	0.00
Carbon	L/4	0.71723	-73.44
E-Glass	L/4	0.70698	-73.82
Hemp	L/4	0.72950	-72.98

The table shows the percent difference in strain energy for different types of fiber reinforced polymers. For the Carbon FRP, it decreased 73.44 percent strain energy from the Control Group. Hence, this indicates that upon wrapping Carbon FRP it will decrease the strain energy of the beam-column joint. On the other hand, E-Glass decreased by 73.82 percent strain energy. Meanwhile, when the beam-column joint is wrapped by Hemp FRP there will be a decrease of 72.98 percent in terms of its strain energy. In conclusion, the most effective FRP among the three in terms of strain energy is the E- Glass since it has the highest decreased percentage while the lowest reduced percentage is the Hemp FRP.

5.7 ONE-WAY ANOVA

Table.14. One-Way ANOVA – Different Types of Fiber-Reinforced Polymers

ONE-WAY ANOVA DIFFERENT TYPES OF FIBER-REINFORCED POLYMERS (CFRP, GFRP AND HFRP)						
		Sum of Squares	df	Mean Square	F	Sig.
DEFORMATION	Between groups	.000	2	.000	47.35 5	.000
	Within groups	.000	6	.000		
	Total	.000	8			
EQUIVALENT STRESS	Between groups	95733555555 .554	2	47866777777 .777	.011	.989
	Within groups	2585787933333 3 .330	6	430964655555 5 .555		
	Total	2595361288888 8 .883	8			
EQUIVALENT ELASTIC STRAIN	Between groups	.000	2	.000	.007	.993
	Within groups	.000	6	.000		
	Total	.000	8			
STRAIN ENERGY	Between groups	.001	2	.000	.275	.769
	Within groups	.010	6	.002		
	Total	.010	8			

Upon observing the results, the statistical significance value in the deformation is 0.000, which is less than 0.005, indicating that there is a significant difference in the deformation of the three (3) types of Fiber Reinforced Polymer, namely Carbon FRP, E- Glass FRP, and Hemp FRP.

However, there is no significant difference in the equivalent stresses of the three types of FRP's because the statistical significance value in the equivalent stresses is 0.000, which is less than 0.005.

Furthermore, the statistical significance value for elastic stress is 0.993, implying that there is no significant difference between the three (3) types of FRP.

Meanwhile, there is no statistically significant difference in the accumulated strain energy of the three FRPs, with a statistical significance value of 0.769.

In other words, based on the data, it is concluded that only the deformation property of the three types of FRPs differs significantly from one another. As a result, equivalent stresses, elastic strain, and strain energy do not differ much compared to deformation

5.7.1 POST HOC TEST (TukeyHSD Test) In Terms of Different Types of FRP – Multiple Comparisons for Different Types of FRP

Table.15. Post Hoc Tests – Multiple Comparisons for Different Types of FRP (Deformation)

POST HOC TESTS MULTIPLE COMPARISONS FOR DIFFERENT TYPES OF FRP - DEFORMATION					
DEPENDENT VARIABLE	**(I) GROUP (FRP)**	**(J) GROUP (FRP)**	**MEAN DIFFERENCE (I – J)**	**STD. ERROR**	**SIG.**
DEFORMATION (mm)	CARBON	E-GLASS	$5.633x10^{-3}$	$6.810x10^{-3}$	.701
		HEMP	0.054	$6.810x10^{-3}$	.001
	E-GLASS	CARBON	$-5.633x10^{-3}$	$6.810x10^{-3}$	.701
		HEMP	-0.06	$6.810x10^{-3}$	.000
	HEMP	CARBON	0.054	$6.810x10^{-3}$	.001
		EGLASS	0.06	$6.810x10^{-3}$	.000

In terms of deformation, the results show that Carbon FRP and E-Glass FRP have no significant difference because the statistical significance level is 0.701, which is greater than 0.005, whereas Carbon FRP and Hemp FRP have a significant difference because the statistical significance level is 0.001, which is less than 0.005. Similarly, Hemp FRP and E-Glass FRP have a substantial difference with 0.000 statistical significance value, which is certainly less than 0.005. As a result, in terms of deformation, Hemp FRP differs significantly from the other two FRPs, in contrast to Carbon FRP and E-Glass which do not have significant difference.

Table.16. Post Hoc Tests – Multiple Comparisons for Different Types of FRP (Equivalent Stress)

POST HOC TESTS MULTIPLE COMPARISONS FOR DIFFERENT TYPES OF FRP – EQUIVALENT STRESS					
DEPENDENT VARIABLE	**(I) GROUP (FRP)**	**(J) GROUP (FRP)**	**MEAN DIFFERENCE (I – J)**	**STD. ERROR**	**SIG.**
EQUIVALENT STRESS (MPa)	CARBON	E-GLASS	-0.034	1.695	1.000
		HEMP	-0.234	1.695	.990
	E-GLASS	CARBON	0.034	1.695	1.000
		HEMP	-0.2	1.695	.992
	HEMP	CARBON	0.234	1.695	.990
		EGLASS	0.2	1.695	.992

Meanwhile, there is no significant difference in equivalent stress between Carbon FRP and E-Glass FRP, with a statistical significance value of 1.000. Similarly, with a statistical significance value of .990, there is no significant difference between Carbon FRP and Hemp FRP. The statistical significance level of Hemp FRP and E-Glass FRP is 1.000, which is more than 0.005, indicating that no significant difference exists. In conclusion, the equivalent stress of the three (3) FRPs is not significantly different from one another.

Table.17. Post Hoc Tests – Multiple Comparisons for Different Types of FRP (Equivalent Elastic Strain)

POST HOC TESTS MULTIPLE COMPARISONS FOR DIFFERENT TYPES OF FRP – EQUIVALENT ELASTIC STRAIN					
DEPENDENT VARIABLE	**(I) GROUP (FRP)**	**(J) GROUP (FRP)**	**MEAN DIFFERENCE (I – J)**	**STD. ERROR**	**SIG.**
EQUIVALENT ELASTIC STRAIN (m/m)	CARBON	E-GLASS	$3.767x10^{-7}$	$2.996x10^{-5}$	1.000
		HEMP	$-2.957x10^{-6}$	$2.996x10^{-5}$	.995
	E-GLASS	CARBON	$-3.767x10^{-7}$	$2.996x10^{-5}$	1.000
		HEMP	$-3.333x10^{-6}$	$2.996x10^{-5}$	.993
	HEMP	CARBON	$2.957x10^{-6}$	$2.996x10^{-5}$	.995
		EGLASS	$3.333x10^{-6}$	$2.996x10^{-5}$	.993

Additionally, with regards to elastic strain, Carbon FRP and E-Glass FRP has a statistical significance level of 1.000 hence, there is no significant difference between them similarly to the other two groups which is (Carbon FRP and Hemp FRP) and (Hemp FRP and E-glass FRP) there is also no significant difference with a 0.995 and 0.993 statistical significance level consecutively.

Table.18. Post Hoc Tests – Multiple Comparisons for Different Types of FRP (Strain Energy)

POST HOC TESTS MULTIPLE COMPARISONS FOR DIFFERENT TYPES OF FRP – STRAIN ENERGY					
DEPENDENT VARIABLE	**(I) GROUP (FRP)**	**(J) GROUP (FRP)**	**MEAN DIFFERENCE (I – J)**	**STD. ERROR**	**SIG.**
STRAIN ENERGY (J)	CARBON	E-GLASS	0.018	0.033	.851
		HEMP	-0.005	0.033	.987
	E-GLASS	CARBON	-0.018	0.033	.851
		HEMP	-0.023	0.033	.769
	HEMP	CARBON	0.005	0.033	.987
		EGLASS	0.023	0.033	.769

Moreover, in strain energy Carbon FRP and E-Glass FRP has no significant difference with a statistical significance value of 0.851, while Carbon FRP and Hemp FRP has statistical significance value of 0.987 which implies that there is no significant difference. Similar to this, E-Glass FRP and Hemp FRP has a 0.769 which is greater than 0.005 hence, there is also no significant difference between them.

The results show clearly that since in ANOVA test the deformation is the only property that took significance in difference, therefore Post Hoc Test shows which group exactly affects the significance level. Which according to the table, it has a significant difference between Hemp FRP and Carbon FRP and also the E-Glass FRP and Hemp FRP. Thus, Hemp FRP has an extensive difference to the other two types of FRPs in terms of deformation proper.

VI. CONCLUSION

6.1 Summary of Findings

The researchers conducted this study in order to compare the different types of FRPs in terms of their parameters. The researchers found out that carbon, glass and hemp FRP has a density of 1.8, 2.6 and 1.5 g/cc, modulus of elasticity of 290, 73, and 41 GPa and Poisson's ratio of 0.2-0.4, 0.22 and 0.034 respectively. The structural plan that the researchers gathered and used for STAAD simulation is the DHVSU CEA Extension building. Geometry and the detailing of the most critical external beam-column joint was extracted. It was obtained that the column axial load, lateral load due to earthquake and gravity load acted at the beam as 500 kN, 14.178 kN and 70 kPa. For boundary condition, displacements at top and bottom-end of columns were restricted and beam-end displacement was set to be free in all direction.

In order to came up with the most optimum wrapping length and most effective FRP composites, numerical results from ANSYS have been compared. In deformation with CFRP wrapped at L/3, L/4 and L/5 against control beam, it decreases at 55.94%, 56.03% and 55.79%. Hence, L/4 governs as it gives the highest percentage reduction. Similar to E-glass FRP with following data of 56%, 56.02% and 55.97%, L/4 also governs. On the other hand, hemp FRP wrapped at L/4 with 55.38% is the highest among the other two wrapping length. To summarize, deformations on the specimen wrapped at L/4 are as follows: carbon with 56.03%, E-glass with 56.02% and hemp with 55.38%. Therefore, Carbon FRP governs against the other two in terms of deformation.

In terms of equivalent stresses, wrapping length of L/4 also gave the highest percentage reduction against control beam on all three FRP composites (carbon, glass and hemp) with the following data: 12.43%, 13.13% and 11.14%. In here, E-glass FRP exhibited the largest stress decrease compare to other two composites.

For percent increase in equivalent elastic strain, wrapping length of L/5 in carbon, glass and hemp FRP yielded as 19.98%, 19.8% and 20.58% which are slightly higher against wrapped at L/4 with both carbon and glass increased 17.68% and hemp with 18.76% percent increase. Although, as one-way Anova result stated that there is no significant difference between the two, the researchers selected L/4 as the optimum wrapping length. Using L/4 results, hemp FRP governs between carbon and glass with 17.68 percent increased.

Furthermore, when it comes to strain energy, retrofitted specimens wrapped at L/4 showed the highest strain energy percent reduction against the other wrapping length with 73.44% in carbon, 73.82% in E-glass and 72.98% in hemp FRP. Thus, among the three FRP composites, E-glass FRP governs in terms of strain energy.

Lastly, to find out if the researchers reject the null hypothesis and accept the alternative one, one-way Anova test has been conducted between the three FRP composites and the four parameters which are deformation, equivalent stresses, equivalent elastic strain and strain energy. It shows that there is a significant difference between carbon, glass and hemp FRP in terms of deformation because it is less than the p-value of 0.005. On the other hand, the results shown that there is no significant difference between the other three parameters (equivalent stresses, equivalent elastic strain, strain energy) since their p-values are greater than 0.005.

6.2 Conclusion

The primary objective of this study is to compare and investigate the effectivityof different types of Fiber-Reinforced Polymers (FRP) on the performance of beam-column joint under a given actual load conditions.

Based on the results of the study, the following conclusions can be drawn:

- L/4 is the most optimal wrapping length to be used in wrapping the beam-column joint since it gave the most optimum result from all the parameters namely deformation, equivalent stress, elastic strain and strain energy.
- Based from the results, all types of FRPs gave a promising result upon wrapping it in the beam-column joint section compared to the non-retrofitted section.
- In deformation the most effective type of FRP is the Carbon FRP and the least effective type of FRP is the Hemp FRP.
- In terms of equivalent stress, the most effective type ofFRP is the E-Glass FRP and the least effective type is the Hemp FRP.
- Hemp FRP is the most effective form of FRP in terms of elastic strain, whereas E-Glass and Carbon FRP have the same effectivity.
- E-Glass FRP is the most effective form of FRP in terms of elastic strain while Hemp FRP has the least percent difference

- Using ANOVA which refers from the table 3.34, researchers were able to determine which group are statically different given by the four parameters. It was concluded that only the deformation parameter of the three types of FRPs differs significantly. In contrast, equivalent stresses, elastic strain, and strain energy do not differ significantly.
- To determine which on the groups differ from each other, table 3.35 presented which on the group mainly affects the significance level especially on the deformation property. It was concluded that Carbon and Hemp; E-Glass and Hemp has a significant difference in contrast to E-Glass and Carbon FRP which has no significant difference.
- Based from the statistical analysis, deformation is the only parameter that differs significantly to all the three types of FRP's. Since Carbon FRP governs in terms of its deformation, it can be concluded that it is the most effective type of FRP.

Recommendations:

Upon accomplishing the study, the researchers recommend the following to provide possible improvements for future studies.

- Since the study was executed through a simulation using an engineering software (ANSYS Workbench), the researchers recommend in-depth actual experimentation to further compare the effectiveness of the three chosen FRP when subjected to cyclic or actual loading conditions considering the effect of earthquake load.
- Considering that the study focused on low to mid-rise structures only using static structural analysis, it is recommended to further extend the study on high-rise structures by performing dynamic analysis.
- It is also recommended to conduct a study focusing old structures or the ones built before 2000 to further examine the effectivity of using FRP composites where the design codes and parameters used were outdated.
- Since the researchers only limited the field of comparison between the three chosen FRP composites (carbon, glass and hemp), inclusion of other type of FRP composites is recommended to test also their effectivity against one another.
- Additionally, the investigation for the effect of strengthening of beam-column joint to other structural members is also recommended to conduct.
- Based from the findings, hemp FRP (natural fiber) exhibited a promising numerical result. Hence, the researchers recommend to further study the capability of it to replace the more expensive synthetic fibers in retrofitting structures through the use of FRP composites.
- Lastly, cost analysis of these different types of chosen FRP (carbon, glass and hemp) is also recommended for future research to fulfill the economic aspect of this study.

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