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VIBRATION CHARACTERISTICS STUDY OF DIFFERENT PIPE LENGTH WITH DIFFERENT END CONDITIONS

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ABSTRACT

In the present work, a free vibration analysis of a straight pipe span with various lengths was investigated. Finite element models were prepared using ANSYS Workbench software to obtain the natural frequencies and mode shapes numerically and the results were compared with the analytical calculation. Two end pipe supports (fixed-fixed and fixed-supported) were adopted to investigate the natural frequencies and their corresponding mode shapes. From the analysis, it was found that the natural frequency calculated using numerical and analytical results for the straight pipe with different lengths were having a good agreement. The same pipe settings were repeated for different types of pipe materials. The effect of the pipe end conditions, the fluid contained in the pipe and the pipe materials on the modal characteristics were then further investigated. It was found with the increase of pipe length; the natural frequencies decrease. For all pipe materials, with and without fluid, fixed-fixed pipes have higher natural frequencies than fixed-supported pipes. In all cases, the results show that the natural frequencies with any fluid inside the pipe were lower than the case of pipe without fluid. To predict the natural frequency, a linear equation is formulated using regression analysis relating the connection between the pipe length and its natural frequency. It was found that that there is a correlation between the first natural frequency and the length of the pipe. The regression equation has the form of a power function and the coefficient of determination is $R^2 \geq 0.8$ for all cases. This vibration characteristics analysis is important as it is the basic analysis to other dynamic analyses such as response spectrum analysis or harmonic analysis.

Keywords: pipe free vibration, modal analysis, natural frequency, mode shapes, pipe support condition, finite element analysis, regression analysis.

1. INTRODUCTION

Piping systems in plants are exposed to damage due to various reasons, including vibration. Vibration of pipelines is common in refining industry and has been identified as the main cause of piping failures due to fatigue. A pipe vibrates because of many factors and the most common factors are due to mechanical resonance, excessive pulsation and poor supports and/or support structure due to various excitation mechanism. Excessive vibration from the equipment may propagate to the interconnected pipe structure and cause damage to the equipment and other connecting pipes as well. Often, vibrational issues are not even considered until the pipe movement is observed or failures occur. This could lead to catastrophic events.

All physical structures have their own natural frequencies. The natural frequency of a body is the frequency of a system which freely oscillates around its equilibrium without any disturbance by external influence. Structural natural frequency is a built-in property of a system and depends on the distribution of mass and stiffness of the system. When the system is exposed to external forced vibration and one of the natural frequencies of the system coincides with the frequency of excitation, resonance will happen and the response of the vibration amplitude are amplified [1]. Therefore, determining the vibration characteristics of the system is crucial to predict and prevent resonance. This can be done through modal analysis to better understand the motion of the system by obtaining the natural frequency and mode shapes of the structure. It is also a necessary to carry out modal analysis prior to other dynamic analysis such as vibration fatigue analysis [2].

Modal analysis can be done through experimental approach, theoretical method or numerically using finite element commercial software. The vibrations of pipes conveying fluid with guided pipe supports were studied by Sutar *et al* [3] using theoretical analysis. The influence of the pipe end condition on the natural frequency of the pipe without fluid, static fluid and flowing fluid were investigated. The results are compared with results from numerical analysis. For numerical analysis, a finite element model was established for the guided-guided pipe supports using the ABAQUS structural and fluid modules. Vibration analysis of the pipe with three different materials supported in guided slots were done to calculate the pipe frequencies under three different pipe conditions mentioned above.

Sharma [4] obtained the natural frequency and mode shapes of a simply supported beam by doing experiments, theoretical and numerical modal analysis. Fast Fourier Transform was utilized to convert the time domain signal obtained from the experiment to frequency-domain signal. Then finite element modal analysis was done using ANSYS software. Results from the simulation were then compared with theoretical analysis and were found to be in good agreement. Qu *et al.* [5] proposed a method to analyse the dynamic characteristics of hydraulic pipe expose to basic vibration. The bidirectional fluid-solid coupling analysis method was used in this study to see the influence of different support stiffness with different types of pipe support conditions towards the natural frequencies of the pipe. The effect of the support stiffness on the vibration displacement, on the pipe stress and on the fluid outlet pressure in the pipeline was also investigated. The proposed method was verified with FEM and experimental analysis.

Liu *et al*. [6] proposed a matrix transfer method written in FORTRAN to analysed the vibration characteristics of a multi-span pipe with different span length and different support condition. The pipe support used in this study were rigid supports and elastic supports. Modal analysis was performed to obtain the natural frequencies and the mode shapes of the pipeline. The results obtained were then compared with results from ABAQUS for validation purposes and are found to be in good agreement. Sekacheva *et al*. [7] established a method to find the possibility of increase in vibration in pipeline by finite element modal analysis. The influence of pipe diameter, length and pipe wall thickness on the natural frequencies of the pipe were studied. Pairwise and multiple regression analysis were done to obtain the regression equations to represent the correlation between the length, diameter and the thickness of the pipe with its natural frequency.

Alnomani [8] used finite element analysis to do stability analyse of a fluid conveying pipe with linear spring. The influence of the spring's stiffness and spring location with diameter ratio on the dynamic behaviour of the pipe were studied as well. Author [9] developed an FEA tool to do the modal analysis of multi-span subsea pipelines to see the dynamic response of the pipelines for different beam and pipeline configurations. The developed FEA tool is then compared with results obtained by analytical and from simulation using FEA software ABAQUS. A free vibration study was done by Venkateshappa *et al*. [10] on isotropic and laminated plates with central cut-out under clamped-free-clamped-free boundary conditions. The natural frequencies of the plates were determined experimentally and numerically by using MSC/NASTRAN software. The influence of cut-out shape, aspect ratio and cut-out size on the natural frequencies of the plates were studied. Comparison has been made between both results and are found to be in good agreement.

Modal parameters of isotropic and rectangular plates have been investigated by author [11] using wave propagation method for various boundary conditions. The boundary conditions considered in this study are simply supported - simply supported (SS-SS), clamped-clamped (CC-CC), and simply supported-clamped (SS-CC). The effect of the boundary conditions on the dynamic behaviour of the plates with various lengths and width of the plates has been studied by changing the axial wave modes. The results obtained were verified with earlier simulation work. Sharman [4] performed experimental, theoretical and numerical modal analysis of free-free and simply supported beam to find the natural frequency and mode shapes of the beam. From the experiment, the time domain signal was converted to frequency domain using Fast Fourier Transform. Numerical modal analysis was done using ANSYS software. The natural frequency and mode shapes obtained were compared with theoretical results and all the three results were in a good agreement.

Author [12] studied the influence of geometry by varying depth and different height ratios of simply supported beams towards the natural frequency of the beam. The main objective of this study is to determine the desirable geometry for a beam which give minimum vibration response at its mid span when traversed by a single point load. Free vibration numerical analysis was done using ANSYS software. Results from numerical analysis were validated with experimental results. Madhurya *et al*. [13] computed the natural frequency and the mode shapes of cantilever beams for different materials theoretically and through finite element analysis. ANSYS software was used to performed modal analysis to obtain the first three natural frequencies of the beam with various crack depths. The results from both methods were then compared.

Review of previous studies showed that few research studies have developed the regression analysis and obtained the regression equations to see the correlation between natural frequency and pipe length with different pipe end conditions. Therefore, this study is done to investigate the vibration behaviour of pipe span with and without fluid under free vibration due to different types of pipe end conditions: fixed-fixed and fixed-supported. Finite element models using ANSYS Workbench were prepared to determine the natural frequencies and mode shapes and the results were compared with analytical method. The effect of the fluid contained in the pipe, the support conditions and materials of the pipe on the dynamic characteristics were then investigated. Based on the numerical results, equation of functions to describe the correlation between the first natural frequency and pipe length due to fluid contain in pipe and pipe end conditions were formulated using regression analysis.

2. METHODOLOGY

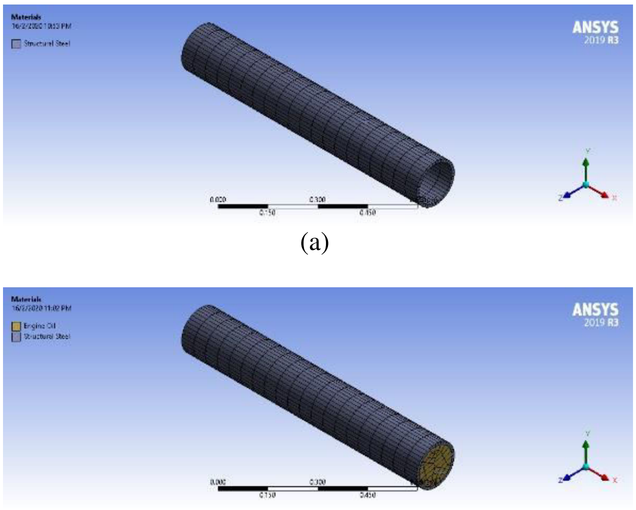
In this paper, finite element modal analysis using ANSYS software was developed to investigate the natural frequency and mode shapes of the steel pipe and results were validated through analytical method. The pipe was evaluated under two types of conditions; empty pipe and fluid filled pipe. The fluid was assumed filled full throughout the pipe length. Two different types of boundary conditions were studied which are fixed-fixed and fixed-supported for both types of pipe condition. These types of pipe end conditions are mainly used in actual plant, for example, a pipe is constructed to or from a pump to another column or vessel (fixed-fixed) or subjugated with a pipe support at the end (fixed-supported). The finite element model settings were then repeated using different types of materials that are mainly used in the plant which are ASTM A106 Gr B carbon steel and SS 304 stainless steel for both types of end condition with and without fluid pipe. Regression analysis was done for numerical analysis results to obtain the equation of function to express the relationship between all the parameters.

2.1 Finite Element Modal Analysis

To conduct the finite element modal analysis of the pipe span, the pipe is first modelled in 3D CAD software with different length of pipe span; 1m, 2m, 4m, 8m, and 10m. The geometric parameters and material properties used to model the pipe is as shown in Table-1. The material used for the pipe is structural steel. This 3D pipe model was then imported into the ANSYS Workbench software for finite element modal analysis.

Table-1. Properties and dimensions of the pipe section.

Pipe outside diameter (m)	**0.16**
Pipeline wall thickness (m)	0.01
Modulus of Elasticity of pipe material (GPa)	200
Pipeline Density (kg/m^3)	7850
Fluid Density (kg/m^3)	900
Poisson Ratio	0.3



(a)

(b)

Figure-1. Meshing of the straight pipe using solid element (a) without fluid (b) with fluid.

In ANSYS, solid element meshing was used for both pipe and fluid in the pipe, as shown in Figure-1. Solid element meshing is computationally intensive, but it is the most accurate one. Since the pipeline configuration was not complex, solid element was used for all the analysis. In ANSYS, the boundary condition was assigned as fixed support at both ends of the pipe for fixed-fixed end condition. For fixed-support end pipe, the boundary condition was assigned as fixed support at one end and displacement at the other end with only x-axis was set as free displacement. This scope of the study was not covered the fluid flow inside the pipe, hence the fluid inside the pipe was considered as static. Modal analysis was then performed to calculate the natural frequencies and mode shapes of the pipe under free vibration. To see the influence of pipe length on natural frequency of the pipe, the analysis started with 1m pipe length then the length is increased gradually to 2m, 4m, 8m and 10m for both types of boundary conditions, with and without fluid.

The finite element model settings were then repeated using ASTM A106 Gr B and SS 304 material properties for both types of end conditions with and without fluid. The material properties are as shown in Table-2. Then, finite element modal analysis was done to obtain the behaviour of the natural frequency of the pipe span for each pipe end conditions, with and without fluid.

Table-2. Material properties for different types of pipe material.

Material Properties	**Steel**	**ASTM A106 Gr B**	**SS 304**
Density (kg/m3)	7850	7850	7850
Elastic Modulus (GPa)	200	210	215
Poisson Ratio	0.3	0.3	0.3

2.2 Validation of Finite Element Modal Analysis

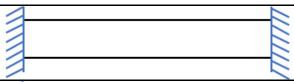
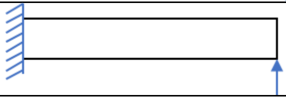
The natural frequencies and mode shapes obtained from the finite element modal analysis were validated by comparing them with the results from analytical calculation. For a straight uniform piping span, its natural frequency can be calculated using Equation (1)

$$f_o = \frac{\lambda}{2\pi}\sqrt{\frac{gEI}{\mu l^4}} \quad (1)$$

Where:

f_o = Pipe span natural frequency, Hz
λ = Frequency factor, dimensionless
g = Gravitation constant, 386 in/sec^2
E = Modulus of elasticity, psi
I = Moment of inertia, in^4
l = Pipe span length, in
μ = Weight per unit length of beam (including fluid and insulation), lbs/in
(Equal to ρA if the weight of fluid and insulation is egligible)
ρ = Pipe density, lbs/in^3
A = Pipe cross − section area, in^2

Table-3. The first two frequency factors according to the support condition [14].

Boundary Condition	**Pipe Configuration**	**1st Frequency Factor**
Fixed-fixed		22.40
Fixed-Supported		15.4

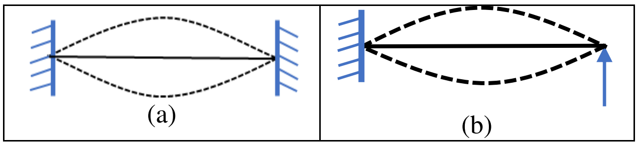


Figure-2. Vibration mode-shapes for (a) fixed-fixed and (b) fixed-supported pipe span configuration [14].

To calculate the pipe with fluid, the natural frequency calculated for empty pipe was multiply by the square root ratio of the weight of the pipe divided by the total weight per length of the pipe, plus the fluid and the insulation if any. The frequency factors for calculating the first natural frequency of the straight pipe are given in Table-3 while the mode shapes for fixed-free and fixed-fixed pipe configuration are illustrated in Figure-2.

2.3 Regression Analysis

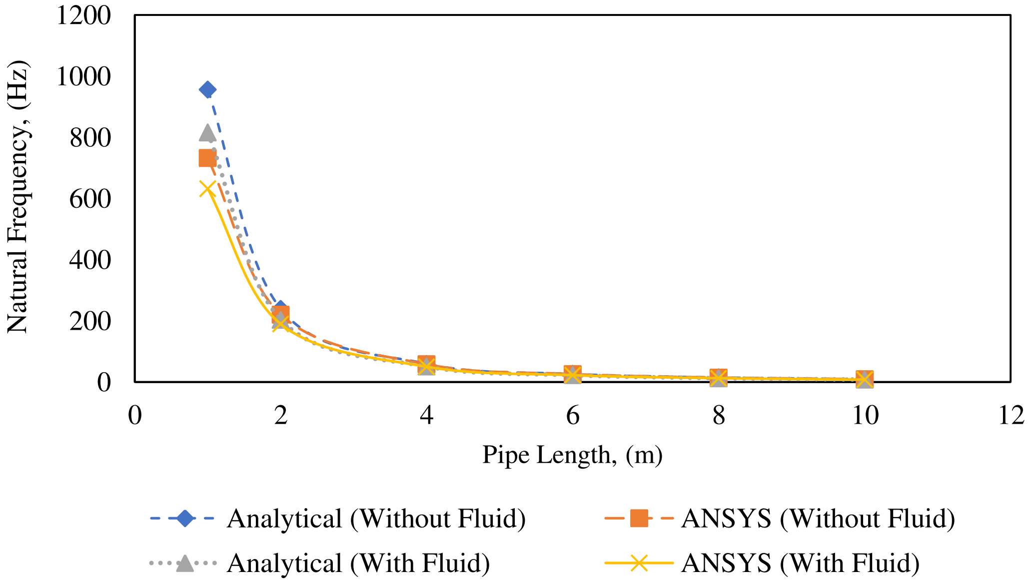
Regression analysis is one of the most important types of data analysis. Regression analysis is a mathematical way of describing the connection between variables. Regression models are categorized depending upon number of independent variables or regressors in it. If the regressor is only one, then it is termed as a simple linear regression model and if regressors are two or more, then it is termed as a multiple regression model [22]. For the present case, a simple regression analysis was done and regression equations were obtained to describe the correlation between the first natural frequency and the length of the pipe span for both types of pipe end conditions. Regression analysis were performed using MS Excel to obtain the equations that most closely describe the numerical analysis results. The regression model was considered acceptable when the R value is R2 ≥ 0.8 [8].

3. RESULTS AND DISCUSSIONS

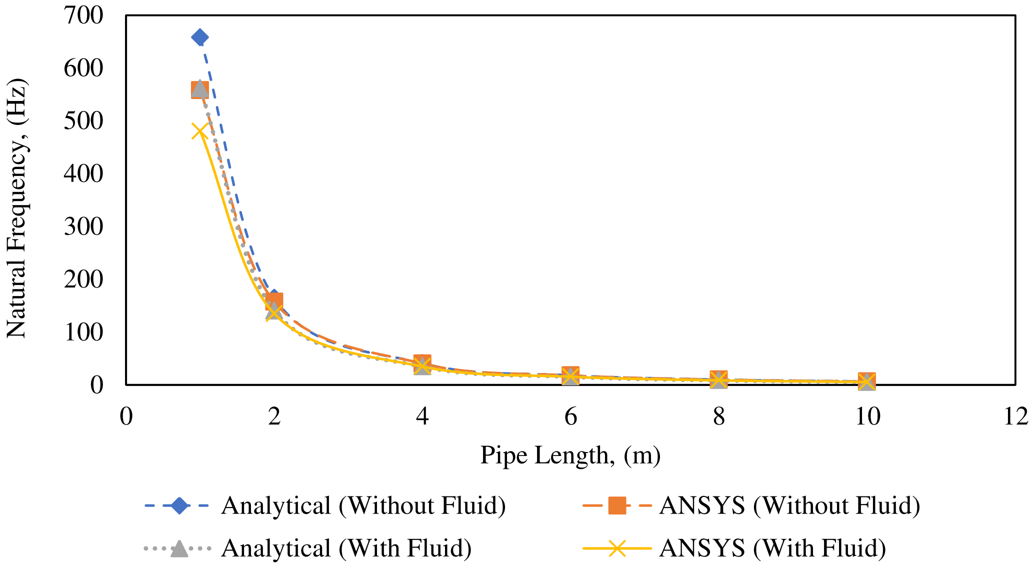
According to various pipe lengths, the natural frequencies of a steel pipe span has been studied using Finite Element Modal Analysis. The acquired numerical simulation results were compared with analytical calculation using the same set of material and geometrical properties for verification purposes. Two types of supports were used which are fixed-fixed and fixed-supported pipe end condition. The influence of fluid contained in the pipe, natural frequencies values and mode shapes were studied.

3.1 Verification of Numerical Results

The solutions obtained from numerical and analytical approaches are shown in Figure-3(a) and (b) for steel pipe. From the graphs, it was found that the natural frequency from simulation follows the same trend as analytical calculation for both fixed-fixed pipe and fixed-supported pipe, with and without fluid. The natural frequency from numerical and analytical both shows high values for 1m length pipe for all pipe conditions and starting to decrease when the pipe length is 2m and longer.



(a)



(b)

Figure-3. Comparison between numerical (ANSYS) and analytical values of 1st order natural frequency for (a) fixed-fixed pipe (b) fixed-supported pipe.

The percentage difference between numerical and analytical is calculated and plotted as shown in Figure-4. From the results shown in Figure-4, the percentage difference between numerical and analytical method was high at first before significantly decreasing at 2m pipe length. The percentage difference is below 10% with the increase of pipe length for fixed-fixed pipe and below 5% for fixed-supported pipe. The numerical and analytical results for the straight pipe starting to have a good agreement for pipe length 2m and longer. Both the numerical and analytical results are found to be in good agreement with each other. This shows that present approach using ANSYS simulation is reliable to be used to study the vibration characteristics of the pipe span for both types of end pipe condition, with and without fluid. Hence, the simulation and results shown in the next section will be from finite element modal analysis using ANSYS software to investigate the influence of pipe end condition, fluid contain and different types of pipe material on modal characteristics of the pipe span.

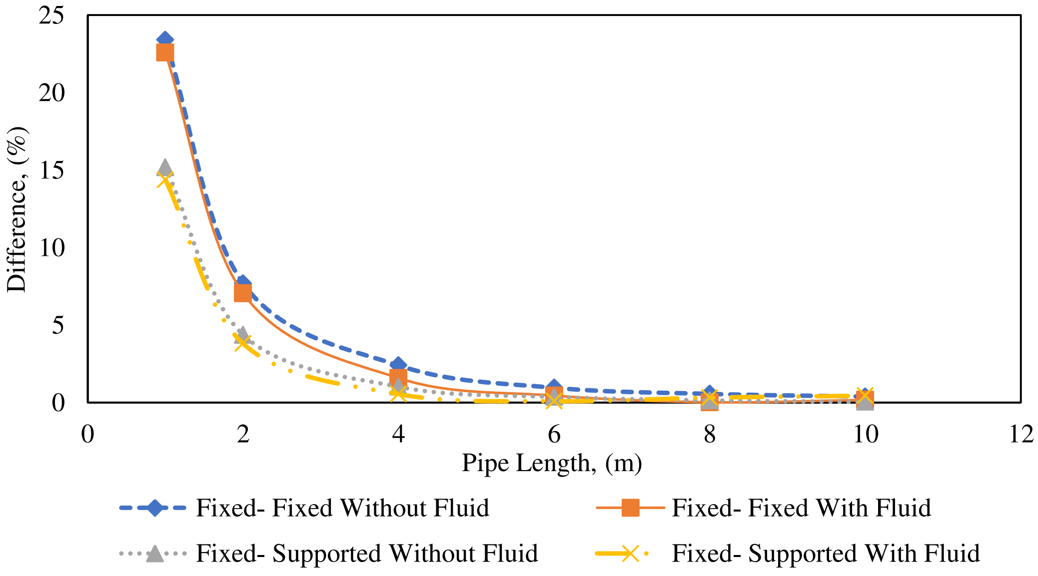


Figure-4. Percentage difference between ANSYS simulation and analytical calculation.

3.2 Effect of Pipe End Condition

The effect on natural frequencies for two different types of pipe end condition, with and without fluid can be seen in Figure-5. It is observed that the natural frequency is decreasing as the pipe length is increasing for both types of pipe end conditions, with or without fluid inside. This is because with the increase of pipe length, the mass will also increase. From Equation (1), natural frequency of a pipe span will decrease with the increase of mass. Therefore, this study shows that the change in pipe lengths cause changes on the natural frequencies' values for both types of pipe end conditions. Also, from the graph in Figure-5, it can be concluded that pipe with fixed-fixed end condition has higher natural frequency compared to fixed-supported pipe, with fluid and without fluid. This is because the overall stiffness of the system in fixed-supported pipe is much lower, and the flexibility is higher compared with fixed-fixed pipe.

3.3 Effect of Fluid in Pipe

The behaviour of natural frequencies for empty pipe and pipe with fluid can also be seen through the graph plotted in Figure-5. Pipe without fluid has higher natural frequencies compared to pipe with fluid inside for both types of pipe end conditions. Empty pipe produces higher natural frequency compared to fluid filled pipe as the fluid inside the pipe act as damping. Also, with fluid inside the pipe, there is increase of total mass of the system hence lowering the natural frequency of the pipe compared with empty ones.

3.4 Effect of Different Materials

Vibration analysis of the pipe span was performed for other pipe materials which is ASTM A 106 Gr B and SS 304L. Table-6(a) and (b) show the comparison of natural frequency for Structural steel pipe, ASTM A 106 Gr B pipe and SS 3041 pipe. It can be seen from the results that the natural frequencies do not differ much between all three pipe materials. The difference was approximately 2% between structural steel and ASTM A106 Gr B while for structural steel and SS 304L the difference approximately 0.4% to 1%. Overall, ASTM A 106 Gr B pipe has the highest natural frequency for both types of end condition, without and with fluid. The trend of the natural frequencies can be seen decreasing with the increasing of pipe length for all three materials because natural frequency is inversely proportional to the length of the pipe. Also, the natural frequencies for fixed-fixed pipe are higher than fixed-support pipe for all three materials. Fixed-fixed pipe is rigid support which restrain both rotation and translation. Therefore, the flexibility is very low which leads to increase in pipe stiffness and hence it's natural frequency.

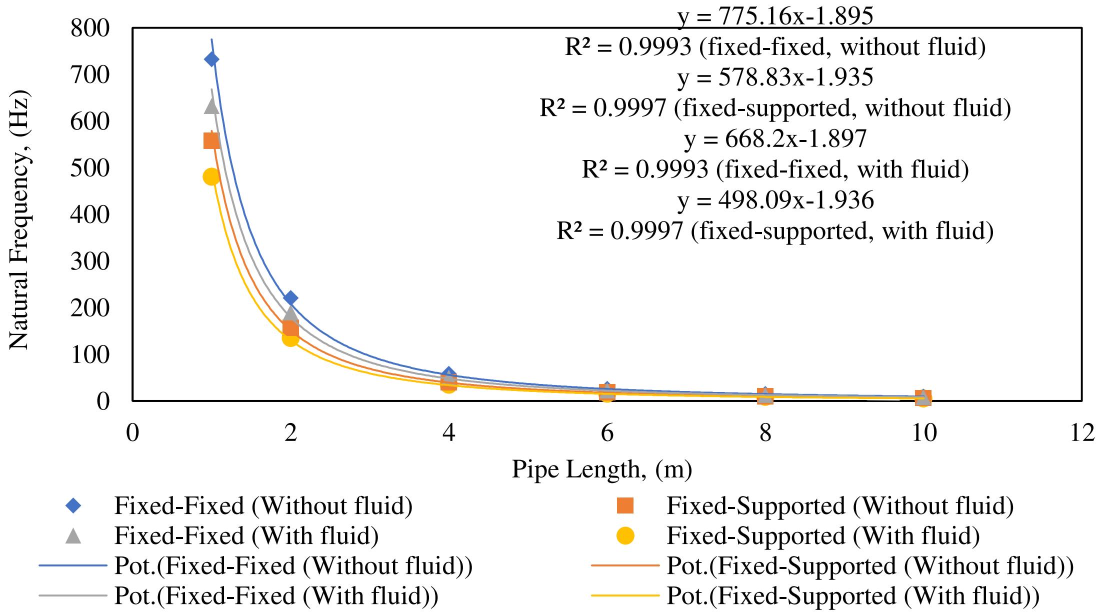


Figure-5. Natural frequency for fixed-fixed pipe and fixed-supported steel pipe.

The influence of fluid in the pipe on the behaviour of natural frequencies for different types of pipe materials can be seen in Table-6 (a) and (b) as well. Overall, the natural frequencies are decreasing with the increase of pipe length for both pipe without and with fluid. It is also observed that pipe without fluid has higher natural frequencies compared to pipe with fluid for all three materials. This occurs because when the pipe has fluid in it, based on equation (1), the pipe weight per unit length increases, therefore, the natural frequency decrease.

Table-4. Influence of different pipe materials on the natural frequency of pipe (a) without fluid and (b) with fluid.

(a)

1st Order Natural Frequency Pipe without Fluid						
	Fixed-Fixed Pipe End Condition			**Fixed- Supported Pipe End Condition**		
Pipe Length (m)	**Structural Steel**	**ASTM A106 Gr B**	**SS 304l**	**Structural Steel**	**ASTM A106 Gr B**	**SS 304l**
1.00	732.43	751.21	730.83	557.68	571.78	555.86
2.00	220.71	226.20	219.73	157.18	161.08	156.45
4.00	58.34	59.96	58.22	40.67	41.68	40.47
6.00	26.31	26.96	26.18	18.20	18.65	18.10
8.00	14.86	15.23	14.78	10.26	10.51	10.21
10.00	9.53	9.76	9.48	6.57	6.73	6.54

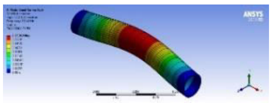
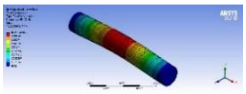
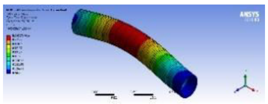
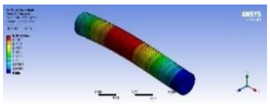
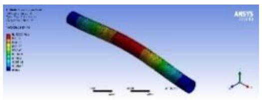
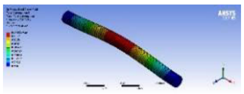
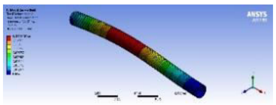
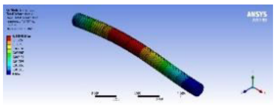
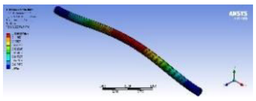
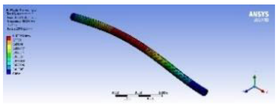
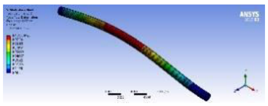
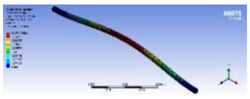
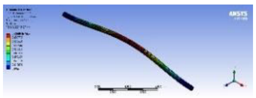
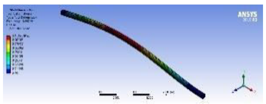
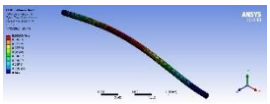
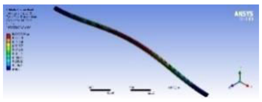
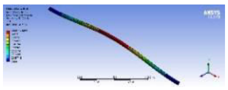
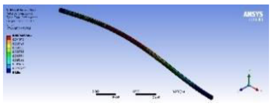
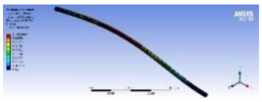
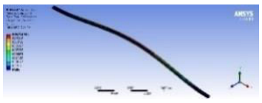
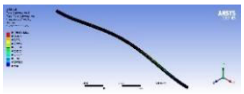
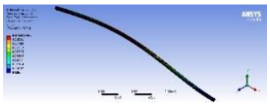
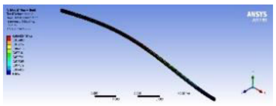
(b)

1st Order Natural Frequency Pipe with Fluid						
	Fixed-Fixed Pipe End Condition			**Fixed- Supported Pipe End Condition**		
Pipe Length (m)	**Structural Steel**	**ASTM A106 Gr B**	**SS 304l**	**Structural Steel**	**ASTM A106 Gr B**	**SS 304l**
1.00	631.94	647.69	625.42	480.43	492.31	478.79
2.00	189.66	194.31	188.81	134.95	138.25	134.30
4.00	50.20	51.43	49.95	34.88	34.23	34.70
6.00	22.57	23.12	22.45	15.60	15.98	15.52
8.00	12.76	13.06	12.68	8.80	9.01	8.75
10.00	8.18	8.38	8.13	5.64	5.77	5.61

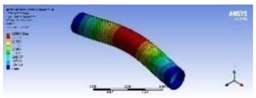
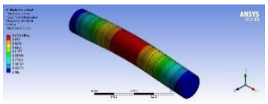
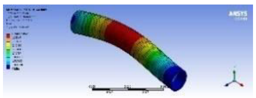
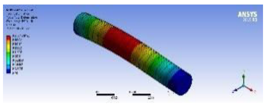
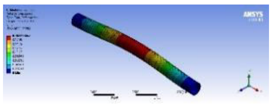
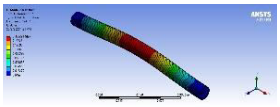
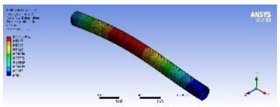
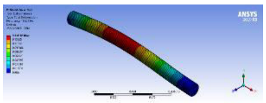
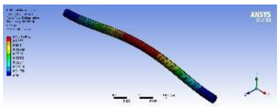
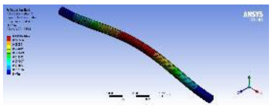
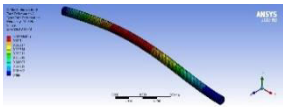
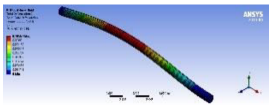
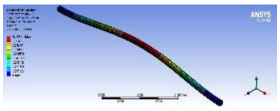
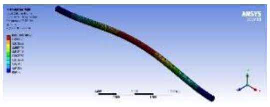
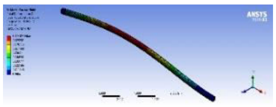
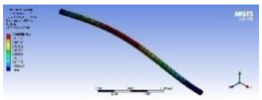
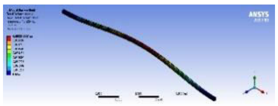
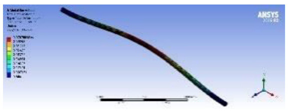
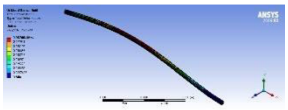
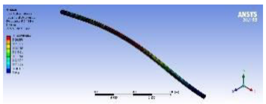
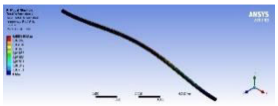
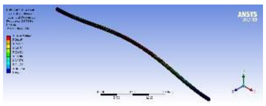
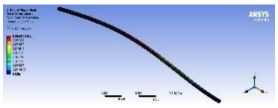
Mode shapes of a structure can be used to evaluate the dynamic interaction between the structure and its support when vibrating. The corresponding numerically obtained mode shapes for different boundary conditions of the pipe, with and without fluid for different types of pipe materials are shown in Table-7 (a)-(c). It can be observed that the mode shapes obtained from the ANSYS simulation following the shapes described in Figure-2 for both pipe end conditions which is bending mode.

Table-5. Mode shapes for the 1st natural frequency for different types of pipe materials (a) Structural Steel (b) ASTM A106 Gr B and (c) SS 304L.

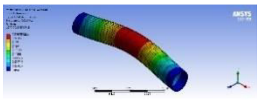
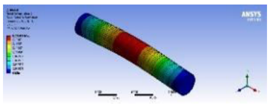
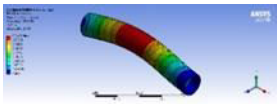
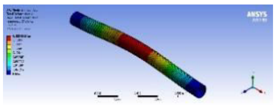
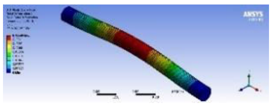
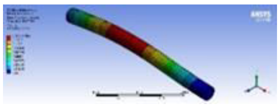
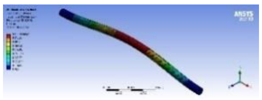
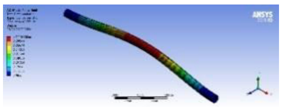
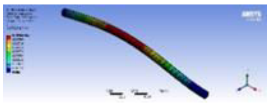
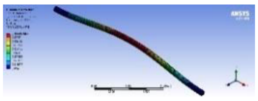
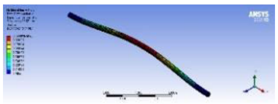
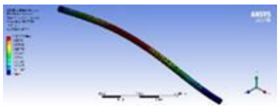
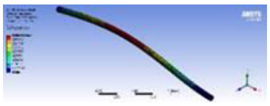
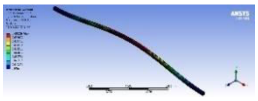
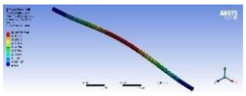
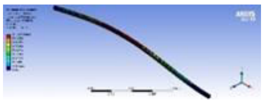
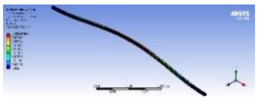
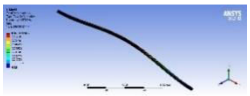
(a)

Pipe Length (m)	**Structural Steel (Fixed-Fixed)**		**Structural Steel (Fixed-Supported)**	
	Without Fluid	**With Fluid**	**Without Fluid**	**With Fluid**
	Frequency (Hz) and Mode Shape	**Frequency (Hz) and Mode Shape**	**Frequency (Hz) and Mode Shape**	**Frequency (Hz) and Mode Shape**
1	732.43 Hz 	631.94 Hz 	557.68 Hz 	480.43 Hz 
2	220.71 Hz 	189.66 Hz 	157.18 Hz 	134.95 Hz 
4	58.34 Hz 	50.20 Hz 	40.67 Hz 	34.88 Hz 
6	26.31 Hz 	22.57 Hz 	18.20 Hz 	15.60 Hz 
8	14.86 Hz 	12.76 Hz 	10.26 Hz 	8.80 Hz 
10	9.53 Hz 	8.18 Hz 	6.57 Hz 	5.64 Hz 

(b)

Pipe Length (m)	**ASTM A106 Gr B (Fixed-Fixed)**		**ASTM A106 Gr B (Fixed-Supported)**	
	Without Fluid	**With Fluid**	**Without Fluid**	**With Fluid**
	Frequency (Hz) and Mode Shape	**Frequency (Hz) and Mode Shape**	**Frequency (Hz) and Mode Shape**	**Frequency (Hz) and Mode Shape**
1.	751.21 Hz 	647.69 Hz 	571.78 Hz 	492.31 Hz 
2	226.20 Hz 	194.31 Hz 	161.08 Hz 	138.25 Hz 
4	59.96 Hz 	51.43 Hz 	41.68 Hz 	34.23 Hz 
6	26.96 Hz 	23.12 Hz 	18.65 Hz 	15.98 Hz 
8	15.23 Hz 	13.06 Hz 	10.51 Hz 	9.01 Hz 
10	9.76 Hz 	8.38 Hz 	6.73 Hz 	5.77 Hz 

(c)

Pipe Length (m)	SS 304L, Fixed-Fixed		SS 304L, Fixed-Fixed	
	Without Fluid	With Fluid	Without Fluid	With Fluid
	Frequency (Hz) and Mode Shape	Frequency (Hz) and Mode Shape	Frequency (Hz) and Mode Shape	Frequency (Hz) and Mode Shape
1.	730.83 Hz 	625.42 Hz 	555.86 Hz 	478.79 Hz 
2	219.73 Hz 	188.81 Hz 	156.45 Hz 	134.30 Hz 
4	58.22 Hz 	49.95 Hz 	40.47 Hz 	34.70 Hz 
6	26.18 Hz 	22.45 Hz 	18.10 Hz 	15.52 Hz 
8	14.78 Hz 	12.68 Hz 	10.21 Hz 	8.75 Hz 
10	9.48 Hz 	8.13 Hz 	6.54 Hz 	5.61 Hz 

A simple regression analysis was performed using MS Excel for four cases: to determine the dependence of the value of the first natural frequency from the simulation results on the length of the pipe span. The simple regression analysis only done for steel pipe. From the simple regression analysis results shown in Figure-5, we can conclude that there is dependency of the first natural frequency on the pipe's length. The regression equation has the form of a power function and the coefficient of determination is $R^2 \geq 0.8$ for all cases. Equation (2) and (3) describes the equation for pipe with fixed-fixed end condition without and with fluid while Equation (4) and (5) describes the equations for fixed-supported pipe end condition without and with fluid respectively.

$$F_{1\ \text{fixed-fixed without fluid}} = 775.16l^{-1.895} \quad (2)$$

$$F_{1\ \text{fixed-fixed with fluid}} = 668.2l^{-1.897} \quad (3)$$

$$F_{1\ \text{fixed-supported without fluid}} = 578.83l^{-1.935} \quad (4)$$

$$F_{1\ \text{fixed-supported with fluid}} = 498.09l^{-1.936} \quad (5)$$

4. CONCLUSIONS

In this study, a free vibration analysis of a straight pipe span with various lengths and with two different types of pipe end condition, with and without fluid was investigated numerically using ANSYS Workbench software and the results obtained were compared with analytical calculation. From the analysis, it is found that the natural frequency calculated using analytical and numerical results for the straight pipe are having a good agreement. Therefore, the rest of the modal analysis was done numerically. Two types of pipe end conditions; namely fixed-fixed and fixed-supported were used to demonstrate the effect of pipe end conditions, with or without fluid, on the natural frequencies and their corresponding mode shapes. It was found that the natural frequency decreases when the pipe length is increasing for both pipe end conditions, with and without fluid. The natural frequency for fixed-fixed pipe was found to be higher than fixed-supported type of pipe. Also, pipes without fluid inside have higher natural frequencies compared to pipe with fluid inside for both pipe end conditions. The same pipe settings were repeated for different types of pipe materials to study the effect of pipe materials on the dynamic behaviour of the pipe span. It was found that the natural frequencies between those materials do not differ much. With the increase of pipe length, the natural frequencies decrease. Fixed-fixed pipes has higher natural frequency than fixed-supported pipe, for all pipe materials, with and without fluid. In all cases, it was found that the natural frequencies with any fluid inside the pipe were lower than the case of pipe without fluid inside. A regression analysis was performed as well to determine the dependence of the value of the first natural frequency on the length of the pipeline for both boundary conditions. From the simple regression analysis, we can conclude that there is dependency of the first natural frequency on the length of the pipeline. The study can be extended for further cases of pipe geometries and may be helpful in subsequent dynamic analysis such as a response spectrum analysis or a harmonic analysis.

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