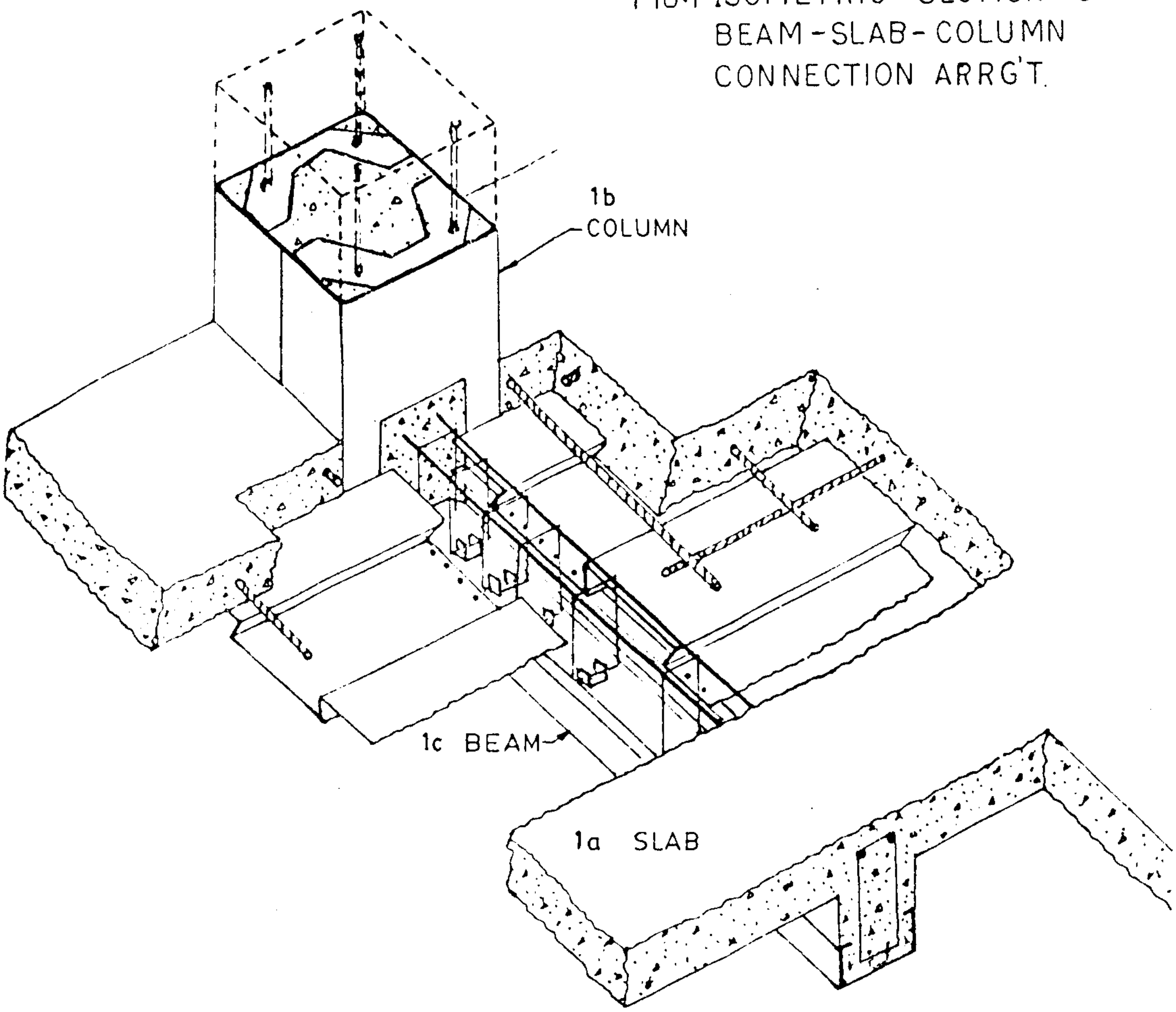
CHAPTER 1
INTRODUCTION

FIG·1 ISOMETRIC SECTION OF BEAM-SLAB-COLUMN CONNECTION ARRG'T.



CHAPTER 1 : INTRODUCTION

Positive trends in industrial production today towards light gauge - cold formed steel sections, are likely to increase the availability of these products, so that new avenues are opened for their optimal use in composite construction and as permanent formwork. According to a study in Ukranian Institute of Metals (CIS), the economical effectiveness of the cold formed steel products compared to hot rolled sections, is about 20% by way of reduction in cost of material and a further around 10% by reduction in cost of labour. Application of these sections in steel-concrete composite construction, is intended to offer products with high strength-to-weight ratio, better formability and surface finish inherent in the steel component. The added benefits are improved serviceability and durability, stricter tolerance limits and better self-forming ability. Consequently the speed of construction can increase many fold (by way of ease in handling and erection and reduced formwork), aesthetics are improved and material costs are reduced in addition to enhancement in structural efficiency of the sections.

The concept is also intended to meet the requirements of energy conservation and environment protection laws which are gaining importance of late. For example in manufacture of the raw material (hot rolled steel strip) through continuous casting and subsequent cold working, energy requirement is about 0.25 G cal/t less than ingot and hot working route. Faster production of light guage sections by electronically controlled cold-roll forming for more varieties of shapes with closer tolerance, online value addition techniques by operations like punching, indenting etc, and introduction of variety of coating techniques to tackle corrosion problems associated with products of thinner gauges are some of the encouraging trends of development in this regard. Use in permanent formwork conserves wood, a scarce energy resource (25% of the overall requirement of energy per tonne of erected R.C.C., amounting to 0.25 G cal, is conserved), in addition to the savings offered by elimination of formwork. Site-made temporary formwork is observed to be more than 2- times costlier than the concrete it encloses.

Application of light gauge steel as permanent formwork calls for special attention towards the following aspects. Large width-to-thickness ratios(up to 150) of the flat elements of the sections or large diameter-to-thickness ratios in tubular sections necessitate the check against dimensional tolerances and local buckling criteria and may call for the provision of stiffeners. Increase in strength due to cold working and effect of residual stresses are the further considerations. Need for temporary propping of permanent formwork calls for usual checks against propped construction like ponding deflections, effects of settlement of props etc.

Earlier applications as permanent formwork in slabs have led to significant development in the field of composite deck slabs with profiled light gauge steel sheet decking. Research developments in applications for supporting structure of slabs are felt not entirely adequate. Present investigation aims at developing the composite system having composite beam with light gauge steel channel soffit and concrete-filled rectangular steel tubular column (Fig. 1).

When light guage steel and concrete are ingeniously made up into a structure, the composite system offers a great deal of flexibility to the designer to see that the benefits of both the materials are well exploited and can also restrain and limit the disadvantages of both.

The steel component in the composite,

i) can be conveniently placed at critical location to increase effective depth and improve crack resistance leading to improved working strength under both static and dynamic loading conditions.

ii) can form an effective envelope for better curing and confinement of the concrete infill (16% increase in strength of hardened concrete and increase in ultimate compressive strength of 2.5 times cube strength in filled tubular columns and 2.3 times cube strength in soffitted compressive zones of beams are observed).

iii) can provide an interface with good bond characteristics (minimum ultimate bond strength 0.7 N/sq. mm and minimum allowable bond strength 0.1 N/sq.mm) which can be further improved by development of mechanical bond through ribs or indentations,

iv) can enhance the overall ductility of the composite system (ultimate compressive strains can be 10 times those in conventional R.C.C. beams and strains up to 15% are reached in filled tubular columns).

v) can improve the longterm performance (longterm deformations of filled tubes are observed to be 50% those of equivalent R.C.C. columns)

vi) can offer feasibile zones for faster and simpler welded site connections and

vii) can act as a durable protective surface with better maintainability (about 40% of the surface in contact with concrete needs no maintenance).

The infill concrete contributes by,

i) forming an effective compression zone,

ii) restraining the thin envelope from premature failure due to local buckling, thus improving both static and dynamic stability (critical buckling strength of hollow tube is doubled when filled with concrete),

iii) improving overall elastic stiffness (contribution of concrete to the combined modulus of elasticity is 75%, while contribution of steel is 25% in the filled tube),

iv) activating confining forces in the envelope by way of increased lateral deformability (Poisson's ratio increases from 0.2 in the elastic stage to 0.6 in the post yielding stage) and thus enhancing the ductility,

v) protecting the interface from corrosion due to external environment (e.g. hollow tubes need special protection against corrosion due to condensation),

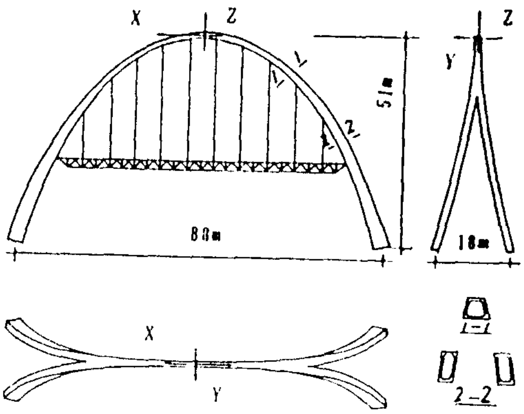
vi) absorbing thermal shocks due to sudden temperature change (say under short duration fire) or due to welding, without degradation,

vii) offering a compatible infill amenable to the provision of extra steel bar reinforcement where necessary, and

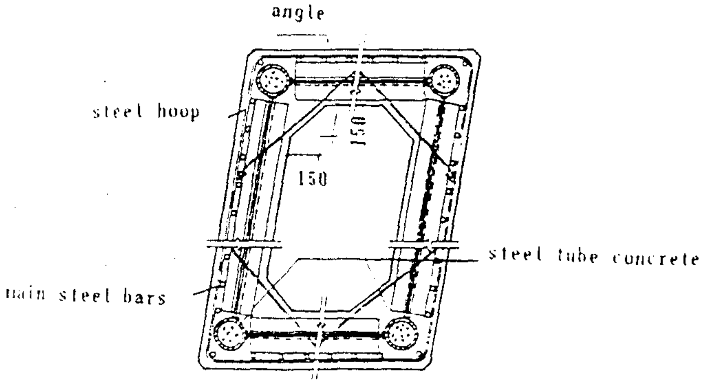
viii) making the addition of admixtures, feasible for special infill properties.

Another potential avenue for exploration, is the early exploitation of the structure for speedier progress of construction of subsequent stages compared to conventional R.C.C. construction. Favourable curing conditions of this composite systems are likely to speed up the hardening process

(d1) Roof system of Jiangxi Gymnasium in China



(d2) General layout of the arch



(e) Cross-section of arch (ring)

FIG.1 APPLICATION OF CONCRETE-FILLED STEEL TUBE IN ARCH RIB

(90% of the 28 days strength is observed to be achieved after 7 days). Admixtures like Alumstone to make expansive concrete are likely to improve the performance further.

Special attention to the selection and design of shear connectors as well as diaphragm stiffeners, is called for in the composite system under investigation. While the shear connector, as the name implies, is primarily intended to maintain, continuity of the interface against longitudinal shear and splitting forces, it is observed to improve the over-all behaviour significantly when disigned to directly link the compressive and tensile zones. There is a good scope for further research in this area. Design in this direction is likely to enhance the scope of functional requirements of the connector to behave as a binder between the stirrup reinforcement and the light guage steel envelope (Fig. 1c). There is a scope for improvisation and optimisation of connector design to simplify the connection detail, while investigating such multifunctional behavioural aspects.

Similarly, the diaphragm stiffener (Fig.1b), while primarily intended to prevent local buckling of the light guage steel envelope, can also be exploited to serve as, i) a spacer to position the bar reinforcement where necessary, ii) an arrester of prying mechanism in joints, iii) a shear connector where typical connector behaviour is called for (e.g due to the presence of longitudinal shear in combined bending and axial load behaviour of columns), and iv) as a component offering restraint to local bond failure and slip of infill (caused due to earth quake type loading in columns).

Stiffness of concrete-filled light guage steel tubular column can be expected to be less than that of robust columns with encased or bare conventional hot rolled steel sections. This transforms the joint rotational characteristics from usual beam stiffness-based behaviour to a typical combined stiffness-oriented behaviour. Thus, the beam-column joint of the composite system under investigation plays a key role in the designer's discretion while fixing the restraint levels. This aspect is also observed to have a significant scope for further research.

Looking at the global scenario of such developments in composite construction, the formation of the Association for International co-operation and Research in Steel-Concrete Composite Structures (ASCCS) in 1988, can be considered as a mile stone in bringing the research communities of different countries together and creating an opportunity for exchange of views and cooperative thinking towards planned development of the concept. China and Japan can be considered as the leading contributors to the application of composite construction. Several applications including heavy industrial buildings (e.g. the columns formed by 14 m tall space truss using 8 nos 114 dia x 4.5 thick filled tubes (Fig. 1d) and the cross section of 88 m span x 51 m high space arch (Fig. 1e) using 4 nos. 140 dia x 5 thick filled tubes, to support the space truss roof of Jaingxi Gymnasium in China) have been reported. In Japan it is claimed that 50% of the multi-storeyed buildings with more than 5 floors are built using such composite construction methods.

Research in Indian context, is yet to be given emphasis in line with the other leading nations. After the publication by H.T.Yan in 1965 [153] and the Indian standard IS:3935-1966 [155], it seems that the time has come for preparation of a comprehensive survey report on the applications of these composites in India till date. Efforts are also needed to update the Indian standard in line with latest revised standards elsewhere.

The chapterwise layout of the subsequent part of the thesis, presented in the following, is intended to give a broad picture of the present investigation.

CHAPTER 2 : REVIEW OF LITERATURE

Historical development of the concept of light guage steel concrete composite over the past 50 years is covered. Applications of permanent formwork using different materials like pre-cast and prestressed concrete, asbestos, fibre reinforced composite, hot rolled steel etc. are presented. Strength, load-deformation characteristics, serviceability and failure modes of the four structural components viz. slabs, beams, columns and joints investigated by earlier contributors are summarized in the respective articles. Important observations on the behaviour of specimens of somewhat similar geometry are presented in detail in view of their relevance, even though the material combinations are different (e.g. Taylor's beams with hot-rolled steel channel soffit, Johnson's and Ansourian's specimens with conventional composite beam components etc.). Investigations on shear connector behaviour using push-out tests are also presented. Apprendix III summarises some of the more recent findings.

CHAPTER 3 : SCOPE

The structural components like beam, column and joint chosen for the investigation and the respective behavioural criteria like flexure, shear, compression, tension etc are specified. Different standards and specifications, recommendations of which are verified by the specimen design and behavioural criteria are also listed.

CHAPTER 4 : EXPERIMENTAL WORK

Investigations are carried out on 4 nos. simply supported beams, 3 nos. beam-type push-out specimens, 2 nos. hogging beams, 27 nos. column/strut specimens, 3 nos beam-column joints and 6 nos, tension specimens. Coupon tests for tensile strength of flat and corner specimens of press-braked and roll-formed light guage steel channels, are conducted to consider the effect of cold forming. The strength of concrete used, ranges between 15 to 35 N/sq.mm.

Specimen geometry and design aspects related to selection of channel soffit, shear connector, diaphragm stifferers, welded connections etc. are presented through tables and discussed in detail along with salient analytical expressions. Load-deformation characterstics and failure modes are also presented.

CHAPTER 5 : ANALYSIS AND DESIGN

The analysis has two distinct stages, a) the construction stage and b) the composite behaviour stage. Salient features of stage a) are dealt in CHAPTER-4, while stage b) is covered in this chapter for the features such as flexure, shear and continuity aspects in beams, compression behaviour at early age of matuirity in columns, compression behaviour of columns with extra bar reinforcement and diaphragm stiffeners, strength, rotation and shear distortion behaviour of joints under combined flexure, shear and axial loading conditions, and stiffness of shear connectors in the shear span zones of beams. The different analytical approaches chosen for each of the above behavioural aspects are mentioned as follows:

1. Analysis for flexural strength of simply supported beams, is based on an iterative approach using partial interaction between steel and concrete.

2. Modified Zsutty's shear-bond equation based on dimensional analysis considering contribution of channel soffit to dowel action, is proposed in the analysis of shear strength.

3. Moment-curvature relationship using strain compatibility is proposed at the Zones of continuity in beams.

4. Expression for the trilinear compressive stress-strain characteristic are derived based on proposals of earlier investigations with the corresponding values of strength and elastic modulus of concrete at early age for different levels of confinement offered by tubular sections of different shapes and thickness

5. The negative effect of bar reinforcement on confinement is introduced while analysing the effect of confinement on the superposed compressive strength of columns.

6. The analysis of strength of the beam-column joint considering rotational charecterstics of both beam and column elements and panel zone shear distortions is based on transformed section subjected to combined axial compression bending and shear loading conditions.

7. The analysis of elasto-plastic behaviour of push-out specimens designed to simulate connector behaviour in shear span zones, is based on exponential function of pushout specimen behaviour in conventional composite system, with the exception that proportionality limit is chosen from the elastic behaviour exhibited in the tests.

Design limit states for strength and serviceability are specified for the different behavioural aspects, along with the basis (e.g. elastic limit state for early strength and ultimate limit state for strength after maturity in filled tubes).

CHAPTER 6 : DISCUSSION ON ANALYSIS vs TEST RESULTS

Reasons for the assumptions during design and analysis in each case and the corresponding behaviour exhibitted in test results are discussed.

CHAPTER 7 : CONCLUSIONS

Conclusions are drawn on the compliance of the analytical approach and results with experimental behaviour so as to establish the technical feasibility of the concept of light guage steel-concrete composite. The remaining inadequacies left to the scope of further research, are also highlighted.

The appendices to the thesis cover some important aspects of relevance to the present investigation as follows.

APPENDIX : I

Behaviour of conventional composite beams with different levels of interaction and different types of shear connectors.

APPENDIX : II

Microstructural and metallurgical aspects of cold work in cold forming.

APPENDIX : III

Recent developments in the study and appplication of steel-concrete composite after the formation of ASCCS are summarised. Miscellaneous behavioural aspects like effects of in-situ welding, shrinkage, creep, fire resistance etc. are also covered in this appendix.

APPENDIX : IV

Details of mathematical working and computer programmes are given in this appendix.

BIBLIOGRAPHY:

The reference of about 150 earlier investigations are listed to form a reckoner for future research.