Experimental Investigation on Wire Rope Isolators

By

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Dissertation submitted in partial fulfilment of

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(Mechanical)

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CERTIFACTION OF APPROVAL

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Approved by,

____
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UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK

January 2020

CERTIFICATION OF ORIGINALITY

This certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

MICHAEL TRISTAN DAVIS

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ABSTRACT

This dissertation experimentally investigates stiffness properties of wire rope isolators intended to serve as vibration dampeners in drones. Two designs of wire rope isolators has been fabricated (e.g. different wire diameters, number of wires, wire rope length) and put to test using universal tensile testing machine. The literature review needed for the project is completed. The methodology generally explains the steps taken during the experimental investigation of the wire rope isolators and how the data has been analysed. In the results, the stress-strain data along with the load-displacement data is analysed and plotted to differentiate the two wire rope isolators. From the plots, the stiffness characteristics is calculated and the data is used to apply the models to different stabilizer applications.

ACKNOWLEDGEMENT

First and foremost, praises and thanks be to God, the Almighty, for His showers of blessings throughout my final year project to complete the research successfully.

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I am immensely thankful to my parents for their love, their prayers, their care and their sacrifices to educate and prepare me for my future. Whom without, I would not have been able to have the opportunity to study at UTP. They have been my pillars of strength in supporting me in not only emotionally but also financially throughout the 5 years of Foundation and Undergraduate studies.

Finally, I want to express my gratitude towards my course mates and friends that has helped me in completing my last semester with a success by always being there for me whenever I am in need of their assistance.

CHAPTER-1 : INTRODUCTION

1.1 Background

Vibration is a mechanical phenomenon that occurs due to oscillation of an object about the equilibrium point. In certain cases, vibration is useful and needed, as seen in applications such as speakers and handphones. However, vibration can often be unwanted as it will eventually lead to wear-outs, and in worse scenarios, possibly causing danger to its environment. Furthermore, vibration that propagates through mechanical waves are more destructive as they are more efficient. Thus, vibration isolators are designed to dampen these mechanical waves in order to preserve machinery life. In the market, there are currently two types of vibration isolators, which are Passive Vibration Isolators and Active Vibration Isolators.

Active vibration isolators are designed to cancel out any mechanical waves using its own disruptive waves. This works through a series of sensors such as an accelerometer, which detects any sudden or unwanted vibrations. Thus, with the help of a feedback or feedforward controller, the structure can produce its own waves to dampen the vibrations. One of the ways these structures are designed is using a structure that can react to external disturbances, also known as Smart Structures. Some examples of these smart structures are shape-memory alloys and piezoelectric materials. Active vibration isolators are commonly applied in automotive, whereby commercially distributed vehicles are in demand for a smooth and comfortable ride. These vibration isolators help dampen vibrations which can cause vibrations from engine to transmit to the chassis.

Passive vibration isolators however, are designed in such a way that no electronic mechanisms are needed to dampen vibrations. This mechanism works in a fully mechanical way by combining spring stiffness (K) and a damper with damping coefficient (C). Knowing this, the spring then provides the elasticity for the structure which then, the energy dissipation is supported by the damper [2]. Recently, passive vibration energy dissipation systems are the most broadly utilized vibration isolators in industries and structures on account of its low cost and simplicity in design [5]. Furthermore, numerous types of passive vibration isolation systems are designed to suit its environment. A few examples of them are pneumatic isolators, mechanical springs and spring dampers and wire-rope isolators.

One of the many advantages of the wire rope isolator is mainly due to its high ability to combine shock and vibration isolation. Moreover, wire rope isolators are maintenance free and has a high resistance towards corrosion thus, making it favourable in harsh environments. Furthermore, the use of wire rope isolators in oil & gas industry where environments can be not very favourable, is best suited as there would not be any need for maintenance.

Besides that, studies have shown that wire rope isolators can operate at temperatures ranging between -100°C to +250°C [2]. As shown in the figure below, wire rope isolators have different designs that are suited for different environments however, serves the same purpose which is to eliminate shock and vibrations.

FIGURE 1.1:Various types of Wire Rope Isolators (WRI) taken from ITT Enidine

1.1.1. Helical Isolator

A helical wire rope isolator as seen below is designed with large stainless steel braids commonly used for heavy duty vibration isolations. These wire rope isolators are able to provide one of the highest damping in multi-dimensional vibrations compared to other wire rope isolators as the number of braided cables are maximized in a tighter space. These isolators can be applied in buildings as they have high loads that require more vibration isolation.

FIGURE 1.2: Example of a Helical Wire Rope Isolator taken from VMC Group C Series

1.1.2. Compact Isolator

A compact wire rope isolator also known as special wire rope isolators, are designed for applications where space is limited. Its smaller and minimal design can provide the same vibration isolation as any other wire rope isolators, however in certain machinery such as drones or cameras, there is very little space for mounting a vibration isolator. Thus, the compact wire rope isolator comes in handy in providing the same capability to isolate shock and vibration while solving mount limitations.

FIGURE: 1.3: Example of a Compact Wire Rope Isolator taken from ITT Enidin

1.2 Problem Statement

From automobile to unmanned aerial systems, vibration isolation is one of the main problems that is needed to be tackled. One of the main reasons why wire rope isolators serve a much more efficient alternative as compared to hybrid isolation systems or active systems, is because of the simplicity in design and also the cost effectiveness of the system.

Thus, wire rope isolators are best suited as not only a cost-effective option but also, one of the easiest ways of mounting a vibration isolator to a system. This is due to its simplicity in design which enables the isolator to be mounted in practically any direction on the equipment. Moreover, wire rope isolators for systems such as drones can provide a much simpler method as compared to having sensors and actuators to stabilize a drone. For example, drones used in delivery systems need to ensure a shock proof landing thus, making wire rope suitable as they can isolate vibration as well as shocks.

As stated previously, passive vibration isolators have different types of systems in order to adapt to its environment. Whether it is being used in buildings or use in automation, passive isolators serves as a key role in this research as its simplicity in design and low cost effectiveness raises an important role in drone transportation. Out of the many types of vibration isolators, I will be conducting my research on wire rope isolators as an experimental investigation for use in stabilizer systems.

To summarize, my research will be conducted mainly on compact wire rope isolators as they provide the suitable application such as aeronautics, automobiles and unmanned aerial systems. Furthermore, compact wire rope isolators are also small in size thus, making it easier for laboratory testing using a tensile testing machine.

1.3 Objectives

The objectives of this project are as stated below:

i. To develop concept models for wire rope isolators applicable for use in vibrational damping and/or shock absorbing devices.
ii. Experimentally investigate stiffness characteristics of the isolator models.
iii. Analyse the result form addressing Obj. #2 to draw conclusion that could be applied in the design and selection of wire rope isolators for use in different stabilizer applications.

1.4 Scope of Study

The study will be focusing on the various designs of a wire rope isolator which is suitable for use in the shock absorber and stabilizer industries. Our scope of study will be including the use of laboratories equipped with a Universal Testing Machine. This testing will be done in order to find the comprehensive strength of the wire rope isolators. Furthermore, this testing can also determine the stiffness characteristics of the wire rope isolator.

CHAPTER 2 : LITERATURE REVIEW

2.1 Overview

Vibration have been analysed by using many different techniques in order to foresee the detrimental effects it brings on equipment and machinery. As mentioned by Balaji, the source of vibration could be natural or man-made [2]. This proves a point that vibration can occur in many different environments, especially harsh environments whereby both sources merge to create unwanted vibrations. Thus, vibration isolators are the solution to tackle these problems. In addition to that, Balaji argues that damping and isolating are two different things as damping is the absorption of kinetic energy and converting it into another form of energy, whereas isolating means solely preventing vibration from entering into the system [2]. That being said, vibration isolators have two different types which are, active vibration isolators and passive vibration isolators. In this literature review, we will be investigating the factors involve in vibration isolators which play important roles in choosing an isolator and how different wire rope isolator designs have an impact onto different systems.

As stated in [6], vibration isolation does not occur until a frequency of $\sqrt{2k/m}$, which means that a mass, *m* when supported by a linear stiffness, *k* on a hard platform, will only have vibration isolation in an ideal condition. Theoretically, a lower stiffness can provide a larger and wider range of frequencies that can isolate vibration [1]. However, in machines or equipment that have high loads or in need of transporting high mass, the degree of material stiffness needs to be rather stiff. This is done in order to avoid material deformation and deflection. In addition to that, stiffness is one of the most significant structure criteria for mechanical segments, frameworks and machine apparatuses. That being said, the stiffness has a direct effect on the position exactness and presents one of the key parameters utilized for examination of machine apparatuses with various kinematic type [7]. An example of the change in stiffness on a Force vs Displacement graph can be seen in Fig. 4.

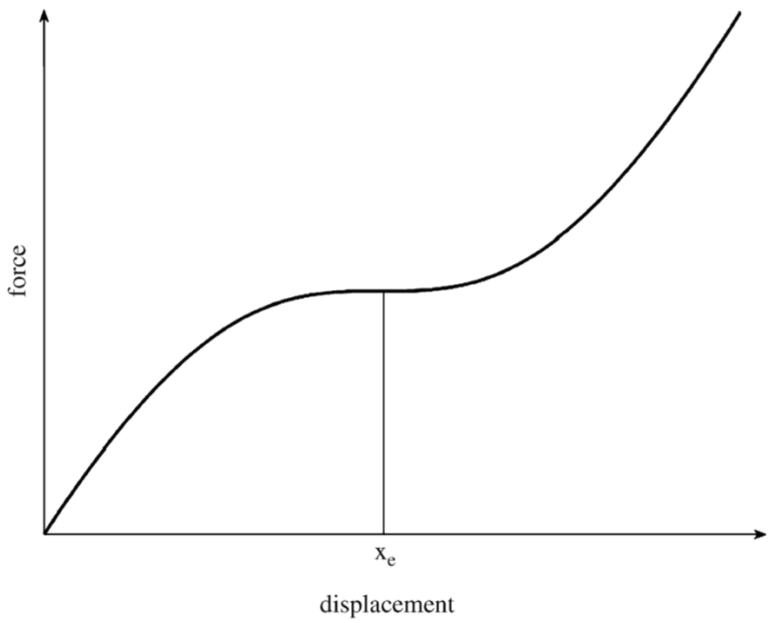

FIGURE 2.1: Force vs Displacement of a vibration isolator taken from Static analysis of a passive vibration isolator with quasi-zero-stiffness characteristic [1]

Apart from material stiffness, vibration isolation also depend on another factor which is known as transmissibility. Transmissibility can be defined as a ratio of a certain vibrational force that is presently being measured in a system to the vibrational force entering the same system. In other terms, transmissibility can be deduced as a measure of vibrational force transmitted by the system [2]. Furthermore, the graph shown below depicts the relationship between the natural frequency/forced frequency and transmissibility.

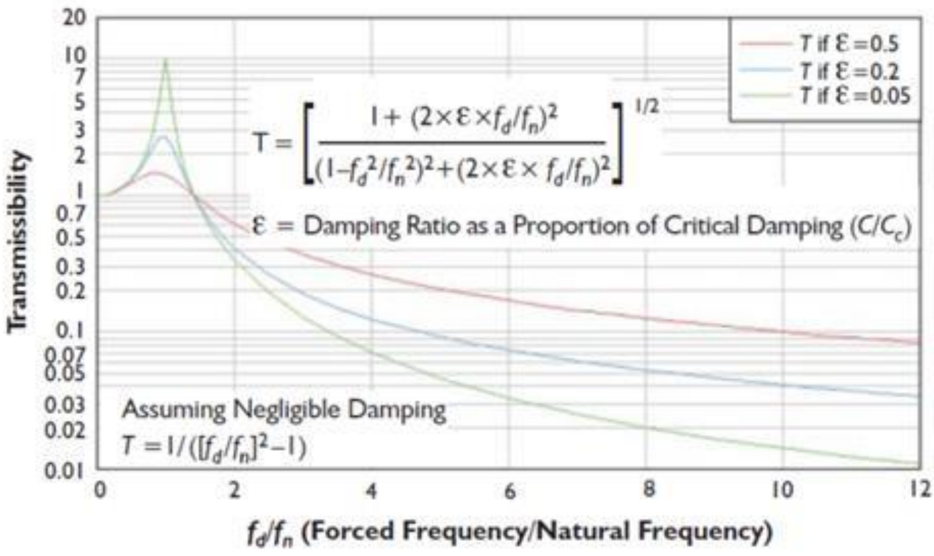

FIGURE 2.2: Frequency vs Transmissibility graph taken from Wire rope isolators for vibration isolation of equipment and structures – A review [2].

To summarize the factors needed to consider when developing a vibration isolator, it is indeed a complicated process of calculation and experimentation. Thus, deliberate amount of time is needed in order to distinguish the different vibration isolators suitable for its environment. With that being said, passive vibration isolators are one of the ways to isolate vibration using efficient, mechanical methods. One of the methods of passive vibration isolation which we will be focusing on is wire rope isolators.

Firstly, Polycal Wire Rope Isolator (PWRI) is a type of wire rope isolator that efficiently isolates vibration from the devices and sensitive structures from vibrational disturbances [3]. In addition to that, PWRI selection is based on the static stiffness required for the system application [8]. This means that selecting a PWRI depends on one of the main factors affecting vibration isolation. However, one of the disadvantages of using this PWRI may arise from the height difference of the isolator. As researched by Balaji and Hussain, the PWRI showed significant difference in lateral and vertical stiffness when it comes to working on comprehensive testing using the Ultimate Tensile Machine [3]. Results can be seen in Fig 7 & 8.

FIGURE 2.3: Example of Polycal Wire Rope Isolator (PWRI) taken from Stiffness characteristics of a polycal wire rope isolators [3].

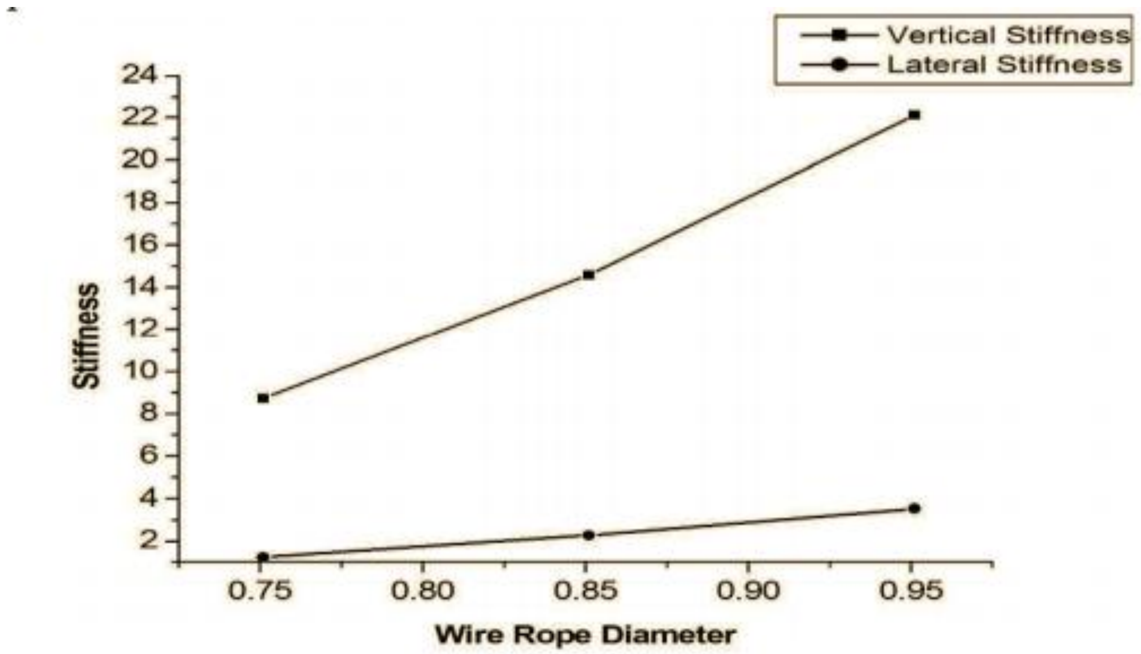

FIGURE 2.4: Effect of Wire Rope Diameter on PWRI Stiffness taken from [3].

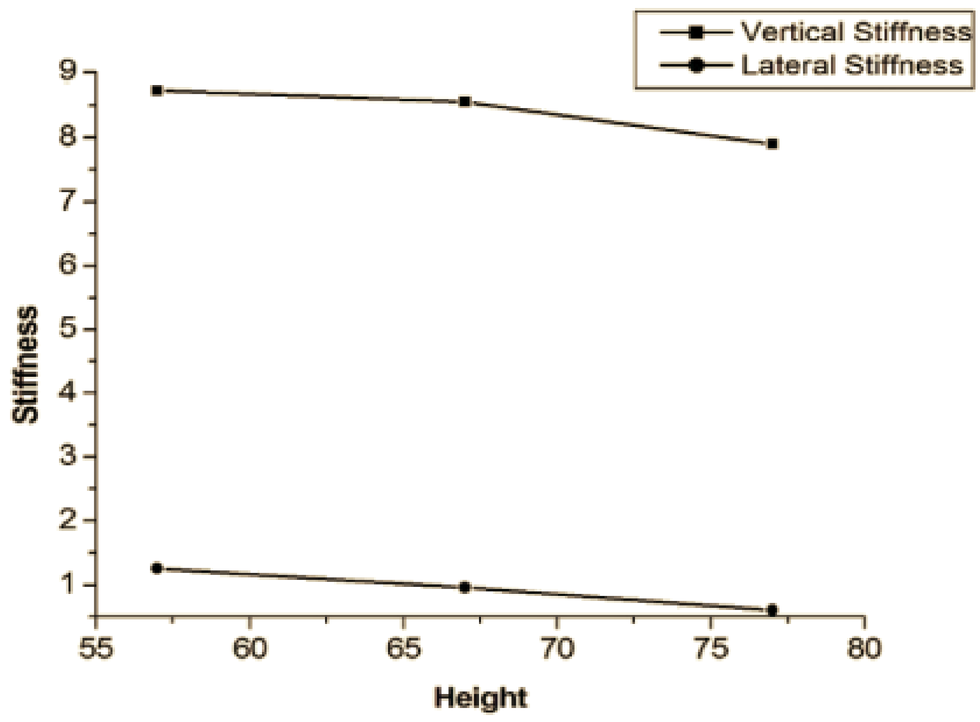

FIGURE 2.5:Effect of Height on PWRI Stiffness taken from [3]

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In relation to the PWRI, the next wire rope isolator known as the Helical Wire Rope Isolator (HWRI), have been widely used in space and military applications due to their highly effectiveness in both shock and vibration isolation [4]. Furthermore, HWRI can be mainly described as a wire rope isolator, which has been cable-winded in a helix shape, fastened with end clamps. In addition to the PWRI, the HWRI too, has damping characteristics depending on the cable diameter, number of loops and lastly, the number of steel wire strands. According to Piyovarov and Vinogradov, the damping in wire rope systems, highly depend on the sliding friction of the wire cables [9]. This can be proven in Tinker's experiment whereby a small part of Coulomb friction occurs during the stiffness experiment. In other words, the experimental hysteresis curve made can be deemed similar to a Coulomb friction hysteresis curve. In conclusion to the study, it is proven that the HWRI causes damping through cable friction and also that the geometry of the cables placed, has an effect to the vibration isolation.

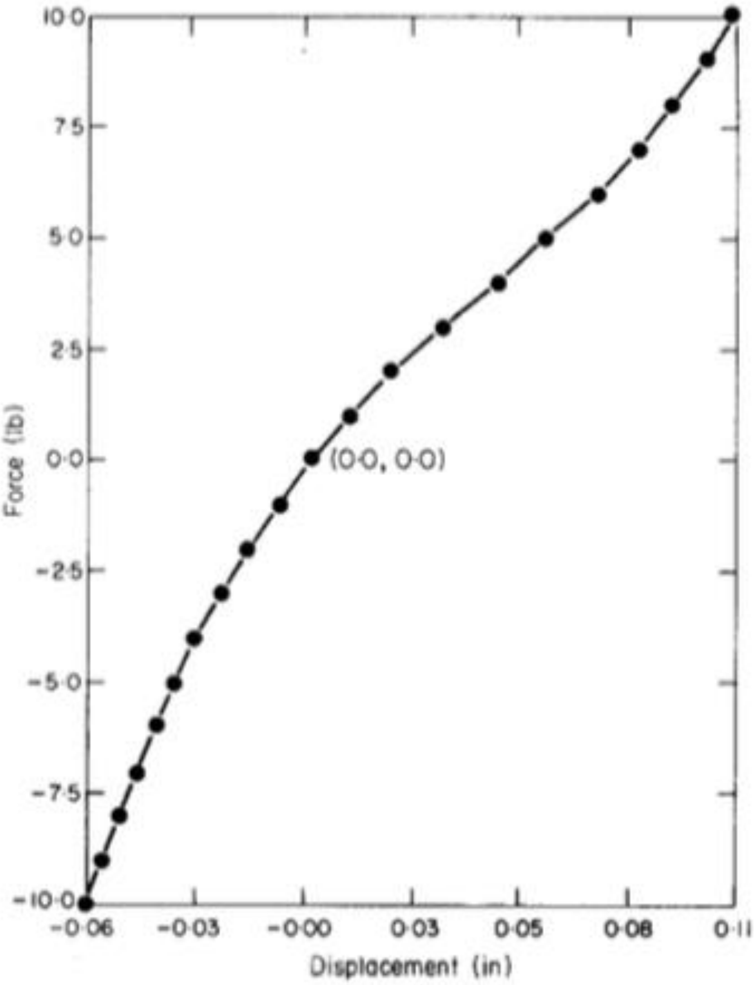

FIGURE 2.6: HRWI Experimental Stiffness curve taken by [4].

In conclusion, the two types of wire rope isolator designs prove that vibration isolation depends on numerous characteristics such as the wire strands, the geometry of the cables, the number of loops used and the diameter of the cables. With light from the research, it can be said that the use of wire rope isolators for miniature machinery such as drones, do not require excessive vibration isolation. A proper and efficient design will suffice as there are numerous factors to consider, such as the economic factor.

CHAPTER 3 : METHODOLOGY

3.1 Introduction

This chapter will explore the methods used in completing the experimental investigation. A flow process is made to show clearly the steps that will be taken and how it affects the project outcome. Firstly, this project generally covers on three (3) main stages of completion which are Planning, Implementing and Evaluating (PIE). This PIE method can be used as datum points that the author can use to refer to at different stages of the project. Furthermore, this tool may assist the author to have a clear and precise understanding of what the project flow and outcome is. In general, the project objectives can be achieved when the project flow is understood clearly.

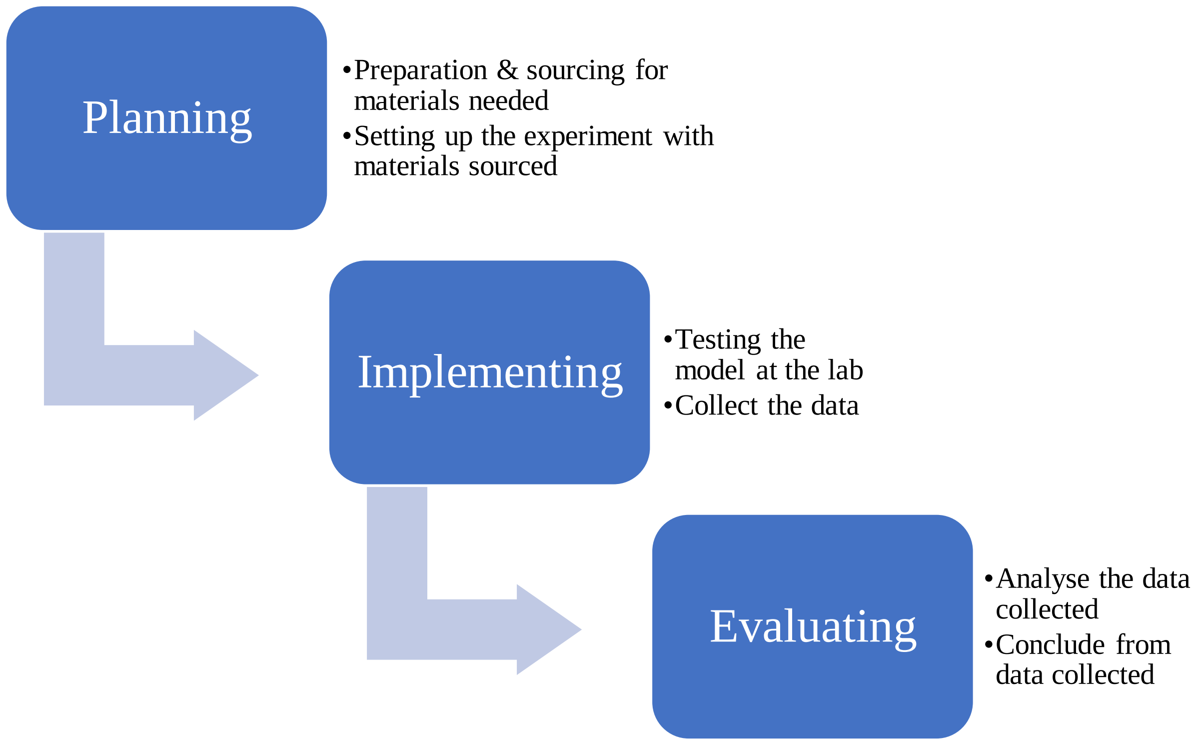

FIGURE 3.1: PIE Methodological Steps

3.2 Planning

Planning is a crucial step before starting an experimental investigation such as testing a wire rope isolator. It can be defined as an intellectual act of thinking before the action occurs. This means that anything that has a significant importance, needs proper planning procedures. A few examples of steps taken when planning are :

1. Defining the objectives
2. Identify alternatives
3. Selecting alternatives

For the case of experimentally investigating a wire rope isolator and its characteristics, the initial step would be to do research on the topic. That being said, literature reviews on vibrational analysis using different types of vibration isolators, experiments that determine the stiffness characteristics of a wire rope isolator and many more, are one of the steps taken by the author in understanding the project.

3.2.1. Deciding the parameters

In order to plan the experimental investigation, a few parameters were taken into consideration. The parameters can be classified as the size of the blocks and the diameter of the wire rope. To simplify the results and data to be analysed, the author has decided to only fabricate two wire rope isolators with different wire rope diameters to see the difference in stiffness characteristics.

Firstly, the mounting block material that has been chosen for the wire rope isolators design is carbon steel. One of the main reason this material is selected is due to the durability of the material during the Tensile test. To conduct the experimental investigation, the material for the mounting block needs to have a high strength and hardness. Alongside that fact, carbon steel is much cheaper compared to stainless steel material, despite stainless steel has a high corrosion resistant layer. In regard to the author's first choice of material, he had chosen a simple electrical block (plastic), which of course was not a well-planned idea as the author at the time, had not discussed with the lab technologists involved in the Tensile testing. To simplify, the chosen material, carbon steel, was due to it being a strong requirement for the wire rope isolator to be test in the Universal Tensile Machine.

Furthermore, the main component of the wire rope isolators are the wire ropes. The wire rope material that is best suited for this experimental investigation would be Stainless Steel (SS316). Moreover, the strand type that is chosen as seen in figure 3.2 & 3.3, is also known as a marine grade SS316 core strand. In addition to chromium and nickel, marine grade 316 also includes 2% to 3% molybdenum, a rough, silver white metallic product used to toughen steels and improve the resistance to corrosion in nickel alloys. This simple 1 core and 6 strand wire rope combination is best suited for uses of flexibility while integrating a high tensile strength. To conclude, the author has chosen the same wire rope configuration for both wire rope isolator models, thus only deferring the wire rope diameters to 5 mm and 3 mm.

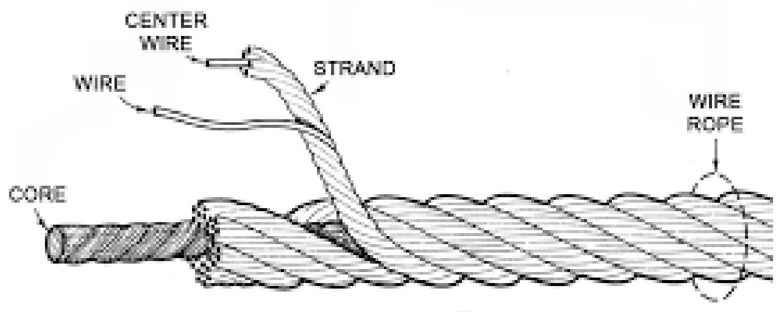

FIGURE 3.2: 6-Strand, 1-Core Wire Rope Example-1

FIGURE 3.3: 6-Strand, 1-Core Wire Rope Example-2

As seen below, the chosen parameters for the wire rope isolator models can be classified according to its Mounting Block Material, Wire Rope Material and Wire Rope Diameter.

TABLE 3.1: Parameter of wire rope isolators

Wire Rope Model No.	Mounting Block Material	Wire Rope Material	Wire Rope Diameter (mm)
WRI-1	Carbon Steel	SS316	5
WRI-2	Carbon Steel	SS316	3

3.3 Implementing

Implementing is the method of applying what is learned and understood to an action plan. It can also be defined as the act of begin using a certain system or plan. As said previously, the planning stage is a crucial step before taking any action, thus implementing the plans is the next step to fulfil the author's project objectives. The steps that will be implemented are as shown below :

1. Testing the wire rope isolator using a Universal Tensile Machine located at Block 17, UTP.
2. Collecting the static characteristics from the test, while running a few different tests in order to get an accurate result from the experiment.

3.3.1 Tabulation of Experimental Investigation

As stated above, the Wire Rope Isolators (WRI-1/WRI-2) will be undergoing monotonic tensile loading test using a Universal Testing Machine. Due to inaccuracy and systemic error of the machine, it is unable to plot a proper compressive results. In accordance, the hysteresis plot will be incomplete as it can only plot a tensile result.

Furthermore, the accuracy of the results is dependent on how reliable the tests are. Having good test reliability means the internal validity of a test and guarantees that over time the measurements obtained in one sitting are both representative and reliable. Thus, in order to have a reliable result, the author has planned a flow chart procedure in which the wire rope isolators will be tested using the Universal Testing Machine.

3.3.2 Experimental Investigation Procedure on Tensile Test

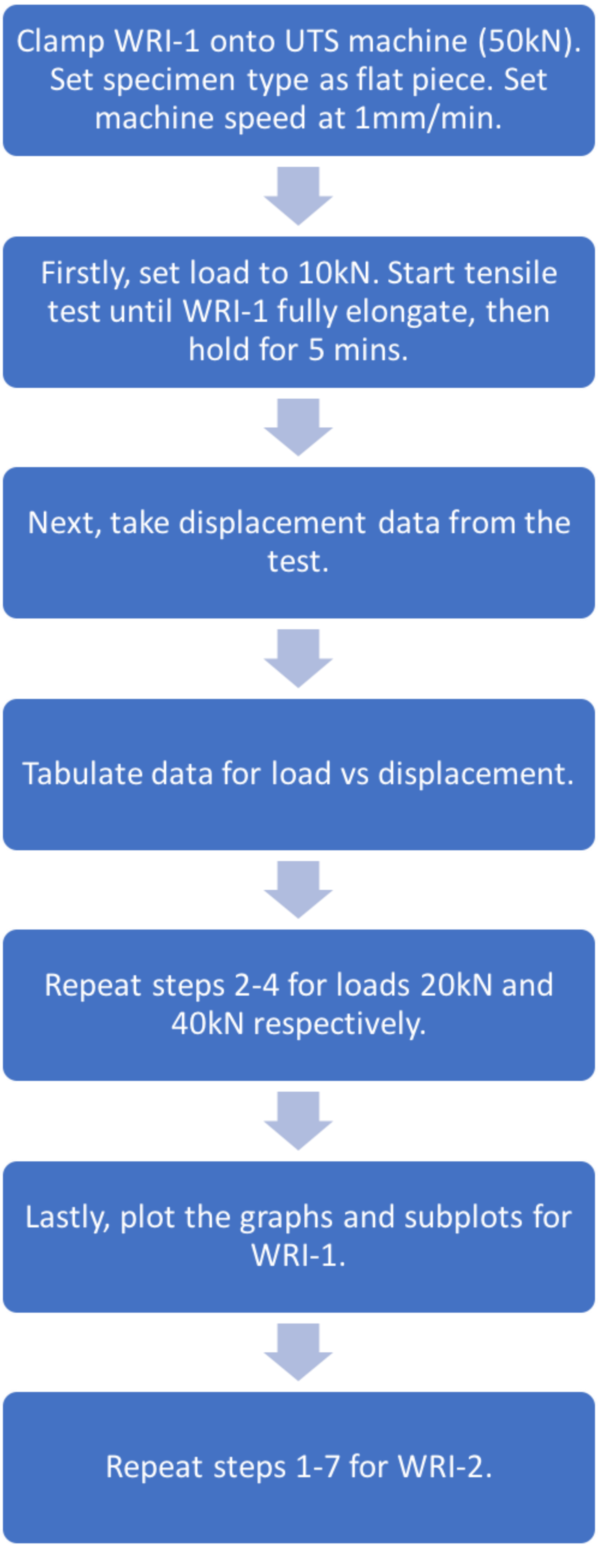

FIGURE 3.4 : Process of Wire Rope Isolator Tensile Testing Procedure

3.4 Evaluating

The evaluating process can take on different paths, depending on the type of approach a project is taking. As every process has many paths, the aim of the project can have different evaluating systems as below.

3.4.1 Process evaluation

The assessment dimension evaluates whether the curriculum is performed as expected rather than evaluating improvements in performance. It involves creating, according to the program's goals, a list of metrics to be calculated. The findings will help identify the strengths, shortcomings and enhancements of the system.

The system evaluation focuses on the implementation process and seeks to evaluate whether the plan was successful in implementing the logic model strategy and how the results / impact assessments worked together in three segments of the logic model (Inputs, activities and outputs). A process evaluation concentrates on the first three segments of the logic model. System tests allow evaluators to differentiate between failure in execution and failure in theory.

For the author, the tests that were conducted now yield the Stress-Strain and Load-Displacement data. From this data, the evaluation process is in determining the wire rope isolators' stress and strain in order to analyse the stiffness of the wire rope isolator. Furthermore, the data gathered can also indicate the different characteristics of the models such as its ability to withstand a certain maximum load, thus analysing a safety factor for the models when using them.

3.4.2 Impact Assessment

As the name suggests, impact assessment is the current process of carrying out an assessment of the project based on the future impact it has. Moreover, it refers to measuring future consequences of a current project to determine the difference it brings towards society.

FIGURE 3.5: Impact Assessment methodological steps

From this assessment, the author managed to identify the uses of the fabricated wire rope isolator models. In detail, the data gathered from the test are analysed and can be applied for general uses, thus completing objective #3, the application of these wire rope isolator models. The data used to find the impact to society, economic and environmental are such as the material used for the models which fulfils a cost factor in terms of designing a vibration isolator. Furthermore, the maximum load data gathered from the experiments can be used as benchmarks for the applications of the models.

With the experimental data, the analysed results can be used for future analysis whether or not the wire rope isolators has a better impact as a more economic solution to vibration dampening. Moreover, the environmental effects of using the wire rope isolators as substitution from electronically powered vibration isolation devices may be further investigated as these wire rope isolators are a fully mechanical system, they can provide not only a cost-effective solution but also a safer, cleaner approach to vibration isolation systems.

3.5 FYP I Gantt Chart

TABLE 3.2: FYP 1 Gantt Chart

FYP I		PROJECT :	Experimental Investigation on Wire Rope Isolator													
		DOCUMENT :	Project Activites Milestone													
		DATE :	29/10/19													
NO.	PROJECT ACTIVITIES	MONTH	Sep-19				Oct-19					Nov-19				
		DURATION	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W13	W14
1	Project Title Selection	1 week														
2	Project discussion with FYP SV	1 week														
3	Background study on WRI	1 week														
4	Literature Review on WRI	3 weeks														
5	Develop Project Methodology	3 weeks														
6	Preparation for Proposal Defence	2 weeks														
7	Completion of Interim Report	2 weeks														
8	Review oF interim Report by FYP SV	2 weeks														
9	Submission of Interim Report	1 week														

3.6 FYP II Gantt Chart

TABLE 3.3: FYP II Gantt Chart

FYP II																
		PROJECT :	Experimental Investigation on Wire Rope Isolator													
		DOCUMENT :	Project Activites Milestone													
		DATE :	2/12/19													
NO.	PROJECT ACTIVITIES	MONTH	Jan-19				Feb-19				Mar-19				Apr-19	
		DURATION	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W13	W14
1	Project Items sourcing	2 week														
2	Designing WRI	2 week														
3	Modelling WRI	2 weeks														
4	Experimental Investigation on WRI	2 weeks														
5	Data Collection	1 week														
6	Compile Completed Report	2 weeks														
7	Project VIVA Presentatioon	2 weeks														
8	FYP Dissertation Submission	1 week														

CHAPTER 4 : RESULTS & DISCUSSION

4.1 Wire Rope Isolator Model Design

As part of the objectives, the author had designed a model of the type of wire rope isolator that is intended on carrying the experimental investigation. The simplest and most commonly used type of wire rope isolator that is chosen as an example is the Compact Wire Rope Isolator design. The reason behind this, is due to its simplicity in design. As an example of its application, a compact wire rope isolator design is most commonly used as camera stabilizers.

Furthermore, modelling the wire rope isolators are important as they provide a clear dimension on how the actual product will be fabricated. Modelling is an established engineering technique which is well embraced.

The author has accomplished three goals by modelling:

- Models defines a system's structure or behaviour
- Models gives a structure to help us in building a system.
- Models portrays the decisions made.

In addition, the type of designing that the author had chosen to model the wire rope isolators is using an Orthographic Drawing. Using several two-dimensional views of the object, an orthographic drawing depicts a tri-dimensional object. Moreover it can be called an orthographic projection. Furthermore, an Orthographic Drawing is chosen as a designing approach due to its simplicity in understanding the dimensions of the models. Moreover, during the fabrication, it is more readable to the common fabricators. In the depicted sketches below, the author had followed the sequence as shown in figure 4.1.

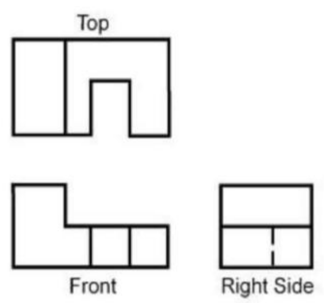

FIGURE 4.1: 2D Orthographic Projection

4.1.1 Design for WRI-1

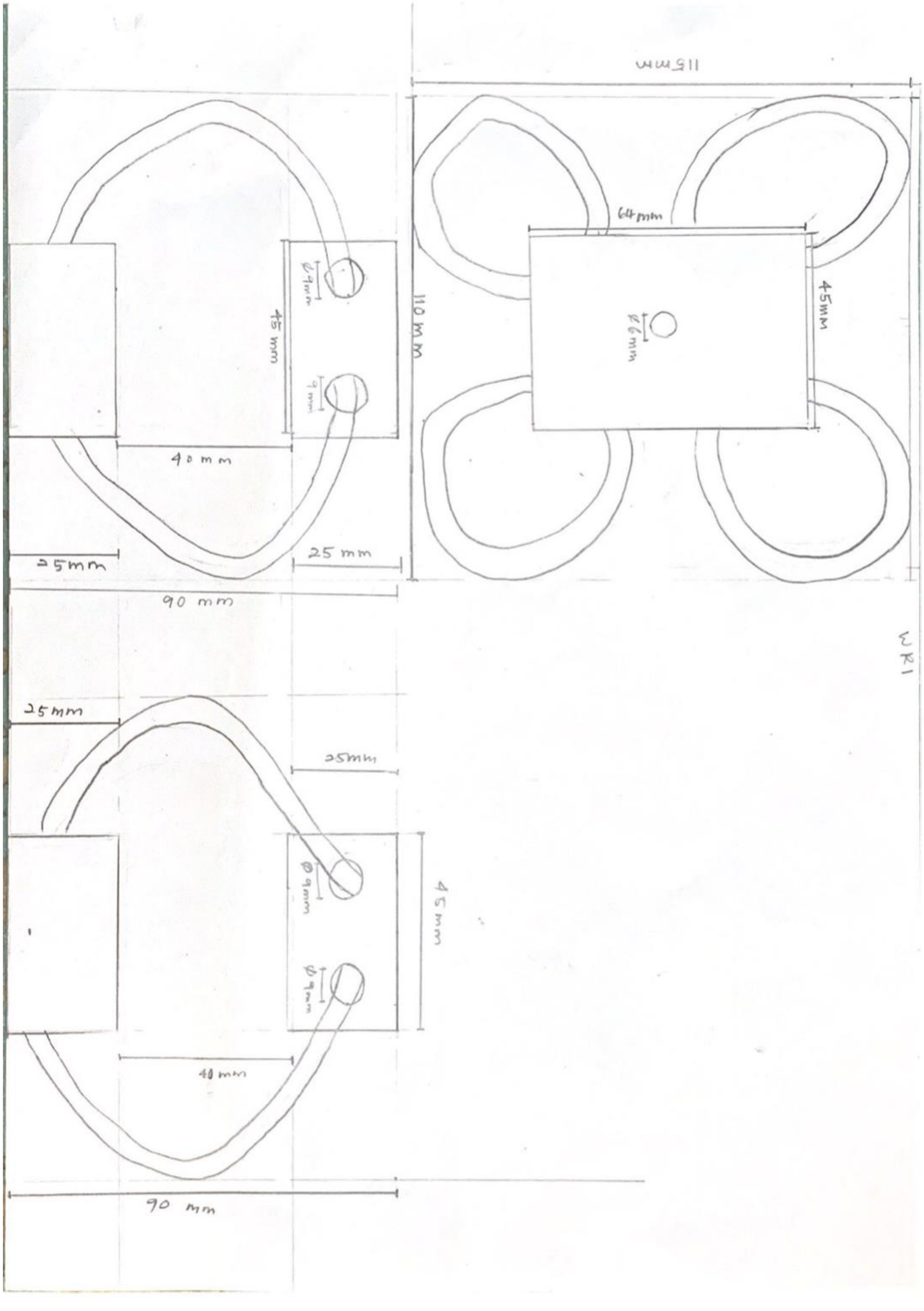

FIGURE 4.2: WRI-1 Orthographic Projection

4.1.2 Design for WRI-2

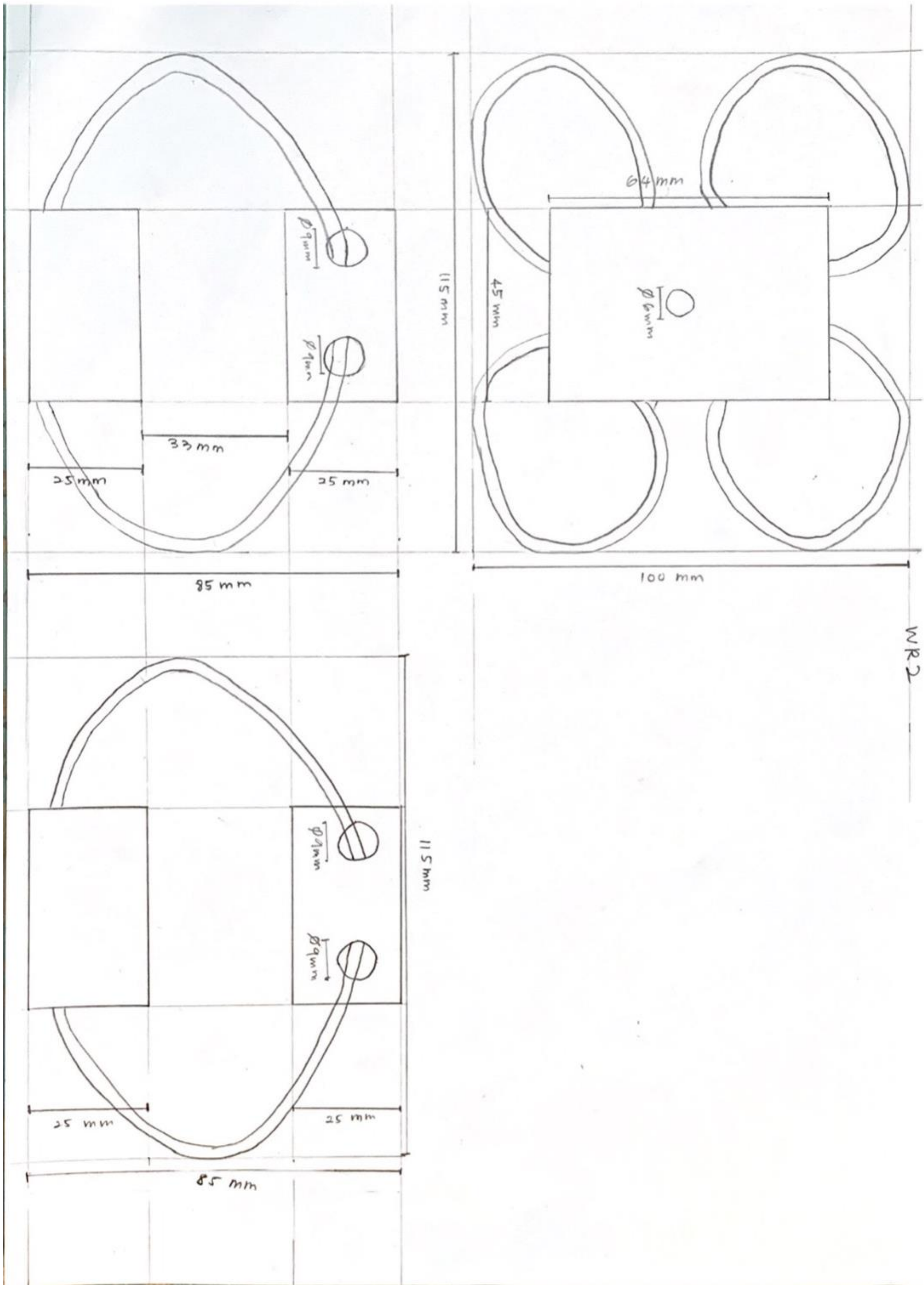

FIGURE 4.3: WRI-2 Orthographic Projection

4.2 Stress-Strain Results

4.2.1 WRI-1 Stress-Strain Results

According to figure 4.4, WRI-1 undergoes maximum engineering stress value of 18 MPa at around 98% strain. However, figure 4.5 indicates a maximum true stress value of approximately 35 MPa at an estimated 67% strain value. This can be explained due to the cross-sectional area of the specimen constantly decreasing throughout the experiment [10]. As the wire rope isolator begins to neck due to the decrease in cross-sectional area, the value of the stress calculated increases.

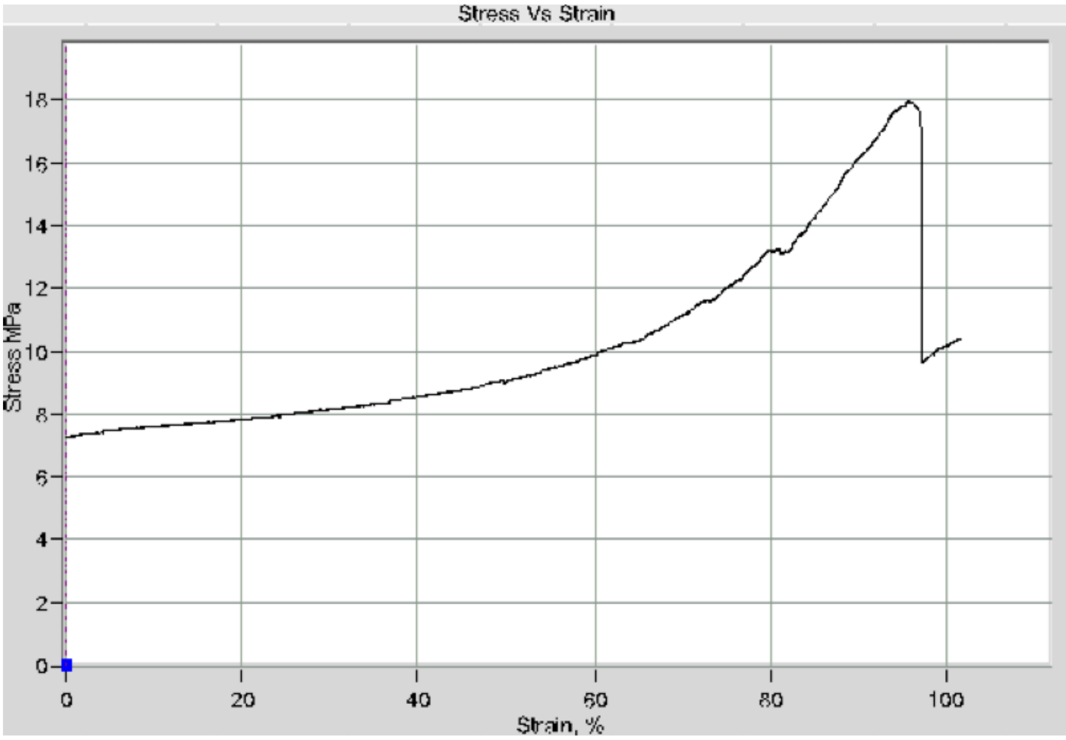

FIGURE 4.4: WRI-1 Stress-Strain graph

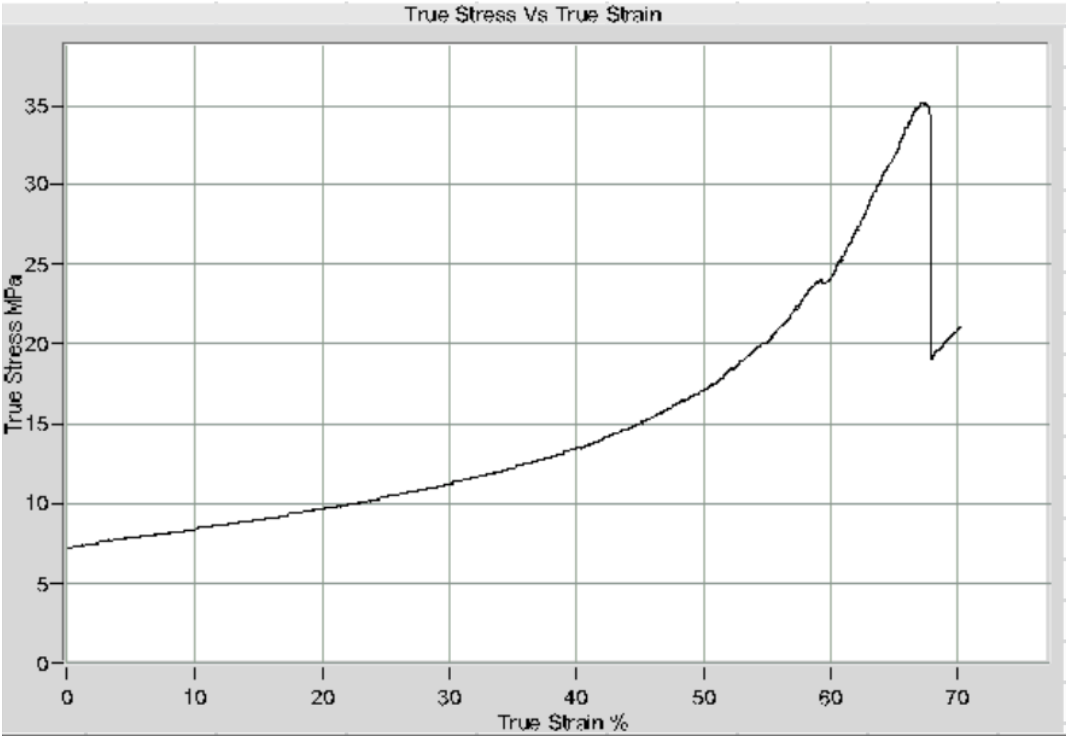

FIGURE 4.5: WRI-1 True Stress-True Strain graph

As seen in figure 4.6 below, the maximum stress calculated is 7.30 whereas the maximum true stress is 7.32. This graph is the representation of the stress-strain data taken from the experimental investigation. In the graph, the author had only plot the significant difference between the true stress and stress in order to illustrate the break whereby the true stress and stress data is clearly shown.

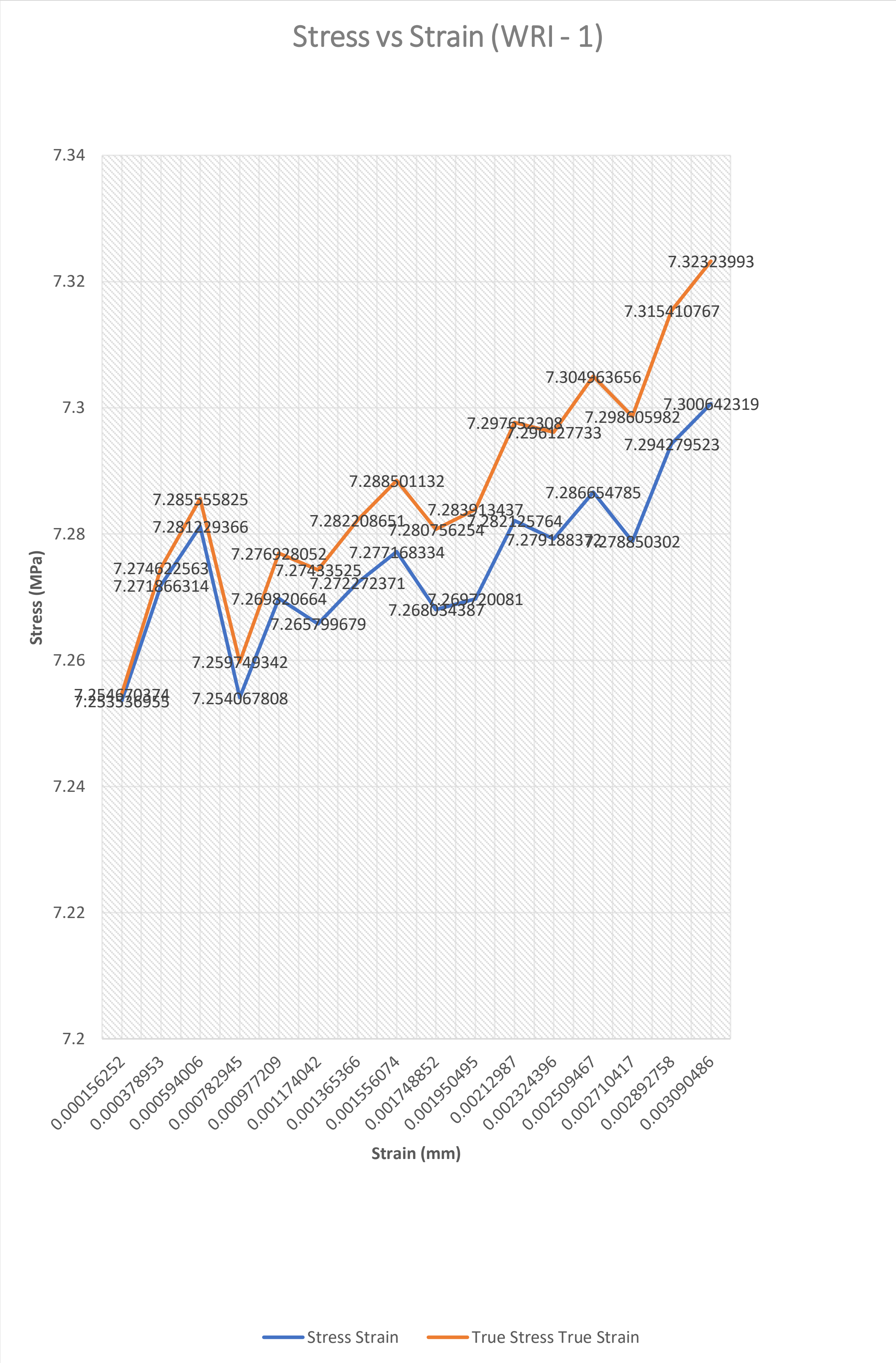

FIGURE 4.6: WRI-1 True Stress-True Strain and Stress-Strain graph

4.2.2 WRI-1 Tensile Test Report

TABLE 4.1: WRI-1 Tensile Test Report

Type of Data	**Results**	**Units**
Peak Stress:	17.956	MPa
Peak Load:	1.142	kN
0.2% Offset Yield Stress:	0	MPa
Yield Strain:	0	%
Yield Load:	0	kN
0.02% Offset Yield Stress:	0	MPa
Modulus:	0	GPa
0.1% Offset Yield Stress:	0	MPa
0.5% Offset Yield Stress:	0	MPa
Upper Yield Stress:	7.264	MPa
Lower Yield Stress:	7.258	MPa
Limit Of Proportionality:	0	MPa
Total Energy:	23.126	kN
Energy under Plastic Region:	-244.834	kN
Strain Hardening Exp:	0	
Strain Hardening Coeff:	0	MPa
Yield Point Extension:	0	mm
Yield Point Elongation:	0	%
Elongation at Break(using Strain):	101.867	%
Elongation at Break(User input), 35, 0:	100	%
% Reduction Area at Break(User input), 63.64, 0:	100	%
Avg. Load over Extension Range, 0, 0:	0	kN
Energy under Selected Region, 0, 0:	0	kN
Extension at Load, 0:	0	mm
Load at Extension Point, 0:	0	kN

4.2.3 WRI-2 Stress-Strain Results

In figure 4.7, there is an increase of stress as compared to the previous experiment of WRI-1. This is due to the smaller diameter of the stainless steel wire rope which is 3 mm as oppose to WRI-1 which is 5 mm. In addition to that, a smaller cross-sectional area of the wire rope isolator would cause a high pressure at a certain area which means there are higher stress present in the stainless steel wire ropes.

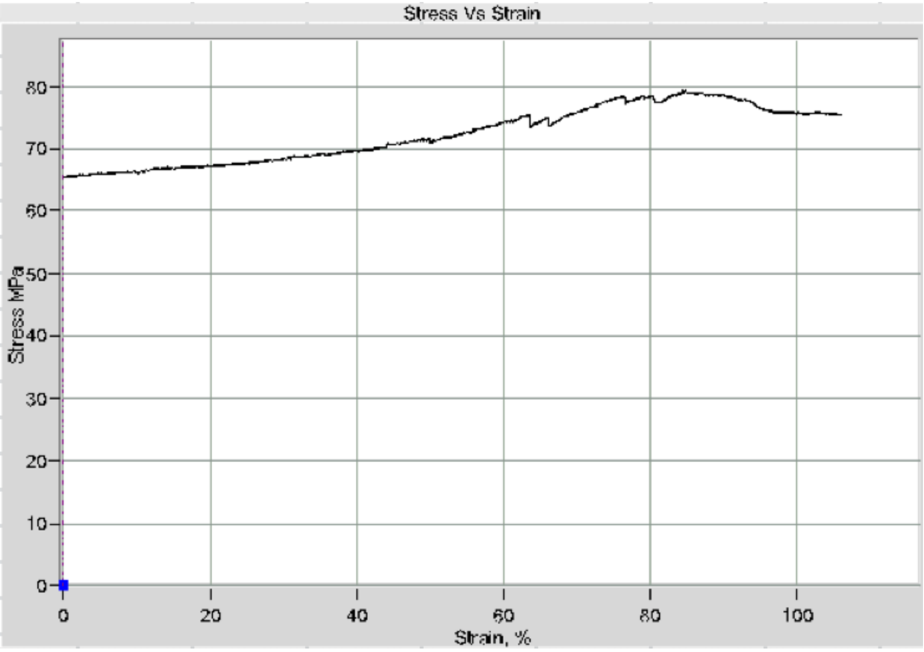

FIGURE 4.7: WRI-2 Stress - Strain graph

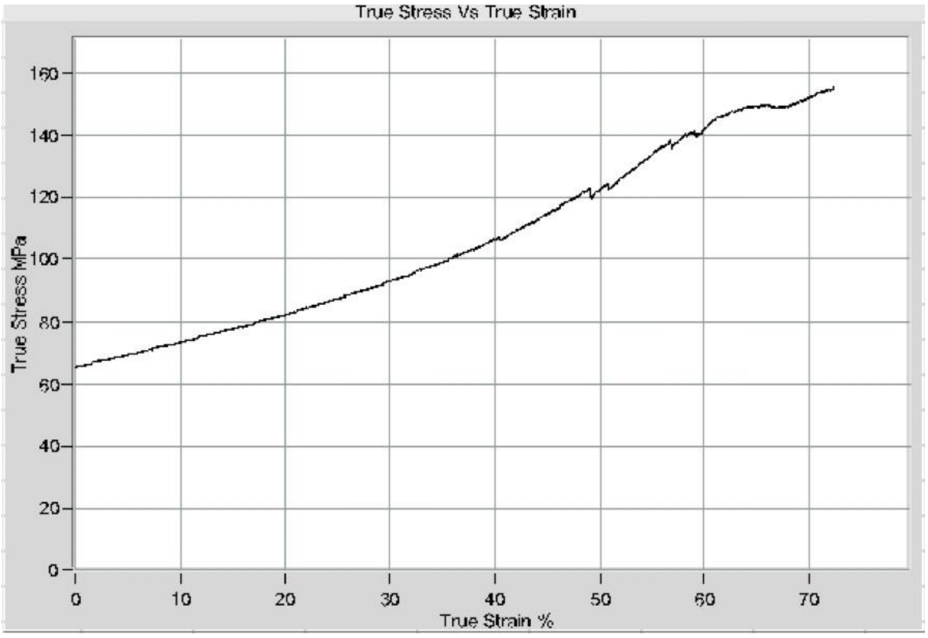

FIGURE 4.8: WRI-2 True Stress - True Strain graph

As anticipated, the true stress and true strain values for WRI-2 are much higher towards the end of the experiment due to the consideration of decreasing cross-sectional area.

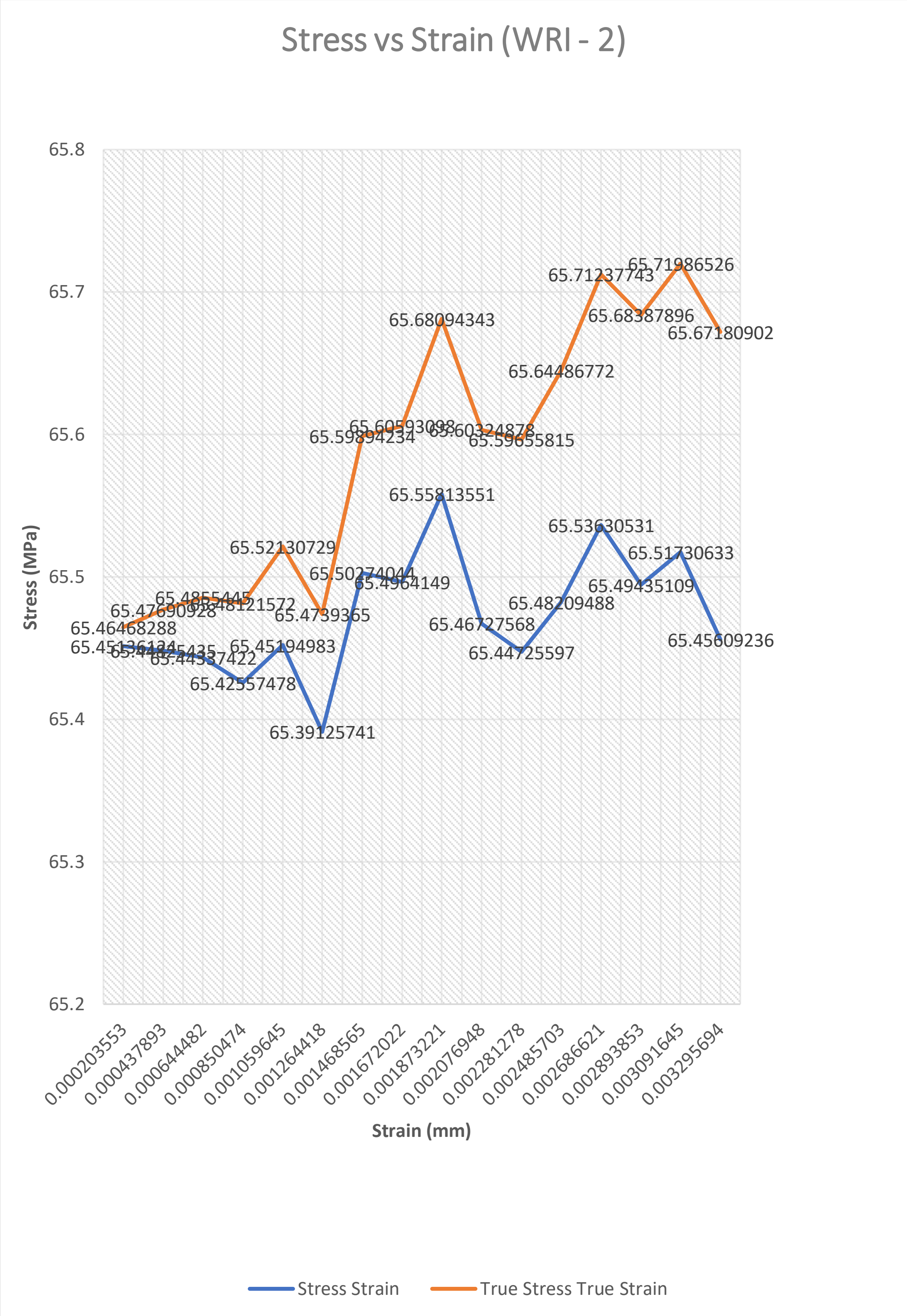

FIGURE 4.9: WRI-2 True Stress-True Strain and Stress-Strain graph

4.2.4 WRI-2 Tensile Test Report

TABLE 4.2: WRI-2 Tensile Test Report

Peak Stress:	79.269	MPa
Peak Load:	0.56	kN
0.2% Offset Yield Stress:	0	MPa
Yield Strain:	0	%
Yield Load:	0	kN
0.02% Offset Yield Stress:	0	MPa
Modulus:	0	GPa
0.1% Offset Yield Stress:	0	MPa
0.5% Offset Yield Stress:	0	MPa
Upper Yield Stress:	65.426	MPa
Lower Yield Stress:	65.373	MPa
Limit Of Proportionality:	0	MPa
Total Energy:	17.886	kN
Energy under Plastic Region:	17.889	kN
Strain Hardening Exp:	0	
Strain Hardening Coeff:	0	MPa
Yield Point Extension:	0	mm
Yield Point Elongation:	0	%
Elongation at Break(using Strain):	106.144	%
Elongation at Break(User input), 33, 0:	100	%
% Reduction Area at Break(User input), 7.07, 0:	100	%
Avg. Load over Extension Range, 0, 0:	0	kN
Energy under Selected Region, 0, 0:	0	kN
Extension at Load, 0:	0	mm
Load at Extension Point, 0:	0	kN

4.3 Load-Displacement Results

4.3.1 WRI-1 Load-Displacement Results

As seen in figure 4.10 below, the peak load that the WRI-1 undergoes reached 1.13 kN at a displacement of 34 mm. From this load-displacement graph, the author can analyse the stiffness of the wire rope isolator. Another reason the load-displacement graph is taken into account even though the stress-strain data is available is due to the accuracy of the experimental results. During the lab testing, the program used by the Universal Testing Machine does not have a pre-set model for the wire rope isolator shape. Moreover, the gauge lengths and the base area of the specimen does not have a proper setting. Thus, the readings of the stress-strain curve may have some inaccuracy. In further considerations, the stiffness characteristics of the wire rope isolators will be determined using the Load-Displacement curve.

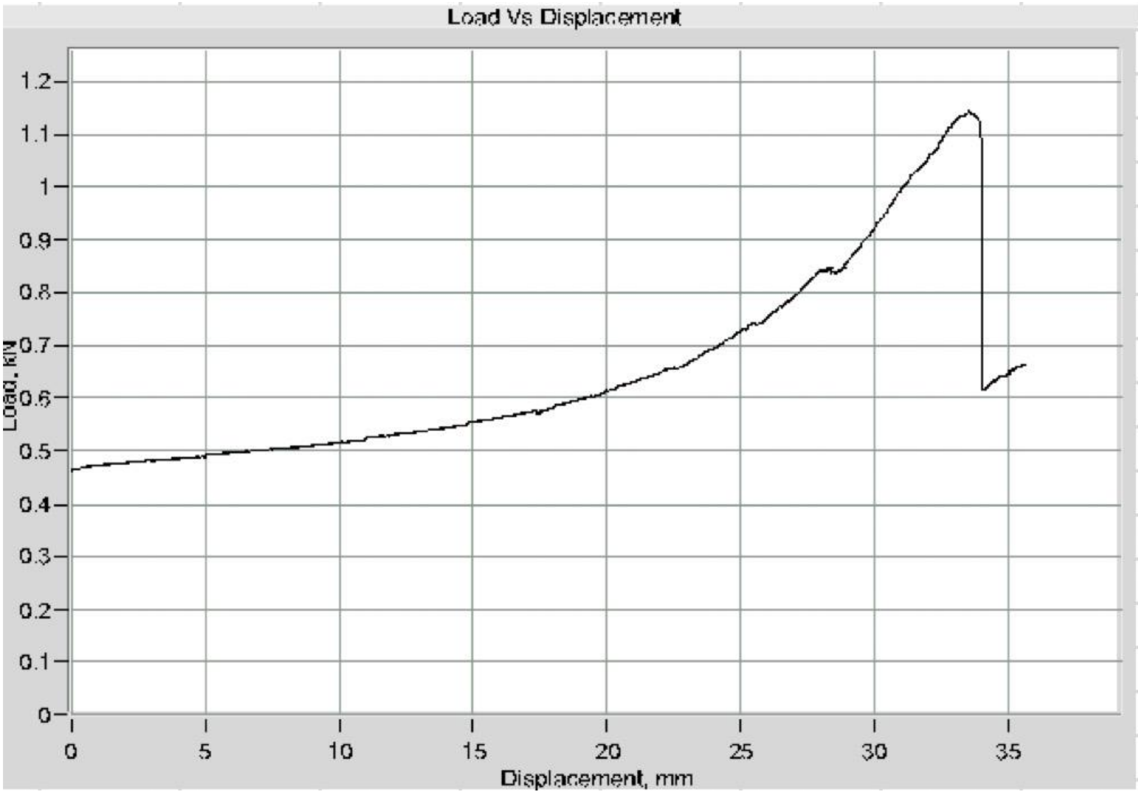

FIGURE 4.10: WRI-1 Load-Displacement graph

4.3.2 WRI-2 Load-Displacement Results

In figure 4.11 below, it is seen that there is only a peak load of around 0.56 kN with around the same displacement as WRI-1 at a maximum displacement 35 mm. In this experiment, the constant variables were the displacement and time which helps in investigating the difference in load needed to deform the wire rope isolators. Thus, concluding the fact that WRI-2 needs less load than WRI-1 to displace the wire rope length to 35mm.

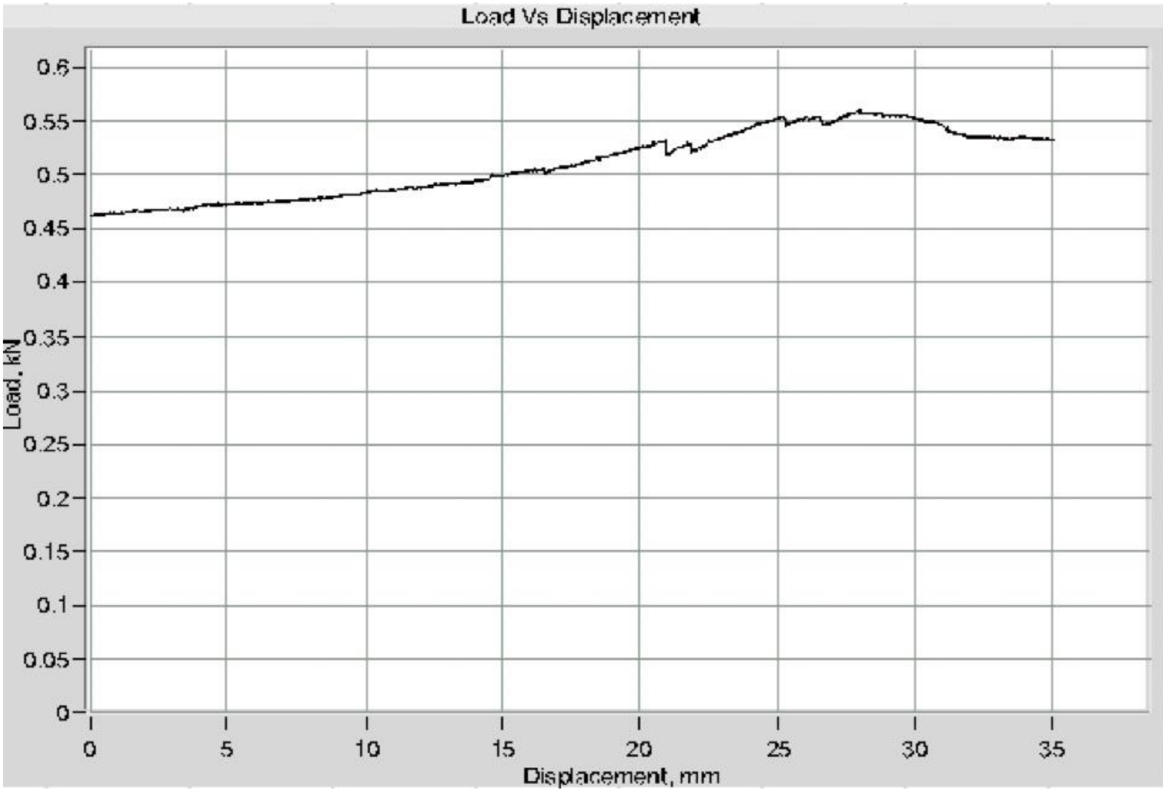

FIGURE 4.11: WRI-2 Load-Displacement graph

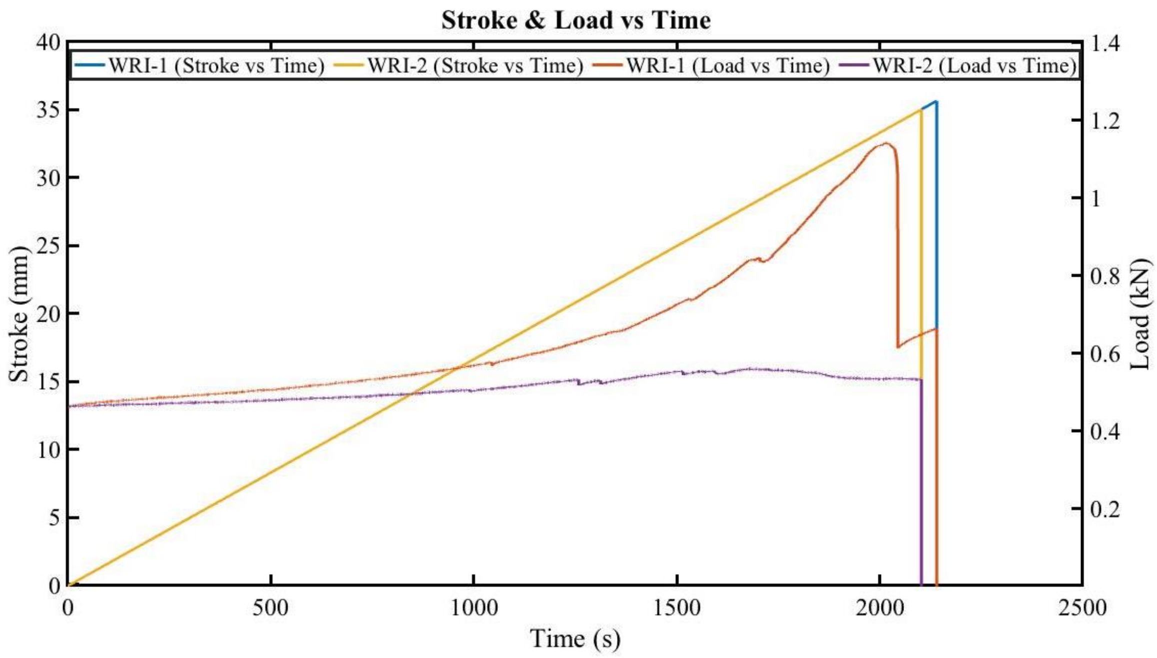

FIGURE 4.12: Load-Displacement vs Time graph

To put things in a clearer perspective, figure 4.12 indicates the difference between WRI-1 and WRI-2 in terms of stroke (displacement) and load with respect to time. As the displacement is merely a constant variable in which both wire rope isolators testing are stopped at almost the same stroke, both WRI-1 and WRI-2 show a linear graph with respect to time. Besides that, the load difference begins to show as early as less than 250 s between the two wire rope isolators. Furthermore, WRI-1 clearly shows a better increase in handling load as it continues to rise whereas WRI-2 shows a more strenuous loading with barely reaching 0.6 kN. Moreover, at around 1900 s, WRI-1 and WRI-2 shows its greatest difference in peak loads.

4.4 Stiffness Analysis

According to Hooke's Law, the force that is needed to extend or compress a spring is directly proportional to the displacement. Thus, leading to the graphical explanation whereby the slope of the Force vs Displacement curve is the stiffness of the spring-like object. In other words, in order to find the stiffness of the wire rope isolators, the slope of the Force vs Displacement graph needs to be calculated.

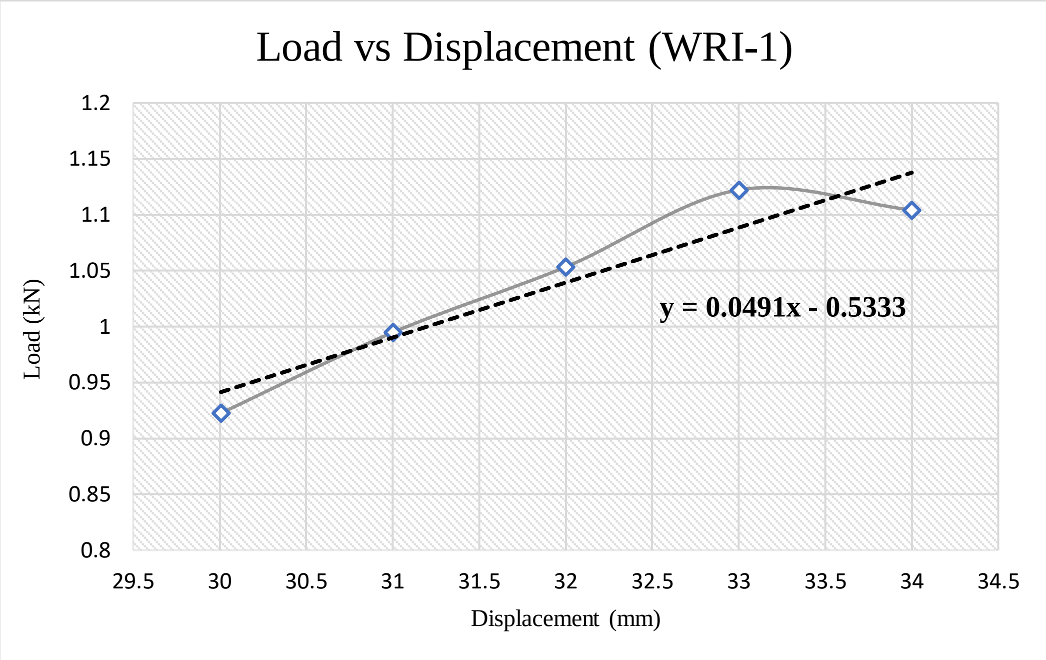

FIGURE 4.13: WRI-1 Stiffness Analysis from Load-Displacement graph

From the data gathered from the tensile tests, the author have analysed the key points in both Load-Displacement graphs whereby the wire rope isolators both showed steep load inclinations. Thereby, as seen in figure 4.13 above, the stiffness of WRI-1 is 0.0491. Furthermore, in figure 4.14 below, the stiffness of WRI-2 which is taken from the displacement points around 5 mm to 10 mm where the load has a steep incline, is at 0.0025.

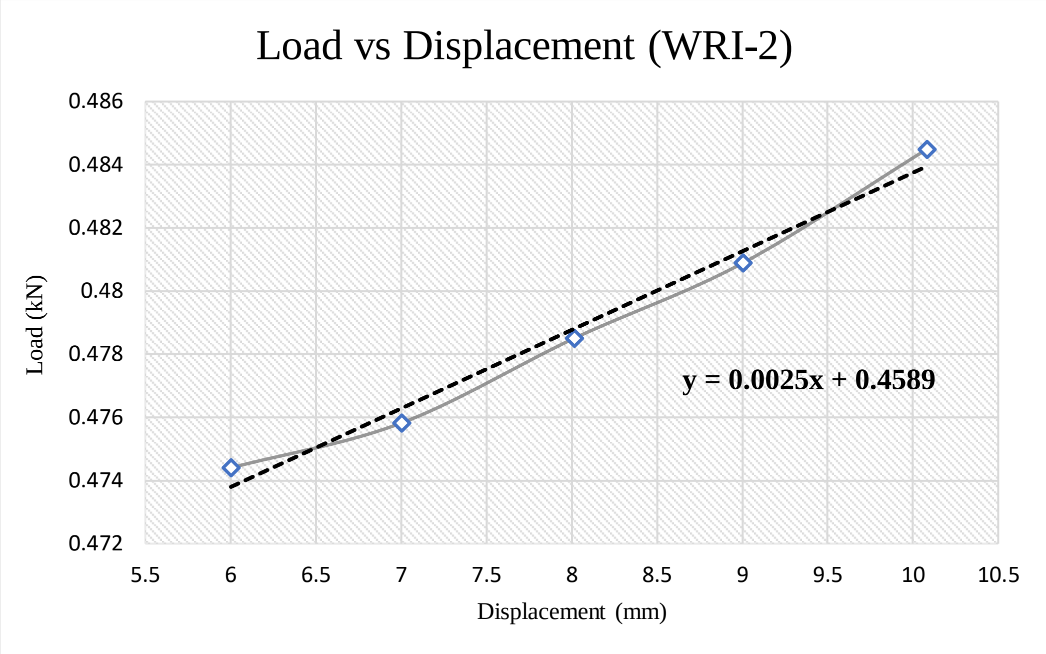

FIGURE 4.14: WRI-2 Stiffness Analysis from Load-Displacement graph

To conclude the stiffness analysis of the wire rope isolators, the author have discovered that WRI-1 has a higher stiffness as compared to WRI-2. Theoretically, the hypothesis is accepted as the larger area of wire rope provides a higher stiffness. As stated in the literature review, a more stiff isolator can help when high loads are involved however for maximum vibration isolation, it is preferably to choose the isolator with the least stiffness.

CHAPTER 5 : CONCLUSION & RECOMMENDATIONS

According to the expected experimental results, both wire rope isolators have proven successful in proving the hypothesis. To reiterate, the smaller cross-sectional area of a vibration isolator provides less stiffness whereas a larger cross-sectional area can accommodate higher loads. As WRI-1 has a stiffness value of 0.0491 while WRI-2 shows a stiffness value of 0.0025, the difference between stiffness is very drastic.

In relation to the problem statement, these wire rope isolator are designed generally for use of lightweight machinery such as drones and automated machines. This means that both WRI-1 and WRI-2 are only suited for lightweight uses and not heavy loads such as plant systems. Regarding their applications, WRI-1 is best suited for uses in the automation industry where there are robotic-operated machinery. This is due to the precision needed by these industries and how a wire rope isolator can minimize any stabilizing errors in order to yield a more accurate result while able to handle high loads. Furthermore, WRI-2 is more suitable in use for daily applications such as a camera stabilizer or drone stabilizers. It is much lighter and compact thus better in providing efficient vibration isolation in a smaller size.

In conclusion, both these isolators have deemed to be useful in providing isolation with still very little stiffness results and with the materials used, they are sturdy, reliable and a cost-effective method for passive vibration isolation. The objectives of this study in developing concept models for wire rope isolators applicable for use in vibrational damping and/or shock absorbing devices is achieved. Moreover, these wire rope isolators have been experimented using Universal Testing Machine in determining each of their stiffness characteristics with an accepted hypothesis.

There are a few recommendations the author have that may assist in this continuing experimental investigation. Firstly, regarding the Universal Testing Machine used in Block 17. In hopes that for further experimentation, there will be a proper experimental procedure in which the wire rope isolators can be tested. Moreover, the program being used in the machine cannot properly detect the wire rope isolators shape as they are of irregular shape, thus the readings for the stress-strain curve may be inaccurate.

Furthermore, there are other types of vibration isolators known as active-passive vibration isolators. This is the integration of electronics such as controllers, sensors and actuators in helping a passive vibration isolation system. For future works, the author highly recommends that future researchers may design a wire rope isolator that has active isolation systems involve as to enable the wire rope isolator to be more efficient in combatting vibration in real time or even predicting the vibration before isolating it.

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