CHAPTER 1: INTRODUCTION
This chapter highlights the primary significance of the present work, related to the lateral stability of the building structures. It defines the terms ‘infill’, ‘soft storey’, ‘braced frames’, ‘partial infill’ and ‘epoxy repaired frames’. The objectives, scope and methodology are indicated, and the outline of this thesis is provided.

1.1 Opening remarks
Due to the earthquake and ageing of the buildings, partial or severe cracks develop in the frames. A structure should be safe from collapse due to gravity loads but the need of safety from damage due to the lateral actions is equally important which is still ignored. Such actions on structures arise from earthquakes, wind, blasts, vibrations and differential movements of the foundation. These actions may result in excessive deformations or tilting of a structure. Accordingly, a building may undergo damage to the finishes and cracks in walls, leading structural damages up to a complete collapse. In order to provide building structures with the resistance to the lateral actions, it is a practice to incorporate diagonal steel cross braces in sections of roofs or walls and even provide shear walls around the stairways, lifts and core used for general services. It is essential that a structure should be protected against the effects of the lateral actions.

1.2 Building with infills
Infilled frames are the beams and columns confining walls. Such beams and columns, which are part of the supporting frames, are usually made out of steel or reinforced concrete. The walls referred as ‘infill walls’, commonly occur as space fillers or as claddings to the exterior envelope of the buildings. Generally, such walls are designed for fire resistance and acoustics, rather than its structural properties. The significance of infill is understood since the last four decades. Usually for such infills, brick walls are used and works as an element which bears lateral load, though they are not designed or not even considered as an integral part of the structure.

1.3 Soft storey with framed structures
A typical soft storey building is an apartment building or a multi-storied building of three or more stories located above the ground level with a large open area, such as parking, garage and shops. Now days, in the multi-storied structures, soft stories are common at the parking level as there is absence of infill walls whereas the storeys above are filled with the partition walls. Such frames have less capacity to bear the
lateral loads. Buildings with soft storeys are severely affected due to the lateral movements caused by tremors. But such space is usable for parking, so the lesser obstruction with a proper balance of stiffness and deflection control is required. The building with soft storey is susceptible to weakness and collapse due to the lateral loading. Based on the studies of the soft storey structures, it can be confirmed that this kind of structures exhibit a less safe behavior than the similar regular structures. The phenomenon of the soft storey buildings that are vulnerable to collapse due to the lateral loading in a moderate to severe earthquake is known as a ‘soft storey collapse’. Soft storey partial collapse due to inadequate shear strength at the ground level is shown in Plate 1.1 of California’s Loma Prieta earthquake of 1989.

Soft storey failure was responsible for nearly half of all the homes that became inhabitable. (http://en.wikipedia.org/wiki/Soft_story_building)

![Plate 1.1 Soft storey partial collapses at California's Loma Prieta earthquake](image)

Plate 1.1 Soft storey partial collapses at California's Loma Prieta earthquake

Such collapse is very dangerous for human beings and property. Although much research has been done on steel bracings and infilled frames in the recent past, there have not yet been any detailed research about soft storey’s which would be practically be applicable with sound theoretical background. For minimizing the effects of soft storey, the idea of bracings with partial infill has been developed, which can be proved as an efficient solution for the resistance to the lateral load within the acceptable limits.

1.4 Frames with bracings and partial infills

For the designing of ground storey of the soft storey frames, usually extra reinforcement and more size of column is provided in comparison to the upper storey. Such structural arrangement may lead to inefficient and uneconomical designs. That means available stiffness and strength goes unused while larger frame member sizes and more rigid connections than necessary provided. In today’s vastly competitive
business environment, limiting side sway of building frames using bracings with partial infill walls can lead to a significant cost savings.

Even, the idea is to know the behavior and the effect on ultimate strength of such frames which are repaired by epoxy resin in comparison to the bare frames. The lateral load capacity and the stiffness will increase if shear walls which are used at the corners from bottom to top floor level, are braced by the steel bracings at the corner, central and diagonally with reinforced cement concrete infill. Also, it will contribute to the stability of high-rise structures.

The motivation of this research, therefore, necessitated assessing the role played by a progressively more popular construction practice and material on the structural behavior of building frameworks. It is stated that:

The use of steel bracing and partial infill to stiffen frames could lead to structurally more resourceful and cost-effective construction for structures of buildings.

However, design of such frames is destitute by the lack of guidelines. By understanding the behavior of these frames, taking into concern of construction details is a prerequisite to the development of the much preferred design guiding principle.

1.5 Objectives, scope and methodology

The existing rules for designing the soft storey structures do not yet completely reflect the past observations and only some empirical rules have been adopted, namely inducing higher seismic coefficients whenever certain regularity criteria are not satisfied. The purpose of this work is to analyze the structural response for open ground storey of soft storey framed structures, aiming at showing that their safety for seismic loading is compatible to the safety exhibited by the regular structures.

This research is aimed at developing design guidelines for steel and R.C. braced frames with partial infills and subjected to external in-plane loads. In this regard, the objectives are set to experimentally establish the general behavior, develop a numerical model, calibrate it and perform the parametric studies.

- To review and identify the gap in the literature for the analysis and performance evaluation of the infilled frames
- The purpose of this work is to perform the experiments and analyze the structural response for the infilled structures, accounting for the contribution of bracing and infill walls (even partial infills), in resisting the lateral loads.
- Investigate the braced steel frames with the partial infill of the cement mortar and concrete up to collapse to obtain the solution for soft storey frames to bear the seismic loads.
- To develop an effective module for the R.C.C. infilled steel frames with the provision of steel bracings as per the requirement for an economical and safer design.
- To evaluate the performance of the R.C. frames for the ultimate strength with steel bracing and partial infill of concrete.
- The collapse braced partial infilled steel and R.C. frames are repaired with epoxy and tested again in order to know how much strength can be recovered.
- To propose a mathematical model based on the plastic theory to simulate the ultimate strength of the braced and infilled steel and R.C. frames.
- To compare the experimental ultimate loads for the different frames with the theoretical loads and to establish the design recommendations based on the practical design approach.

Single-storey, single-bay infilled frames with bracings and infills are treated. Steel frames with bracings at the top corner, top central, full corner, partial infill of concrete and cement mortar are tested up to collapse. R.C. frames models with bracings at the corner, central, diagonal and partial infill of concrete are tested up to collapse. Even shear wall, in which generally the R.C.C. walls are used as an infill is also braced at the top corner, top central and diagonal for enhancing the lateral load capacity. The idea is also, to understand the behavior of repaired frames which are partially or fully collapsed due to the moderate or severe seismic forces, in general such structures are repaired and reused. After testing the frames up to failure, the frames are repaired by applying cement slurry for the major cracks first and epoxy resin is used to fill the top surface of the minor cracks and tested again up to failure. Ultimate loads are experimentally obtained for the different frames and are compared with the bare frames. Deflections of braced and partial infill frames are compared with each other and also with bare frames. The current investigation is limited to steel and R.C. frames with monotonic in-plane horizontal loading. Other types of loading such as cyclic and out-of-plane loading are not treated. It is acknowledged that the other forms of loading are important issues which need to be investigated in follow-up research.
work. For each category, two frames are tested and average is taken for the ultimate loads and deflections.

Present work is predominantly experimental oriented. In the current investigation, the solution of the research work is defined in threefold. Firstly, it has solutions for the ground storey of soft storey frames of the steel buildings by providing the steel bracings and partial infills. Secondly, solutions for R.C.C. shear wall with the provision of steel bracings as per the requirement. Thirdly, to provide solution for the ground storey of soft storey framed structures and shear wall R.C. frames with the steel bracings and concrete infill. A mathematical model using the plastic theory is developed for all such frames and for calculation of the theoretical ultimate loads. On the basis of the experimental and the numerical studies, simplified equations for approximating the failure loads of braced, partial infilled and braced shear wall frames are suggested.

1.6 Outline of thesis

The thesis is divided into seven chapters. In the current, introductory chapter, the relevance of the subject has been anchored in the area of lateral stability of the building structures of soft storey, shear wall and the control of deflection. The possible use of steel bracing and infill has been described. The scope and limitations of the investigation have been mentioned. The organization of this research thesis is summarized in the flow chart. The next chapter deals with the literature survey.

In the next chapter 2, the general behavior of the infilled frames, as found in the literature, is described. Infill frames have drawn attention of several investigators in the recent past due to inherent structural advantage of such frames. This chapter provides an overview of findings from the experimental and analytical research on the infilled frames during the last half century. The focus is kept on steel and reinforced concrete infilled frames as they are relevant. Experimental investigations have been conducted by several researchers using a wide range of testing scales, infill materials, experimental set-ups, constraint studies and number of specimens. The studies are classified as methods based on concept of equivalent strut, finite element analysis, experiential investigations and plasticity and collapse approach. Experimental research has been complimented by the analytical attempts to model infilled frame behavior. The infilled frame structure is however still difficult to model, partly, due to a nonlinear phenomena associated with the infills and with frame-to-infill contact areas. There is few design guidelines for the infilled frames. There is also very less
experimental and analytical data regarding the use of partial infill with steel bracings for the infilled frames. Therefore, this research is to investigate a relatively new but considerably a prevalent method for a soft storey and shear wall construction. Herein, the key factors which affect the behavior of infilled frames are discussed. The next chapter contains experimental set-up for the steel and R.C. frames.

Information regarding the experimental investigations is described in the chapter 3. The experimental study reported herein consists of a number of tests on the models of bare, braced and partial infilled; steel and R.C. frames subjected to the lateral loads alone. The details of frames, bracings, partial infills, experimental set up and test procedure are discussed. All the experiments are performed on the models with single bay, single storey frames. Two models are tested of each category. The parameters included in the experimental investigation consist of different types of steel bracings and partial infill. A series of forty-two steel frames with the top corner, top central, full corner and horizontal bracings with cement mortar and concrete infills are tested up to the collapse. Twenty R.C. frames with corner, central and diagonal bracings with concrete infill are tested up to the collapse. Displacement controlled in-plane horizontal load is applied at the roof beam level. Auxiliary tests are performed to monitor the characteristics of the infill materials as per relevant IS code. Test models are fabricated to reduced scales following the laws of similitude by scaling down the geometric and material properties of the prototype. The observations and results of experimental work are dealt in the next chapter.

Observations and results from these experiments are evaluated in the chapter 4 and related tables, graphs, figures and photographs are presented at the end of chapter. Load-deformation curves show a two or three stage trajectory prior to cracking. In general, there was an initial stiff stage followed by a much less stiff stage during which a frame-wall separation occurred and another stiff range leading to, in the majority of cases, diagonal tension cracking in the infill walls. A basic load-deflection curve shows that the behavior of the partial infilled steel frames prior to major cracking in the infills. The detailed observation of crack the patterns for infilled frames provided data for calculating the ultimate loads of the following chapter.

Details of the developed analytical model, simplified equations for prediction of the failure loads of the different frames are proposed and evaluated in chapter 5. The mathematical model predictions are based on plastic analysis; considering the
separation at frame-to-wall interfaces, primary stiffness and the onset of cracking in
the infill wall. Linear elastic behavior was assumed for the steel. The material
properties used in this model are obtained either from auxiliary tests conducted
alongside the infilled frame tests or estimations based on the available literature. The
model was validated by a comparison of the numerical and experimentally determined
ultimate loads of all the specimens of the partial and full infills. In the following
chapter the ultimate loads from the numerical results are compared and results are
discussed.
In the chapter 6; observations, problems occurring during the experiments and reasons
for the failure patterns has been discussed. While designing columns of the bottom
storey of the soft storey framed structures with braced partially infilled frames,
modified load factor is suggested. For the horizontal braced frames; brick masonry,
concrete and cement mortar partial infills are used. As the contribution of the brick
masonry, partial infill is not significant in comparison to the cement mortar and
concrete partial infills; therefore for further research, only cement mortar and concrete
partial infills are considered. Further, to avoid the excessive stiffness between the two
consecutive floors, it is suggested that as per the requirement; corner, top corner or
diagonal bracings can be used for a particular storey in a shear wall. With an
appropriate material and load partial safety factors, the simplified equations can be
used as a basis of design guidelines. Theoretical results obtained using these
simplified equations have been compared with the experimental results.
Finally chapter 7 summarizes the contents of this work in terms of the experimental
and proposed theoretical methods engaged and the main findings. A possible
sequence of the recommendations in future continuation of this research is given.
At the end, the following appendices with their details are provided.

Appendix A: Calculation of the ultimate load for a bare steel frame and design of the
connections

Appendix B: Material properties for the steel frames

Appendix C: Material properties for the R.C. frames

Appendix D: Calculation of the ultimate load for the infilled Steel Frames

Appendix E: Calculation of the ultimate load for the infilled R.C. frames

Patent and Publications
The organization of the thesis is summarized in the flow chart as shown in Figure 1.1.

Figure 1.1 The organization of the thesis in the flow chart
1.7 Limitations
High costs and Practical difficulties are involved in conducting large-scale tests and therefore the experimental tests are carried out on models. In this work only monotonic in plane static lateral load was applied to study the effect on the bracing with various infills. As an immediate continuation of this research, specimens similar to those used in this investigation could be subjected to cyclic and out of plane loading. All the experimental and analytical tests carried out in this study deal with single storey and single bay panels. The results of this research still need to be set in the context of more realistic multi-bay and even the multi-storey configurations. Experiments are conducted on the contribution of bracing and partial infills, so the aspect ratio for frame is kept constant.

1.8 Concluding remarks
This research aims at proving a scientific basis for the development of a practical utility and guidelines for steel and R.C. braced frames with infill, thus, providing stability to the building frameworks. Generally contributions of infills are commonly ignored. But, this research postulates that this role must be consider for lateral stability rather than simply assumed or unnoticed. The next chapter deals about the literature review.