Faculty of Engineering

SMALL SCALE STRUCTURAL DEFECTS USING VIBRATION MONITORING TECHNIQUE

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BORANG PENYERAHAN PROJEK TAHUN AKHIR

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Approval Page

The project report attached hereto, entitled "Small Scale Structural Defects Using Vibration Monitoring Technique" prepared and submitted by MUHAMMAD SYAFIK BIN JUMALI in partial fulfilment of the requirement for Bachelor of Engineering with Honours in Mechanical Engineering and Manufacturing System is hereby read and approved by:

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March 2004

SMALL SCALE STRUCTURAL DEFECTS USING VIBRATION MONITORING TECHNIQUE

MUHAMMAD SYAFIK BIN JUMALI

This project is submitted in partial fulfilment of
the requirements for the degree of Bachelor of Engineering with Honours
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Dedication

To my parents, for their continuous love and support.

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ABSTRACT

Engineering structures are designed to withstand stresses and loads while in service. These structures are often tested for a few times larger than the force that it will experience in the field. However, as time goes by, defects will occur unnoticed. These defects will extend further and if no rectification is done, failure will result.

Vibration monitoring technique is a very useful and economic way of monitoring the condition of structures. This is done by monitoring the natural frequency, as natural frequency of material change due to defects. This in the end will provide an early warning to engineers to avoid catastrophic failures.

The technique was able to determine the first five modes of natural frequency and the change of natural frequency due to the introduction of defects. The natural frequency obtained by experiment was compared with the experimental values and showed a rather low percentage difference which points out the reliability of the method.

With the introduction of defects, the natural frequency changes accordingly. This corresponds to the change of geometry of the material due to the existence of defects.

ABSTRAK

Sruktur-struktur dalam bidang kejuruteraan direkabentuk untuk menangani beban. Struktur-struktur ini diuji dengan beberapa kali ganda daya yang akan dihadapi semasa berkhidmat. Walaubagaimanapun, setelah sekian lama, kerosakan akan berlaku tanpa disedari. Kerosakan ini sekiranya tidak dikesan dan diperbaiki, akan menyebabkan kegagalan kepada struktur.

Teknik mengawasi getaran adala satu kaedah yang sangat berguna dan ekonomi untuk mengawasi keadaan struktur. Ini dilakukan dengan mengawasi frekuensi asli kerana frekuensi asli akan berubah dengan kewujudan kerosakan. Ini adalah sangat berguna kepada jurutera-jurutera sebagai amaran awal untuk mengelakkan kegagalan.

Teknik ini mampu menentukan 5 mod frekuensi pertama dan juga perubahan frekuensi asli disebabkan oleh kerosakan. Frekuensi asli yang diperolehi melalui eksperimen dibandingkan dengan nilai yang dikira menggunakan formula. Perbandingan ini menunjukkan perbezaan yang rendah yang menunjukkan bahawa kaedah ini boleh diharap.

Dengan kehadiran kerosakan, frekuensi asli berubah mengikut kadarannya. Ini berlaku kerana perubahan geometri bahan tersebut dengan kewujudan kerosakan.

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CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

Mechanical properties of structures often change due to performing its intended function in the corresponding field. It is therefore important to monitor the changes and identify any abnormalities or defects that may lead to failure. This is vital in order to avoid premature failure of any structure.

Any engineering structure is always exposed to crack. Cracks are defined as external or internal separations with sharp outlines; cracks that require a magnification of 10X or higher are called micro cracks[1]. Cracks usually occur due to cyclic loading or stresses and can propagate along the path. This in the end leads to failure of the material. Therefore in order to avoid that, it is very useful if it can be detected and necessary actions be taken to avoid the letdown.

Vibration is a repetitive, periodic, or oscillatory response of a mechanical system. Natural vibrations occur in these systems due to the presence of two modes of energy storage namely kinetic and potential energy. The stored energy converts to one another during motion. The rate of the vibration cycles is termed frequency with unit Hertz (Hz). Repetitive motions that are somewhat clean and regular, and that occur at relatively low frequencies, are commonly called oscillations, while any repetitive motions, even at high frequencies, with low amplitudes, and having irregular and random behaviour falls into the general class of vibration.

Vibrations can naturally occur in an engineering system and may be representative of its free and natural dynamic behaviour. Also, vibrations may be forced onto a system through some form of excitation. The excitation forces may be generated internally within the dynamic system, or transmitted to the system through an external force. When the frequency of the forcing excitation coincides with that of the natural motion (natural frequency), the system will respond more vigorously with increased amplitude. This condition is known as resonance, and the associated frequency is called the resonant frequency. For many engineering systems, operation at resonance would be undesirable and could be destructive.

For the purpose of this project, mild steel is used as the specimen. Mild steel is categorised as low carbon steel with approximate carbon content in the range of 0.10% to 0.15%. Low carbon steels are characterised by low strength and high ductility and non-hardenable by treatment except by surface treatment processes. Mild steels are readily formed into intricate shapes because of their good ductility and also readily welded without danger of hardening and embattlement in the weld zone. Frequency surface hardened of mild steel by various methods as carburizing, carbonitriding and cyaniding which diffuse carbon into surface. A hard, wear resistant surface is obtained upon quenching. Apart from that, the frequencies are the main source in testing to measure the defects of the mechanical properties of structure by vibration monitoring technique.

Faults will be intentionally introduced throughout the experimental test in order to analyse and monitor vibration characteristics of mild steel. The faults on the mild steel beam are obtained by machine equipment.

Apart from that, the surface discontinuities present on the surface of the specimen can act as stress raisers. The stress raisers will reduce the mechanical strengths such as bend strength and fatigue strength. Therefore, the mechanical properties of the structure can be determined by monitoring vibration characteristics. In application, structural material will experience a complex combination of tension, compression, bending, shear and torsion forces. Effective and appropriate vibration monitoring technique can be practiced in order to determine changes in physical and mechanical properties of a structure. This can also be taken into account to determine the allowable load of the structure before it fails.

1.2 VIBRATION MONITORING SYSTEM

Vibration level of machineries is a great concern in manufacturing. The vibration monitoring system is designed with the philosophy to be used as a rather economical method to warn of forthcoming problems in machineries. If necessary, more sophisticated equipments can be used to further analyse the situation.

It is therefore designed as permanent installation to provide early indications and cautions of machine failure. It measures vibration in the frequency range of 10 Hz to 1 kHz and provides a 4-20 mA signal proportional to this. No particular form of analysis of the vibration signal provided, only overall figures.

The system is economic enough to replace scheduled maintenance. If a machine overhaul is to be done, the cost should be more than enough to pay for the system. Labour cost for scheduled maintenance can be saved by equipping machines with this equipment in order to avoid unnecessary machine overhaul caused by unforeseen circumstances.

Scheduled vibration measuring using portable equipment can be less costly initially but added cost for trained technician to take regular readings will cost more in long term. In between measurements, failure can happen without any indications. It is therefore feasible for the installation of this system.

Usually there are three vibration parameters often measured for machine protection namely acceleration, velocity and displacement. Vibration represents wasted energy, therefore the higher the vibration, the higher the energy wasted. Energy does not go away unnoticed, it induces movement, which in turn sooner or later will cause damage. Therefore the ability to determine the amount of energy will give us an idea on the condition of the machine whether it needs attention or simply wait and see the outcome.

Basic physics suggests that a moving particle or object contains kinetic energy. Kinetic energy is simply stated as $E_k = \frac{1}{2} mv^2$ where m and v represents mass and velocity respectively. Vibration is directly proportional to velocity therefore simply stated that if the energy increases by a factor of 4 whenever the velocity is doubled. This simple rationale brings us closer on how vibration affects the reliability of machines.

It is useful to point out that the velocity is seemed to be independent of the vibration frequency. However it is also noted that there are no simple mathematical relationship involving energy with acceleration or even energy with displacement. The choice velocity measurement is hence rather logical.

1.3 VIBRATION TECHNIQUE

In this project, vibration monitoring is used as the tool to evaluate the behaviour and changes in mechanical and physical characteristics of the tested structure. Vibration testing is a method of evaluation on how the given structure will respond to the energy supplied in the form of vibration. This is rather an issue of the reliability, as machines are often designed and tested for quality. Reliability will be thoroughly tested during its operation in the plant.

In this technique, a vibration exciter is used to provide the needed vibration while sensors are placed at convenient places along the mild steel bar. The sensors are connected to a computer equipped with the necessary software to interpret the response of the bar and represent it graphically on a chart. Interpretation of the graphical form of response determines the reaction of the bar due to the vibration.

Interpretation is done based on modal analysis which is a method of categorising the response by looking at the trend of the graph. If the graph follows certain trends, it will be interpreted accordingly. If somehow a unique trend is obtained, the process is repeated to confirm the corresponding trend.

Any material has its own natural frequency. The natural frequency will change due to the existence of defects. Monitoring this change will go a long way in determining or pointing out the source of the defects. It may also be possible to pinpoint the location of the corresponding defect so that it can be rectified.

1.4 AIMS AND OBJECTIVES

The main aim of this project is to establish the effects of the geometry and dimensions of the defects to the natural frequency and vibration characteristics of mild steel. This is done by monitoring the vibration characteristics to confirm that the defects introduced gave sufficient amount of change in natural frequency.

Before establishing the effects of geometry and dimension changes, the technique of vibration in this experiment used is tested to determine whether the technique is suitable for the task. This is done by comparing formula values and experimental values to assure that the experiment setup is feasible to evaluate the change in natural frequency.

The result of this experiment can be used to investigate further whether the pattern of the defected beam can be sufficient enough to pinpoint the location of the defects. This is very important in structural beams where defects can bring harm to the society. This is an important safety precaution for structures.

CHAPTER 2

LITERATURE REVIEW

2.1 VIBRATION ENERGY EXCHANGE AND MODE SHAPE

An engineering system, when given an initial disturbance and allowed to execute free vibrations without subsequent forcing excitation, will tend to do so at a particular "preferred" frequency and maintaining a "preferred" geometric shape. This frequency is termed the "natural frequency" of the system, and the corresponding shape (or motion ratio) of the moving parts of the system is termed a "mode shape".

The sum of energy remains constant within a structure. It can only change from one form to another. Natural frequency reflects the periodic exchange of kinetic and potential energies within the structure. Potential energy is relates directly to elastic strain or deformation of the structure from the equilibrium position while the kinetic energy is proportional to the square of the speed with which the structural mass is deforming. Therefore when a structure is deformed, it is supplied with potential energy and will then gradually change to kinetic energy as soon as the deformation is removed.

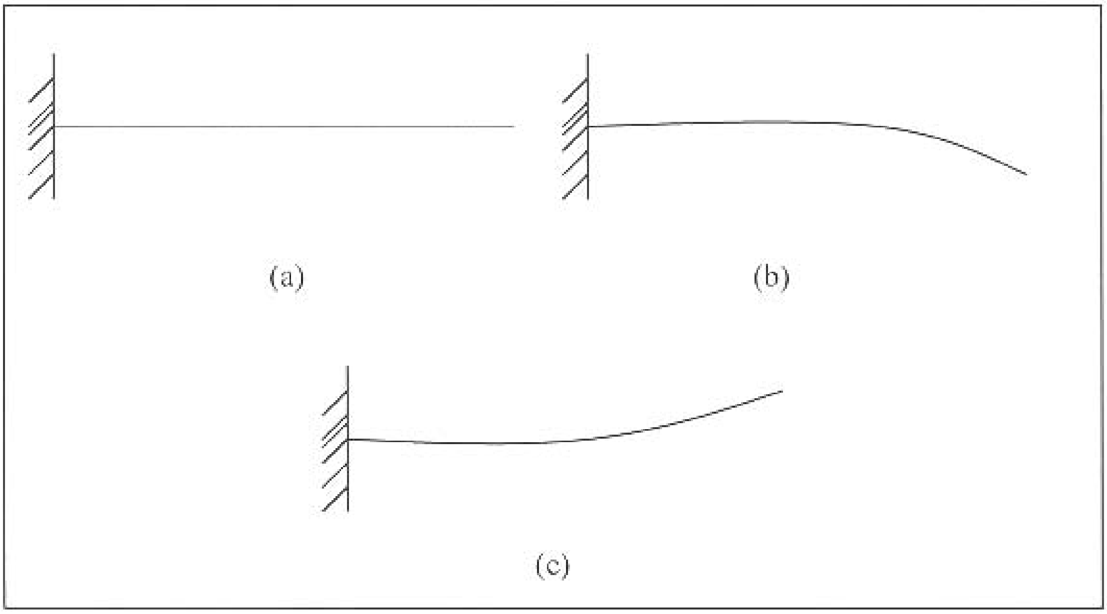

Figure 2.1: Beam Positions during Vibration

Figure 2.1 shows the configuration of a beam when subjected to vibration. While at rest, the beam is at position (a). In this position, the beam possesses zero potential and kinetic energy. When supplied with external force, e.g. downward force, the beam deforms to position (b). In this position the beam possesses maximum potential energy, zero kinetic energy and zero velocity. If the force is removed, the potential energy will gradually change into kinetic energy. At position (a), the beam will have maximum kinetic energy i.e. the potential energy is fully converted to kinetic energy. This reflects to it having maximum velocity. As the beam continues to vibrate, it will reach position (c). At this position, the beam will have zero kinetic energy thus zero velocity and maximum potential energy. The vibration continues with the beam returning to position (a) and the cycle continues.

As vibration continues, energy will be lost due to internal friction and air resistance. This applies to vibration in non-vacuum environment. The total energy will decrease, resulting in a decrease in maximum deformation and also maximum speed. The loss of energy will bring the beam to halt when both the kinetic energy and potential energy equal to zero. When that happens, the beam is said to return to its equilibrium position.

When a structure deforms during vibration, it has certain shapes. The shapes are known as the vibration-mode shape. For beams and plates there are infinite numbers of degrees of freedom which determine the vibration modes. Number of vibration modes is directly proportional to the degrees of freedom. A few types of beam configurations are shown in Figure 2.2, 2.3 and 2.4.

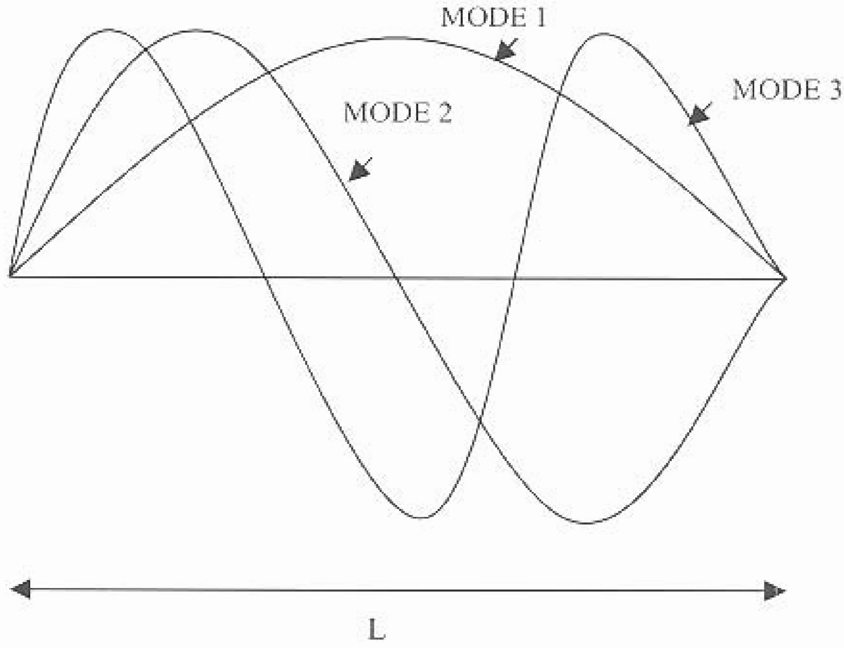

Figure 2.2: First three mode shapes of a slender beam clamped at both ends

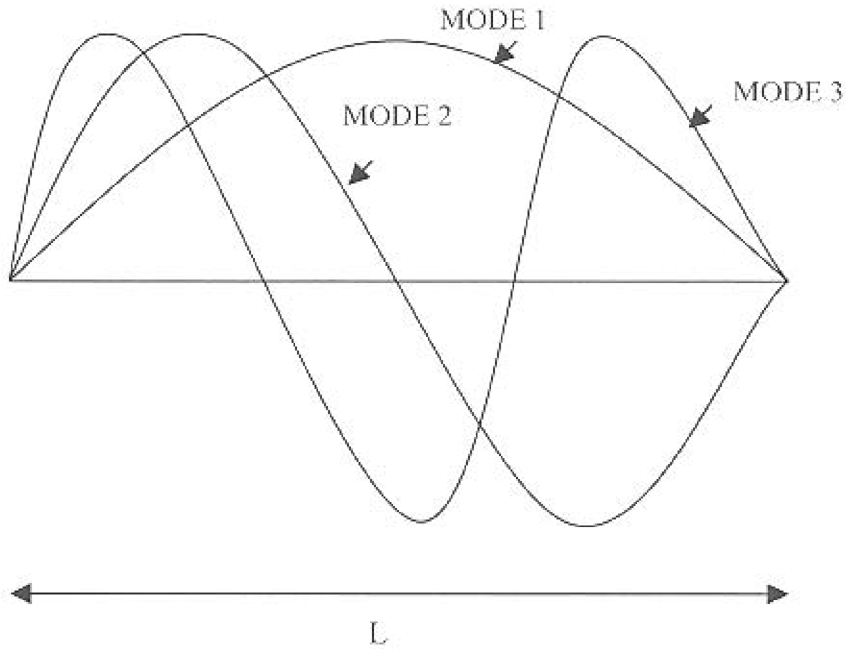

Figure 2.3: First three mode shapes of a slender beam clamped at one end and pinned at the other end

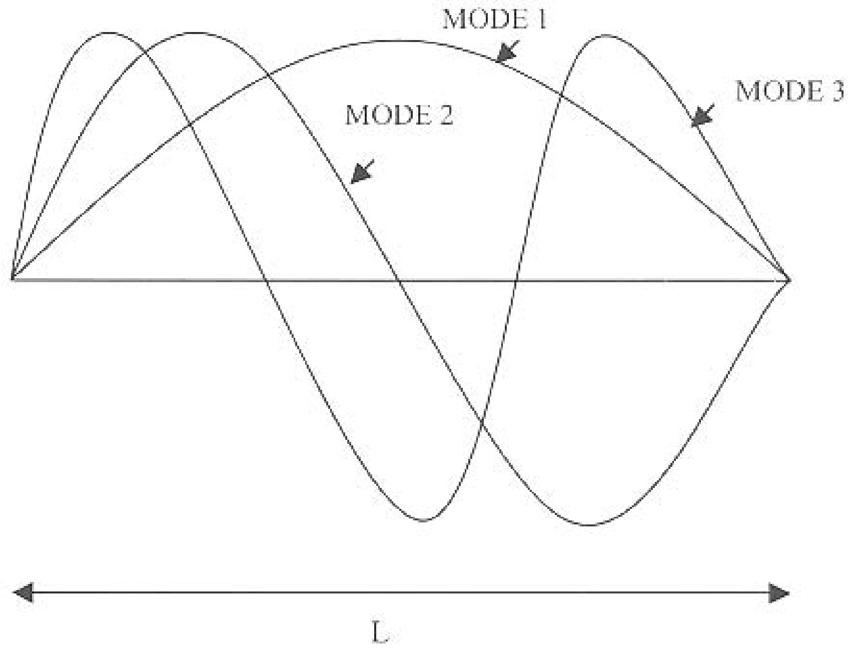

Figure 2.4: First three mode shapes of a slender beam pinned at both ends

From Figure 2.2, 2.3 and 2.4, the first three modes are similar in which the first mode is half a sine wave, second mode is a complete sine wave and the third mode is one and a half sine wave. This indicates the increment of half a sine wave each time. Therefore the next n modes will follow similar pattern of increment of the sine wave.

The natural frequency of a material is constant provided it has a uniform geometry. It does not depend on the amplitude of the maximum deformation supplied by the external force. The beam shown illustrates cantilever beam and the type of vibration energy exchange applies to structural vibrations.

As safety precautions, structures should be designed to tolerate the maximum and repeated stresses that are imposed by the service in the corresponding environment. This is due to the fundamental natural frequency, which has the greatest displacements and often responds to excitation most easily. In practice, structures are designed up to five times the force it will experience in the field of service.

2.2 DEPENDENCE OF NATURAL FREQUENCY ON MATERIAL, GEOMETRY, SUPPORT, LOADING AND MODE OF VIBRATION

As stated before, the natural frequency depends on a few factors. The few factors are namely material properties, its geometry, loading and support, and mode of vibration.

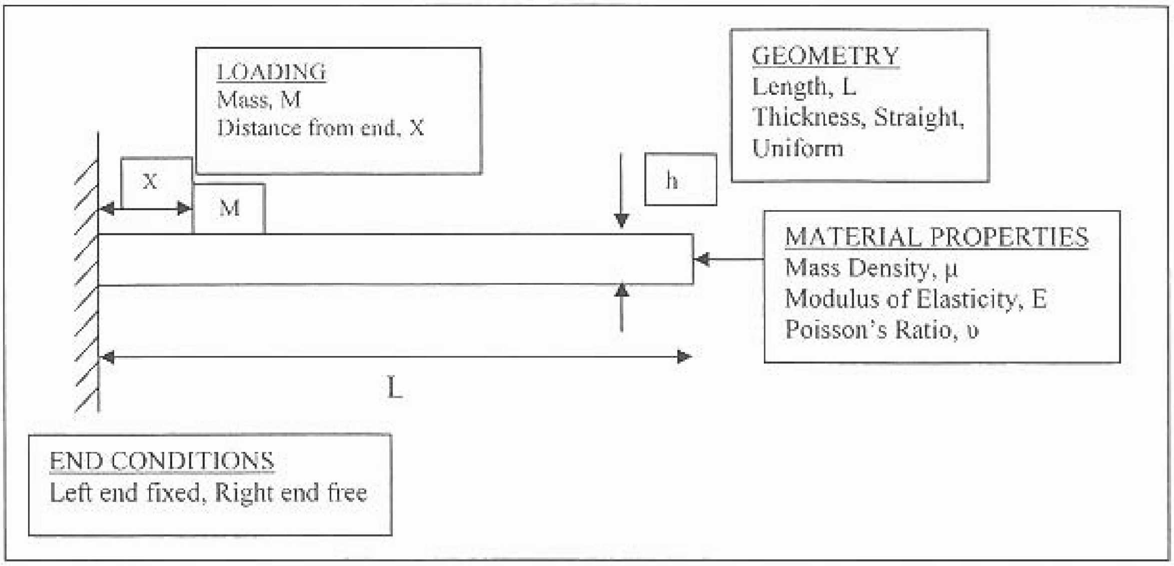

Figure 2.5: Method of Support

Natural frequencies are often associated with flexural (bending) deformation. An extended structure is always subject to tension or compression, in contrast to bending.

The flexural natural frequencies for many of the structures have a common form. For slender beams, arcs, and rings, the flexural natural frequency has the form,

$$F = (\lambda/2\pi L^2)\,(EIg/w)^{1/2} \qquad \textbf{(2.1)}$$

where,

λ = constant determined by type of structure support and mode number.

L = length of the beam or the radius of the arc or ring; mm

E = modulus of elasticity; N/m^2

I = area moment of inertia about the neutral axis or a principal axis; Nm

w = weight per unit length of structure; N/mm

g = gravitational acceleration

For plates, the flexural natural frequency has the form,

$$F = (\lambda/2\pi L^2)\ [Eh^3g/\rho\ (1-\upsilon^2)]^{1/2} \quad \textbf{(2.2)}$$

where,

λ = constant determined by type of structure support and mode number.

L = dimension of the plate; mm

E = modulus of elasticity; N/m^2

h = plate thickness; mm

g = gravitational acceleration

ρ = weight per unit area of the plate; N/mm

υ = Poisson's ratio

w = weight per unit length of structure; N/mm

For curved shells the dependence of F on the geometry is more complex. In many references, both λ and λ^2 are used in the frequency equations (3.1) and (3.2), the choice depending on the specific structure under consideration.

Note in equations (3.1) and (3.2) the natural frequency decreases with increasing structural dimension and increasing weight per unit length or area; and the frequency increases with increasing modulus of elasticity and moment of inertia or shell thickness. Note also that any change of the effective dimension for the material, it will decrease the natural frequency.

The terms EI/L and $Eh^3/12\ (1-\upsilon^2)$ are sometimes referred to as the stiffness of the beam or plate. A larger stiffness leads to a higher natural frequency.

A mechanically connected system may have similar or different boundary conditions for each end. A few types of boundary conditions are given below.