In this chapter the objective of the present investigation has further been consolidated through a comprehensive literature survey on the subject. Works published in a wide spectrum of journals have been collected, analysed and the goals for the present study have been given a firm foundation with the information derived from the survey. They are presented in the subsequent sections.

The major objective of the present investigation is to develop a theoretical analysis for dynamic characteristics of structures with a crack. In this section, the history and development of dynamic analysis of structures with crack has been presented. The presence of crack in structural members changes the dynamic response as has been established by [1,4,10,16,23,24,37,54,55,67,68,84,98].
2.2.1. STRUCTURAL VIBRATION AND ITS ANALYSIS

The development of vibration theory, as a subdivision of mechanics, came as a natural result of the development of the basic sciences i.e. mathematics and mechanics. The sciences were founded in the middle of the first millennium B.C. by the ancient Greek philosophers. The term vibration was used from Vedic times of India, approximately 10,000 B.C.. Pythagoras of Somas (570-497 B.C.) conducted several vibration experiments with hammers, springs, pipes and shells. He established the first vibration research laboratory. Moreover, he invented the monochord, a purely scientific instrument to conduct experimental research in the vibration of taut strings and to set a standard for vibration measurements.

Extensive experimental results were available for the vibrating strings since Pythagoras times. Daniel Bernoulli explained the experimental results using the principle of superposition of the harmonics and introduced the idea of expressing the response as a sum of the simple harmonics. The problem of the vibrating string was solved mathematically fist by Lagrange considering it as sequence of small masses. The wave equation was introduced by D' Alembert in a memoir to the Berlin Academic. He used it in his memoir also for longitudinal vibration of air columns in pipe organs. Experimental results for the same problem were obtained by Pythagoras. Euler obtained the differential equation for the lateral vibration of bars and he determined the functions that we now call normal functions and the equation that we now call frequency equation for beams with free, clamped or simply supported ends, while Daniel Bernoulli supplied him with experimental verification. The first systematic treatise on vibration was written by Rayleigh [110]. He formalised the idea of normal functions. He introduced systematically the energy and approximate methods in vibration analysis, without solving differential equations. This idea was further developed by Ritz [112]. Rayleigh
[110] introduced a correction to the lateral vibration of beams due to rotatory inertia and Timoshenko the correction due to shear deformation.

2.2.2. DYNAMICS OF STRUCTURE WITH CRACK

The problem on crack is the central problem of science of resistance of materials. The mechanics of fracture as an independent branch of the mechanics of deformable solids has originated quite recently. Galileo Galilei is rightly considered the founder of fracture mechanics. He stated that the breaking load is independent of the length of a tension bar and is directly proportional to its cross sectional area. In general the first stage of the investigation on fracture mechanics, associated with the names of Galileo Galilei, Robert Hooke, Charles Augustin de Coulomb, Barre de Saint Venant, Otto Mohr, is characterised by extensive studies of deformation properties of solids and by the development of various failure criteria termed strength theories. These theories state that fracture occurs at the moment when at a certain point of a body a particular combination of parameters, such as stress, strain, etc., reaches its critical value. In this approach the process of fracture propagation through the volume of the body is completely ignored, which is justified only in cases where the development of defects causing failure takes place in a small vicinity of the critical region.

Irwin [57] first studied about cracked beam, for finding out local flexibilities of the beam at crack location. Later Paris [123] developed theories for strain energy density function with the help of stress intensity function at the crack section. With the light of above theory Pafelias [94], Gasch [36] and Henry et al. [42] analysed the dynamic behavior of a simple cracked rotor. Also Mayes et al. [83] analysed the vibrational behavior of a rotating shaft system containing a transverse crack. Freud et al. [33] have analyses the dynamic fracture of a
beam or plate in plane bending. Subsequently Adeli et al. [5] have analysed the effect of axial force dynamic fracture of a beam or plate in pure bending. In eighties Dimarogonas et al. [27] investigated about the vibration of cracked shaft in bending. Dentsoras et al. [29] in their investigation they have taken coupling effect of various type of vibration (such as bending vibration, torsional vibration and longitudinal vibration) for analysis of dynamic behavior of cracked beam. Wong et al. [137] diagnosed the fracture damage in structures by modal frequency method. Also Nian et al. [91], Quain et al. [108], Ismail et al. [56], Rizos et al. [113] and Sekhar et al. [115] used the vibrational diagnosis approach for detection of structural fault.

2.3 EFFECT OF DIFFERENT PARAMETERS ON DYNAMIC RESPONSE OF STRUCTURES WITH CRACK

From the literature surveyed on the development of dynamic analysis of structures with crack, it is established that there are number of parameters which affect the dynamic response of structures with crack [16, 21, 26, 29, 36, 60, 65, 67, 68, 79, 91, 93, 96, 97, 99, 100, 101, 108, 113, 124, 136].

These parameters can be broadly divided into three parts.

1) Physical parameters of the structure as well as the crack on it.

2) The moving load on the structure.

3) The medium surrounding the structure.
PHYSICAL PARAMETERS:

Usually the physical dimensions, boundary conditions, the material properties of the structure play an important role for the determination of its dynamic response. Their vibrations cause changes in dynamic characteristics of structures. In addition to this presence of a crack in structures modifies its dynamic behavior. The following aspects of the crack greatly influence the dynamic response of the structure [16,21,26,36,60,68,91,96,97,99-105,108].

1) The position of crack.
2) The depth of crack.
3) The orientation of crack.
4) The number of cracks.

MOVING LOAD:

It is natural that the dynamic response of a structure is affected by the load moving on it. Jeffcott [58], Kenney et al. [54], Florence [31], Steele [122], Benedetti [14], Nelson [89], Hino [43], Stanisic [121], Saigal [114] and Argento et al. [11] have presented their findings during seventies and nineties. It has been reported that the dynamic response of the structure changes with the change in the intensity and velocity of the load moving on it. The theory so far developed for the dynamic response of structure with moving load has considered only a single mass for simplicity. However analysis for number of moving mass has not been reported so far.
MEDIUM SURROUNDING THE STRUCTURE

The presence of viscous medium around rotating structures greatly affect its dynamic behavior, mainly due to two reasons;

1) Damping effect of the viscous media.
2) Virtual mass effect on the rotating structure.

These effects have been studied [66,128] extensively for rotating shaft with/without disks. However, no study has been reported on the dynamic response of rotating shaft with crack in viscous medium.

As in the present investigation major thrust has been given on the analysis of dynamic characteristics of structures with crack, subjected to moving mass and working inside a fluid media, it has been planned to divide the total project into three major parts.

1) DYNAMIC CHARACTERISTICS OF BEAM/SHAFT WITH TRANSVERSE CRACK.

2) DYNAMIC ANALYSIS OF CRACKED BEAM/SHAFT WITH MOVING MASS.

3) DYNAMIC ANALYSIS OF ROTORS WITH TRANSVERSE CRACK ROTATING IN VISCOUS MEDIUM.

Literature available in this fields have been surveyed and details are presented in the subsequent sections.
As mentioned earlier the characteristics of transverse vibration of elastic structures under go change due to presence of crack. This has been reported by number of reporters working round the globe. Intensity of crack i.e. crack depth, location of crack have been taken into consideration in the theory developed so far for determination of natural frequency and mode shape of the structure. The different literature surveyed and their findings are presented below.

The fracture response of a long beam of brittle elastic material subjected to pure bending was first studied by Freund et al. [33]. The main assumption on which his analysis rests was that, due to multiple reflections of stress waves across the thickness of the beam, the stress distribution on the perspective plane ahead of the crack was adequately approximated by the static distribution appropriate for the instantaneous crack length and net section bending moment.

Petroski et al.[107] constructed a dynamic weight function using a finite-element solution for a cracked beam. The weight function suffices to determine the time dependent stress intensity factor corresponding to other dynamic loadings of the same cracked beam. For illustration and verification of their technique, they have taken a pinned-pinned center cracked beam. Also Adeli [5] in his paper investigated about the dynamic fracture response of a long beam of brittle elastic material subjected to a transverse time-dependent concentrated load. The analysis presented by him took the transverse force, the bending moment, the axial force, and the crack length at the fracture section into account. In his analysis the crack length and other parameters of interest can be determined for any given force.
Dimorogonas et al.[27] have done vibrational analysis of cracked rotating shafts, which exhibit a certain particular dynamic response due to local flexibility of the cracked section. In their analysis most of the features of the response of a shaft with dissimilar moments of inertia can be identified. They have considered the system as bi-linear. They have taken a De Laval rotor with an open crack for their analysis. They have obtained the analytical solutions for the closing crack under the assumption of large static deflection. Finally they have developed a solution for the case in which local flexibility function they have found out experimentally.

The modal frequency method to diagnose the fracture damage experimentally in simple structures was adopted by Ju et al.[59]. They have illustrated that the damage geometry uniquely defines the spring constant of the "fracture hinge," for which it is independent of the loading strength, the frequency of vibration, and the damage location. They have also done the experiment which also exhibited the change in modal frequencies, by which the damage in the beam can be located. They have predicted that with an accurate analytical model for the experimental samples, the location of the damage can be predicted to within a accuracy of one percent of the length.

Papadopoulos et al.[98] in their paper studied the stability of cracked rotors in the coupled vibration mode. They have treated the local flexibility coefficients at the crack section in form of matrix. The matrix had off-diagonal terms which caused coupling along the directions which were indicated by the off-diagonal terms. For the rotating cracked shaft they have developed the differential equations of motion which gave the varying stiffness coefficients. They have developed a method for the determination of the intervals of instability of the first and second kind. The results had been presented in stability charts in the frequency vs. depth of the crack domain.
Chondros et al. [21] showed that the cracks that develop on machine members and structures influence their dynamic behaviour. They have used the Rayleigh principle for an estimation of the change in natural frequencies and modes of vibration of the structure if the crack geometry is known, assuming that the eigenvalue problem for the uncracked structure had been solved in advance. Their method reduces the computational effort needed for the full eigen solution of cracked structures and gave acceptable accuracy. To demonstrate the change in the dynamic behaviour of linear structures with the crack depth, they have analysed a cylindrical shaft and a plane frame consisting of prismatic bars for dynamic sensitivity to surface cracks. Nian et al. [91] in their paper analysed the sensitivity of structural vibration parameters to fault. The frequency response function, which is sensitive to structural fault and able to reflect structural dynamical properties, was chosen by them as a parameter for fault diagnosis. They have adopted the least square identification method, Kalman filtering method, and the adaptive filtering method to diagnose structural fault. They have showed by simulation tests that, the diagnosis approaches presented in their paper were feasible and accurate.

Ismail et al. [56] in their paper depicted that vibration measurements can offer an effective, inexpensive and fast means of non destructive testing of structures. Their work was based on the investigation of the effect of crack closure on the frequency changes of cracked cantilever beams. That closure causes the frequency response function to exhibit a non-linear characteristics. Their study had been conducted by using both computer simulation and experimental modal analysis. They have identified crack flexibilities for open and closed position of several crack depths. They have also studied the effect of static preloading on the crack closure. By them, both simulations and experimental results led to the conclusion that, relying on the
drop in the natural frequencies alone, especially the higher modes, may lead to serious under-estimation of the crack severity. They have also stated that the investigation done by them can be used for vibration testing method in detecting the presence and the nature of the crack.

Rizos et al. have studied about measurement of flexural vibrations of a cantilever beam with rectangular cross-section having a transverse surface crack extending uniformly along the width of the beam. They have used the analytical results to relate the measure vibration modes to the crack location and depth. They have stated that from the measured amplitudes at two points of the structure vibrating at one of its natural modes, the respective vibration frequency and an analytical solution of the dynamic response, the crack location can be found out and depth can be estimated. Also Qian et al.[108] studied about the dynamic behaviour and crack detection of a beam with a crack. In their paper, an element stiffness matrix of a beam with a crack was first derived from an integration of stress intensity factors. They have analysed the beam using finite element method.

Kikidis et al.[65] studied about the slenderness ratio effect on cracked beam. They have stated that vibration characteristic of cracked beams and shafts became more important as the slenderness ratio decreases. For their investigation they have taken Euler Bernoulli theory and Timoshenko theory. They have found out the numerical results, for different crack depths and different slenderness ratios of the beam using both Euler-Bernoulli and Timoshenko beam theory. Papadopoulos et al. [97] in their paper discussed about the coupling of vibration modes of vibration of a clamped-free circular cross-section beam with a transverse crack. They have used the local stiffness matrix to simulate the crack. the nondiagonal terms of that matrix represented the coupling terms. They stated that their method is very sensitive even for small cracks.
Krawczuk et al. [67] have analysed the transverse natural vibrations of a cracked beam loaded with a constant axial force. They have used the finite element method for modeling the beam. They have modeled the part of the cracked beam by beam finite elements with an open crack. Parts of the beam without a crack were modeled by standard beam finite elements. They have presented an algorithm for calculation of linear stiffness matrix and global stiffness matrix for a cracked element. They compared their results with the results that are given in their literature. Abraham et al. [1] presented a method which utilised substructure normal modes to predict the vibration properties of a cantilever beam with a transverse crack. Their method can be used for crack detection. But they have verified their method experimentally.

Recently, Kam et al. [60, 61] investigated about the detection of crack using modal test data. They have also given a method for identification of crack size. Bradon et al. [16] analysed about the quasi periodic motion in the autonomous vibration of a cracked Timoshenko beam. In their analysis they have presented a method that utilises substructure normal modes to predict the vibration properties of a cantilever beam with transverse crack.
2.5 DYNAMIC ANALYSIS OF CRACKED BEAM/SHAFT WITH MOVING MASS.

For several decades, engineers have been investigating on the potential hazard produced due to moving masses on structures. The dynamic response of structures carrying moving masses is a problem of widespread practical significance. At the beginning of the twentieth century, engineers such as Jeffcott [58] managed to calculate the dynamic response of simple structures with a moving mass. However, no report is available on the dynamic response of structures with crack, under moving load. But the findings of investigators on dynamic behavior of uncracked structure under moving load are presented below.

Kenney et. al [64] in their paper presents an analytical solution and resonance diagrams for a constant velocity moving load on a beam on an elastic foundation including the effect of viscous damping. In their paper they have investigated the limiting cases of no damping and critical damping. They have found out the possible velocities for the free bending waves and studied their relationship to the critical velocity of the beam.

Florence [31] in his paper discussed about the analysis of traveling force on a Timoshenko Beam. His analysis was a wave theory applied to a Timoshenko Beam, by which he showed the effect of a force in supersonic velocity on a semi infinite beam. Two different end conditions were treated, one with a pinned end the other maintained at zero rotation with no shear. The second choice corresponds to a central initiation of a strip of explosive on a beam. He had carried out some numerical computations for both problems to
obtain velocity distribution curves and those were compared with corresponding curves using the Euler-Bernoulli theory.

Steele [122] in his paper obtained a series solution 'method of images' which converges rapidly for a simply supported, long beam with a high velocity, moving concentrated load. Each term of the series was a Fourier integral solution for an appropriate semi-infinite beam problem. The integrals were evaluated in closed form for the beam without a foundation and have a simple asymptotic evaluation for the beam with an elastic foundation. In particular, the asymptotic results provided a solution for the 'critical' load velocity, for which a 'steady state' solution did not exist, and for the limiting case of infinite load velocity, for which the beam was given an initial uniform lateral velocity.

Dynamic stability of a beam carrying moving mass was considered by Nelson et al. [89]. For their analysis they have taken the beam rested on a uniform elastic foundation and considered the damping by including a distributed viscous damping coefficient. They have taken the moving particles of uniform speed. They have used the Galerkin method to generate a set of approximate governing equations of motion possessing periodic coefficients. They have used Floquet theory to study the parametric regions of stability. Also Benedetti [14] in his paper the dynamic stability of beam loaded by a sequence of moving mass particle, he pointed out that, in general, multiple regions of unstable will occur instead of single boundary line as that in Nelson et al.[89]. He also pointed out that for certain particle spacing and foundation module a single region of unstable region occurs.

The paper by Yoshizawa et al.[135] dealt with flexural vibration of a simply supported beam, along which a body with pendulum moves slowly at constant velocity. The governing equations of the whole system, which were
simultaneous nonlinear ordinary differential equations with slowly varying coefficients, were asymptotically solved by using the method of multiple scales. They have estimated the maximum deflection in the internal resonant case.

The analysis of dynamic deflection and acceleration of a concrete bridge which is subjected to a moving vehicle load was done by Hino et al. [43]. They have taken the bridge constructed across the river Brahmaputra in India, which consist of 20 main spans, each main span is assumed to be double cantilever type with a small suspended span. They modeled the moving vehicle as one degree of freedom and analysed the deflection and acceleration at a specific location on the bridge when the vehicle at constant speed using finite element analysis. Hino et al. [44] in their paper analysed beams subjected to moving load. There the dynamic deflections of the beam were computed by using a Galerkin finite element formulation, and the time differential terms were integrated by using the implicit direct integration method. They used three types of approximations for solving the non-linear problem, in the first of which both the longitudinal deflections and the inertia are considered, in second only the longitudinal deflections being considered and in third neither the longitudinal deflection nor the inertia effect.

Yoshimura et al. [134] have analysed the dynamic deflections of a beam, including the effects of geometric non-linearity, subjected to moving vehicle loads. They assumed the beam to be elastic and simply supported with immovable ends and assumed the vehicle to be single degree of freedom spring mass damper. They have computed the dynamic deflection of the beam and the vehicle, as the vehicle moving on the beam from one end to the other, by using Galerkin method. They assumed the dynamic deflection to be a set of time functions multiplied by approximate functions, respectively. They computed the time function numerically.
Stanisic [121] studied the dynamic behaviour of structures carrying moving mass. He expressed the solution in terms of eigen functions satisfying the boundary, initial and transient conditions, for a heavy mass moving over a simply supported beam. Saigal [114] found out in engineering practice there are problems that involve more complex boundary conditions. For the above he went for the extended study that was done by Stanisic. In his paper he studied the dynamic behaviour of a clamped and a cantilever beam under moving masses. The effects magnitude and location of the moving mass on the deflection of the structure were studied.

Dynamic stability and response of a beam subjected to a deflection depended moving load was studied by Katz et al. [62]. They have taken up this problem keeping in view the cutting forces in machining operation. They have used Galerkin’s method to obtain a set of ordinary differential equations with periodic coefficients. They have found that the parametric instability can be expected for a continuous sequence of moving loads.

Dynamic response of a spinning Timoshenko beam with general boundary conditions subjected to moving mass was considered by Zu et al. [138]. They obtained the solution by formulating the spinning Timoshenko beam as a non-self-adjoint system. They computed the system dynamic response using modal analysis technique, for which they determined the eigen quantities of both the original and adjoint systems. They invoked the bi-orthonormality conditions in order to fix the adjoint eigen vectors relative to eigen vectors of the original system. In order to ensure the validity of their method, they have compared the results with those from Euler-bernoulli and Rayleigh beam theories. Akin et al. [8 ] in their paper used an analytical numerical method to determine the dynamic behaviour of beams, carrying a moving mass. The showed the response of moving mass instead of moving force.
Argento et al. [11] studied the response of a rotating Rayleigh beam subjected to an axially accelerated distributed surface line load. Clamped-clamped, clamped-pinned, and clamped-free support conditions and four types of load velocity profiles were treated. They have used Galerkin's method to suppress spatial dependence in the equations of motion. Results were presented for the beam displacement in the direction of the load. They have also studied the effects of load speed.

**2.6 Dynamic Response of Rotors with Transverse Crack Rotating in Viscous Medium.**

Rotor dynamics plays an important role in many fields of engineering, such as the gas and steam turbines, turbogenerators, reciprocating and centrifugal compressors. On account of the ever increasing demands for high power, high speed and light weight, which are the main reasons of failure in performances and fatigue in structures of the rotor-bearing systems. Critical speed is one of the important parameters in design of rotating shafts. Evaluation of such critical speeds are carried out using established standard procedures. However when a shaft rotates in a different media other than ambient air, viscosity of media plays an important role on the determination of critical speed. Further, crack in such rotors/shafts, as usually met in practice, will modify the dynamic behaviour of the system. Although a lot of work has been reported on dynamic response of shafts, rotating in viscous medium but no significant report is available on cracked rotors/shafts, rotating in viscous media. The literature surveyed along with their findings have been reported in detail, starting from the simple rotors in ambient air and the rotors rotating in viscous media. Findings on cracked rotor in ambient air as reported in some literature are also presented.
The study of free vibrations for a stationary Timoshenko beam can be traced back to the middle of this century when Kruszewski [70] obtained the frequency equations for the fixed-free and the free-free beams. Anderson [9] and Dolph [30] presented general solutions for the simply-supported boundary conditions. An almost complete theoretical treatment of the problem was published by Trail-Nash and Collar[127], giving the frequency equations and mode shapes for all six types of boundary conditions, namely, simply-supported or hinged-hinged, hinged-free, free-free, fixed-fixed, fixed-free, and fixed-hinged. However they only presented results for half the mode shapes as those associated with the bending angle were not derived. Using a more systematic approach, Huang [47] independently resolved this problem, again for the six boundary conditions. His analysis was complete, both with regard to the frequency equations and the mode shapes. With the exception of the simply-supported beam, the solution of the frequency equations requires a fair amount of computational effort as they are transcendental in nature. This led to the popularity of approximate techniques, mainly based on energy methods, for analysis and solution. Huang [46], and later Hurty and Rubenstein [50], gave some results for the simply-supported beam. Carr [20] presented solutions for all the six boundary conditions.

A very systematic and comprehensive analysis on rotor dynamics can be found by Dimentberg [28]. Bauer [13] carried out free as well as forced vibration analysis on rotating shafts for all types of boundary conditions. Hashis and Sankar [41] in their paper highlighted the vibration analysis of spinning Timoshenko beam system under stochastic loading conditions by the help of finite element method. In there paper they have taken flexible rotor bearing system and went for the solution taking into account the linear and nonlinear stiffnesses, and flexible bearing support. Ulsoy et al. [75] proposed a modal analysis for a spinning Rayleigh shaft. They have also presented the
Galerkin's approach to analyze the forced response of an undamped gyroscopic effect. Katz et al. [63] in their paper used a finite integral transform technique to calculate transient response for spinning Rayleigh and Timoshenko beams with the simply supported boundary conditions and subjected to a moving load.

Wong and Zu [137] carried out a complete free vibration analysis of a spinning, finite Timoshenko shaft with general boundary conditions. Subsequently Zu and Han [138] carried out the dynamic response of a spinning Timoshenko beam with general boundary conditions and subjected to a moving load. Recently Segalman et al. [117] used Quadratic Component method to analyze the dynamics of rotating flexible structures.

In order to study the effect of fluid forces on rotor rotating in liquid, Kito [66] analyzed an eccentrically rotating circular rod in a cylindrical container with an assumption that the flow velocity distributes linearly over the gap between the rod and the cylinder surface. Idea [51] also treated a rod rotating in an infinitely extending water region for its dynamic behaviour, but influence of liquid viscosity and the gap between rod and cylinder surface were not taken into account in the analysis. Further, Fritz [34] analyzed the similar problem, taking into account the influences of turbulence and Taylor vortex for a smaller rod-cylinder gap. Brenner [17] analyzed theoretically the fluid forces acting on a cylinder for high and low Reynold's number.

Walston et al. [128] in their paper discussed about the behavior of rotating shaft in viscous fluid, but no clear-cut distinction is made between virtual mass effect and damping effect on the rotating shaft. Vibration analysis of submerged beam are also reported by many authors. The response of a cylinder beam of finite length has been considered by Crighton [22]. These authors used an approximation where by the finite length beam is continued
into an infinitely long one. Achenbach and Qu [3] in their paper discussed about the forced transverse vibration of a submerged beam. They found out the solution numerically and check for this, was provided by the balance of rates of energies.

So far, the dynamic behaviour of a cracked shaft and crack detection have been studied in many papers. Some ideas about early crack detection proposed in the papers included in a comprehensive literature survey on the dynamics of cracked rotors [129] are helpful. The simplest model of the so-called De Laval rotor, which is a elastic but mass less shaft with an unbalanced disk, provides an equation of motion for a cracked shaft, enabling one to discuss natural frequencies, amplitudes of forced vibrations and areas of dynamic stability change related to the crack conditions at various rotational speeds [27,36,42]. More considerations of local stiffness coupled in bending and longitudinal directions affecting the dynamic behaviour have been discussed for the same model [96]. Parhi and Behera [99] in their paper discussed about the vibrational behavior of cracked cantilever beam with the help of influence coefficients at the crack section. They have also verified their results experimentally. Mayes and Davies [83,84,85] described a theoretical and experimental project designed to locate a transverse crack in rotor systems. Also Nelson et al. [90] discussed the same problem using perturbation technique. Sol [120] proposed an analytical model and correlated his results with those from an experimental rig. He demonstrated that the presence of a crack influences vibration amplitudes at the critical speed. Papadopoulos et al. [97,98] have discussed the behavior of rotating cracked shaft, but virtual mass effect (added mass) and external damping effect are not discussed separately. Dimentberg [28] has followed a very systematic approach for the analysis of a rotating shaft. Using Euler-Bernoulli beam theory Bauer [13] carried out the vibration analysis of spinning shafts for all possible combination of the classical boundary conditions. Hasis and Sankar [41] solved a spinning
Timoshenko beam system under stochastic loading conditions. They analyzed a flexible rotor bearing system, taking into account the linear and non-linear stiffnesses and bearing support flexibility. Inagaki, Kanki and Shiraki [53,54] have used the transfer matrix method, modeling the crack open/close mechanism by a step function for the bending moment.

Research works have been reported in which a simple rotor model has been used, and in those the reduced stiffness due to crack opening was introduced in the direction of weaker axis coinciding with the crack direction. While many investigators [36,42,83] used a step function to express the change of stiffness, assuming a sudden occurrence of crack opening and closing.

Ishida, Ikeda, Yamamoto & Masuda [55] in their paper discussed about the change in the resonance curve caused by the occurrence of a crack. Their results show that the shape of the resonance curve changes extremely due to the direction of the unbalance. Wu et al.[45] and Papadopoulos et al.[98] analysed about the stability of cracked rotors.

. the rotating elastic shafts in machines, such as steam turbines, the occurrences of crack due to fatigue have been reported [81,120]. In these cases the sudden increases of amplitude in the neighborhood of the critical speed were investigated in the non-rotating state by various kinds of tests [53,54], and the occurrences of crack were detected by these static tests.

2.7. CONCLUDING REMARKS

From the above survey it is evident that the present investigation on dynamic behavior of structural systems having crack, subjected to moving load and working in a viscous fluid medium is very much essential to generate
information, which will be useful in actual practice. Therefore it has been planned to conduct the present investigation in the following sequence.

1) Development of theoretical analysis for the dynamic characteristics of simple structures with a transverse crack using crack depth and its location as the variable parameters.

2) Derivation of theoretical expression for dynamic response of structure with a transverse crack, subjected to moving load, using the intensity and velocity of the load as variable parameters.

3) Development of theoretical expressions for dynamic response of cracked rotor rotating in viscous fluid using virtual mass and damping effect of the viscous fluid as variables.

4) For all the above cases, numerical analysis was also planned to generate numerical results in order to compare with corresponding experimental ones for establishing authenticity of the theories developed.