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Design and Analysis of a Rocket Launch Pad for Weather Observation

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***Abstract*: This paper deals with the structural design and analysis of a Rocket Launch Pad for Weather Observation CHED funded research of Holy Angel University (HAU) under the Discovery Applied Research and Extension for Trans/Interdisciplinary Opportunities (DARE TO) Research Grant. Detailed 3D Model and analysis of the Launch Pad configurations are carried out to arrive at a mass optimized configuration which meets the specifications. The loads are estimated considering the distributed weight of the Rocket and the own weight of the Launch Rail. The Normal frequencies are estimated from the finite element analysis. The Modal Analysis of two configuration Designs are also compared. Accordingly, two different configurations are arrived. Initially, a Portable Platform and then a Mobile configuration is designed with the suitable specifications. Design includes dimensions of Launch pad, Launch Rail, and rocket. The components are meshed, and the member and material properties are allocated to the model, the composed model is then analyzed with finite element software, Solid works.**

***Keywords*: Design, Finite Element Analysis, Rocket, Structural Analysis, Weather Observation.**

1. Introduction

A launch pad is a platform from which a rocket is launched. The purpose of a launching system is to place a weapon into a flight path as rapidly as the situation demands. In this study the weapon being considered is the rocket for weather monitoring purposes. The project titled 'Design and Development of Rocket System for Environment, Atmospheric and Weather Observation' is a CHED funded research of Holy Angel University (HAU) under the Discovery Applied Research and Extension for Trans/Interdisciplinary Opportunities (DARE TO) Research Grant.

The objective of building a rocket system for environmental monitoring is relevant to the current development in the space program of the Philippines and its application to issues on the environment, agriculture, disaster mitigation and even for national security. The research project is multidisciplinary/interdisciplinary in nature, and such is the composition of the team, with members coming from various engineering and technology disciplines namely Aeronautical, Chemical, Computer, Electrical, Electronics, Industrial and Mechanical Engineering. A rocket is a complex vehicle consisting of many different subsystems including, propulsion, payload, and recovery to name a few. This study will focus specifically on the structure of the rocket launch pad. First, examine the design process used to arrive at a functioning rocket launch pad structure. This includes setting design constraints, and targets, as well as, indicating the iterative design process and performing calculations to verify crucial components. The launch pad must satisfy the capability requirements of the rocket model. The launch pad will be designed to be transported from one location to the other for easy mobilization especially during the testing stage. It should assist in holding the rocket in straight position. The igniter can be installed at the launch site because it is separable from the rocket motor.

The ground control station will be Rocket Launch Pad established at a safe distance from the launch pad taking in consideration the safety of the technical personnel involved. Secondly, the details of the fabrication of the rocket launch pad structure which comprises of the design requirements, material selections, simulation, test, and analysis Propulsion Engineer at Bellatrix Aerospace. There are different types of rocket launch pads based on the type and size of the rocket. For Model Rockets, a small-scale rocket which can go up to 4 km in altitude the launch pad has to support the rocket and hold it in vertical position. It must guide the rocket up to some distance. The initial acceleration will be very high and if not controlled, the rocket will be going in all directions and may cause accidents. For Sounding rockets, small scale rockets which is normally used to launch smaller payloads into the atmosphere (Not into space). Since sounding rockets are heavy, the launch pad should assist in holding the rocket in straight position. Some big sounding rocket launch pads will have a platform for people to work on it in final stages of integration. And for Heavy rockets, orbital launcher, launch pad location is a prime importance. It should not be near any populated area, yet it should have good accessibility. Most launch pads are located near ocean for the same reason [1].

The launch pad system for weather Rocket System is designed to guide the rocket during Deployment consider the stability, weight, and aerodynamic drag or the Vibration cause by the Acoustic load the goal is Minimize rocket induced launcher reactions by computing the Natural Frequency of the model and configure different support. This is done with Launch rail platform with portable on each and by bolt and nuts mounting to the system when closed as shown in figure 1, and by mean of additional parameter for Movement, mobile Launch Pad is addition to the design shown in figure 2. This design study for Optimum stiffness, and mass placements.

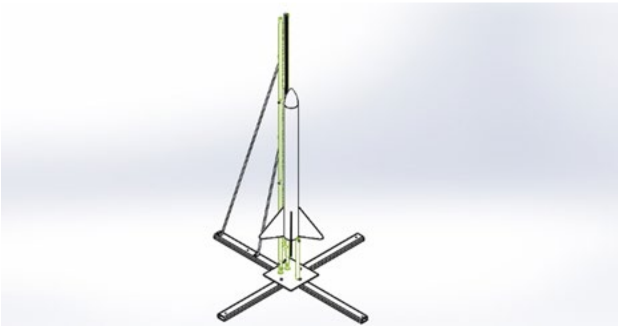


Fig. 1. Portable launch pad 3D model

Figure 1 show the Design of the Launch Pad with Portable Platform to carry without difficulty in every test range or site, the Launch pad consist of; (a) the Portable Platform which is the main platform of the pad made with Fabricated bar of 100 x 50 x 3 size in mm with a 400 x 400 mm base Plate and hinge system, with four (4) anchor support each end of the bar For the stability of the whole Platform and (b) the Launch Rail Support mounted with Launch Rail Standard 1010 made of aluminum.

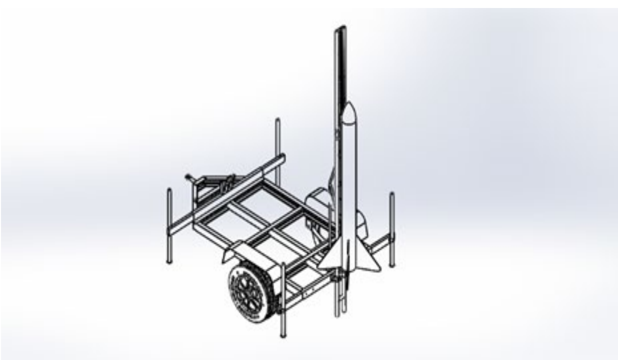


Fig. 2. Mobile launch pad 3D model

Figure 2 show the Design of the Mobile Launch Pad to move similarly without difficulty, the Trailer type of the Launch pad consist of; (a) the Trailer which is the main platform of the pad made with C Channel 50 x 25 x 5 x 6 size in mm with a 15 inches wheel size and leaf spring Suspension system, with four (4) anchor support for the stability of the whole trailer and (b) the Launch Rail Support mounted with Launch Rail Standard 1010 made of aluminum.

Based on the classification of the rocket model to be fired in this study, to meet its requirements. The structural design of the launch pad model in terms of its functionality and stability are as follows: Launcher consists of a boom of length 3 meters and a rail length at least 2.4384m or 8 feet long Rocket Launch Pad, Desirable working height maximum of 1.5 m from ground, Material for launcher shall be preferably Mild steel, Structural factor of safety shall be 1.5, The rocket is rail guided made of aluminum, The projected mass of the rocket vehicle including all payloads and ballast, if there is any, shall not be heavier than 20 kg, The structure should Optimum stiffness, damping, inertia, and mass placements, The launch pad should be transported from one location to the other for easy mobilization especially.

2. Methodology

An Input-Process-Output (IPO) model was made to define the requirement in conducting the study, processing of the requirements, and the final output. The design and development of rocket launch pad for weather observation shall cover the Following steps as highlighted in Figure 3.

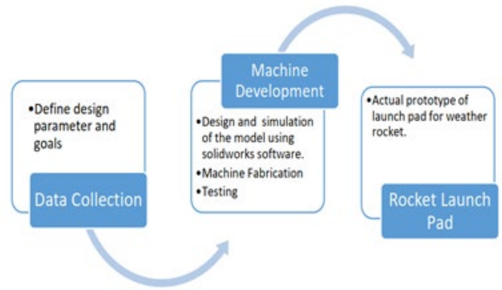


Fig. 3. Conceptual framework of the study

A. Data Collection

The rocket vehicle employs four trapezoidal fins for stability with rounded profile with 51 cm span. The airframe in general is made up of composite materials for strength but lightweight with 2 m in length and the inner diameter of not be less than 10 cm.

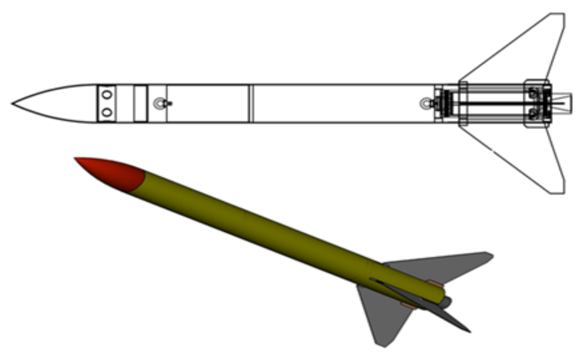


Fig. 4. Weather rocket model design

The motor casing material is made of aluminum alloy metal. The projected mass of the rocket vehicle is 20kg. The propellant is to be a mixture of potassium nitrate and sucrose with 65/35 ratio, the fuel and oxidizer, respectively. It uses black powder as charge upon firing for the igniter. The rocket vehicle can launch with wind speed of up to 40 kph and gust of 20 kph. The CAD model is shown in figure 4. All models were drawn in Solid works to perform finite element analysis (FEA).

Table 1 presents the components list for all subsystems and their respective materials and Mechanical Properties of the materials given.

B. Machine Development

A CAD Design Software will be use in the mechanical design, all the parts will be design and analyze using SOLIDWORKS software. Critical parts will also be subjected to worst case scenario studies using the stress analysis and flow simulation capability of the software. Material selection and application will also be analyzed and simulated in the 3D model design of the launch pad. As a result, a detailed and realistic design model will be produced with technical drawings and bill of materials for economic study. The structure of the launch pad is crucial to the weigh, so the goal is to maximize strength and stiffness while minimizing weight.

Table 1
Material used and mechanical properties of the launch pad

Components	Material	Size (mm)	Thickness (mm)	Diameter (mm)	Modulus of Elasticity kN/mm²	Poisons Ratio	Yield Strength N/mm²
Platform Base	**Mild Steel**	100 x 50	3	-	200	0.3	240
Base Plate	**Mild Steel**	400 x 400	3	-	200	0.3	240
Launch Rail Guide	**Mild Steel**	25	1.5	-	200	0.3	240
Launch Rail	**Aluminum**	25 x 25	-	-	690	0.3	276
Anchor Support	**Mild Steel**	150 x 10	-	10	200	0.3	240
Pillow Block	**cast iron**	UCP205	-	25	240	-	420
C Channel	**ASTM-A36**	50 x 25 x 5 x 6	3		200	0.260	250
M12x1.50 bolt and nut	**Grade 8.8 high tensile**	12 x 1.50	-	12	210	-	660
M5 x 1.50 flat head Screw	**Grade 8.8 high tensile**	12 x 1.50	-	5	210	-	660

The Launch Pad consist of two Attachment the Launch Rail standard 1010 [2] and Button Rail mounted to the Rail Support with the use of M5 x 1.50 Cross Head Bolt and nut and Rail Button Attached to the Main Body of The Rocket with the braces bracket also acting as a centering hole for the Launch Rail as shown in figure 5. Due to the weight of the Rocket a support was made at the bottom of the rocket to keep the stability of the rocket before the flight. Shown in figure 6 and 7. And correspondingly the hinge and the pillow block size UCP205 of the Rail support design in the way to easily put on the Weather rocket to the Launch Rail for Reloading access.

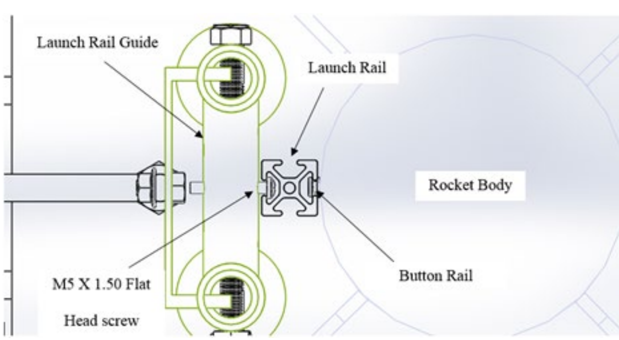


Fig. 5. Design of rocket mounting

The configuration of launch Pad being considered consists of a Rail Guide of length 3 m and a rail length of 2.4384 m or 8 feet for rail and the Launch guide supported by rope and braces show in figure 8 and 9 for mobile Launch Pad.

The tension in the rope mention are generally no more than 10 lbs. [3]. each in any diameter of rope and the anchor support planned to be in fixed position or embedment depth not less than 12d where d is the Diameter of the Anchor [4]. To support the whole rocket weight plug was design in the rail show in Figure 10.

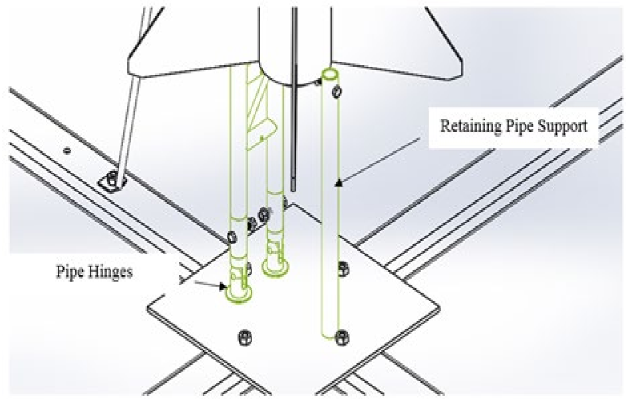


Fig. 6. Design of rocket support

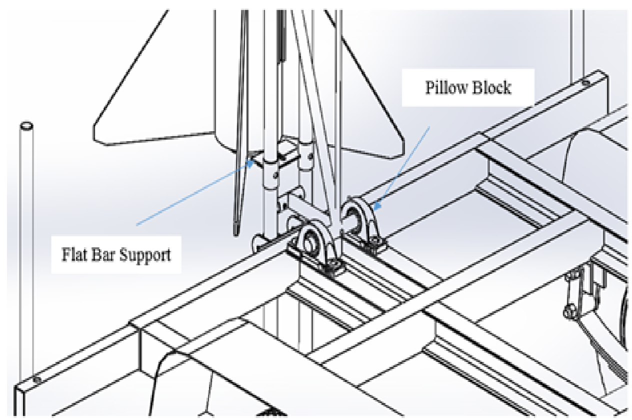


Fig. 7. Design of rocket support in the mobile launch pad

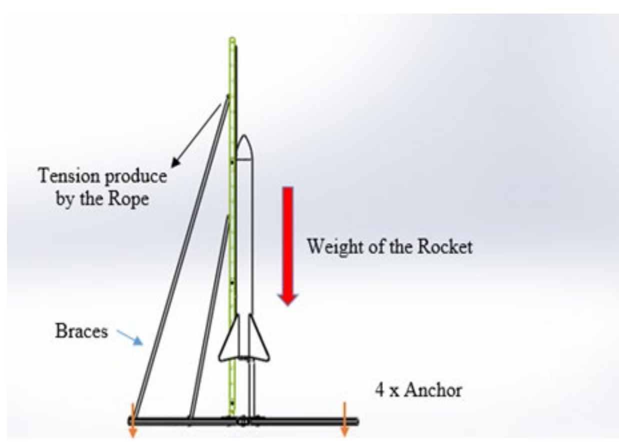


Fig. 8. Diagram of launch pad before the liftoff

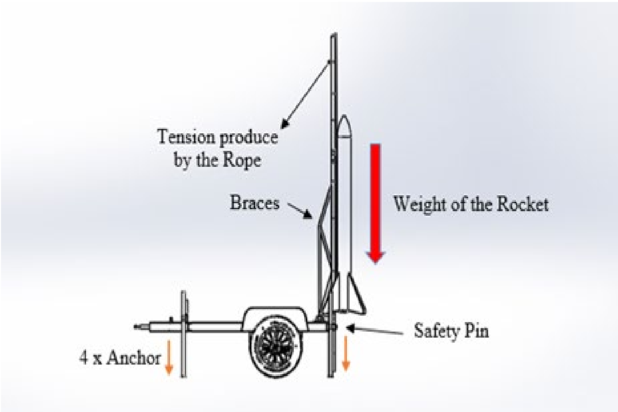


Fig. 9. Diagram of mobile launch pad before the liftoff

To secure the stability of the whole rail guide and to absorb the tension produce by the rope. The Mobile Launch Pad locking pin is to be consider under the bottom rail to pull the tension to the other side of the rail guide show in figure 11.

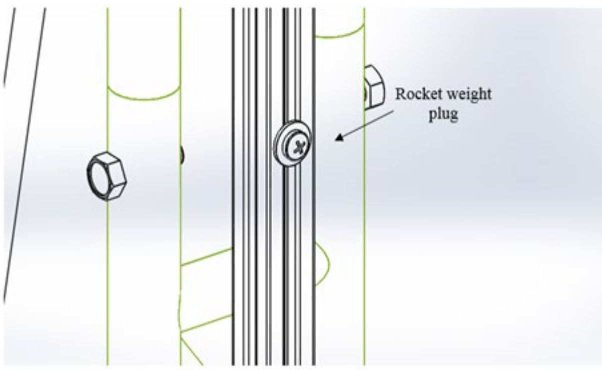


Fig. 10. Rocket bolt plug of launch rail before the liftoff

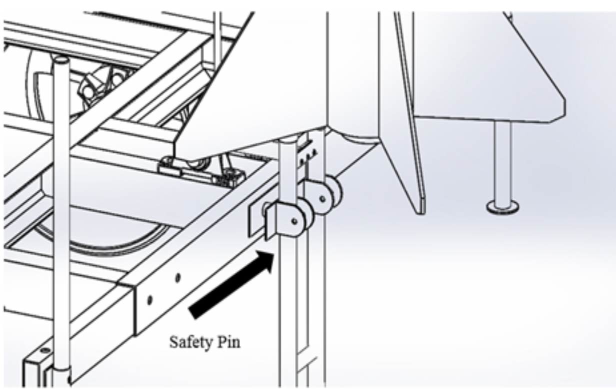


Fig. 11. Safety pin of mobile launch pad before the liftoff

Machining for the rocket Launch Pad. Machining took place in the Machine Shop in Angeles City Pampanga and Mechanical Engineering Lab of Holy Angel University. Machines used include a Drill Press, horizontal and vertical band saw, manual vertical mill, lathe, and welding Machine, some parts of the Launch Pad were readily available in the market like the Launch rail standard 1010 a 8 foot long, extruded aluminum launch rail is perfect for your high power rockets. It is the standard 1010 size (25 X 25 cross section) and accepts most "standard-size" 1010 rail buttons. Most part are Machine Fabricated according to the Accepted Design parameters.

C. *Simulation Analysis*

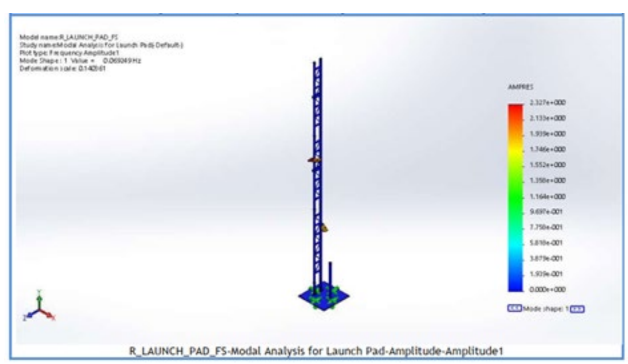
The optimal Flight system for The Weather Rocket would be Launch Rail Guide that hold the body of the Rocket before Deployment, the primary goal was determining the Stiffness get by Natural Frequency of the Structure that hold the rocket before the liftoff, the stiffness define as object resists deformation in response to an applied force or weight [5]. Natural frequency of the structure is defined as which a system tends to oscillate in the absence of any driving or damping force. The motion pattern of a system oscillating at its natural frequency is called the normal mode. Virtually all objects, when apply a forces or pressure, will vibrate.

Frequency analysis were performed in order to determine the stiffness of the structure and to arrive at a mass optimized design of the two design the Launch Pad and the Mobile Launch Pad, establishment of the validity of the deterministic method for predicting natural Frequency of structures, latter was also driven by the fact that the natural frequency of most pad structure is in the 1 to 20 hertz[6], the loading condition is the self-weight of the structure with the addition of the effect of the weight of the Rocket and the wind load assumed negligible to the height terrain of the pad. Natural frequency of Guide Rail support in the assembled configuration should be in the Range of 1 to 20 Hertz.

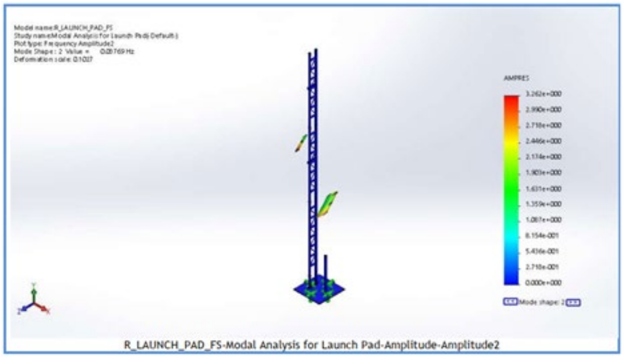
The development flight tests of the rocket prototypes will be conducted at CERAB, Crow Valley, Capas, Tarlac in coordination with the Philippine Air Force (PAF). CERAB, which spans for more than 18,000 hectares land area, is the secured facility under the jurisdiction of PAF.

3. Results and Discussion

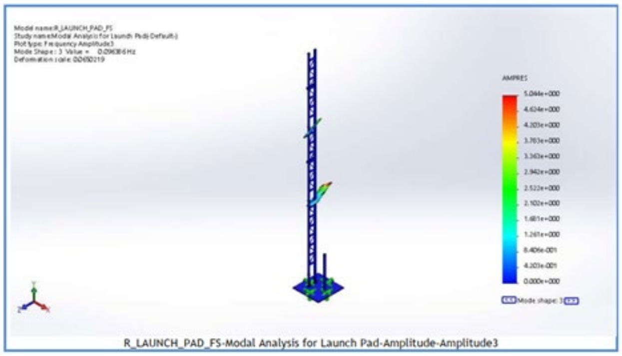
Figure show the first 5 Modal Shape of the Launch Pad Guide Rail are extracted from free vibration analysis and the corresponding frequencies are reported. The mode shapes for the configurations are also obtained are shown in figures 12 (a), (b, (c), (d) and (e). and figure 13 the graph natural frequency versus mode number.



(a)



(b)



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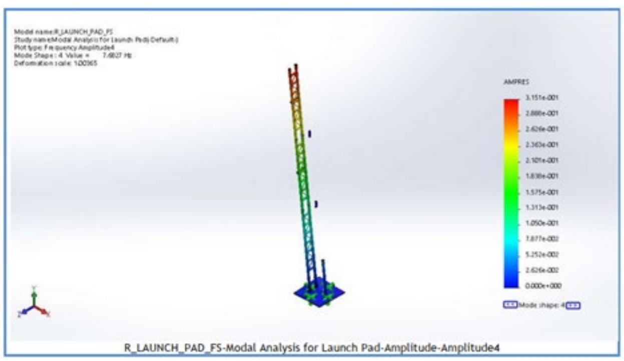
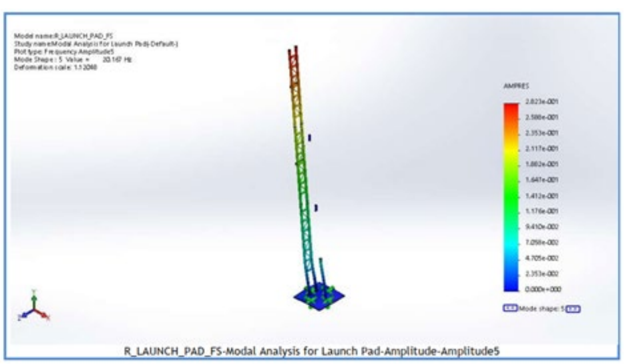


(d)



(e)

Fig. 12. Frequency Analysis for launch pad (a) Amplitude 1, (b) Amplitude 2, (c) Amplitude 3, (d) Amplitude 4, and (e) Amplitude 5

Similarly, Figure 14 (a), (b, (c), (d) and (e). show the free vibration analysis and the corresponding frequencies are reported for the Mobile Launch Pad. And figure 15 the graph natural frequency versus mode number.

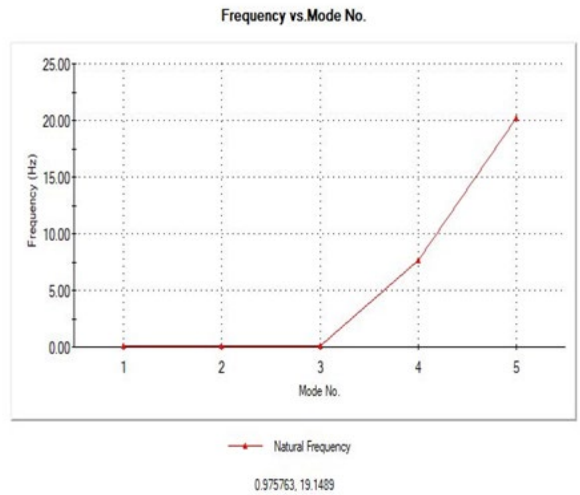
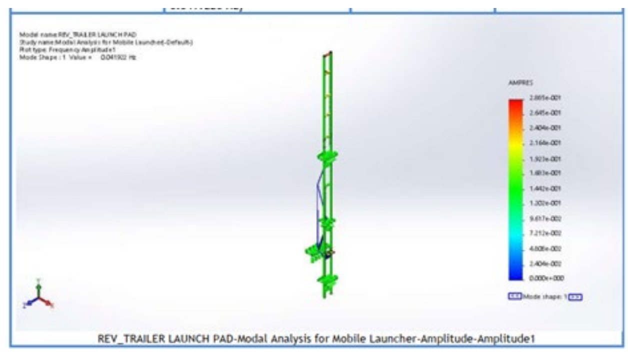
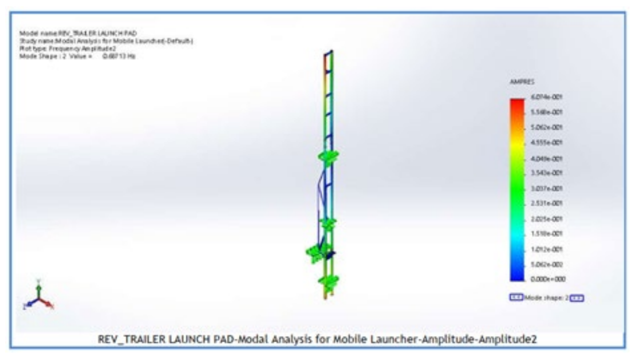


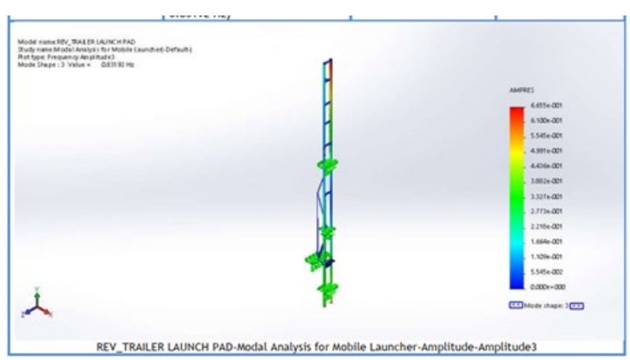
Fig. 12. Natural frequency vs. Mode number for launch pad



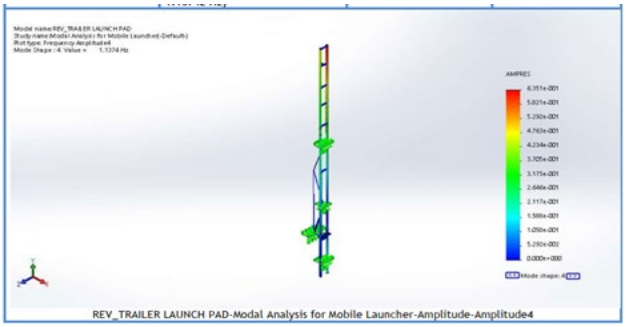
(a)



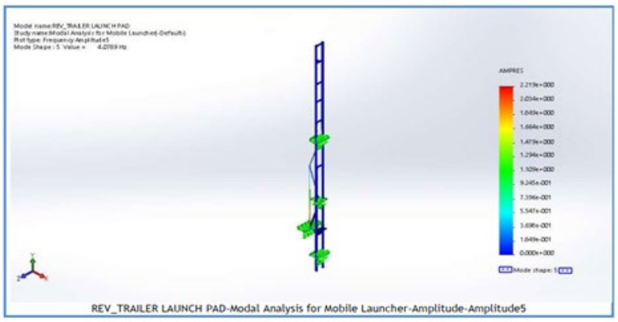
(b)



(c)



(d)



(e)

Fig. 14. Frequency analysis for mobile launch pad (a) Amplitude 1, (b) Amplitude 2, (c) Amplitude 3, (d) Amplitude 4, and (e) Amplitude 5

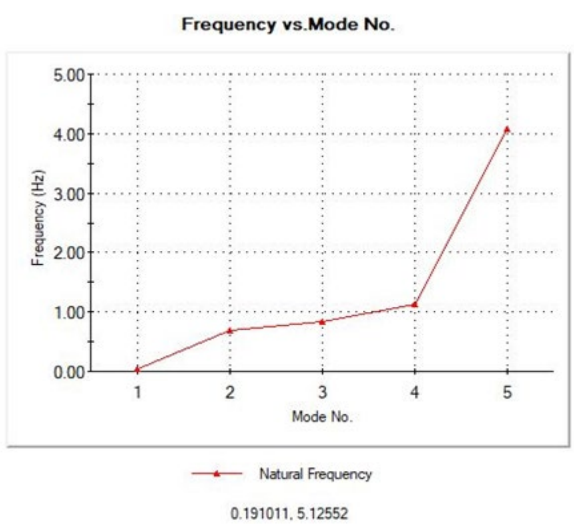


Fig.15. Natural frequency vs. Mode number for mobile launch pad

4. Conclusion

From the Results, natural frequency is an inverse function of Launch pad height. Structures constructed with same material with different fixtures configuration and attachment showed a great variation in natural frequency. Research showed that Mobile Launch pad will undergo in resonance condition with lower frequency of vibration when dynamic condition occur. Therefore, Platform fixed to the ground will be affected by high frequency vibration of Ground within short time. This concept is in well agreement with this study in range of 1 to 20 hertz of the structure design which meets the frequency requirements for both Configuration. Dimension of Rail Support are also controlling factor of natural frequency because it relates to the stiffness and total mass of structure. Increased pipe diameter of the Rail support causes increased in mass and increased in stiffness of total structures.

5. Recommendation

Based on the research findings, here are the recommendations to optimize the natural frequency and overall stability of launch pad structures:

- Since natural frequency is inversely related to launch pad height, carefully select the height to avoid resonance conditions. Lower heights may help in achieving higher natural frequencies, reducing the risk of resonance.
- Use materials and fixture configurations that enhance the stiffness of the structure. Experiment with different attachment methods to find the optimal configuration that minimizes variations in natural frequency.
- Conduct thorough dynamic condition analyses to predict and mitigate resonance conditions. Implement damping mechanisms or isolation techniques to reduce the impact of lower frequency vibrations on mobile launch pads.
- For fixed platforms, incorporate vibration isolation systems to protect against high-frequency ground vibrations. This could include using shock absorbers or base isolators to decouple the platform from ground vibrations.
- Carefully design the dimensions of rail supports to balance stiffness and mass. Increasing the pipe diameter can enhance stiffness but ensure that the added mass does not negatively impact the overall natural frequency.

6. Acknowledgements

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