3. LITERATURE REVIEW

In **1964, Chapman [21]** described the behaviour of simple composite section and shear connectors. He suggested that the relatively large shape factor of the composite section, for ultimate load design, is advantageous. Restrictions are, however, necessary to provide the limited rotational ductility of the composite section. The importance of the standard testing procedure for the shear connectors was emphasized. He also mentioned that for most of the loading conditions the shear connector spacing can be uniform.

Also, in **1964, Chapman** and **Balakrishnan [22]** investigated the behaviour of seventeen simply supported composite T-beams under static concentrated and distributed loading applied on the axis of the beam. The amount of shear connection was varied within the range which might be contemplated for design purposes and the effect of interface slip on elastic and ultimate load behaviour was observed. They recommended that the shear connection should be designed to carry the horizontal shear force existing in the beam at ultimate load. For this purpose it was recommended that 80 percent of the experimentally determined ultimate capacity of the shear connectors should be used.

In **1985, Vallenilla** and **Bjorhovde [23]** explained that the deflection of composite beams with formed steel deck is influenced most significantly by the beam span, the slab width and the degree of shear connection. They also pointed out that the procedure used in the AISC Specification for determining the effective width gives excessive beam stiffness properties. As a result, beams designed on this basis tend to underestimate actual deflections. Results of the proposed formulation for the effective width were found in good agreement with actual test data. Use of the suggested approach gives the designer a better way of accounting for the effects of partial shear connection on the strength and behaviour of a composite beam with formed steel deck.

In **1987, Leon et.al. [24]** indicated that the composite semi-rigid frames offer very large gains in strength and stiffness over "bare" steel connections. For the service load range, these connections offer rigidities similar to those of rigid frames; while for the ultimate state they provide excellent ductility and energy-dissipation capacity. For the stability limit state, the continuous composite action over the column lines provides significant additional stiffness resulting in decreased drifts and associated P-δ effects. Moreover, semi-rigid composite frames provide a large degree of redundancy and have excellent force redistribution characteristics leading to increased safety. Thus, semi-rigid composite frames represent a very economical and structurally efficient solution to the design of low-rise frames.

In **1988, Vinnakotas** and **Foley [25]** proposed a simplified approach for the design of composite beams using the new LRFD Specification. The approach is applicable to composite beams with flat soffit slab, with haunched slab or with composite metal decking wherein the ribs run perpendicular to the beam. Both partially composite and fully composite beams were included in the study. Unlike the design tables, the design charts provided in this paper are quite useful, because in using them it is possible to isolate a range of alternate designs that satisfy the LRFD strength design criteria. The most desirable or the most economical design could then be selected from this set using engineering judgement.

Razaqpur and **Nofal** in **1989 [26]** developed a three dimensional bar element to model the nonlinear behaviour of the shear connectors in composite concrete-steel structures. To establish the shear stiffness properties of the element the available shear force deformation relationship were used. The axial deformations were considered while flexural and torsional stiffness of the bar was neglected. Comparison was made with the available experimental data. The results of the analysis show that the assumption of negligible flexural and torsional deformations in the connectors is reasonable for the problems analysed.

In **1990, Lloyd** and **Wright [27]** conducted 42 'through-deck' push-out tests on specimens that incorporated trapezoidal profiled steel sheets and headed shear connectors to study the effects of varying basic through-deck push-out test parameters in order to recommend a standard configuration for such tests and to study the effect of practical sheeting-joint details on connection strength. As ultimate connection strength for the majority of the tests fell below current code-design values, a method to predict the observed ultimate strength was proposed based upon a wedged-shear-cone failure mode as observed throughout the tests.

In **1990, Murrey** and **Hillman [28]** investigated the potential of reducing the dead load of a structure by creating new light-weight floor systems using various configurations of building materials. The experimental versus theoretical values for the deflection at center slab were measured. The floor system was also tested for susceptibility to annoying vibrations induced by human occupancy. The vibrations were measured using a seismic accelerometer and the digital signals collected and filtered using a lap top computer. Once the vibration measurements were recorded, the natural frequencies were determined by processing the data using a Fast Fourier Transform (FFT) algorithm. The measured frequencies were found relatively close to the theoretical values. Thus, it is possible to predict the first natural frequency of this type of floor system with reasonable accuracy for use in vibration perceptibility analysis.

In **1993, Chien** and **Ritchie [29]** conducted study on composite floor framing systems including conventional beam-girder systems, composite steel trusses and the stub-girder systems. Each of these systems was evaluated and discussed, including the concomitant deck-slab system, and slab reinforcing requirements. The quality of structural concrete, especially the shrinkage and creep characteristics that affect either structural performance, serviceability, or both, were noted. The problem areas of composite design and construction were also addressed. They concluded that, the features of composite floor framing utilizing composite deck-slabs in multi-storey buildings that have made it economically attractive include access to alternative structural systems, efficiency on longer spans, improved integration of structure with mechanical systems, and superior flatness of floors with minimal deflections under both superimposed dead and live loads.

In **1993 Daniels** and **Crisinel [30-31]** provided an alternative approach to full-scale testing for composite slabs with ribbed decking used in buildings. The procedure consists of combining shear-bond test results with a numerical analysis to predict the behaviour and strength of composite slabs. The procedure incorporates certain simplifications and assumptions that allow for a reasonable yet conservative prediction of both behaviour and strength. Advantages of using this procedure rather than full-scale test results are versatility and reduced cost, the estimation of deformations at working loads, the inclusion of additional variables such as end anchorage (over the end supports), additional positive moment reinforcement (in the span), and reinforcement in negative moment regions (near interior supports). This procedure may also be used for the development of new decking and to improve the performance of slabs with existing decking.

In **1993, Xiao, Choo** and **Nethercot [32]** described a test programme to study systematically the moment resistance, initial stiffness and rotational capacity of composite connections. A wide range of variables were considered to investigate these properties under the influence of the composite action. Full details of the experimental behavior of all the specimens were reported. The initial stiffness, moment resistance and rotational capacity were found to be dramatically affected by changes in the reinforcement ratio in the slab, metal decking, steel joint type, column web stiffening and moment shear ratio. Flexible finplate composite connections can produce appreciable resistance moment if properly designed. The bearing capacity of the bolts in the lower portion of the finplate was found to control the final moment capacity of the connection.

In **1995, Krige** and **Mahachi [33]** tested composite slabs statically and dynamically in bending with special interest to bond failure between the concrete and steel deck. The effect of both small and large amplitude loading on fatigue strength and deformation characteristics was examined. Based on the fatigue strength results, some guidelines for the design of composite slabs subjected to fatigue loading have been provided. The information is given in the form of modified Goodman diagrams and algebraic expressions that can be utilized for design. In composite slab, for a 2-point line loading an improved endurance was indicated to repeated loading, as compared to the central line loading for a given minimum load.

In **1996, Hanswille [34]** discussed the effect of tension stiffening of concrete on the internal forces, stresses and the flexural stiffness with regard to the serviceability, ultimate and fatigue limit states of composite beams. For continuous composite beams the serviceability and the ultimate limit states as well as the limit state of fatigue are significantly influenced by the effects of cracking of concrete in hogging moment regions. In the limit state of fatigue the effects of tension stiffening of concrete are relevant for the reinforcement, the shear connection and the failure of the top flange of the steel beam.

Wang [35] in **1998** calculated the maximum deflection of steel-concrete composite beams with partial shear interaction. Under the guidance of various available design codes, this deflection is related to the strength of shear connectors in the composite beam. He developed a shear connector stiffness based approach based on the solution for a simply supported beam under uniformly distributed load. In both the finite-element analysis and the proposed method, uniform distribution of shear connection stiffness along the beam length was assumed. In the absence of a reliable way to calculate the shear connector stiffness, this paper suggested a simple procedure to obtain this value for use in practice.

In **1999, Chung** and **Narayanan [36]** introduced the provisions of the Eurocode 4 (EC 4) and the UK International Application Document related to the design of steel concrete composite columns. The terminology employed in Eurocodes was explained first, followed by the design philosophy of composite columns with encased I sections and concrete filled hollow sections. The objective was to assist designers to deal with practical problems encountered by them in their day to day work. The simplified method of designing composite columns based on EC 4 was explained in step by step manner and a design example was solved to illustrate the procedure for an isolated non sway column. Design tables for composite columns with concrete encased I-sections and concrete filled hot finished hollow sections were also presented to assist designers at the scheme design stage.

In **1999**, **Dissanayake, Davison** and **Burgess [37]** investigated the influence of composite beam-to-steel column joints on the behaviour of composite beams. A computer model was developed to simulate the behaviour of steel-framed buildings with composite floor decks. The program is capable of simulating the behaviour of two-dimensional subframes. It is also capable of taking into account the partial interaction between the steel beam and the composite slab, the orientation of the profiled metal deck, the effect of additional reinforcement over supports and the semi-rigid nature of the joint between the composite beam and steel column. In contrast to the usual observations made in isolated joint tests, the study indicated very low values of strains in reinforcing bars at the composite beam-to-steel column joint at the ultimate limit state. The results also indicated that the common types of composite joints available are capable of providing the rotation capacity required to sustain the ultimate load with about 1% of reinforcement over the support, without the use of expensive column web stiffeners.

In **1999, Gattesco [38]** presented a numerical procedure for the analysis of steel and concrete composite beams considering nonlinear behaviour of concrete, steel and shears connectors. The most refined stress-strain constitutive relations were used. An empirical nonlinear load-slip relationship was used for shear connectors. He pointed out that the shear transfer between concrete slab and steel beam occurs only where connectors are located and this procedure is capable of tracing the detailed response of composite beams over the whole loading range up to failure, provided failure is not initiated by buckling.

In **1999, Jasim [39]** applied a linear partial interaction theory to determine the deflections at mid span of simply supported composite beams with partial shear connection. The differential equations governing the behaviour of beams, when the distribution of connectors along the span is triangular, were developed. The exact solution was found and the results were so arranged that the deflections of partially composite beams were defined as ratios of the corresponding deflections of the equivalent fully composite beams. A design chart for determining the central deflections of beams was constructed. This chart can be used irrespective of variations in type of loading, geometry of beam and properties of materials.

In **2000, Dissanayake, Burgess** and **Davison [40]** developed a computer program to analyse the behaviour of steel-framed buildings with composite floor decks, taking into account both geometric and material non-linearities. The validation of the computer program against experimental results showed very good agreement not only in terms of load-deflection response but also in load–joint rotation and load-reinforcing bar strains.

In **2000, Galambos [41]** presented a brief review of the status of the structural steel research in the US at the end of the twentieth Century. They highlighted some of the needed research in steel structures like systems reliability tools development for bridges and buildings, area of fatigue and fracture mechanics, performance of members, connection and connectors under severe cyclic and dynamic loading etc.

In **2001, Chiew, Lie** and **Dai [42]** investigated the moment resistance of steel I-beam to concrete-filled tube (CFT) column uniplanar connections under monotonic static loading. An empirical formula was derived based on more than 100 numerical parametric analysis results. The proposed formula was found effective in predicting the moment resistance of the composite connection with or without stiffening details. The difference between the predicted values and finite-element analysis results, as well as the experimental results, was found less than 10% in most of the cases. The empirical formula shows that the tube thickness is one of the main parameters that influence the moment resistance. To verify the empirical formula and to understand clearly the static behaviour of the composite connections, eight specimens were designed and tested to failure, of which four specimens were semi rigid beam-to-column connections and others were rigid connections with different types of stiffening details. It was found that the best way to improve the moment resistance is by improving the boundary conditions at the interface, as well as moving the failure cross section far away from the column face.

In **2001, Fabbrocino, Manfredi** and **Cosenza [43]** proposed a method of analysis for the continuous composite beams based on a specific kinematic model of the cross section. The main feature of the model is the capability to take into account the slip at the slab-profile interface and the slip at the concrete-reinforcement interface. This approach allows the introduction of a constitutive relationship for bond between reinforcing bars and concrete in the theoretical analysis; thus, the tension stiffening effect in the negative bending moment regions can be computed, and the actual mechanical behaviour of reinforcing bars of the slab can be analysed. The results of numerical analyses are compared with the experimental data; a very good agreement is indicated.

In **2001, Liew, Chen** and **Shanmugam [44]** described a method of inelastic analysis that provides the necessary degree of accuracy for studying the limit-state behaviour of steel frames with composite floor beams subjected to the combined action of gravity and lateral loads. The proposed composite beam model is based on the closed-form M-Ø relationships. To ascertain the accuracy of the composite beam model, two composite beams and a steel portal frame are analysed and the results are compared with those obtained from tests and the more established methods. Finally, the robustness of the model is demonstrated by studying 2D and 3D building frames using various floor beam models so that their effects on the serviceability deflection and limit load can be compared. Studies indicate that the limit load of steel frames while considering the composite beam effect is about 30 % higher than that of the pure steel frames and the lateral stiffness can be significantly enhanced by considering the composite action.

Tryland, Hopperstad and **Langseth [45]** in 2001 investigated aluminium and steel beams subjected to concentrated loading and compared the results with experimental data available in the literature. The modelled test specimen referred to simply supported beams where the concentrated loading is applied either at the midspan or at the end support. The modelled cross sections cover a wide range of web geometries and flange stiffnesses, and loading through both circular and rectangular bars. The contact between the beam specimen and the loading bars is modelled with a contact algorithm, and the problem is solved by an explicit code. The correlation between the experimental and numerical results is quite good, especially for the ultimate capacity where the difference between predictions and tests is not prominent when compared to the scatter in the test results. The error in the ultimate capacity from finite-element simulations is within 14% of the measured value, and for the web deformation, simulations could predict the main effects that are obtained from the tests. The results showed that small elements are necessary for predicting the correct mode of failure, and the development of the local instability depends on the mass scaling and assumed imperfection field.

In **2002, Amadio** and **Fragiacomo [46]** analyzed the problems connected to the effective width evaluation for serviceability and ultimate analysis of steel–concrete composite beams. By a parametric study carried out by them through the ABAQUS code it was pointed out that how the actual codes do not provide, in general appropriate results, for elastic and ultimate limit state checks. The most important parameters that influence the effective width were analyzed. Some preliminary criteria for an adequate design were presented and they concluded that for two or three span continuous composite beam, a practically constant effective width along the beam axis may be considered.

In **2002, Campione** and **Scibilia [47]** investigated the experimental and theoretical flexure and compressive behaviour of short tubular steel columns filled with plain concrete and fiber reinforced concrete (FRC). In the case of short columns in compression, the presence of concrete inside steel tubes increases the bearing capacity with respect to unfilled columns and this effect is more evident in the square section. In flexure tests, the behaviour of composite members is strongly influenced by steel characteristics and the presence of FRC does not alter the maximum bearing capacity of beams with respect to beams filled with plain concrete. The presence of FRC inside the steel tubes determines higher values of deformation at maximum load. Load-deflection curves based on the cross section analysis in the hypothesis of perfect bond between the concrete and steel tubes allow acceptable prediction of the experimental behaviour.

In **2002, Hajjar [48]** presented work on a number of composite lateral resistance systems, including un-braced moment frames consisting of steel girders with concrete-filled steel tube (CFT) or steel reinforced concrete (SRC) columns; braced frames having concrete-filled steel tube columns; and a variety of composite and hybrid wall systems. The benefits of these structural systems relative to more common systems include their performance characteristics when subjected to service or ultimate loads, and their economy with respect to both material and construction. He also presented more in-depth research results on composite systems, consisting of partially-restrained steel frames with composite reinforced concrete infill walls.

In 2002, Mediratta [49] presented the steps for the analysis and design of composite truss using limit state method while using the Indian standard sections. In support of this they also provided detailed solution of a composite truss design problem showing the use of methodology.

In **2002, Foutch** and **Yun [50]** designed 9-story and 20-story buildings. Different models for these structures were developed and analyzed statically and dynamically. The models investigated involved the use of centerline dimensions of elements or clear length dimensions, nonlinear springs for the beam connections, and linear or nonlinear springs for the panel zones. A second group of models also incorporated the fracturing behavior of beam connections to simulate the pre - Northridge connection behavior. Two suites of ground motions were used for the dynamic analysis. The differences in structural responses among different models for both suites of motions were investigated. According to static pushover analysis with roof displacement controlled, the benefits of the increase in capacity that results from the detailed models was observed for both 9-and 20- storied buildings.

In **2003, Chen [51]** found that in many cases, the load carrying capacity of composite slabs depends on the shear-bond resistance at the steel-concrete interface. At the ultimate state, the tension forces in the hogging region of a continuous composite slab are mainly transferred by the negative bending reinforcement and the shear-bond resistance in the region do not significantly influence the load carrying capacity of the slab. To identify the shear-bond action in composite slabs, seven simply supported one-span composite slabs and two continuous composite slabs were tested. The slabs with end anchorage of steel shear connectors were found to bear higher shear-bond strength than that of slabs without end anchorage. The prediction of the shear-bond resistance was also found in close agreement with the vertical shear force at the onset of the initial shear-bond slip in the two-span continuous composite slabs. He suggested that the shear-bond slip model is reasonable to predict the shear-bond resistance of a continuous composite slab. However, the shear span of the continuous composite slabs must be related to the sagging region, which could be derived on an elastic analysis basis or simply taken as 0.8 times span for the side span and 0.6 times span for the interior span. At the onset of the initial shear-bond slip, the mean ratios of the vertical shear force to shear-bond resistance are found as 1.065 for the one-span slabs and 1.165 for the two-span continuous composite slabs, which are on the safe side.

In **2003, Miranda** and **Ruiz-Garcia [52]** found that analysis and design of various mid-rise and high-rise composite building structures is controlled by drift rather than by strength criteria. Hence, adequate estimation of lateral deformation demands is particularly important.

A simplified method to estimate peak interstorey drift demands in multi-storey composite buildings was presented. Results from the simplified method were compared with the results from nonlinear response history analyses. It was concluded that for a wide range of building structures simplified seismic criteria may be used to estimate interstory drift demands and lateral stiffness requirements. Comparison of result suggested that for periods of vibrations longer than 1.2s, maximum inelastic deformations could be underestimated for certain seismic resisting systems.

In **2003, Sabelli, Mahin** and **Chang [53]** conducted research to identify ground motion and structural characteristics that control the response of concentrically braced frames, and to identify improved design procedures and code provisions. The focus of this paper was on the seismic response of three- and six- story concentrically braced frames utilizing buckling-restrained braces. A brief discussion was provided regarding the mechanical properties of such braces and the benefit of their use. Buckling-restrained braces provided an effective means for overcoming many of the potential problems associated with special concentric braced frames. Results of detailed nonlinear dynamic analyses were then examined for specific cases as well as statistically for several suites of ground motions to characterize the effect on key response parameters of various structural configurations and proportions.

Viest and **Ivan [54] in 2003** reviewed historical development of the requirements for the design of composite structures made up of steel elements and concrete, as practiced in the United States. He concluded that the composite construction is a system suitable for areas of high seismicity. The first U.S. seismic provisions for composite construction were included in the 1994 version of the National Earthquake Hazards Reduction Program's Recommended Provisions for Seismic Regulations for New Buildings issued by the Federal Emergency Management Agency in 1994. AISC included composite construction in the 1997 Seismic Provisions for Structural Steel Buildings and the provisions were also included in the 2000 edition of the International Building Code.

In **2004, Amadio et al. [55]** evaluated effective width for elastic and plastic analysis of steel–concrete composite beams. The experimental study was performed on four specimens. Both cases of sagging and hogging bending moments were investigated, with the influence of the beam-to-column joint. It was found that for all specimens the effective width increases with the load, approaching the width of the whole slab near the collapse. The presence of a beam-to-column joint does not affect the result. The comparison with the Eurocode 4 formulation demonstrated that such an approach is adequate for elastic analysis, whereas it may be too restrictive for plastic analyses. They highlighted that the use of the effective width evaluated for an elastic analysis is not appropriate for plastic analysis of composite beams. A simple approach was therefore presented for collapse analysis of composite beams under hogging bending moment.

Gopal and **Manoharan [56]** in **2004** studied the strength and deformation of both short and slender concrete filled steel tubular columns under the combined actions of axial compression and bending moment. Sixteen specimens were tested to demonstrate the influence of fiber reinforced concrete on the strength and behaviour of concrete filled steel tubular columns.

In **2004, Liang et al. [57]** evaluated the ultimate strength of the composite beams in combined bending and shear based on a finite-element analysis. They mentioned that the design models for vertical shear proposed for the design of the simply supported composite beams in combined bending and shear should provide an economical solution when the concrete slab connected to the top steel flange contributes to the shear strength of the beam as long as the shear connection is efficient.

In **2004, Loh, Uy** and **Bradford [58]** described the development of an iterative based analytical model to study the behavior of composite beams subjected to hogging type bending. Partial interaction concepts allowing for interface slip were considered, in conjunction with the inherent equilibrium and compatibility principles. The analysis results showed reasonable agreement with the results of the eight experimental beams. The full flexural response of the beams including shear connector slip was predicted adequately. Comparison with available results further verified the reliability and robustness of the model. An extensive parametric study was undertaken using the model that has been properly calibrated. In addition, a modified rigid-plastic method was proposed to improve the approach for use in practice, and to facilitate the inclusion of partial shear connection in the hogging moment regions of composite structures.

In **2004, Neal and Johnson [59]** presented the design procedure for the composite truss using BS codes and British sections. They focused on the important parameters of the composite truss design which affect the design considerably. They also suggested the various geometry options for the design of composite trusses.

In **2004, Nie, Fan** and **Cai [60]** reported that in negative bending regions near interior supports, tension in concrete is unfavourable and is a complicated issue, which deserves a special study. In this work, a mechanics model based on the elastic theory was established to investigate the stiffness of composite beams in negative bending regions by considering slips at the steel beam–concrete slab interface and concrete–reinforcement interface.

In **2004, Sapountzakis [61]** presented a solution to the dynamic analysis problem of reinforced concrete slabs stiffened by steel beams with deformable connection including creep and shrinkage effect. The adopted model takes into account the resulting inplane forces and deformations of the plate as well as the axial forces and deformations of the beam, due to combined response of the system. The analysis consists of isolating the beams from the plate by sections parallel to the lower outer surface of the plate. The forces at the interface producing lateral deflection and inplane deformation to the plate and lateral deflection and axial deformation to the beams are linearly related with the interface slip through the shear connector stiffness.

In **2004, Spacone** and **El-Tawil [62]** described the current state of the art of nonlinear analysis of steel-concrete composite structures. It mainly discussed frame elements which are computationally faster than continuum finite element models. Models with lumped and distributed inelasticity, as well as models with perfect and partial connections are covered. Rigid and partially restrained joints are reviewed and discussed at length.

In **2004, Thermou et al. [63]** discussed the seismic design and performance of composite steel-concrete frames. The deficiencies of the codes and the clauses that cause difficulties to the designer were discussed. One of the main issues observed in the analysis is the high over strength exhibited by the frames. This is due to design code constraints on section selection, such as second order effects ($h \leq 1$), leading to grossly over-conservative design. The inelastic static pushover analysis was employed for obtaining the response of the frames.

In **2005, Cheng** and **Chen [64]** investigated the seismic behavior of steel beam connected to RCC column with or without the floor slab, acting as a proof test for a three-story three-bay reinforced concrete column and steel beam in-plane frame tested at the National Center for Research on Earthquake Engineering (NCREE), Taiwan. Parameters considered included composite effects of the slab and beam, the tie configuration in the panel zone, effects of the cross-beam, and the loading protocol. All the specimens performed in a ductile manner with plastic hinges formed in the beam ends near the column face. Ultimate strength of the composite beam was found to increase by 27% compared to of the steel beam without the slab. On the basis of the comparison of the force–deformation simulation and test results, it was found that distortions in the panel zone accounting for the concrete bearing in addition to the panel shear can appropriately predict the total shear stiffness in the panel zone of RCS connections.

In **2005, Castro, Elghazouli** and **Izzuddin [65]** conducted study of the panel zone region within beam-to-column connections in steel and composite moment-resisting frames. The method rationally accounts for the effect of different boundary conditions, as well as shear and flexural deformation modes, in evaluating the elastic and inelastic responses. Validation of the proposed approach was carried out through comparisons against available experimental results in addition to more detailed continuum finite element analyses. The panel zone response within a composite frame was found to be significantly affected by several geometric and loading parameters, including the influence of beam-to-slab interaction on the stress distribution and distortional demand imposed on the panel. The results demonstrated that the approach developed provides a more realistic representation of the behavior in comparison to existing models, especially in case of composite connections. It was shown that, for composite joints, commonly used simple moment–distortion relationships may not be adequate which is primarily due to the dependency of the behavior on the internal force distribution at the joint. The study described the implementation of the suggested approach within frame analysis procedures, and substantiated the important role played by the panel zone in the response of moment frames under lateral loading conditions.

In **2005, El-Dardiry** and **Ji [66]** developed isotropic and orthotropic flat plate models for predicting dynamic behavior of composite floors with reasonably accurate. The two equivalent flat plate models were developed using the equivalence of the maximum displacement of a sophisticated 3D composite panel model. Thin shell elements were used to model the steel sheet and 3D-solid elements to represent the concrete slab. Parametric studies were conducted to examine the effects of boundary condition, loading condition, shear modulus and steel sheet on the equivalent models. The isotropic flat floor model was found more accurate than the orthotropic flat floor model, but it required the calibration using a 3D composite panel model. Significant time saving is achieved when either of the two simplified models is used. It is found from the study that the variation of floor thickness due to construction can significantly affect the accuracy of the prediction and the locations of neutral axes of beams and slabs are not sensitive to the prediction provided they are considered in the analysis.

In **2005, Han et al. [67]** attempted to study the monotonic and cyclic behaviour of steel tube confined concrete (STCC) columns. The main parameters varied in the tests were column section types, tube diameter to thickness ratio and load eccentricities ratio. Comparisons were made with the predicted column strengths and flexural stiffness using the existing codes. It was found that the STCC columns exhibit very high level of energy dissipation and ductility, particularly when subjected to high axial loads. Generally, the energy dissipation ability of the columns with circular section was much higher than those of the specimen with square sections. The formula developed for concrete filled steel tube columns was found to underestimate the moment capacity of STCC members.

In **2005, Jurkiewiez** and **Hottier [68]** studied a new connection device, based on horizontal shear connectors and avoiding welding through a steel–concrete composite beam subjected to a static bending test. Test results indicated behaviour similar to those of steel–concrete composite beams with usual connectors. A flexural failure occurred with a plastic hinge in the mid-span cross-section accompanied by yielding of the steel girder and crushing of the concrete. Therefore, the connection did not fail during the test and allowed to efficiently transmit shear forces from the slab to the girder though it was designed with no safety factor from ultimate capacity measured during push-out tests. Slip and up-lift remained low. Consequently, this study validated the proposed connection device under static loading and showed that it suits the structural modern code requirements.

In **2005**, **Lam** and **Lobody [69]** presented a paper on "Behaviour of Headed Stud Shear Connectors in Composite Beam" and developed a finite element model to simulate the load slip characteristic of the headed shear stud in a solid RC slab. The model takes into account the linear and nonlinear material properties of the concrete and shear stud. The FEM results compared well with the results obtained from the experimental push-off tests and specified data in the codes. All the modes of failure were accurately predicted by the FE model. The formulas given in EC4 gave a good correlation with the experimental results and FE solutions. Furthermore, all the codes seem to overestimate the shear capacity of the 22 mm diameter headed stud. They concluded with the remark that it may be possible to replace the need for expensive experimental push-off tests in the future to determine the shear capacity of the shear connector.

Lee, Shim and **Chang [70] in 2005** investigated the static and fatigue behaviour for shear stud and compared it with design equations. The ultimate strength of the shear connection showed that the design shear strength in Eurocode-4 and AASHTO LRFD gives conservative values for large studs. The fatigue endurance obtained from the tests was slightly lower than the current design codes in Eurocode-4. Based on the push-out test results on large studs, partial composite beams with about 38% degree of shear connection were fabricated and static tests were performed. They observed that the ultimate strength of the shear connection is about 1.59 times of that obtained from push-out tests.

In **2005, Vesey, Kwan** and **Xu [71]** described some recent and unusual designs using structural steel or composite steel and concrete which have been carried out in Hong Kong and East Asia Region. They mentioned that the well designed and properly fabricated steel structure can benefit the environment and permit faster and cleaner on-site construction by carrying out fabrication in high quality factories and by use of modular design. Modern design codes should improve design efficiency, provide clear and simple clause for normal structures and also contain guidance for more complex structures and design issues. The benefits of life cycle cost evaluation should become more widely recognised.

In **2005, Yao, Chen** and **Yu [72]** made attempt to study the monotonic and cyclic behaviour of steel tube confined concrete (STCC) columns. It was found that STCC columns exhibit very high level of dissipation of energy and ductility.

In **2005, Zeghichea** and **Chaouib [73]** conducted tests on 27 concrete-filled steel tubular columns. The test parameters considered were the column slenderness, the load eccentricity covering axially and eccentrically loaded columns with single or double curvature bending and the compressive strength of the concrete core. They also concluded that the column squash resistance calculated in accordance with the EC4 method is a reasonable estimate of the actual failure load of a stub column of concrete-filled CHS. The increase in the column slenderness decreases the load carrying capacity of composite columns. The use of high concrete strength enhanced the load carrying capacity of the tested columns, but with a load–slenderness relationship decreasing at a higher rate compared to that for columns using normal strength concrete. EC4 predictions for axially and eccentrically loaded columns with single curvature bending were on the safe side and in good agreement with the experimental and numerical failure loads. A comparison of experimental failure loads with the method described in Eurocode 4 Part 1.1 showed good agreement for axially and eccentrically loaded columns with single curvature bending whereas for columns with double curvature bending the Eurocode loads were higher and on the unsafe side.

In **2006**, **Lobody** and **Young [74]** proposed an accurate and efficient nonlinear finite element model to investigate the behaviour of shear connection in composite beams with profiled steel sheeting perpendicular to the steel beam. The models take into account the nonlinear material properties of the concrete, steel beam profiled steel sheeting, reinforcement bars and headed stud shear connectors. The capacity of shear connection, load-slip behaviour of headed stud and failure modes were predicted by the finite element analysis which compared well with the experimental results. The comparison of shear connection capacities obtained from the finite element analysis with the design rules specified in the American Specification, British Standard and European Code has shown that the American and British specifications overestimate the capacity of shear connection with a maximum value of 27% and 25% respectively. The design rule specified in the European Code are generally conservative, except for some cases that overestimate the capacity of shear connection with a maximum value of 11%.

In **2006**, **Marciukaitis, Jonaitis** and **Valivonis [75]** pointed out that the deflection of composite slabs depends directly on the shear stiffness of the connection between profiled steel sheeting and concrete. A method for calculating deflections of slabs is presented in this paper which is based on a theory of built-up bars, which allows one to take into account directly the shear stiffness of the connection. Influences on the stiffness of the structure of normal cracks in the concrete layer and plastic deformations of concrete that has been subjected to compression are also taken into account in the analysis. The method gives an opportunity to assess variations of these factors at all stages of the slab's behaviour from the start of loading up to the ultimate moment. In the results of these investigations, three stages of behaviour of the contact are distinguished. A connection shear characteristic is determined for each stage, which is used for calculating the deflection of the slab. Experiments are performed on deflections of composite slabs with a Holorib type of profiled sheeting. Variations in experimental deflections of slabs are explored from the beginning of loading up to the ultimate moment.

In **2006**, **Ranzi, Gara** and **Ansourian [76]** presented an analytical formulation for the analysis of two-layered composite beams with longitudinal and vertical partial interaction. The pecularity of this model is its ability to incorporate an interface connection deforming both longitudinally, i.e., along the beam length, and vertically, i.e., transverse to the connection interface, which is modelled by means of a uniformly distributed spring. The partial interaction problem is then solved by means of the finite element method. A parametric study is presented to investigate the effects of different combinations of longitudinal and transverse connection rigidities on the overall structural response. For the purpose of these simulations, a bi-linear constitutive model has been specified for the transverse interface connection to reflect the more realistic case in which two different responses are observed in the transverse interaction: one in which one layer is bearing against the other and another when the two layers are separating. An iterative procedure has been proposed to obtain the convergence to the final solution.

In **2006, Ranzi et al. [77]** presented a comparison of available numerical structural analysis formulations for composite beams with partial shear interaction. Using the solution of the exact analytical model as a benchmark, the accuracy of the three numerical techniques is tested for the cases of a simply supported beam and a propped cantilever. A qualitative comparison is carried out to highlight the adequacy and characteristics of these numerical formulations. For the two structural systems considered, the minimum spatial discretisations that need to be adopted to keep the error within an acceptable tolerance are provided for each of the formulations. It has been observed that the exact analytical solutions and the direct stiffness formulation provide identical results. It has been noted that the 10 dof element yields good results for relatively coarse discretisations.

In **2006, Vellasco et al. [78]** presented a parametric study of semi-rigid low-rise portal frame. They considered parameters like: connection stiffness and strength, structural system (steel or composite) and lateral frame stability. The parametric analysis, based on the Eurocode 3, led to the development of a simple structural model implemented in the ANSYS software. The model takes into account geometrical and material nonlinearities and the semi-rigid behaviour of their associate connections. Finally, the investigation results are summarized to access the economic potential and efficiency of the semi-rigid solutions. Up to a 15% economy in terms of steel weight was indicated for the investigated structures, even when compared to the traditional most economical solution.

In **2007, Marimuthu et al. [79]** carried out the experimental study to investigate the shear bond behaviour of composite deck slab to evaluate the m-k values. Totally 18 numbers of specimens were cast using M_{20} grade concrete. The specimens were tested as per the

Eurocode 4. They concluded that the shear behaviour of the embossed profiled deck slab depends mainly on the shear span. For the shorter shear spans, strength of slab is governed by the shear bond failure. If the shear span is large enough then the behaviour of the slab is governed by the flexural failure.

In **2007**, **Queiroz, Vellasco** and **Nethercot [80]** focused their investigation on the evaluation of full and partial shear connection in composite beams using the package ANSYS. The proposed 3D FE model is able to simulate the overall flexural behaviour of simply supported composite beams subjected to either concentrated or uniformly distributed loads. This covers: load deflection behaviour, longitudinal slip at the steel–concrete interface, distribution of stud shear force and failure modes. It was shown that the continuation of the shear connection beyond the beam supports of simply supported beams can affect not only the overall system response, but also the slip and the stud force distributions along the beam. It was also demonstrated that, by decreasing the level of shear connection, the composite system becomes more flexible, with reduced strength and stiffness, mainly for beams for which the partial interaction effects are significant and must be taken into account.

In **2007, Yu, Ding** and **Cai [81]** presented an experimental study on the behaviour of circular, concrete-filled, steel tube (CFT) stub columns with self-compacting concrete (SCC) and normal concrete (NC) concentrically loaded in compression to failure. Seventeen specimens were tested to investigate the effects of concrete strength, notched holes or slots, and different loading conditions on the ultimate load carrying capacity and the load–deformation behaviour of the columns. The behaviour of these stub columns in confinement was discussed. By using higher strength concrete, the specimens with the entire section loaded experienced a significant increase in the ultimate capacity, but their residual capacity after failure was almost constant. In some cases the ultimate capacity was also reduced and the steel tube acted more as a transverse confinement than an axial compression component. Eurocode 4 predicted a reasonable capacity for the unnotched CFT stub columns with both SCC and NC when the entire section of the specimen was loaded.

Also in **2007**, **Yahya** and **Kasim [82]** presented a paper on "Effects of concrete nonlinear modelling on the analysis of push-out test by finite element method". This study considers the practical application of nonlinear models using the reinforced concrete model of the general purpose finite element code ANSYS. The consequences of small changes in modelling are discussed and it is shown that satisfactory results can be obtained by relatively simple and limited models. This method can be used to conduct an extensive parametric study.

In **2007, Yassin** and **Nethercot [83]** presented a procedure for the calculation of the key cross-sectional properties of steel-concrete composite beams of complex cross-section. The formulation was developed in a format that is directly suitable for computer programming The procedure was applied to a new type of composite beam known as the PCFC (pre-cast cold-formed composite) beam. This is shown to perform better than equivalent, more conventional composite beams at the ultimate condition, but is slightly less efficient when considering some serviceability aspects.

In **2008, Wang** and **Li [84]** proposed a practical method suitable for the design of semi-rigid composite frames under vertical loads. The proposed method provides the design of the connections, beams and columns for semi-rigid composite frames at the ultimate and serviceability limit states. The rotational stiffness of beam-to-column connections for calculating the deflection of the frame beams and the effective length factor of columns was also determined. In addition, the accuracy of the proposed design method was verified by a pair of tests carried out on the full-scale semi-rigid composite frames. It was shown that the proposed design method is simple and convenient for a designer to use in practice.

In **2009, Cheng** and **Chan [85]** presented the optimal lateral stiffness design of composite steel and concrete tall frameworks subjected to overall and interstorey drift constraints as well as member sizing limits using an efficient numerical approach developed based on the Optimality Criteria (OC) method. A general finite element analysis process using ETABS for tall building structures was incorporated into the automated optimization approach using the developed program OCTB. The necessary optimality criteria were then derived for the design followed by the construction of an iterative scheme to satisfy these optimality conditions while indirectly optimizing the design problem with multiple constraints. The recursive OC process was then carried out with the initial member sizes obtained from a closed-form solution developed for the similar problem with a single drift constraint. A rapid convergence of the design optimization procedure was obtained. The efficiency and applicability of this automated optimization technique was further illustrated through a set of framework design examples.

In **2009, Ernst, Bridge** and **Wheeler [86]** pointed out that the application of trapezoidal type of steel decking with wide open ribs in secondary composite beams can create numerous premature concrete-related failure modes which significantly reduce the strength and deformation capacity of the shear connection and violate the requirement of a sufficiently ductile shear connection to be used in plastic composite beam design. The combined application of waveform reinforcement elements and spiral stud performance-enhancing devices surrounding the individual studs was found to delay the onset and reduce the effects of the concrete-related failure modes; hence they increased the ultimate strength and ductility of the shear connection. As none of the current design approaches distinguishes between brittle and sufficient ductile shear connection behaviours, a new design method has been proposed that differentiates between the various failure modes and specifies the suitable reinforcing measures to ensure ductile shear connection behaviour. Based on the 65 push-out tests performed on the Australian types of trapezoidal steel decking, this new method was found quite reliable for the strength prediction of stud connectors when compared to other recent approaches based on the analytical research.

In **2009, Fan et al. [87]** presented a detailed study of the dynamic characteristics and seismic responses of 508m high, 101 storied Taipei building which is located in Taipei where earthquakes and strong typhoons are common occurrences. The seismic analysis results of the super-tall building indicated that the structural system, with belt trusses at every eighth or tenth story, provides equal stiffness along the height of the building, which can decrease the lateral deformation efficiently. A shake table test was also conducted to determine the constitutive relationships for the CFT columns and steel members for establishing the finite element (FE) model of the tall building. The computational results indicated that the super-tall building with the mega-frame system possesses substantial reserve strength, and this high-rise structure would satisfy the design requirements under severe seismic events.

In **2009, Jia** and **Zhou [88]** carried out the experimental study on vibration behavior of 4 full scale cold-formed steel composite floors. The tested specimens analyzed with finite element program ANSYS. The research was focused on the fundamental frequency of composite floor, considering the influence of screw spacing and rigid blocking under different loading conditions. The finite element analysis model of cold-formed steel composite floors was set up to study the vibration behaviour; results were found close to those of the experiments. The results showed that the flexural rigidity of composite floor can be improved by changing the spacing of screws. It was suggested that the fundamental frequency of cold-formed steel concrete composite floor should be more than 8 Hz.

In **2009, Vasdravellis, Valente** and **Castiglioni [89]** investigated the influence of partial composite action between the concrete slab and steel beam and of partial-strength connections on the seismic response of composite frames. One-story one-bay moment-resisting frames with steel-concrete composite beams, were tested under base acceleration on the shake table. Specimens with intermediate and low shear connection degrees showed the most favorable performance in terms of ductile behavior and energy dissipation. A full shear connection does not necessarily have a good behavior under dynamic excitation, because it may lead to brittle failures of the welded beam-to-column connections, as observed during the tests. Then, FE models simulating the behavior of the tested specimens were developed and, after validation, exhaustive parametric study was carried out. Numerical results confirmed the experimental conclusions and revealed that the use of intermediate and low shear connection degrees with partial-strength joints results in an advantageous seismic design.