Chapter 1
Introduction

1.1 General:

Reinforced Concrete (RC) frames with un-reinforced masonry infill panels are the most widely used type of construction in India and other developing countries. It is a very viable option for medium height multistoried structures where land cost is high. RC framed structures with brick masonry infills are commonly used in regions of high seismicity, especially where masonry is still an economical construction material. Adequate knowledge of the behavior of such structures is required to design this type of structure in order to reduce the loss of life and property associated with a possible structural failure due to seismic shaking. Furthermore, infilled RC frame buildings designed and constructed before the development of actual seismic codes constitute an important part of the high-risk structures in different countries. Multistoried structures irrespective of height need special attention in design. Lateral loads due to one of the three causes namely wind / earthquake / blast needs to be considered in the design. The lateral forces can produce critical stresses in the structure, set up undesirable vibrations apart from causing lateral sway of the structure. Under Seismic loads, additional stiffness due to masonry infill will modify the structural response of RC frames and it significantly alters the natural frequency of the frame. The RC structures can have various kinds of configurations of masonry panels (Fig 1.1). The amount and location of infills greatly affect the natural frequency of the structural system.

The term infilled RC frame represents a composite structure formed by one or more infill panels surrounded by a frame. The panels are usually built with burnt clay brick or concrete block masonry, whereas the frame is constructed with steel or reinforced concrete. RC frames are very widely used in developing countries like India. Different construction techniques have been adopted, depending on the sequence followed to build the infilled RC frames. One option is to build the frame (steel or reinforced concrete) and later to construct the masonry panels which infill the frame. In this case, the shrinkage of the infill material or defects due to inaccurate workmanship usually results in an initial lack of fit. In the other alternative, the masonry panels are built firstly and then beams and columns are cast / fabricated to form a reinforced concrete frame. Thus, it is possible to achieve an adequate bond and shear strength at the panel-frame interfaces. This
Introduction

The technique is mainly used in seismic regions of Latin America, such as Argentina, Chile, Mexico and Peru.

![Various possible configurations of infill walls in a structure](image)

Structural engineers have largely ignored the influence of masonry panels when selecting the structural configuration, assuming that these panels are brittle elements when compared with the frame. The design practice of neglecting the infill during the formulation of the mathematical model leads to substantial inaccuracy in predicting the lateral stiffness, strength and ductility. The reluctance of numerous engineers to consider the contributions of the masonry infills has been due to the inadequate knowledge concerning to the composite behavior of infilled RC frames, and to the lack of practical methods for predicting the stiffness and strength. As could be gathered from literature none of the computer programs commonly used by designers provide rational and specific finite elements for modeling the behavior of the masonry infills.

Even though seismic codes for infilled RC frames have been developed in some countries for some time; numerous design codes and recommendations from all over the world do not contain rules for design of infilled RC frames. Fortunately, there is now a change in this attitude. New design provisions have been introduced in several countries.
Introduction

which require that the effect of the masonry panel be taken into account in the design and analysis of building frames. This has generated a need for better knowledge and for practical tools to be used in design and analysis. Analyzing and designing buildings for static forces are a routine work with the use of affordable computers and specialized programs. On the other hand, dynamic analysis is a time consuming processes and requires additional input information related to mass of structure and for interpretation of analytical results, an understanding of structural dynamics. The main purpose of linear dynamic analysis is to evaluate the time variation of stresses and deformations in structures caused by arbitrary dynamic loads.

Masonry has great compressive strength, but is very weak in tension. In frame and infill wall buildings, masonry is the most rigid element in the system, and as such, the lateral forces on such a building are immediately and almost exclusively felt by the masonry. In comparison to the bounding frame, masonry is weak in absorbing these stresses. The onset of cracking within the masonry panels is thus only the first step in the building's response to the enormous forces. The allowance of cracking then raises the inevitable possibility of hazards of falling debris. Hence the masonry has to be designed to limit the lateral drift to an amount which would prevent any major degradation of masonry, and the resulting danger of it being shed.

The literature shows that experimental and analytical research related to infilled RC frame structures has progressively increased in the last 60 years. Stafford Smith [53, 54, and 55] has extensively studied the behavior of infilled RC frames and has proposed the principle of equivalent diagonal strut for analyzing infilled RC frames. The concept of replacing infill by an equivalent diagonal strut is proposed by many early investigators. The performance of reinforced concrete frames with infill under seismic loads is studied extensively by the early investigators and most of the researchers have concluded that strong infill panels exhibited a better performance than those with weak panels in terms of load resistance and energy-dissipation capability. Limited research work is reported on reinforced masonry or reinforced masonry infilled RC frames. Bhagavan et al [52] have carried out experimental investigation on reinforced masonry and have reported that reinforcing system of masonry can improve its tensile/shear resistance capacity.
1.2 Objectives:

Conventionally RC frames are designed as bare RC frames without considering the interaction of filler walls, though there is considerable difference in the behaviour of bare frames as compared to that of infilled RC frames. Uncertainty associated with the properties of masonry infill, its brittleness, out-of-plane weakness, low tensile strength, etc. may have deterred its use, although it has been a topic of interest for research since several decades. In areas affected by major earthquakes, it has been observed that the presence of walls as infill panels has prevented collapse of structures.

Literature survey carried out till date reveals that studies on reinforced concrete frames infilled with reinforced clay brick masonry are limited, more so on dynamic behavior. Since 1950s much work has been done on RC frames infilled with plain masonry or steel frames with RC infills. Investigators also have worked with various approaches like by replacing infill with an equivalent diagonal strut. Many finite element models have been developed for steel and RC frames by assuming separation between infill and frame. The results were found to agree with theoretical and experimental results. Many attempts have been reported to improve the strength and stiffness of these composite structures. Many two dimensional models with plain infill and reinforced infill have been tested and results were found to be encouraging. But limited attempt has been made to address behavior using three dimensional finite elements. Extensive work has not been done for simulated earthquake loading. Studies have also been made for frames with soft storey. The investigators have long discovered that infilled RC frame buildings possess potential reserve strength. There is a need to study the behavior of reinforced masonry infilled RC frames under earthquake excitation with reliable experimental and numerical techniques to give a comprehensive solution for complex infilled RC frame structures.

Clay brick masonry using Rat-trap bond has been recognised to be an effective method of building walls for reasons of economy in construction and good thermal insulation. Modular masonry reduces wastage of bricks. Cost of masonry is reduced by 25-30% as this technique uses approximately 35% less bricks and 50% less cement mortar compared to the normal English bond. It proposed to explore whether hollow space inside the masonry can be used for placing reinforcement in and subsequent
grouting to develop into a strong and ductile infill for RC frames (Fig 1.2). Reinforcement has to be anchored into the beams and columns for effectiveness. It is expected that reinforced rat-trap bond brick masonry infilled RC frames may prove to be effective bracing system for Earthquake resistance.

![Isometric View](image)

**Fig.1.2: Rat-trap Masonry**

The objective of this work is to explore the possibility of using rat-trap clay brick masonry as infill in RC frames with and without reinforcement, the hollow spaces being grouted with concrete of various grade/mix proportions, which is expected to provide a better deformation and stress response to earthquake induced ground motions.