Fracture due to fatigue loading or static overload has been one of the common failure modes in most of the components of industrial structures such as stiffened panels in aerospace structures, welded joints and hatch regions in ship hulls and tubular connections of offshore structures. The structural components in these structures are generally subjected to a combination of tensile, bending and shear loads. Components of these structures generally have material flaws or cracks, which may have been introduced during the manufacturing process. If these flaws or cracks are not adequately accounted for at the design stage itself, they may lead to damage/failure of the structure/component under service loading over a period of time or due to unexpected overload well below the designed life or load levels. In order to predict the remaining life or residual strength of a structural component with a crack, detailed analysis of the crack growth and/or overload related fracture behavior is needed. Practically for all the high strength materials used in most of the structural components, which involve only small scale yielding around the crack tip, damage tolerant design can be performed through linear elastic fracture mechanics (LEFM) principles, in which case, stress intensity factor (SIF) is the influencing design parameter. It is necessary to develop accurate and economical techniques for the evaluation of this fracture parameter.

Numerical studies on the fracture behavior of structures/structural components involve proper modeling of the solids containing cracks and identification of an effective technique for computation of SIF. Literature on fracture analysis of structural components by using LEFM principles and the finite element method (FEM) is vast and a detailed review of this can not be attempted in this thesis. So, here a critical review of the literature on fracture analysis of 2-D crack problems, cracked plate and stiffened panels subjected to tensile and bending loads has been presented. The review covers methodologies for computing strain energy release rate (SERR) and SIF in various modes of fracture based on LEFM principles, which can be used as post-processing techniques to the finite element analysis (FEA). Current scenario of the R&D in the area has been highlighted and need for further research has been identified.

Among the various methodologies available for computation of SERR and SIF based on LEFM principles, the modified virtual crack closure integral (MVCCI) technique is
reported to be the most effective technique for 2-D as well as 3-D crack problems. For successful application of this technique, it was found from earlier works that it is essential to derive element dependent MVCCI expressions for computation of SERR. The derivation of MVCCI expressions involves evaluation of constants used in the polynomial assumed to represent displacement and stress variation and evaluation of many integrals. In view of these, the derivation of MVCCI expressions becomes a tedious exercise for higher order and singular 2-D and 3-D finite elements. It is particularly so, when singular elements are used near the crack tip. Therefore, a need is felt to overcome this tedious exercise by using a generalized approach involving numerical integration techniques for computation of the constants and to evaluate the associated integrals. There is a considerable scope and need for using this generalized technique for MVCCI evaluation in fracture analysis of cracked plates and stiffened panels. This motivation has resulted in the development of a new methodology for fracture analysis of cracked plates and stiffened panels under combined tensile, bending and shear loads.

The above mentioned new methodology known as numerically integrated modified virtual crack closure integral (NI-MVCCI) technique has been proposed for computation of SERR components and SIFs for crack problems in plane stress/strain fields, cracked plates and stiffened panels under combined tensile, bending and shear loads. NI-MVCCI is a generalized technique and is independent of the type of finite element employed. NI-MVCCI technique has been used as a post-processing technique to FEA for computing SERR and subsequently SIF depending on the assumption of plane stress/strain conditions. NI-MVCCI technique has been demonstrated for 4-noded, 8-noded (regular & quarter-point element (QPE)), 9-noded (regular & QPE) and 12-noded (regular & singular) isoparametric quadrilateral finite elements. Numerical studies on fracture analysis of crack (mode-I and mode-II) problems in plane stress/strain fields have been conducted employing these elements. SIF obtained in the present study by using 2-point integration for 4-noded element, 3-point integration for 8-noded (regular) and 9-noded (regular) elements, 4-point integration for 12-noded (regular) element and 9-point integration for 8-noded and 9-noded QPE and 12-noded singular element are in close agreement with the solutions available in the literature.

NI-MVCCI technique is also proposed for fracture analysis of cracked plates under combined tensile, bending and shear loads. NI-MVCCI technique has been demonstrated for 4-noded, 8-noded (regular & QPE) and 9-noded (regular & QPE).
isoparametric quadrilateral plate finite elements. These elements are based on Reissner-Mindlin plate theory that considers shear deformation. For all the elements, reduced integration/selective reduced integration techniques have been employed in the studies. In addition, for 9-noded element assumed shear interpolation functions (regular & QPE) have been used to overcome the shear locking problem. Numerical studies on fracture analysis of plates subjected to tension-moment and tension-shear loads have been conducted employing these elements. It is observed that among these elements, 9-noded Lagrangian plate element with assumed shear interpolation functions exhibits better performance for fracture analysis of cracked plates.

Later, the proposed NI-MVCCI technique has been used for fracture analysis of cracked stiffened plates under combined tensile, bending and shear loads. NI-MVCCI technique is appropriately modified to account for stiffeners in the stiffened plates. MQL9S2 (modified 9-noded Lagrangian plate element appropriately combined with quadratic stiffener element) stiffened plate finite element (FE) model has been used for idealizing the cracked stiffened panels. MQL9S2 FE model can account for arbitrarily located concentric/eccentric stiffeners. The 9-noded plate element and the stiffener element employed are based on Reissner-Mindlin plate theory and Timoshenko beam theory respectively, which account for shear deformations. NI-MVCCI technique for fracture analysis of cracked stiffened panels has been verified, validated by conducting numerical studies on panels subjected to tension-moment and tension-shear loads. The efficacy of this technique has been demonstrated through parametric studies on fracture analysis of typical stiffened panel subjected to tensile and bending loads. Based on the parametric studies, best fit polynomial equations have been obtained for computation of SIF in cracked stiffened plates subjected to tensile and bending loads. These equations can be used for rapid computation of approximate SIF values without conducting a rigorous FEA.

It is well known that the solutions obtained by using FEM are approximate. Despite the fact that NI-MVCCI technique leads to accurate computation of SIF, the errors due to discretization and the choice of crack tip element size may have significant influence on the reliability of SIF. It is therefore essential to estimate the errors involved due to discretization and refine the mesh adaptively for accurate evaluation of SIF and stresses. A new post factum SIF-stress called K-S error estimator has been proposed for fracture analysis of crack problems in plane stress/strain fields to address such issues and demonstrate its efficacy. The error estimates are computed as a post-
processing approach to FEA and are based on SIF and stresses. The error estimator is based on improved SERR/SIF for the elements meeting at the crack tip and based on smoothed stresses for the elements in the other regions. The performance of the proposed error estimator has been demonstrated for crack problems in plane stress/strain fields by employing 4-noded, 8-noded and 9-noded isoparametric quadrilateral finite elements. The convergence of the error estimator has been studied by using uniform as well as unstructured h-adaptive mesh refinements.

The conclusions based on the studies conducted using the proposed methodologies and the scope for future studies has been highlighted.