Vibrational analysis of Uniform and Tapered Steel Cantilever Beams of Rectangular Section, Channel Section and I-Section

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Abstract— Beams are very common types of structural components and Structural beams can be classified according to their geometric configuration as uniform or taper and slender or thick. If practically analyzed, the non-uniform beams provide a better distribution of mass and strength than uniform beams and can meet special functional requirements in architecture, aeronautics, robotics, and other innovative engineering applications. Beams and beam-like elements are used in many structures and mainly in aircrafts, turbines and light weight structures etc. Design of such structures are important to resist dynamic forces, such as wind and earthquakes and Due to this dynamic forces "Vibrations" can be induced in the structures and these vibrations can adversely affect the structures and can cause cracks in the structure, which ultimately leads to the failure of the structure therefore It requires the basic knowledge of natural frequencies and mode shapes of those structures. In this research work, steel cantilever beams of different cross-section beams are used such as Rectangular cross section beam, I-section beam and Channel section beam and tapered cantilever beams and in this research work, natural frequencies and mode shapes of uniform and tapered section cantilever beams are calculated, with the help of Finite Element Method by using "ANSYS" program.

Keywords: ANSYS, Rectangular Section, Channel Section and I-Section, NDT

I. INTRODUCTION

Research on dynamic characteristics of flexible tapered cantilever beams is very important in different engineering fields. These types of beams appear most frequently as the result of a need for saving in material, reduction in weight, better utilization of material, increased rigidity etc. A significant number of papers dedicated to the solution of this problem have been published.

This paper presents an approach to the determination of natural frequencies of free vibration of cantilever beams of different cross section beams. In this paper natural frequencies of both uniform and non-uniform cross section beams are calculated and different shapes of uniform and non-uniform beams are also taken for example rectangular beams, I-section beams and Channel section beams. These beams of different cross sections are vibrationally analyzed with the help of a software.

Vibration analysis is a general method used to find defects of structures like fractures, cracks initiated by the maximum total deformation. It offers an inexpensive, effective and efficient way of nondestructive testing (NDT). The existence of cracks within the structures drastically minimizes the stiffness and enhances damping within the element. In vibration theory it is well known that reduction in natural frequencies with modifications of vibration modes in structures is associated with reduction in the stiffness. Properties such as damping and stiffness will be influenced by its dynamic loading due to existence of fracture in structural component. The frequencies and respective mode shape of structures provides information regarding the positional and depth data of the cracks. Therefore, for the location of maximum deformation and for the location of cracks vibrational analysis of beams are used. In vibrational analysis Vibration is the most important factor. Vibration is a repetitive type of motion with a pre-defined time interval. The vibration problems occur where there are moving parts or rotating parts in a machinery. And due to this vibrations, the machine foundation will also be affected. The main causes of vibration are unbalanced forces, dry friction between the two mating surfaces, Earthquakes, wind forces etc. The effects of vibration are excessive stresses, undesirable noise and partial or complete failure of parts of the structure. Therefore, due to this ill-effects the analysis and reduction of undesirable vibration is required.

A. Introduction to Vibration:

Vibration is a repetitive type of motion with a pre-defined time interval. The vibration theories comprise of the related analysis of oscillatory motions of bodies and the resulting affecting and effecting forces. External unbalanced force is also one of the cause. In general, vibratory systems will include an elastic member to store the potential energy and an inertia member to store the kinetic energy with a damper wherein the incremental energy loss occurs. An example of vibration system is a simple pendulum which consists of string to act as elastic component and a bob to act as a conductor for kinetic energy. Some of the examples of vibrating system are system with spring mass, cantilever beam, simple supported beam, laterally vibrating string and vehicle suspension system, vibration due to unbalanced reciprocating or rotating force.

Vibrations may be reliable with certain amplitude and frequency but excessive vibrations result in:

1) Resonance and in turn excessive noise.
2) Structural failure of components of the machine.
3) Loss in power transmission in case of gears.
4) Increase in the bearing clearances.
5) Reduction in the working life of components.
6) Effect on the financial growth.

Vibrations are extensively dependent on time with displacements where the particles or systems of particles transform with a constant equivalence location. If there is a repetition of displacements and occur with equivalence condition in uniform period of time, the resultant moment is known as periodic. Natural frequency is one of the significant parameter related to engineering vibration. Every member consists their very own natural frequency to obtain various modes to control its dynamic behavior. Natural frequency of vibration mode in a structure corresponding to frequency of exterior dynamic loading is known as the phenomenon of resonance which leads to excessive deflections and potential catastrophic failures. Tacoma Narrows Bridge is a well-known example for structural failure under dynamic loading due to wind induced vibration in resonant condition.

The vibration analysis is of great importance in practical applications. For example, a great number of researchers are investigating vehicle stimulated oscillation in bridges and related structures that will simulate oscillation with respect to the beams and also different parameters such as suspension design, load of vehicle, momentum, damping, deck roughness etc., have an effect on the dynamic behavior of structures.

B. Classification of Vibrations:

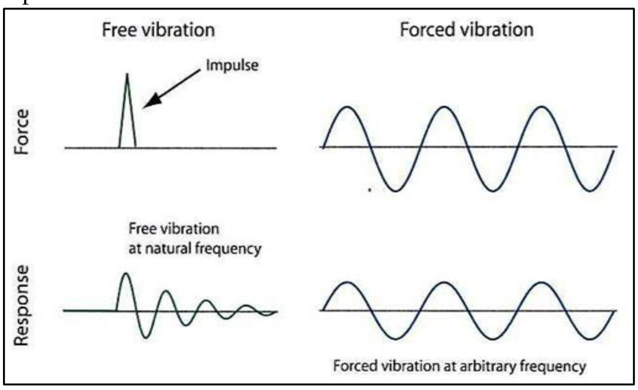
Vibrations are of great importance and in the field of dynamics of structures, each and every type of vibration is very essential and the study of all the types of vibrations are necessary. Therefore, classification of vibrations is studied here. There are various types of vibrations such as

- Free Vibration.
- Forced vibration.
- Damped vibration.
- Undamped vibration.
- Longitudinal vibration.
- Transient vibrations etc.

1) Free and Forced Vibrations:

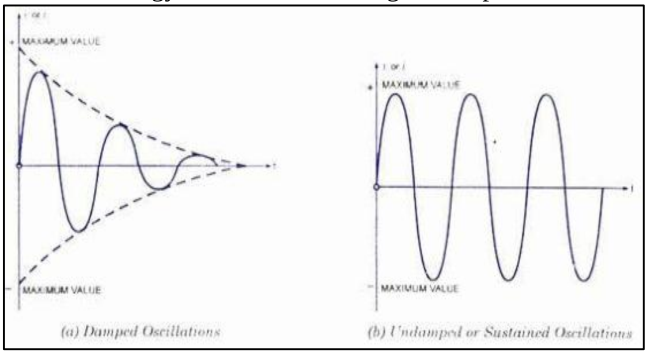
After internal disturbance, when no external force acts on a system and is allowed to vibrate freely on its own, then resultant vibration is called Free Vibration. An example set for free vibration can be given as the oscillation of simple pendulum. Due to the application of an external force, a repetitive force type occurs.

If the entire system vibrates with the application of external load, then resultant vibration is called Forced Vibration. An example for such vibration is oscillation in various machineries such like diesel engines. If system undergoes dangerous large oscillations due to resonance which occurs when the externally acting force of frequency resembles with any of the natural frequency in the system, then there is a failure in system. Such resonance results in failure in structures such as turbines, buildings, bridges and airplane.



2) Un-damped and Damped Vibrations:

If there is no loss of energy or dissipation of friction and additional resistance while the system oscillates within, then the resulting vibrations is termed as Un-damped vibrations. But if the energy is lost then resulting is Damped vibration.



For most of the engineering purposes in physical systems the amount of damping will be very less such that it will be disregarded. However, while analysis of vibratory system near resonance; damping should be considered which becomes extremely important.

3) Linear and Nonlinear Vibrations:

The fundamental constituents of a vibratory system such as mass, damper and spring act linearly leading to different vibrations termed as linear vibrations. Otherwise, if some of the primary elements act in a non-linear way then the resulting vibration is labeled as non-linear vibrations.

C. Crack:

Crack is defined as the break or cause of fracture without being separated from the main element. Beam crack will affect the vibration response of a structure by introducing local flexibility in the structural member. For detection of persistence of a crack, the location of crack and its depth in structural member property may be used. The existence of cracks in a structural member will affect its vibration response under external loads in the structure.

II. MATERIALS AND METHODOLOGY

Structural steel is taken as the material for the analysis of uniform and tapered cantilever beams. The cross sections of materials are considered to be in rectangular shape, I-shape and C-shape.

The analysis on materials is followed by methods such as Finite Element analysis. The Finite Element Analysis (FEA) is done using ANSYS Workbench 16.0. The investigation is done on the cantilever beam at different web taper ratios and the Natural frequencies of cantilever uniform and tapered beam of first six modes of vibrations are analyzed.

The modelling process in which models of uniform and tapered beams is done with the help of “Creo” software and on this models, the vibration analysis is done with the help of ANSYS software.

The cross-section is different for different depth and various web taper ratios are taken such as:

1) 0.375 (150/400)
2) 0.500 (200/400)
3) 0.625 (250/400)
4) 0.750 (300/400)
5) 0.875 (350/400)
6) 1.000(400/400)

III. RESULTS AND DISCUSSION

Vibration analysis of cantilever beam is performed for both uniform and non-uniform beams of different cross-sections such as Rectangular beam, I-section beam and Channel section beam. The variations of natural frequency with respect to different Web Taper Ratios are determined with the help of computer simulation using ANSYS software.

The first six natural frequencies for relative Web Taper Ratios of 0.375, 0.5, 0.625, 0.75 and 0.875 are calculated. The mode shapes for uniform and non-uniform beams are determined. The solutions obtained from numerical approaches are plotted in the form of graphs. The variation of natural frequencies for uniform and non-uniform beams can be seen in the obtained results. The values obtained for uniform and non-uniform Rectangular, I-section and Channel section beams are tabulated in the below tables:-

1) Table 3.1 shows the Natural Frequencies (Hz) for Rectangular Section Beam.
2) Table 3.2 shows the Natural Frequencies (Hz) for I-Section Beam.
3) Table 3.3 shows the Natural Frequencies (Hz) for Channel-Section Beam.

A. *Rectangular Section Beam:*

The vibration analysis of uniform and non-uniform Rectangular Section Beam is studied in this paper.

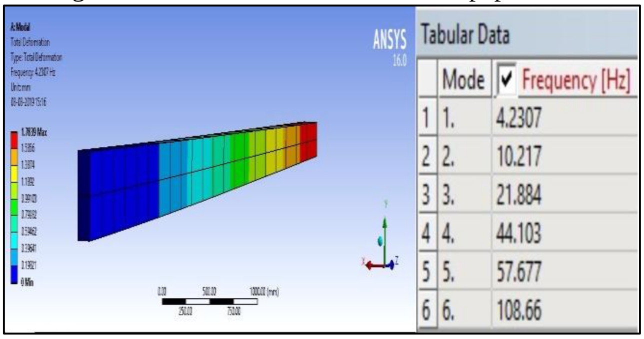
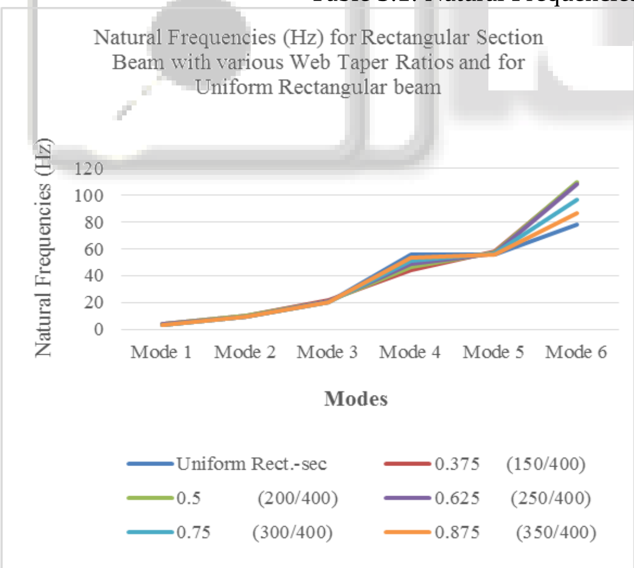


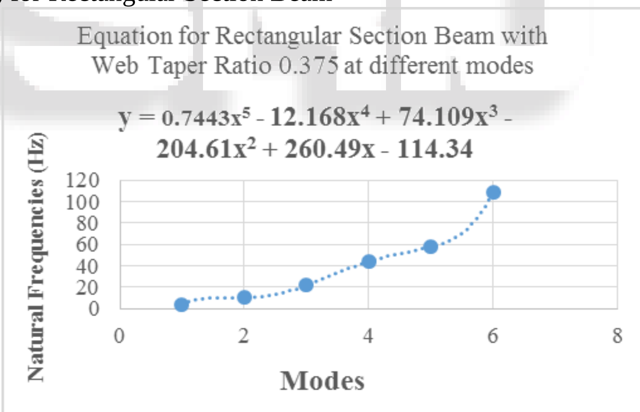
Fig. 3.1: Mode of Vibration of Rectangular-section beam (Web Taper Ratio 0.375)

Natural Frequencies (Hz) for Rectangular Section Beam with various Web Taper Ratios						
Web Taper Ratio (d/D)	Mode 1	Mode 2	Mode 3	Mode 4	Mode 5	Mode 6
0.375 (150/400)	4.230	10.217	21.884	44.103	57.677	108.66
0.5 (200/400)	3.915	9.848	21.300	46.668	57.037	109.95
0.625 (250/400)	3.674	9.576	20.859	49.086	56.582	108.21
0.75 (300/400)	3.482	9.364	20.508	51.373	56.232	96.438
0.875 (350/400)	3.325	9.194	20.215	53.546	55.950	86.523
1.00 (400/400) Uniform Rect.- sec	3.192	9.053	19.965	55.619	55.714	78.148

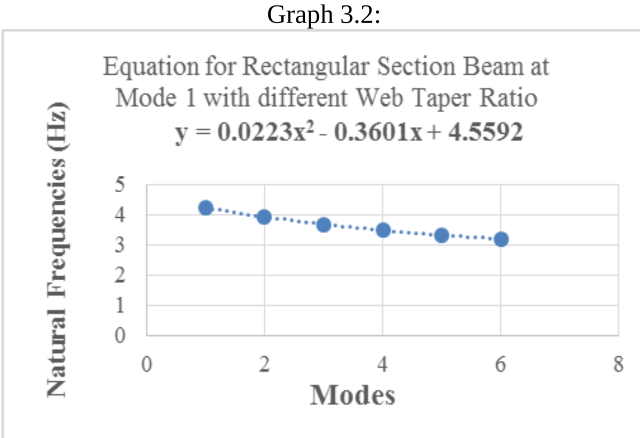
Table 3.1: Natural Frequencies (Hz) for Rectangular Section Beam



Graph 3.1:



Graph 3.2:



Graph 3.3:

1) Discussions:

As shown in Graph 3.1 and Table 3.1, It represents the natural frequencies of Structural Steel beam of Rectangular section from Finite Element analysis. By comparing the natural frequencies in Steel Uniform and Non-Uniform Cantilever beam, observation is that the Web Taper Ratio of 0.375 recorded highest natural frequency while Uniform Rectangular section recorded the lowest.

And Graph 3.2 shows the Equation for Rectangular section beam with particular Web taper ratio of 0.375 at different modes and similarly as Graph 3.2 Equations can be generated for other Web taper ratios such as 0.5,0.625,0.75,0.875 and at uniform rectangular section.

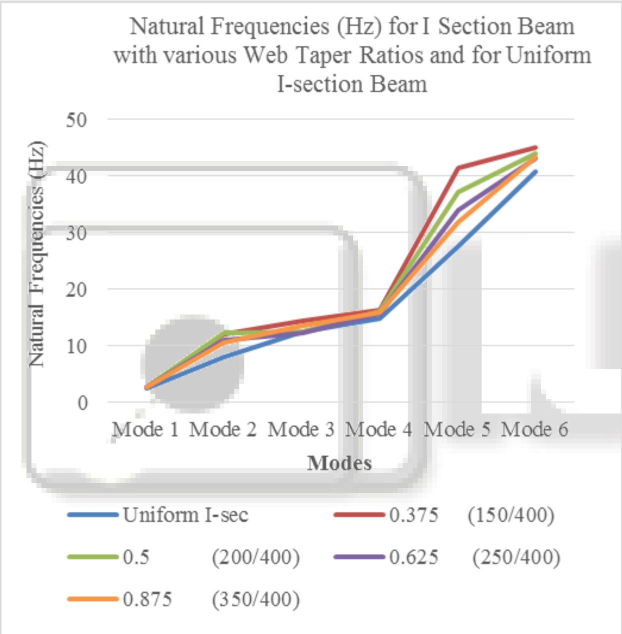
And Graph 3.3 shows the Equation for Rectangular section beam at Mode 1 with different Web taper ratios and similarly as Graph 3.3 Equations can be generated for other Modes also, such as Mode 2, 3, 4, 5 and 6.

B. I - Section Beam:

The natural frequencies of I-section Beam is calculated and tabulated with the help of computer simulation.

Natural Frequencies (Hz) for I Section Beam with various Web Taper Ratios						
Web Taper Ratio (d/D)	Mode 1	Mode 2	Mode 3	Mode 4	Mode 5	Mode 6
0.375 (150/400)	2.713	12.012	14.405	16.296	41.333	44.867
0.5 (200/400)	2.629	12.137	12.492	15.939	37.13	43.973
0.625 (250/400)	2.552	10.952	12.226	15.607	33.818	43.128
0.75 (300/400)	2.692	11.757	13.249	16.003	34.386	43.893
0.875 (350/400)	2.641	10.522	13.406	15.759	31.759	43.245
1.0 Uniform I-sec	2.356	7.880	12.371	14.724	27.453	40.791

Table 3.2: Natural Frequencies (Hz) for I-Section Beam



Graph 3.4:

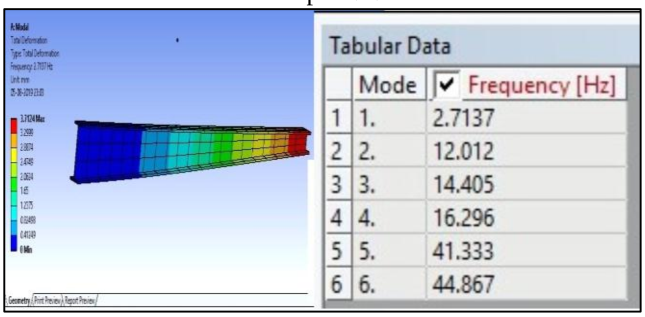
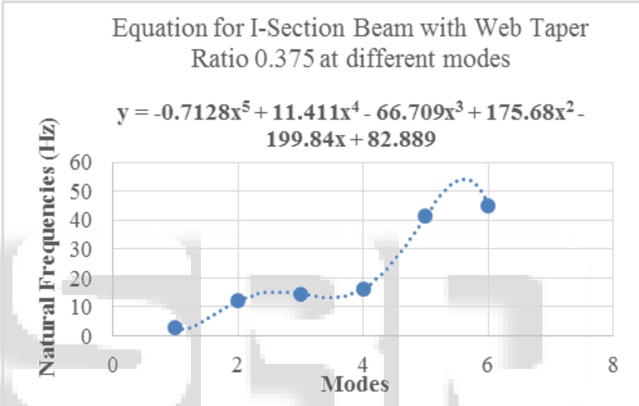
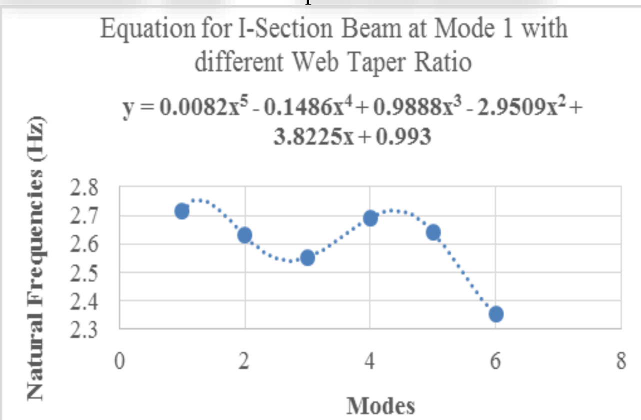


Fig. 3.2: Mode of Vibration of I-section beam (Web Taper Ratio 0.375)



Graph 3.5:



Graph 3.6:

1) Discussions:

As shown in graph 3.4 and Table 3.2, It represents the natural frequencies of Steel beam of I-section. By comparing the natural frequencies in Steel Uniform and Non-Uniform Cantilever I-beam, observation is that the Web taper ratio of 0.375 recorded highest natural frequency while Uniform I-section recorded the lowest.

And Graph 3.5 shows the Equation for I-section beam with particular Web taper ratio of 0.375 at different modes and similarly as Graph 3.5, Equations can be generated for other Web taper ratios such as 0.5, 0.625, 0.75,0.875 and at uniform I-section.

And Graph 3.6 shows the Equation for I-section beam at Mode 1 with different Web taper ratios and similarly as Graph 3.6, Equations can be generated for other Modes also such as Mode 2, 3, 4, 5 and 6.

C. Channel- Section Beam:

The channel section beam is analyzed and the results obtained are tabulated below.

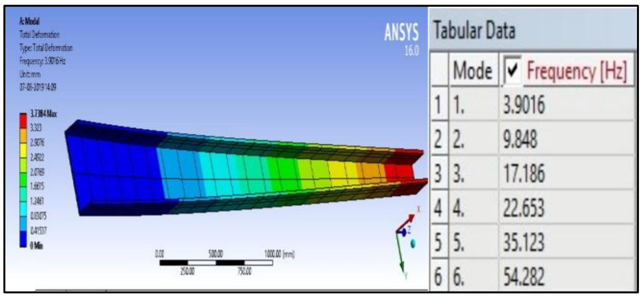
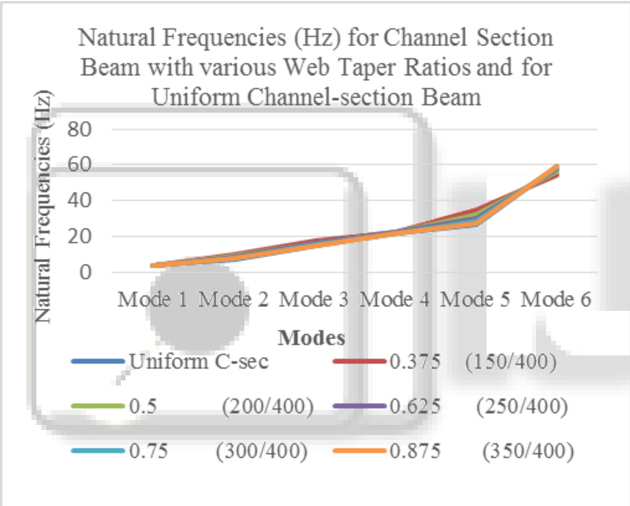


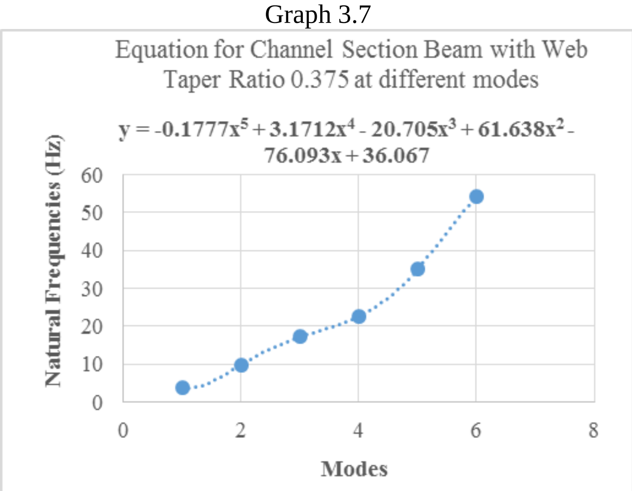
Fig. 3.3: Mode of Vibration of C-section beam (Web Taper Ratio 0.375)

Natural Frequencies (Hz) for Channel Section Beam with various Web Taper Ratios						
Web Taper Ratio (d/D)	Mode 1	Mode 2	Mode 3	Mode 4	Mode 5	Mode 6
0.375 (150/400)	3.901	9.848	17.186	22.653	35.123	54.282
0.5 (200/400)	3.799	9.290	16.385	22.434	32.293	56.385
0.625 (250/400)	3.705	8.693	15.767	22.209	30.198	57.843
0.75 (300/400)	3.6173	8.0852	15.286	21.969	28.586	58.695
0.875 (350/400)	3.536	7.529	14.916	21.736	27.401	59.186
1.0 Uniform C-sec	3.463	7.044	14.628	21.519	26.621	58.917

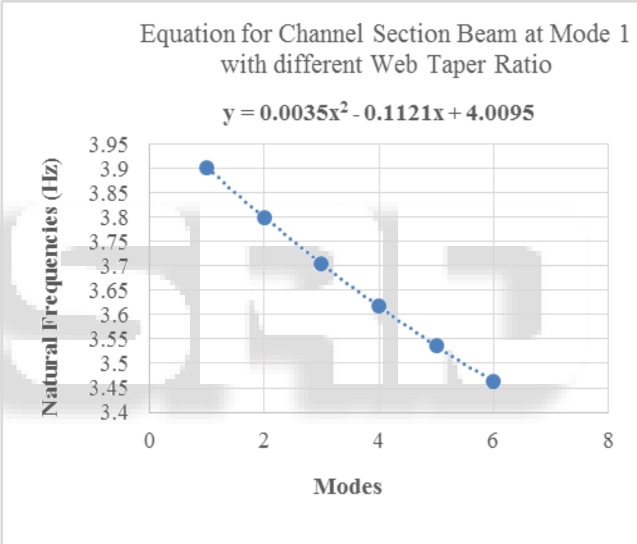
Table 3.3: Natural Frequencies (Hz) for Channel-Section Beam



Graph 3.7



Graph 3.8:



Graph 3.9:

1) Discussions:

As shown in graph 3.7 and Table 3.3, It represents the natural frequencies of Channel-section beam. By comparing the natural frequencies in Steel Uniform and Non-Uniform Cantilever Channel beam, observation is that the Web taper ratio of 0.375 recorded highest natural frequency while Uniform Channel-section recorded the lowest.

And Graph 3.8 shows the Equation for Channel section beam with particular Web taper ratio of 0.375 at different modes and similarly as Graph 3.8, Equations can be generated for other Web taper ratios such as 0.5, 0.625, 0.75,0.875 and at uniform Channel section.

And Graph 3.9 shows the Equation for Channel section beam at Mode 1 with different Web taper ratios and similarly as Graph 3.9, Equations can be generated for other Modes also such as Mode 2, 3, 4, 5 and 6.

IV. Conclusion

The computer simulation using ANSYS software supported to investigate and study of free vibration in cantilever beam to obtain the natural frequencies and their mode shapes.

Based on the simulation investigation and modelling work following conclusions are made: -

1) The first conclusion that is obtained is, if we increase the web taper ratio (d/D), then the natural frequencies of uniform and tapered cantilever sections such as Rectangular section, I-section and Channel section are also increasing.
2) In Uniform cross-section beams, the highest natural frequencies are of Uniform Rectangular section beam and the lowest natural frequencies are of Uniform I-section beam.
3) In tapered beams, the tapered Rectangular section beam has the highest natural frequencies and the tapered I-section beam has the lowest natural frequencies.
4) For tapered I-section beam, the highest natural frequencies obtained after analysis is found out at Web taper ratio of 0.375 (150/400) and the lowest natural frequencies are at Web taper ratio of 0.625 (250/400).
5) For tapered Channel Section Beam, the highest natural frequencies obtained after analysis is found out at Web taper ratio of 0.375 (150/400) and the lowest natural frequencies are at Web taper ratio of 0.875 (350/400).
6) For tapered Rectangular Section Beam, the highest natural frequencies obtained after analysis is found out at Web taper ratio of 0.375 (150/400) and the lowest natural frequencies are at Web taper ratio of 0.875 (350/400).

After all the analysis work, it is concluded that the web taper ratio which has the lowest natural frequencies, will be suitable for structural point of view, because the structure will vibrate at the lower rate, when the frequencies are less. Therefore, in this case, the most suitable uniform section is Uniform I-section beam.

And according to this analysis, the most suitable tapered section is Tapered I-section beam.

V. Future Scope

From this research, there are few recommendations that will be very helpful in the future work of vibrational analysis of Beam:

1) Various other cross section beams such as Hollow rectangular beams can be analyzed in this same manner.
2) In this research work, steel is used as a material of the beam. In future work, other materials can also be taken such as aluminum, magnesium etc.
3) The support end conditions can be changed to simply supported or roller and analysis can be done further. The beam can also be changed from cantilever beam to simply supported beam, fixed beam etc.
4) Analysis can also be done for cracked cantilever beam for dynamic response under the influence of external force. The crack depth and crack location can also be analyzed in future research work.

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