The Effect of Thickness Ratio in Cantilever Pipe for Rectangular Cross Section Conveying water at turbulent flow on Transverse Free Vibrations

Nawal Hussein Al Raheimy
Mechanical Department , College of Engineering , University of Babylon
nawalalraheimy@yahoo.com

Abstract

Raighly – Ritz is the approximate mathematical method which is used to study the vibrations in engineering structures, which employed in this search to guess the natural frequency of the of pipes conveying water at turbulent flow for rectangular cross section at tapered thickness this method have clamped – free boundary conditions in the two cases. The first involves the pipe have a constant wall thickness (h_1) at clamped end equal to (1mm & 2mm) while the thickness (h_2) at free end changes according to the ratio (h_2/h_1=0.25, 0.5, 0.75, 1). In the second case the thickness at free end (h_2) is constant (1mm & 2mm) whereas the thickness at clamped end (h_1) changes at ratio (h_1/h_2=0.25, 0.5, 0.75, 1). The pipe has a constant inner high of cross section (w_2) is (5 cm & 10 cm) with different values of width (w_1) vary at ratio of (w_1/w_2 = 0.5, 1, 1.5, 2) for different lengths of pipe are (1m & 2m). This study shows in the first case at any value of thickness (h_1) and the height (w_2), the natural frequency decreased with increasing the ratio (h_2/h_1) & the ratio of (w_1/w_2) at the same length. While the frequency increase with increasing the thickness (h_1) & the high (w_2). On the other hand the critical velocity increase with increasing thickness (h_1), the high (w_2) and the ratio (h_2/h_1) but decreased with increasing the length of pipe and the ratio (w_1/w_2). In the second case the natural & frequency critical velocity of the system increase with increasing the thickness at free end (h_2), thickness ratio (h_1/h_2) & the high (w_2) but decreasing with increasing the width (w_1) and the length (L). At any formation of the pipe for uniform section the natural frequency decreased when the velocity of flow of water increased from zero to critical velocity. Because of the absence of studies about the turbulent flow induced vibrations in pipes with a rectangular section it has been to compare with the analytical method for different models for pipeline were obtained excellent results.

Key words: Cantilever pipe, Internal flow, Thickness ratio, Regtangular section, Turbulent flow.

الخلاصة

رايلي – ريتز من الطرق الرياضية التقريبية المستخدمة في دراسة طبيعة الاهتزاز في الهياكل الهندسية. استخدمت هذه الطريقة في هذا البحث لتخمين التردد الطبيعي للأنابيب الناقلة للماء بجريان مضطرب ذات المقطع المستطيل المتدرجة السمك وعند شروط حدية مثبت – حر وفي حالتين، الحالة الأولى تتضمن الأنبوب الذي يمتلك سمك جدار ثابت (h_1) عند النهاية المثبتة مساوي إلى (1mm, 2mm) بينما السمك (h_2) عند النهاية الحرة يتغير حسب النسبة (h_2/h_1=0.25, 0.5, 0.75, 1). في الحالة الثانية السمك عند النهاية الحرة (h_2) يكون ثابت (1mm, 2mm) في حين السمك عند النهاية المثبتة (h_1) يتغير حسب النسبة (h_1/h_2=0.25, 0.5, 0.75, 1). يمتلك الأنبوب ارتفاع ثابت (w_2) بالنسبة للمقطع الداخلي (5cm, 10cm) مع قيم مختلفة للعرض (w_1) يتفاوت عند النسبة (w_1/w_2=0.5, 1, 1.5, 2) لأطوال مختلفة للأنبوب تكون (1m, 2m). بينت الدراسة في الحالة الأولى عند أي قيمة للسمك (h_1) والارتفاع (w_2) فان التردد الطبيعي يقل مع زيادة النسبة (h_2/h_1) والنسبة (w_1/w_2) عند نفس الطول. بينما يزداد التردد عند زيادة السمك (h_1) والارتفاع (w_2). من ناحية أخرى فان السرعة الحرجة تزداد مع زيادة السمك (h_1) الارتفاع (w_2) والنسبة (h_2/h_1) لكنها تقل مع زيادة طول الأنبوب والنسبة (w_1/w_2). في الحالة الثانية فان التردد الطبيعي والسرعة الحرجة تزداد مع زيادة السمك عند النهاية الحرة (h_2)، نسبة السمك (h_1/h_2) والارتفاع (w_2) ألا انه يقل مع زيادة العرض (w_1) والطول (L). عند أي تشكيلة للأنبوب المنتظم المقطع فان التردد الطبيعي يقل مع زيادة سرعة جريان الماء من الصفر إلى السرعة الحرجة. بسبب غياب الدراسات حول الجريان المضطرب المسبب للاهتزازات في الأنابيب ذات المقطع المستطيل تم إجراء مقارنة مع الطريقة التحليلية ولنماذج مختلفة للأنبوب وتم الحصول على نتائج ممتازة.

الكلمات المفتاحية :- انبوب ناتيء ، جريان داخلي ، نسبة السمك ، مقطع مستطيل ، جريان مضطرب .

List of Symbols

A_1 Outer cross section area of pipe at clamped end (m^2).
A_2 Outer cross section area of pipe at free end (m^2).
$A(x)$ Cross section area of pipe at part of length (x) (m^2).
A_f Cross section area of fluid (m^2).
b Width of outer cross section, (cm).
b_x Width of outer cross section at length (x), (cm).
c_1 & c_2 Constants.
d High of outer cross section, (cm).
D_h Hydraulic diameter for pipe, (cm).
d_x High of outer cross section at length (x), (cm).
E_p Modulus of elasticity of pipe (N/m^2).
L Length of the pipe (m)
I_p Second moment of area of pipe (m^4).
I_x Second moment of area at part of length(x) (m^4).
k_{ij} Stiffness of pipe (N/m).
m_f Mass of fluid per unit length (kg/m).
m_w Mass of water per unit length (kg/m).
$m_p(x)$ Mass of pipe per part of length x (kg/m).
h_1 Thickness of pipe at clamped end (mm).
h_2 Thickness of pipe at free end (mm).
h_x Thickness of pipe at part of length of pipe (x), (mm).
Re Reynolds Nomber
V_f Velocity of fluid (m/sec).
V_c Critical velocity of fluid flows in the pipe (m/sec).
w_1 Width of inner cross section, (cm).D
w_2 High of inner cross section, (cm).
x Length of part of pipe (m).

Greek symbols

ρ_p Mass density of pipe material (kg/m^3).
ρ_f Mass density of fluid in the pipe, (kg/m^3).
ω Natural frequency of pipe at velocity of flow $V_{f,}$ (rad/sec).
ω_n Fundamental natural frequency of pipe in absence of flow, (rad/sec).
δ Difference.
μ Dynamic viscosity.

1. Introduction

Structural vibrations is one of the important problems that must find solutions for them because of the resulting noise in many fields of engineering works in order to reach for the satisfactory results in design. The noncircular pipes are usually used in applications such as the heating and cooling systems of buildings where the pressure difference is relatively small, the manufacturing and installation costs are lower, and the available space is limited for ductwork. There is a lack of studies on the water flow in pipes with square section causing vibrations so with the references of some studies done about the so called circular section pipes.(Andrew, 2009), investigated in this theses the natural frequency of PVC pipe conveying turbulent flow of an experimentally at different speed of flow pipe diameter and pipe thickness. (Mihaela, 2011), Presented a numerically investigation of the tonal noise generated by air flow through corrugated pipes is. The first part of the work presented detailed two dimensional computations of the aero-acoustical flow in a corrugated pipe: computation around one cavity and computation in a short pipe. The dimensions of the pipe correspond to the detailed measurements that are made by Kristiansen and Wiik10. The frequency of the impinging-shear-layer instability increases with the average of flow velocity. (Princelin, 2014), produced a simulation integrated pipe design which provides comprehensive guide for the p.ipe designing system. The importance of design is safety with optimization; the first design experienced near resonance frequency in its operation, to modify that there are two ways, one is to increase the diameter of the pipe, which in turn increase the weight and cost of the whole system, while the second one is intelligent support; The flow induced vibrations are well above the resonance frequency and hence design is safe. (Krthik, 2014), used an experimental investigation to study the fluid flow characteristics and the flow induced vibrations for square structures of aluminum and brass at the temperature of flow was 22^oC. (Antoine, 2015), introduced an analytical approach to study the response of a rectangular duct under an internal turbulent boundary layer excitation in order to forecast the maximum vibration amplitude. The impact of higher propagating modes to then duct response is also taken into account as the acoustic component. As a result, a good correlation is observed between simulation and measurements. (Nawal , 2015), studied dynamic behavior of pipe conveying water by using Raighly – Ritz method at tapered radius where the maximum radius at clamped end while minimum radius at free end.(Ming,2015) ,investigated numerically flow induced vibrations of square and rectangular cylinders for low Reynolds number 200 by solving Naveir – Stock equation. (Siba, 2016), Studied the flow induced vibrations by using experimental, numerical and theoretical methods. It was intended to implement better applications for controlling the flow using orifice technique for water, oil, gas and vapors in the test.

In this paper, the approximate Rayleigh - Ritz method which is used to estimate the natural frequency of cantilever pipe in rectangular cross section at different values of dimensions of width and high with an internal flow at turbulent flow, the pipe have thickness at different ratio into two cases between thickness at clamped and free end, estimated the natural frequency of vibrations at different ratio of dimensions of inner cross section, the thickness at clamped and free end, different values of velocity flow of water and different values of length.

2.Theoritical Analysis

Figs. 1a and 1b show the uniform inner cross section of clamped – free pipe t tapered thickness of length L, inner dimensions w_1 & w_2, the thickness at clamped end h_1, and at free end h_2 can be derived:-

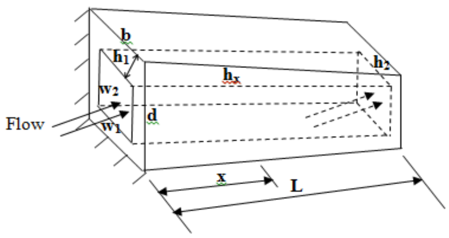


Fig. 1a :Cantilever pipe of tapered thickness $h_2/h_1 \leq 1$

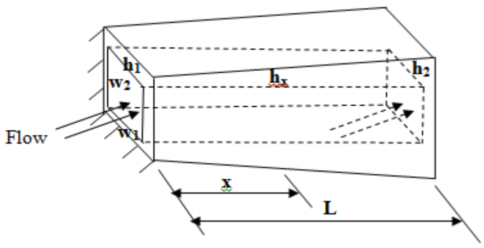


Fig. 1b :Cantilever pipe of taper thickness $h_1/h_2 \leq 1$

From Fig (1a). : $(h_x – h_2) / (L-x) = (h_1 – h_2) /L$ (1-a)

From Fig.(1b) : $(h_x – h_1) / x = (h_2 – h_1) /L$ (1-b)

After simplify above relations yields :-

$h_x = h_1(1-x/L) + h_2 (x/L)$ (2)

At a part length of pipe (x), $A(x) = b_x.d_x – w_1.w_2 = 2 (w_1+ w_2) h_x$,
where $b_x = (w_1+2h_x)$ & $d_x=(w_2 + 2h_x)$,
therefore $m_p(x)= \rho_p * A(x)$, and $I_x= \left\{\frac{b_x\, d_x^3}{12} - \frac{w_1\, w_2^3}{12}\right\}$,
therefore, $I_x= \left\{\frac{(w_1+ 2\, h_x)- (w_2+ 2\, h_x).^3}{12} - \frac{w_1\, w_2^3}{12}\right\}$, for that can be yields:-

$$I_x= \frac{1}{6}\{ 2(3w_1\, w_2^2 + w_2^3)\, h_x + 6(w_1\, w_2 + w_2^2)h_x^2 + 4(w_1 + 3\, w_2)h_x^3 + 8h_x^4\} \quad (3)$$

Now the procedure of Rayeigh-Ritz is applied to derive the natural frequency for transverse motion of tapered cross section of cantilever pipe. Let us use the simple two term approximation (Benoray, 1998).

$$Y_r = c_1\, y_1(x) + c_2\, y_2(x) \quad (4)$$

$$Y_r = c_1 \left(\frac{x}{L}\right)^2 + c_2 \left(\frac{x}{L}\right)^3 \quad (5)$$

By using above equations the values of mass (m_{ij}) and stiffness (k_{ij}) of pipe can be estimated by (Benoraya, 1998):-

$$m_{i\,j} = \int_0^L m(x)\, y_i\, y_j\, dx \quad (6)$$

$$k_{i\,j} = \int_0^L E\, I(x)\, y_i''\, y_j'' \quad (7)$$

After integration equation (6) according to pipe where the pipe is empty from fluid can be yielded:-

$$\left\{ \begin{array}{l} m_{11p} = 2\,\rho_p\ (w_1+w_2) *(h_1/5 + h)\, L/6, \quad m_{12p} = 2\,\rho_p\ (w_1+w_2) * (h_1/6 + h)\, L/7, \\ m_{12p} = m_{21p}, \quad m_{22p}\ m_{11p} = 2\,\rho_p\ (w_1+w_2)\ *h_1/7 + h)\, L /8. \end{array} \right\} \quad (8)$$

The mass of water which is flow through the pipe : $m_w = \rho_w * A_{wi}$,
therefore $m_w = \rho_w * (w_1 . w_2)$, so after using equation (6) and integration it,
$m_{11w}=m_w.L/5$, $m_{12w}=m_w.L/6 =m_{21W}$, $m_{22w}=m_w.L/7$ (9)

Now the employment superposition between equation (8) and equations (9) will be obtained :-

$$\left\{ m_{11}=m_{11p}+m_{11w},\ \ m_{12}=m_{12p}+m_{12w},\ \ m_{21}=m_{21p}+m_{21w},\ \ m_{22}=m_{22p}+m_{22w} \right\} \quad (10)$$

After integration of equation (7) the following relations will represent the stiffness of pipe:

$$k_{11p}=\frac{E_p}{3L^3}\begin{bmatrix} (h_1+h_2)(3w_1w_2^2+w_2^3)+4(h_1^2+h_1h_2+h_2^2)(w_1w_2+w_2^2) \\ +2(h_1^3+h_1^2h_2+h_1h_2^2+h_2^3)(w_1+3w_2) \\ +\frac{16}{5}(h_1^4+h_1^3h_2+h_1^2h_2^2+h_1h_2^3+h_2^4) \end{bmatrix} \quad (11\text{-a})$$

$$k_{12p}=\frac{E_p}{L^3}\begin{bmatrix} 2\left(\frac{1}{6}h_1+\frac{1}{3}h_2\right)(3w_1w_2^2+w_2^3)+12\left(\frac{1}{12}h_1^2+\frac{1}{6}h_1h_2+\frac{1}{4}h_2^2\right)(w_1w_2+w_2^3) \\ +8\left(\frac{1}{20}h_1^3+\frac{1}{10}h_1^2h_2+\frac{3}{20}h_1h_2^2+\frac{1}{5}h_2^3\right)(w_1+3w_2) \\ +16\left(\frac{1}{30}h_1^4+\frac{1}{15}h_1^3h_2+\frac{1}{10}h_1^2h_2^2+\frac{2}{15}h_1^3h_2+\frac{1}{6}h_2^4\right) \end{bmatrix} \quad (11\text{– b})$$

$$k_{21p}=k_{12p} \quad (11 – \text{c})$$

$$k_{22p}=\frac{3E_p}{L^3}\begin{bmatrix} \frac{1}{2}\left(\frac{1}{3}h_1+h_2\right)(3w_1w_2^2+w_2^3)+\frac{12}{5}\left(\frac{1}{6}h_1^2+\frac{1}{2}h_1h_2+h_2^2\right)(w_1w_2+w_2^2) \\ +4\left(\frac{1}{30}h_1^3+\frac{1}{10}h_1^2h_2+\frac{1}{5}h_1h_2^2+\frac{1}{3}h_2^3\right)(w_1+3w_2) \\ +16\left(\frac{1}{105}h_1^4+\frac{1}{35}h_1^3h_2+\frac{6}{105}h_1^2h_2^2+\frac{4}{42}h_1h_2^3+\frac{1}{7}h_2^4\right) \end{bmatrix} \quad (11 – \text{d})$$

Other relations of mass and stiffness in the matrix form can be written as follow :-

$$\begin{bmatrix} k_{11p}-\omega_n^2 m_{11} & k_{12p}-\omega_n^2 m_{12} \\ k_{12p}-\omega_n^2 m_{12} & k_{22p}-\omega_n^2 m_{22} \end{bmatrix}\begin{Bmatrix} c_1 \\ c_2 \end{Bmatrix}=\begin{Bmatrix} 0 \\ 0 \end{Bmatrix} \quad (12)$$

Or in general matrix notation as :

$$\left[\{K\}-\omega_n^2\{M\}\right]\{c\}=\{0\} \quad (13)$$

The evaluation of this determinant provides an estimation of the two fundamental natural frequencies ω_1^2 and ω_2^2 for the pipe carrying fluid which is not moved. In order to complete the natural frequency of pipe especially when the fluid moves at any velocity, firstly the critical velocity of flow should be determined for uniform cantilever pipe from the flowing equation by (Ivan, 2010),

$$\mathbf{V_c} = \frac{1.875}{L} \sqrt{E_p\, I_p\, /\, \rho_f\, A_f} \qquad (14)$$

Thus the natural frequency (ω) of a pipe at any velocity of fluid can be found from the following equation :-

$$\frac{\omega}{\omega_n} = \sqrt{1-\left(\frac{V_f}{V_c}\right)^2} \text{ (Blivens, 2001)} \qquad (15)$$

Thus V_f is represented the velocity of the flow.

Now the following equation can be used for analytical method to estimate the natural frequency for clamped – free boundary conditions of pipe in:-

$$\omega_n = \frac{(1.875)^2}{L^2} \sqrt{\frac{E_p * I_P}{(m_p * m_w)}} \qquad (16)$$

Now in order to guess the nature of flow we use the following equation which is represented the Reynolds number (Re) for pipe :-

$$Re = \frac{\rho_f\, V_f\, D_h}{\mu} \text{ (Pijush, 2011)} \qquad (17)$$

Where μ is dynamic viscosity for water $\mu = 1*10^{-3}$ N.s / m^2 and,

D_h is hydraulic diameter for pipe at square cross section can be represented as follow:-

$D_h = 2w_1*w_2 / (w_1+ w_2)$ (18)

Therefore the equations (17) & (18) the Reynolds number can be written as follow:-

$$Re = \frac{2w1*w2*\rho f\, V_f}{\mu\, (w1+ w2)} \qquad (19)$$

2. Results and Discussion:

The lack of literature for this type of study, motive us to make a brief comparison by using the analytical method. Table (1-a) shows the comparison of the fundamental natural frequency of the first mode for transverse free vibrations of rectangular pipe in absence flow (V_f = 0) for case (1) at different dimensions of pipe and one meter length but table (1-b) for two meter length. The results based on the main properties of material E=207 Gpa, ρ=8000 kg/m. Figures (2 to 9) show that the first mode of vibration of rectangular pipe at tapered thickness in absence flow (V_f =0) is a function of the ratio (h_2/h_1) obtain for the Rayleigh – Ritz method for difference values of ratio (w_1/w_2), thickness at clamped end (h_1), the inner height of pipe (w_2) and the length of pipe (L). It is obviously seen that the natural frequency increases with the increased in thickness (h_1) and the high (w_2). This behavior illustrated the second moment of inertia increasing and caused increase the strain energy of structure therefore that is caused increased the stiffness of system. In the same figures the natural frequency decreased with increase in the ration of thickness (h_2/h_1), the ratio (w_1/w_2), and the length (L) that causes increasing in the mass of the pipe and increase the amount of water which caused an increase in the kinetic energy of the structure that is cause decrease the natural frequency of the system. Figures (10 & 17) show that the first mode of vibration of tapered thickness in absence flow (V_f =0) is a function of the ratio (h_1/h_2) for variation values of ratio (w_1/w_2), thickness at free end (h_2), the inner height of pipe (w_2) and the length of pipe (L). It is clearly seen that the natural frequency increase with increasing the ratio (h_1/h_2), the height (w_2) and the thickness(h_2). This manners illustrated the strain energy of structure increased hence caused increasing the stiffness. In the same figures the natural frequency decreased with increased in the length of pipe and the ratio (w_1/w_2) as similar to the above case. In the figures (18 to 25) show the critical velocity o water as a function with thickness ratio into two cases where the critical velocity increase with increasing the thickness ratio (h_2/h_1 or h_1/h_2) and thickness (h_1 or h_2) and the height (w_2) and decreases with increasing the ratio and the length of pipe. In the figures (26 to 33) the natural frequency as a function with the velocity of flow (V_f) of water for pipe into two case for different values of (h_1, h_2, h_2/h_1, h_1/h_2, w_2, w_1/w_2 & L) can be observed that the natural frequency decreases with increasing the velocity of water regardless of the effect of the above variable on the natural frequency of the system because of the velocity of flow when increased caused the increased of Reynolds number that is caused the increased of the kinetic energy of water transformed into sudden pressure energy normally which is caused the impact force which make an impression pressure on the wall and caused deformation of the pipe therefore will decrease in the flexibility of pipe and the natural frequency of the system.

Table (1-a) shows the fundamental natural frequency (rad/sec) of transverse vibrations of pipe in absence flow (V_f=0) for one meter length.

Length L(m)	High w_2(cm)	Width w_1 (cm)	h_1(mm)	h_2 (mm)	Present work ω_n (rad/sec)	Analytical method ω_n (rad/sec)	**Difference δ %**
1	5	$0.5w_2$	1	$0.25h_1$	263.45	229.26	12%
1	10	w_2	1	$0.5h_1$	363.36	324.95	10%
1	5	$1.5w_2$	2	$0.75h_1$	298.32	279.026	6%
1	10	$2w_2$	2	h_1	462.21	460.74	0.3%

Table (1-b) Fundamental natural frequency (rad/sec) of transverse vibrations of pipe in absence flow (V_f=0) for two meter length.

Length L(m)	High w_2(cm)	Width w_1 (cm)	h_1(mm)	h_2 (mm)	Present work ω_n (rad/sec)	Analytical method ω_n (rad/sec)	**Difference δ %**
2	5	$0.5w_2$	1	$0.25h_1$	65	57.25	12%
2	10	w_2	1	$0.5h_1$	90	81.23	9.7%
2	5	$1.5w_2$	2	$0.75h_1$	74.5	69.75	6%
2	10	$2w_2$	2	h_1	115.5	115.18	0.27%

δ=[(R-Ritz method– Analytical method)/ R-Ritz method] *100%

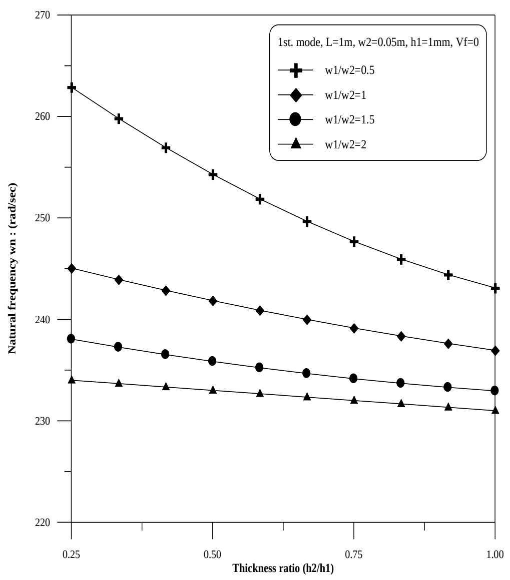


Fig. (2): Natural frequency for 1st mode as a function of thickness ratio (h_2/h_1) in different values of w_1/w_2 for one meter length, w_2=0.05m absence flow and h_1=1mm.

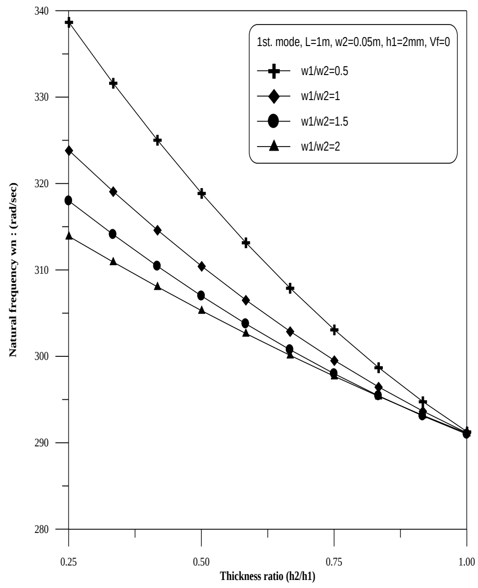


Fig. (3): Natural frequency for 1st mode as a function of thickness ratio (h_2/h_1) in different values of w_1/w_2 for one meter of length,w_2=0.05m absence flow and h_1=2mm.

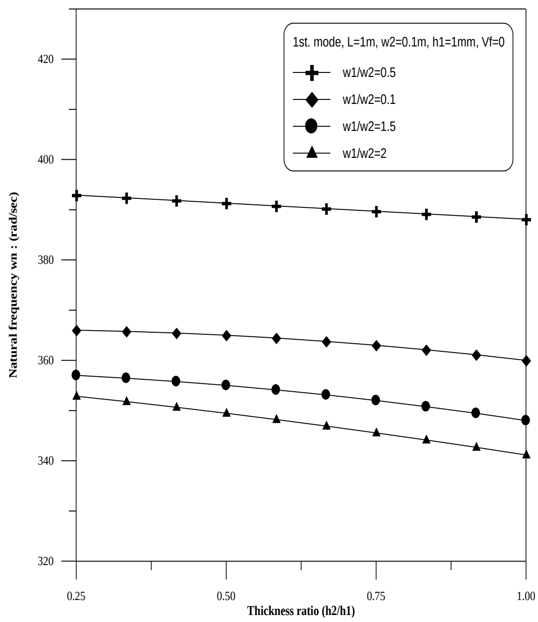


Fig. (4): Natural frequency for 1st mode as a function of thickness ratio (h_2/h_1) in different values of w_1/w_2 for one meter length, w_2=0.1m absence flow and h_1=1mm.

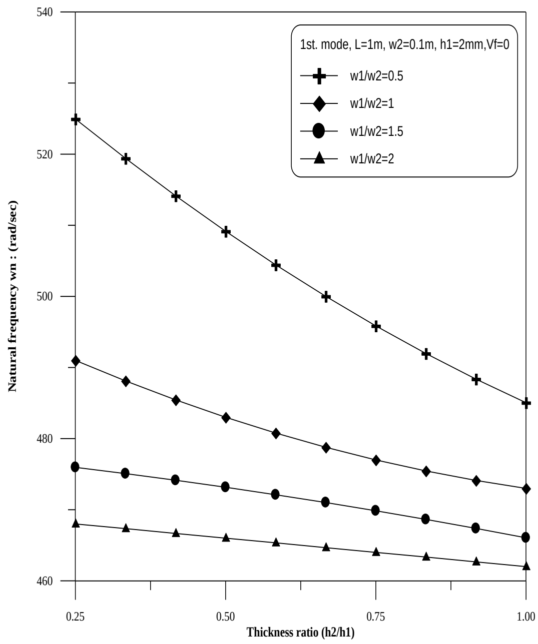


Fig. (5): Natural frequency for 1st mode as a function of thickness ratio (h_2/h_1) in different values of w_1/w_2 for one meter length, w_2=0.1m absence flow and h_1=2mm.

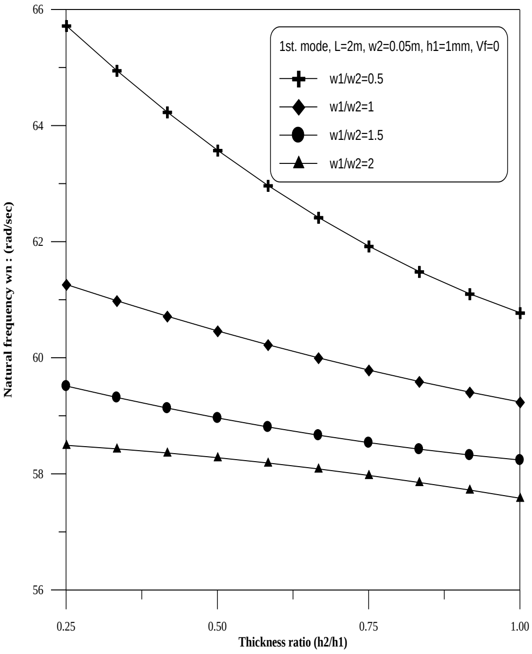


Fig. (6): Natural frequency for 1st mode as a function of thickness ratio (h_2/h_1) in different values of w_1/w_2 for two meter length, w_2=0.05m absence flow and h_1=1mm.

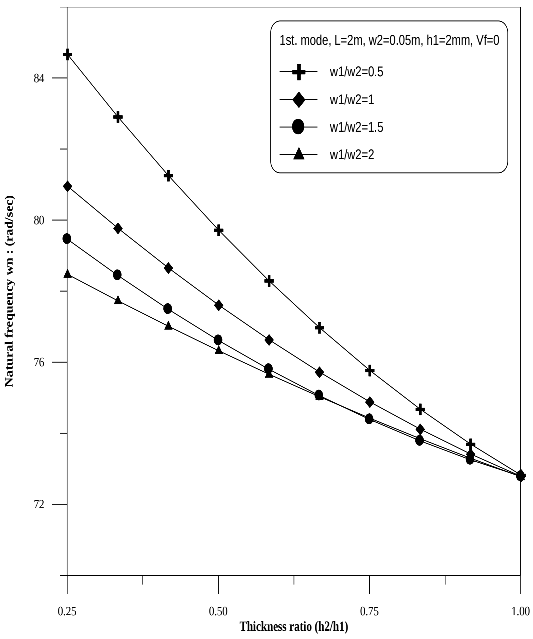


Fig. (7): Natural frequency for 1st mode as a function of thickness ratio (h_2/h_1) in different values of w_1/w_2 for two meter length, w_2=0.05m absence flow and h_1=2mm.

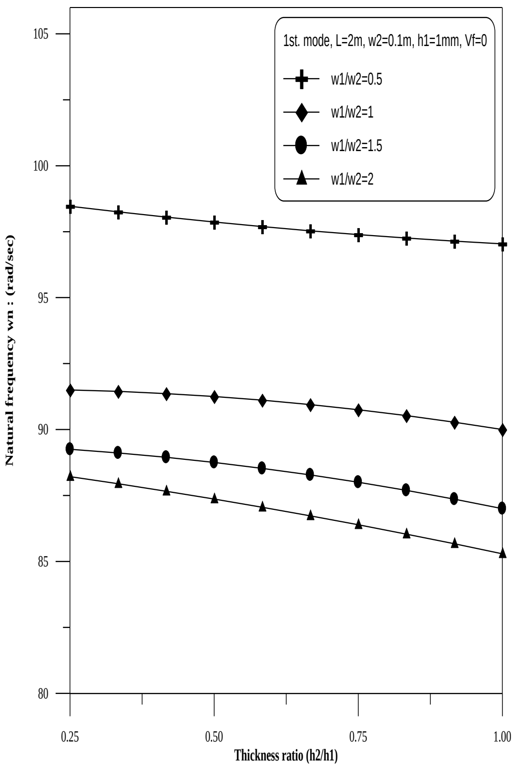


Fig. (8): Natural frequency for 1st mode as a function of thickness ratio (h_2/h_1) in different values of w_1/w_2 for two meter length, w_2=0.1m absence flow and h_1=1mm.

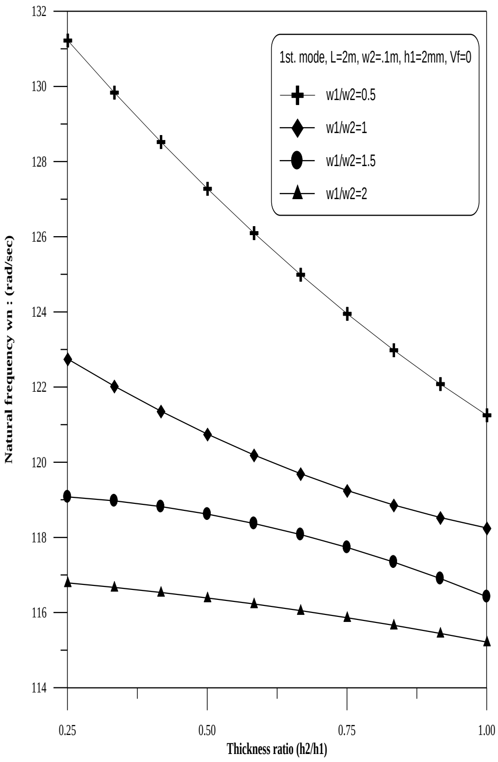


Fig. (9): Natural frequency for 1st mode as a function of thickness ratio (h_2/h_1) in different values of w_1/w_2 for two meter length, w_2=0.1m absence flow and h_1=2mm.

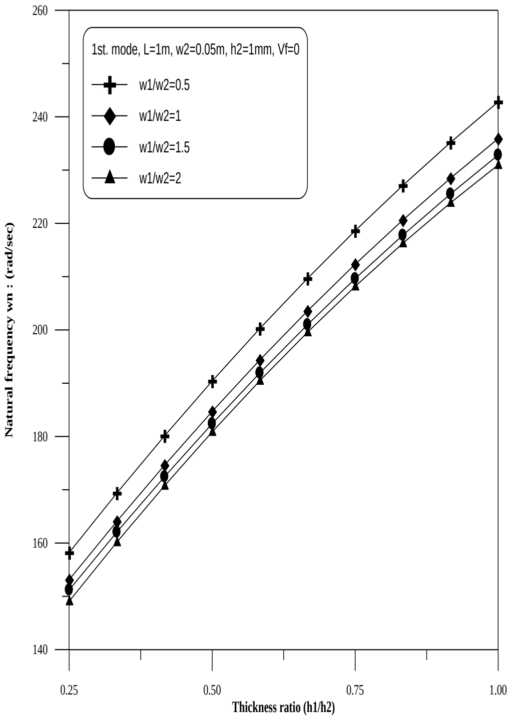


Fig. (10): Natural frequency for 1st mode as a function of thickness ratio (h_1/h_2) in different values of w_1/w_2 for one meter length, w_2=0.05m absence flow and h_1=1mm.

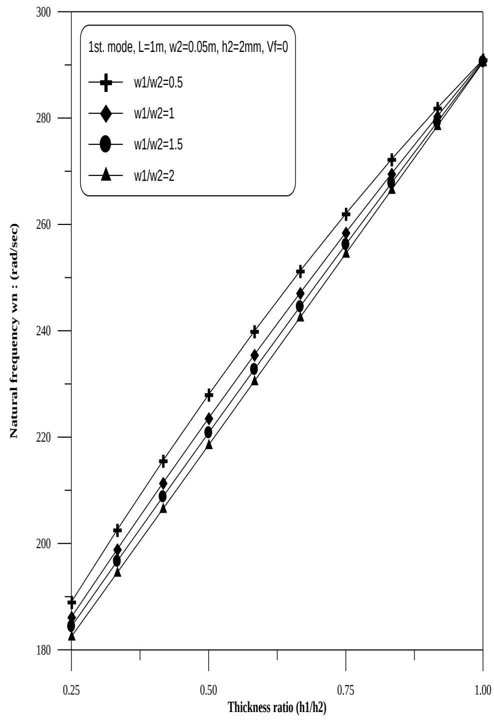


Fig. (11): Natural frequency for 1st mode as a function of thickness ratio (h_1/h_2) in different values of w_1/w_2 for one meter length, w_2=0.05m absence flow and h_1=2mm.

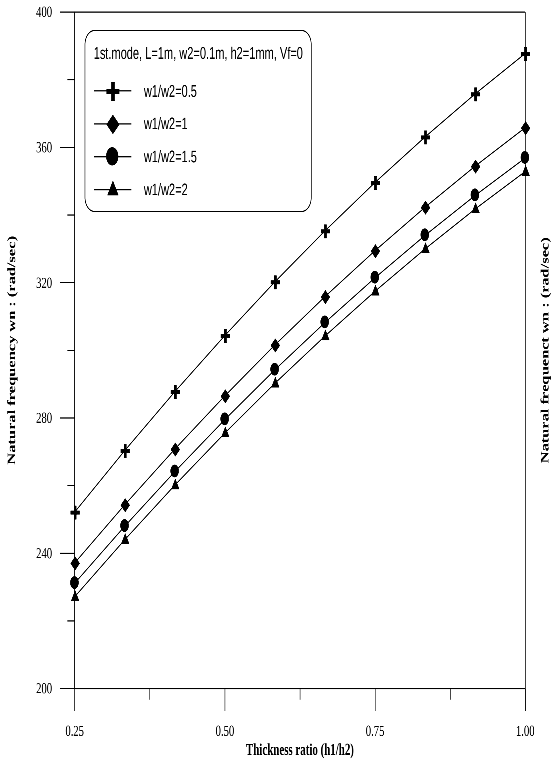


Fig. (12): Natural frequency for 1st mode as a function of thickness ratio (h_1/h_2) in different values of w_1/w_2 for one meter length, w_2=0.1m absence flow and h_1=1mm.

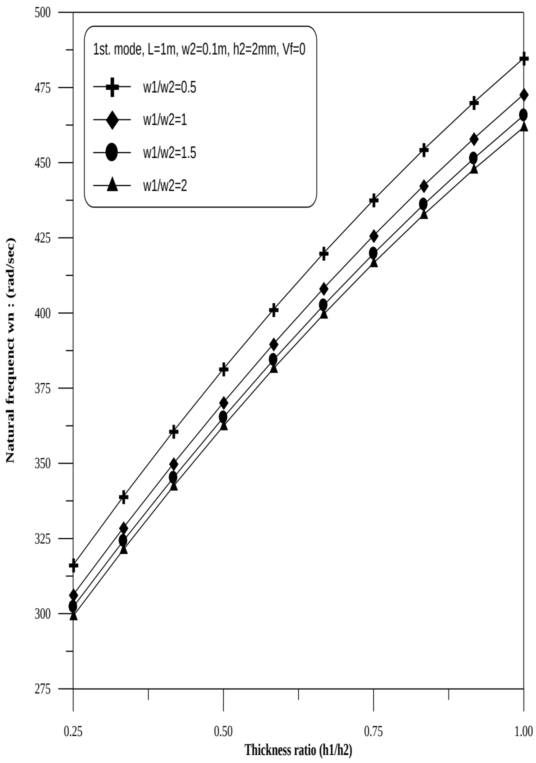


Fig. (13): Natural frequency for 1st mode as a function of thickness ratio (h_1/h_2) in different values of w_1/w_2 for one meter length, w_2=0.1m absence flow and h_1=2mm.

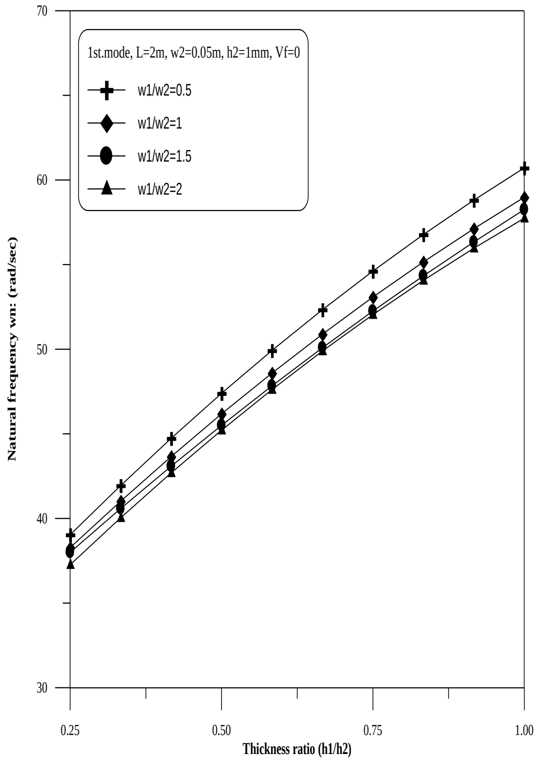


Fig. (14): Natural frequency for 1st mode as a function of thickness ratio (h_1/h_2) in different values of w_1/w_2 for two meter length, w_2=0.05m absence flow and h_1=1mm.

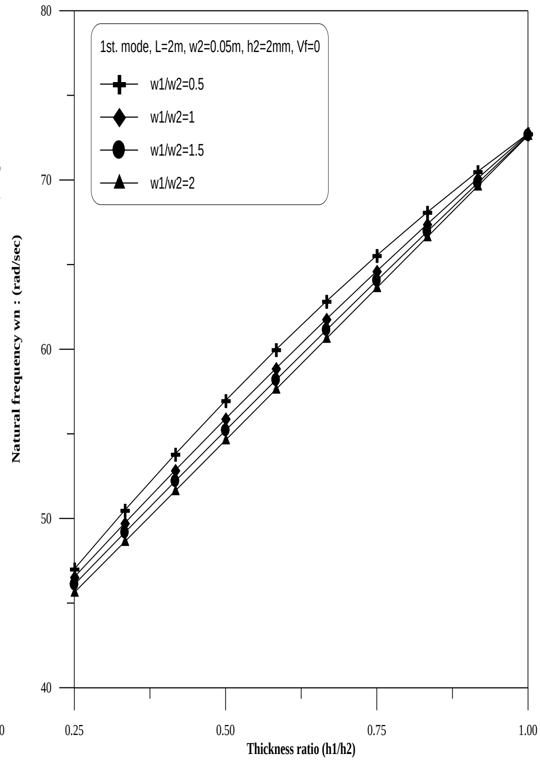


Fig. (15): Natural frequency for 1st mode as a function of thickness ratio (h_1/h_2) in different values of w_1/w_2 for two meter length, w_2=0.1m absence flow and h_1=2mm.

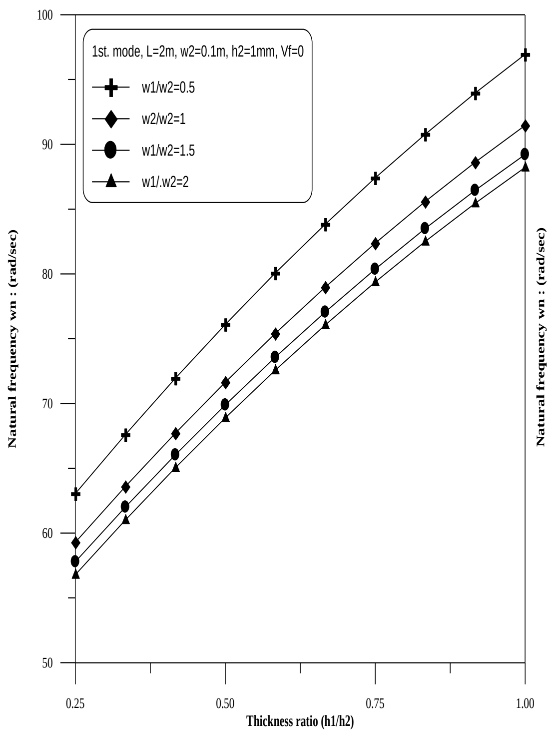


Fig. (16): Natural frequency for 1st mode as a function of thickness ratio (h_1/h_2) in different values of w_1/w_2 for two meter length, w_2=0.1m absence flow and h_1=1mm.

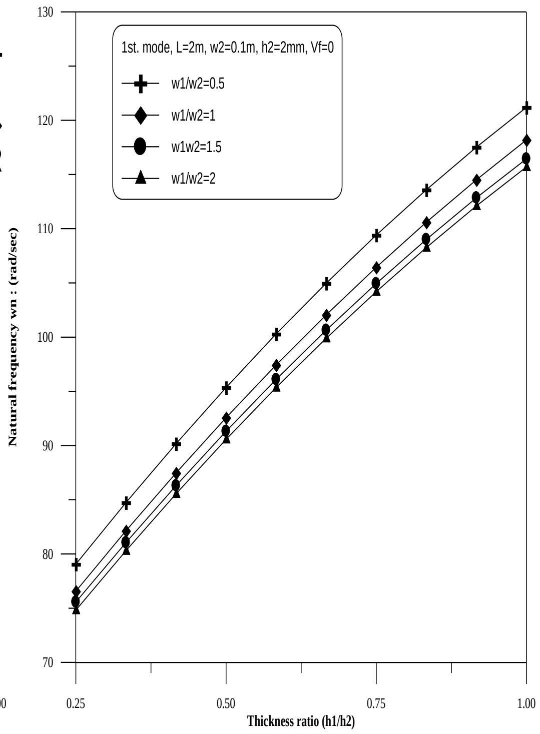


Fig. (17): Natural frequency for 1st mode as a function of thickness ratio (h_1/h_2) in different values of w_1/w_2 for one meter length, w_2=0.1m absence flow and h_1=2mm.

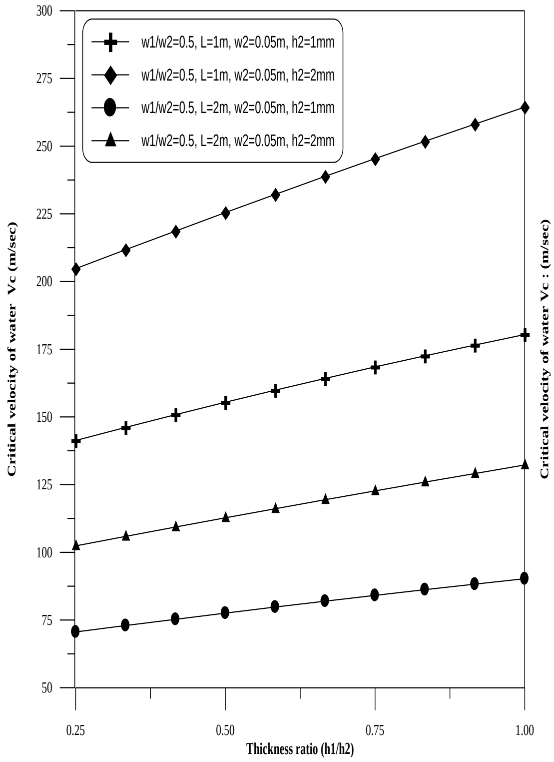


Fig. (18): Critical velocity of flow as a function of thickness ratio (h_1/h_2) in different values of length & thickness at w_2=0.05m, w1/w2=0.5.

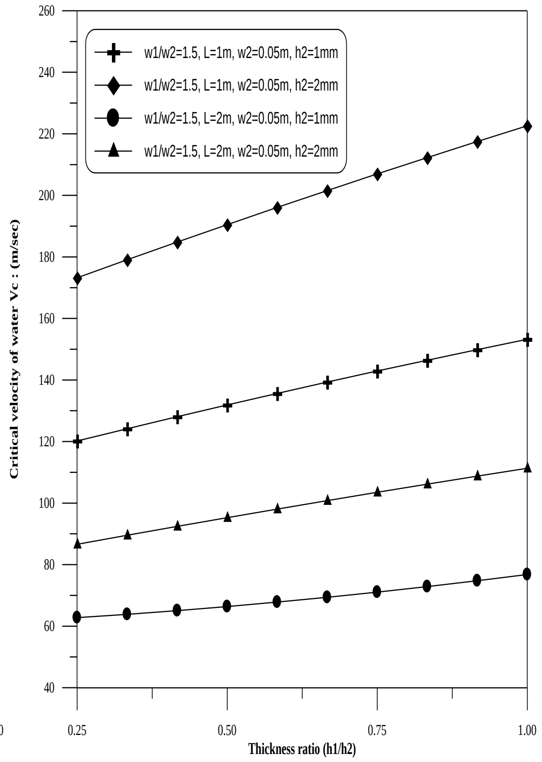


Fig. (19): Critical velocity of flow as a function of thickness ratio (h_1/h_2) in different values of length & thickness w_2=0.05m, w1/w2=1.5.

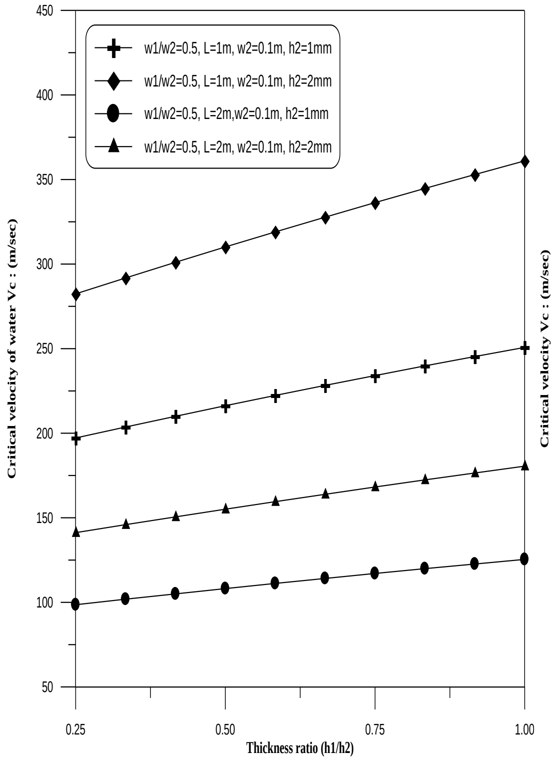


Fig. (20): Critical velocity of flow as a function of thickness ratio (h_1/h_2) in different values of length & thickness at w_2=0.1m, w_1/w_2=0.5.

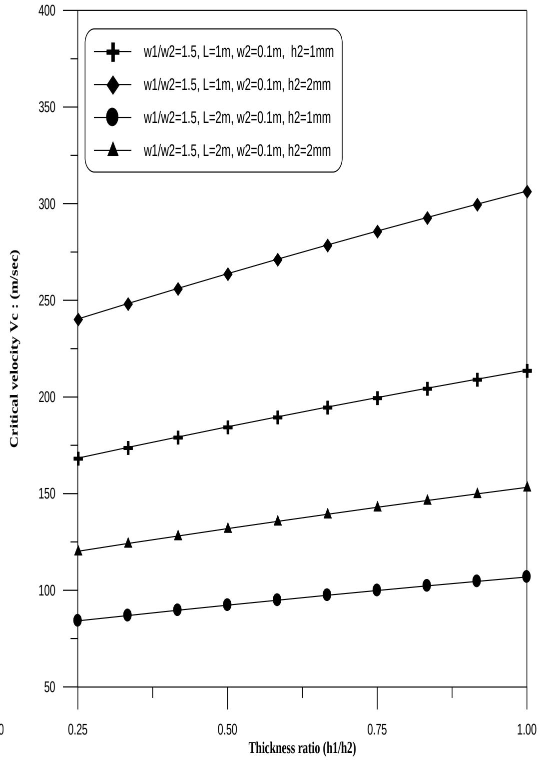


Fig. (21): Critical velocity of flow as a function of thickness ratio (h_1/h_2) in different values of length & thickness at w_2=0.1m, w_1/w_2=1.5.

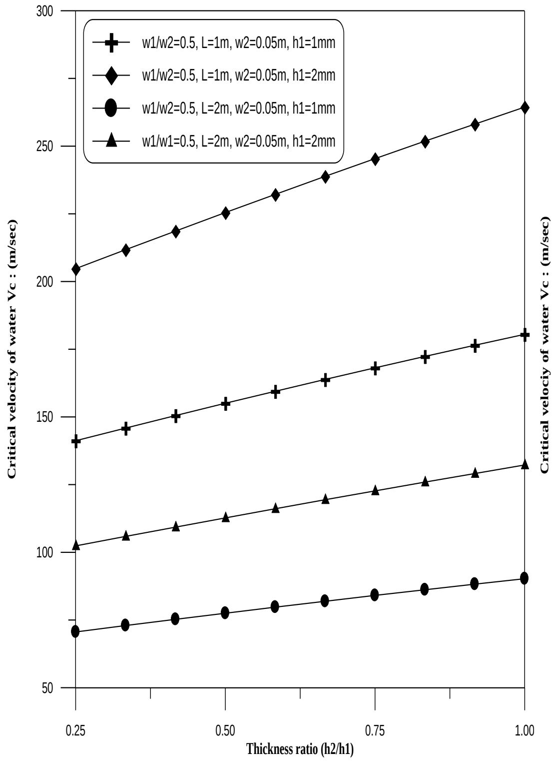


Fig. (22): Critical velocity of flow as a function of thickness ratio (h_2/h_1) in different values of length & thickness at w_2=0.05m, w_1/w_2=0.5.

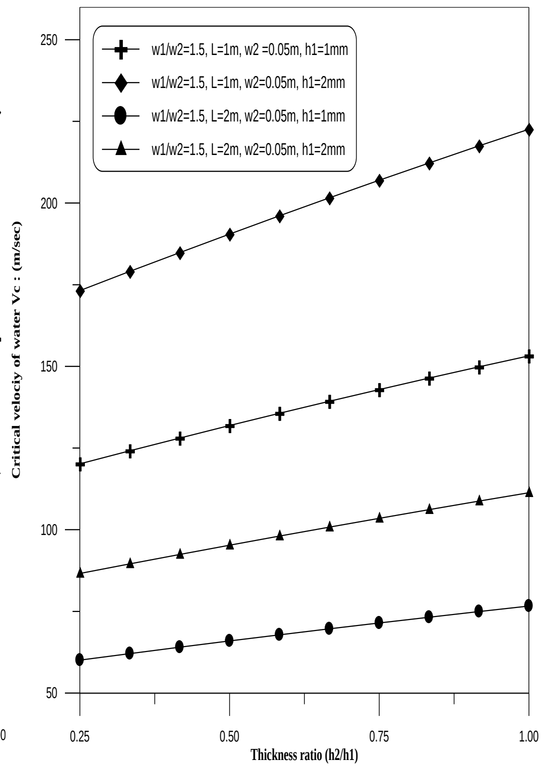


Fig. (23): Critical velocity of flow as a function of thickness ratio (h_2/h_1) in different values of length & thickness at w_2=0.05m, w_1/w_2=1.5.

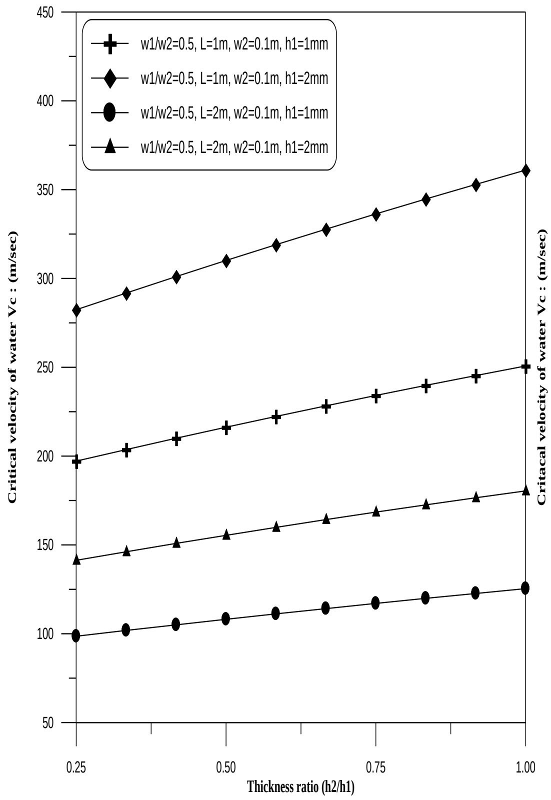


Fig. (24): Critical velocity of flow as a function of thickness ratio (h_2/h_1) in different values of length & thickness at w_2=0.1m, w_1/w_2=0.5.

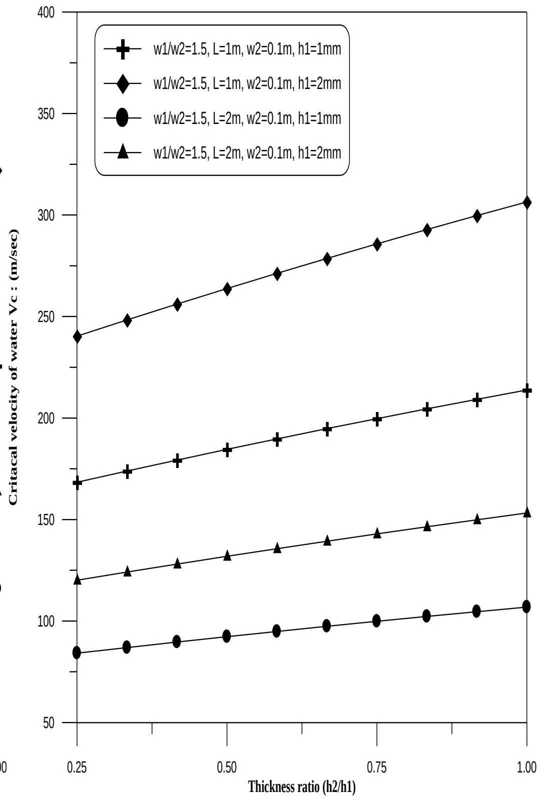
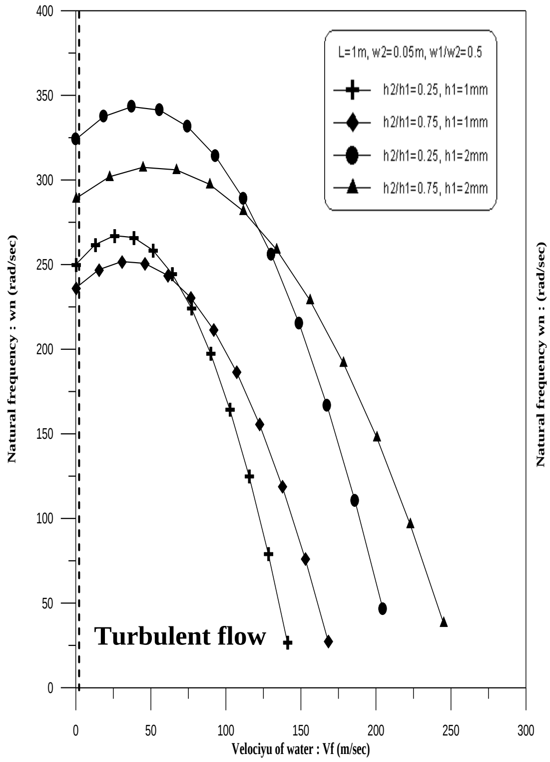


Fig. (25): Critical velocity of flow as a function of thickness ratio (h_2/h_1) in different values of length & thickness at w_2=0.1m, w_1/w_2=1.5.



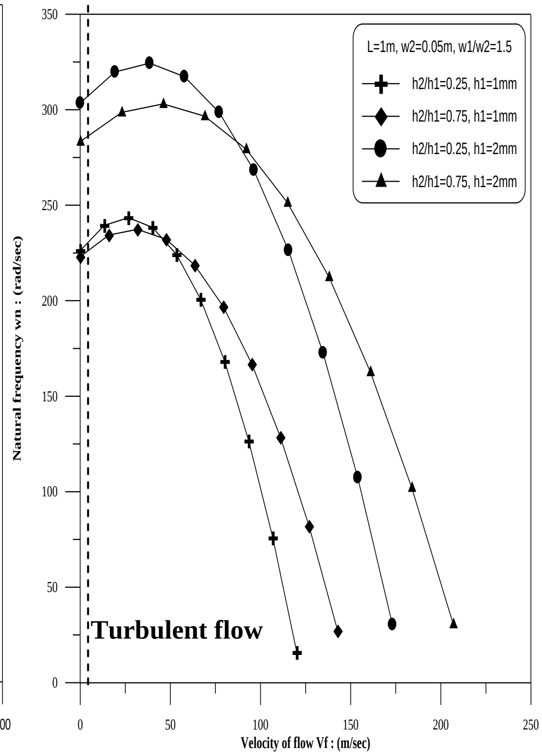
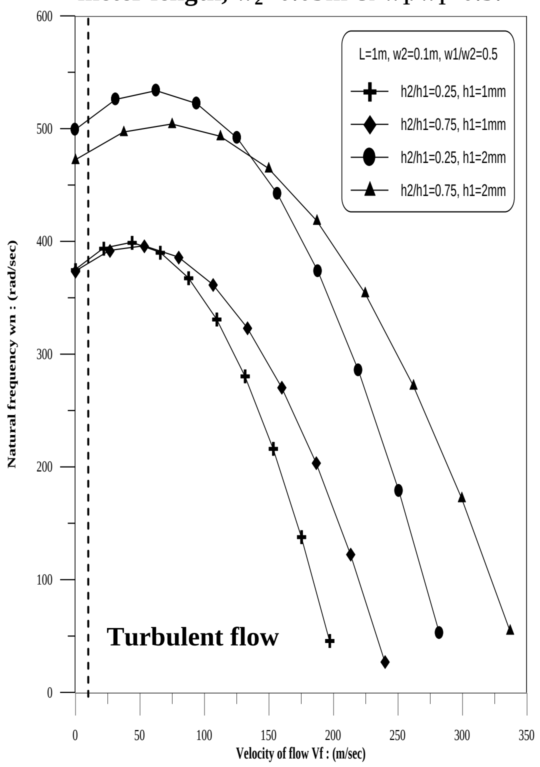


Fig. (26): Natural frequency for 1st mode as a function of velocity of flow V_f in different values of thickness ratio (h_2/h_1) & thickness at one meter length, w_2=0.05m & w_1/w_1=0.5.

Fig. (27): Natural frequency for 1st mode as a function of velocity of flow V_f in different values of thickness ratio (h_2/h_1) & thickness at one meter length, w_2=0.05m & w_1/w_1=1.5.



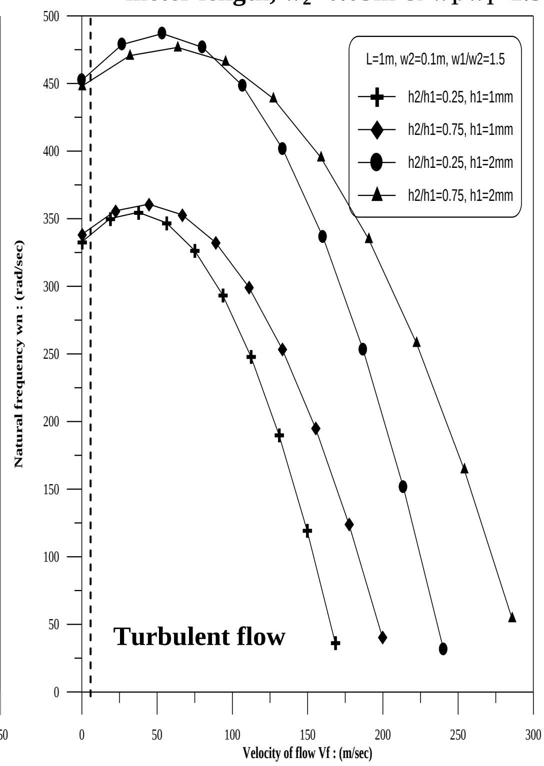


Fig. (28): Natural frequency for 1st mode as a function of velocity of flow V_f in different values of thickness ratio (h_2/h_1) at one meter length, w_2=0.1m and w_1/w_2 =0.5 for different thickness.

Fig. (29): Natural frequency for 1st mode as a function of velocity of flow V_f in different values of thickness ratio (h_2/h_1) at one meter length, w_2=0.1m and w_1/w_2 =0.5 for different thickness.

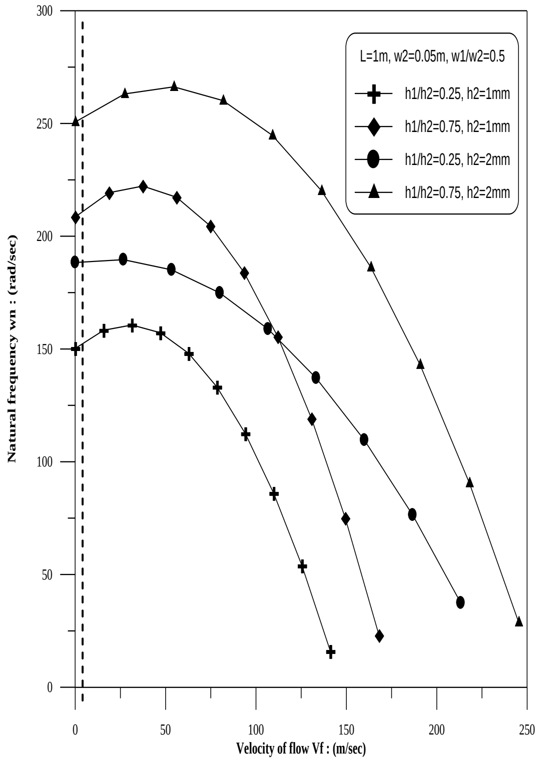


Fig. (30): Natural frequency for 1st mode as a function of velocity of flow V_f in different values of thickness ratio (h_1/h_2) at one meter length, w_2=0.5m and w_1/w_2 =0.5 for different thickness.

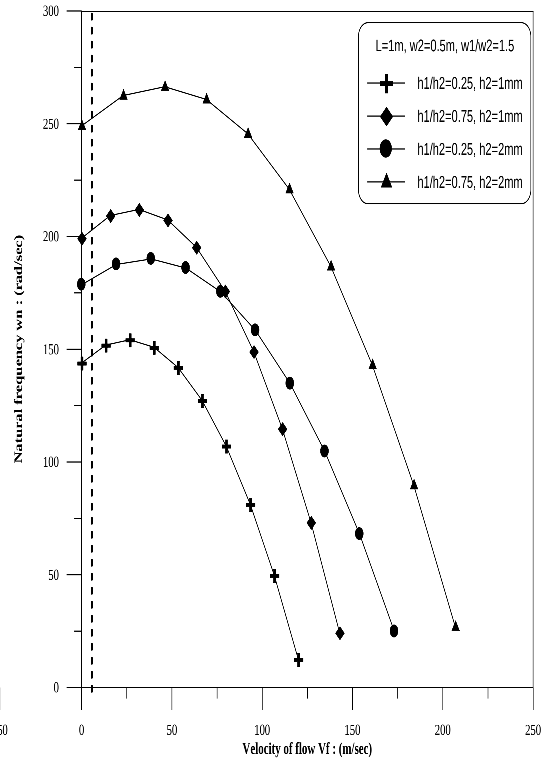


Fig. (31): Natural frequency for 1st mode as a function of velocity of flow V_f in different values of thickness ratio (h_2/h_1) at one meter length, w_2=0.5m and w_1/w_2 =1.5 for different thickness.

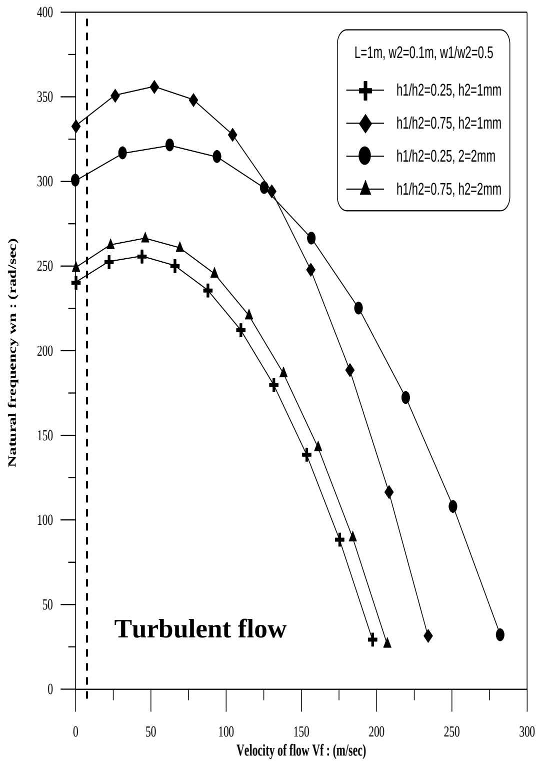


Fig. (32): Natural frequency for 1st mode as a function of velocity of flow V_f in different values of thickness ratio (h_1/h_2) at two meter length, w_2=0.1m and w_1/w_2 =0.5 for different thickness.

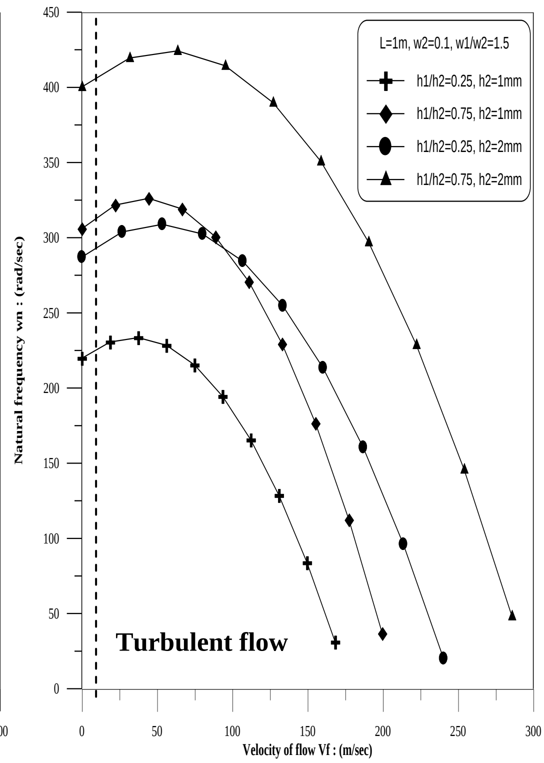


Fig. (33): Natural frequency for 1st mode as a function of velocity of flow V_f in different values of thickness ratio (h_1/h_2) at two meter length, w_2=0.1m and w_1/w_2 =1.5 for different thickness.

5. Conclusion

This study presented the results of theoretical investigation to guess the natural frequency of rectangular pipe conveying turbulent flow for different internal dimensions, thickness and length at clamped – free of boundary conditions. The velocity of flow at different value reach to critical speed. The flow velocity directly affects on the vibration of the pipe as the higher the flow velocity decreases the vibration.

6. Refrences

Andrew S. Thompson ,2009 , "Experimental Characterization of Flow Induced Vibration in Turbulent Pipe Flow", Theses, Brigham Young University – Provo, BY U Scholars Archive Citation.

Antoine David, Nicolas Dauchez ,2015 ," Vibrations Flow by Air Flow Excitation in A rectangular Duct", The 22nd International Congress of Sound and Vibration Sorbonne universities.

Benoraya, Benaroy , 1998 , "Mechanical Vibration", Prentice – Hill, Inc., U.S.A..

Blevines , 2001, "Flow induced vibration" Krieger publishing company, Malabar Florida, 2nd edition.

Ivan Grant, May, 2010, "Flow induced vibrations in pipes, a finite element approach" Cleveland state university.

Karthik K.& Kumarsw L.,2014 , " A study on flow induced vibrations excitation in solid square structures", International Journal of Mechanical and Production Engineering Research and Development (IJMPERD), ISSN(P): 2249, Vol . 4, Issue 4,PP. 15 – 22.

Mihaela Popescu ,2011 ," Behavior of Flow-Induced Vibration in Corrugated Pipes", American Institute of Aeronautics and Astronautics, pp.27-30.

Ming Zhao ,2015 , " Flow-induced vibrations of square and rectangular cylinders at low Reynolds Number" Journal of fluid dynamic research, Vol. 47, 24pp.

Nawal H. Al-Raheimy, 2015 , "Transverse Vibrations of Tapered Cantilever Pipes of Circular Cross Section with an Internal Flow", International Scientific Conference for the Second Technical College Musayyib Disciplines of Engineering and Agricultural.

Pijush K. Kundu, 2011 , "Fluid Mechanics 5th Edition".

Princelin Noel D. D., March 2014 , " Design of Gas Pipes and Analysis of Flow Induced Vibrations", International Journal Of Innovative Trend, ISSN 2349-9842, Volume 1, Issue 1.

Siba M. *et.al.*,2016 , "Flow Induced Vibration in Pipes Challenges and Solutions A review", Journal of Engineering Science and Technology, Vol. 11 No. 3, pp. 362-382.