Asian Journal of Civil Engineering (2022) 23:973–1028
https://doi.org/10.1007/s42107-022-00446-8

ORIGINAL PAPER

A state-of-the-art review on the evolution of performance of masonry infill walls under lateral loadings

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Received: 19 November 2021 / Accepted: 13 April 2022 / Published online: 1 July 2022

Abstract
Masonry is a prevalent human chronicle substance used all over the globe as it offers significant advantages concerning building execution time, consumption, and costs despite being an engineered material manufactured using naturally occurring resources. In burgeoning countries, in particular India, most of the constructions are forged using masonry materials. As this system is in wide usage around the globe, it is cardinal to have cognition about the emergence of the material and the praxis of the same. The purpose of this paper was to review the evolution of masonry and brick masonry from the Stone Age (4000 BCE and 2000 BCE) to the Meghalayan Age and to discuss the details related to the manufacturing processes, composition, classification, and performance of brick masonry under various conditions including those materials that are in use along with the masonry. An efficient survey conducted concentrating on the significant discoveries and perceptions made by each researcher is introduced. A table contains insights about the strengthening process used, and parameters considered results and main observations for every method.

Keywords Masonry infill walls · In-plane and out of the plane · Strengthening and retrofitting · Seismic performance · ABAQUS · Failure modes

Introduction

Masonry-infilled reinforced concrete (RC) frames are one of the most commonly used structural systems worldwide. These structural forms are used for low-to-medium rise structures around the world mainly in developing countries, such as India. For infilled frame buildings, infill panels are used as partitions, whereas the bounding frame is designed as a structural skeleton to withstand vertical and lateral loading. When designing such structural systems against seismic actions, it is common practice not to include the infill walls in the numerical models used for practical structural analysis and design purposes, as these elements are considered to be non-load bearing Elouali (2008). In doing so, their stiffness and strength contribution, as well as their interaction with the load-bearing elements of the frame (i.e. beams, columns, and walls), are fully neglected. Thus, the actual performance of infilled RC frames will differ from the expected performance based on the structural analyses Singh and Verma (2015). The effect of infill walls is usually considered only through the interaction of the frame and infill along the interfaces between the surrounding frame and the infill walls by which it adds stiffness to the whole frame. From the available published experimental and numerical data, it can be observed that masonry infill walls can have a significant effect on the structural performance of RC frames under seismic actions. Even light to moderate earthquake shaking/acceleration or drift levels can cause damage to the infill walls and this damage may result in life safety hazards, immediate evacuation and loss of function of buildings, limiting the use of internal spaces. In many cases, the influence of the infill panels showed to be the reason for extensive damages or even the buildings collapses. Based on the above, it is not surprising that, over the past decade, an increasing interest has been observed concerning the investigation of the effect of infill walls on the seismic performance of infilled frames Mosalam and Günay (2017).

Vulnerability studies are very important to evaluate the seismic risk and its application is particularly interesting in urban areas located in low to moderate seismic hazard regions where the increase of the population and the absence

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of adequate seismic-resistant prescriptions for buildings increment the seismic risk. Very often, in these areas, a large number of RC frame structures have been designed mainly for gravity loads, or their lateral resistance has been determined without adequate seismic-resistant considerations or according to old seismic codes, in which ductile detailing is not explicitly required. It is very likely that these buildings, when subjected to a maximum credible seismic event, suffer more damage than reasonable. Therefore, it became a must job for earthquake engineers to design earthquake-resistant buildings in such a way that the whole structure contributes to the seismic safety.

Material used for construction

The construction processes of dwellings from ancient times have evolved over the period undergoing various stages if explained in chronological order, starting from the Stone Age, ultimately reaching where we are up to the present day.

As we delve into the past, the period from 7000 to 6000 BC was named the Stone Age or Neolithic age. The materials used for the building included bones and skins of animals, bamboo, metals, etc. The tools used to construct these were axe and chopper, made up of stones, rope, grass, etc. Most of the shelter for living was natural and manufactured caves. Next comes the invention of the arches in the Copper and the Bronze Age around 5000 B.C. and 3000 B.C., respectively "The history of bricks and brickmaking" (2017). During the Iron Age, between 1200 B.C. and 50 B.C, carbon and iron form steel. Large palaces and temples were built in this period in which some of them still survive to this date. The significant material used to construct these structures was mudbrick. The manufacture of bricks took place in various shapes and sizes, which were named adobe bricks. The pyramids are live examples of the big feat achieved by the Ancient Egyptians. Roman Builders used volcanic tuff found near Pozzuoli village near Mount Vesuvius in Italy. This volcanic tuff or volcanic ash is siliceous mainly in nature, thus possessing the name Pozzolana. Romans also initiated using glass as a construction material for architectural and aesthetic purposes.

In the seventh century, the Chinese built the most famous Great Wall of China using stones, bricks with lime mortar. They built temples typically consisting of timber standing on a basement carved out of larger stones. The extinction of Roman Civilization began with the rising of the Middle Ages (fifth century A.D.–fifteenth century A.D.), during which castles and cathedrals were considered the most prestigious constructions. Bricks were the most used construction material during this period, even though timber was more popular to construct the superstructure part of the buildings. The seventeenth century witnessed the birth and growth of modern science, which highly impacted building construction and the forthcoming millennia. The path-breaking achievement was due to the invention of the glass manufacturing technique "Evolution of glass as an architectural material," (2017). The construction industry was in recognition as a prestigious profession. Cast iron and wrought iron were popular materials for building structures. The Iron Bridge at Coalbrookdale, constructed around 1779–1780, is the best example, shown in Fig. 1 "The Iron Bridge" (construction started in 1777, ended in 1781). The industrial revolution began in the nineteenth century, which brought up drastic change globally almost in every field, displaying a significant impact on the construction industries such as railways, canals, roadways. Steel became the primary construction material during the mid-nineteenth century. The second industrial revolution occurred in the twentieth century, during which exceptional developments such as elevators, cranes, tall buildings, skyscrapers, and heavier equipment reduced the burden on man by saving time and energy.

Methodology of the review

Related studies were recognised through various bibliographies such as Science Direct, ASCE, Earthquake Spectra, Wiley, Taylor and Francis to conduct an organised review, published from 1988 till 2020. References for this article were selected if they (a) performed the material and mechanical property tests; (b) provided the details of the strengthening materials. Indeed, it was considered suitable to incorporate these works because of the profoundly important and various data on this subject. All these records were segregated using Mendeley Desktop (version 1.19.4). Following this task, titles and year of publication of the articles were filtered to eliminate the irrelevant papers. The tags of each piece were read with utmost care and are categorised based on the type of work carried out by the authors. Initially, they

Fig. 1 Iron Bridge at Coalbrookdale ("The Iron Bridge" construction started in 1777, ended in 1781)

were segregated based on the type of loading, i.e., out-of-plane (OOP) and in-plane (IP) load. Later, it was even more segregated based on the work done by the authors, whether it is numerical or experimental. Full articles related to the selected titles/work were scrutinised thoroughly and complemented the mentioned criterion in the ultimate bibliography. This review paper pertains to the experimental, numerical and analytical work on MIW subjected to IP and OOP.

A total data set inquiry brought about 485 papers. Out of these, 250 documents were eliminated, from which 235 articles were left out to be filtered. Of these, 60 articles were not relevant to this topic. They were rejected because few reasons, like the papers, contain numerical modelling of confined masonry walls, analytical work, and experimental works on masonry walls surrounded by steel frames.

The parameters considered while gathering the information regarding the methods of strengthening and retrofitting of MIW were (a) technical parameters of the strengthening material, (b) specifications regarding strengthening strategies of MIW, (c) failure pattern of strengthened MIW and (d) effect of strengthening material on MIW. As this research topic consists of several parameters, systematic evaluation was contemplated as the appropriate practice as far as this topic is concerned.

Although most of the literature concludes that infills increase the overall lateral stiffness of the whole structure, something is holding back researchers and scientists in considering the infills in the seismic design of RCC structures. In few cases, a small gap pertains between the infill wall and the bounding structural system, and in the remaining cases, innovative strengthening methods of MIW are practices. Contrastingly, strengthening existing MIW constructions is a bit complicated due to the absence of the technical details of the structure, such as the type of masonry units used for building the wall, which leads to the unpredictability of selecting a suitable strengthening technique to adopt for the masonry structure.

Several researchers have carried out and performed studies on masonry infill walls for decades. Studies showed that masonry infill walls contribute to the resistance of lateral forces such as seismic actions. Hence, the presence of infills has the purpose of the overall structure. The masonry infills can also be strengthened with various materials to increase the tensile behaviour as the material is brittle. The research on MIW is divided into three categories, i.e., experimental work, numerical work and analytical work, as discussed in the following sections.

Walls

Masonry infill wall

Brickwork is regularly framed by spreading various interlocking units bound together by mortar. The dry set masonry depends on the friction between the units to forestall movement and does not need mortar. Brick masonry is vital in compression, however less viable at opposing horizontal loading or tension forces.

Types of walls

The wall is a construction characterising an accurate region and giving security and haven. There are different sorts of walls utilised in the development of structures shown underneath.

a) Load Bearing—the walls that carry the imposed load and their self-weight are the load-bearing walls. These walls can be classified as exterior or enclosing walls.
b) Non-Load Bearing—the walls that do not carry the imposed load instead of the gravity load are named the non-bearing wall. An example is partition walls.
c) Masonry walls—the wall constructed using all those building units such as bricks, blocks, stones, tiles, generally horizontal in direction bonded with mortar.

Wall openings

The critical parameter that alters the performance of a wall under lateral loads is the openings provided in the wall. Therefore, the consideration of openings in the design of barriers is of utmost importance. The different types of wall opening available are doors, windows and ventilators. Many researchers study the performance of walls subjected to lateral loads with and without openings. Figure 2 shows some examples of walls with openings.

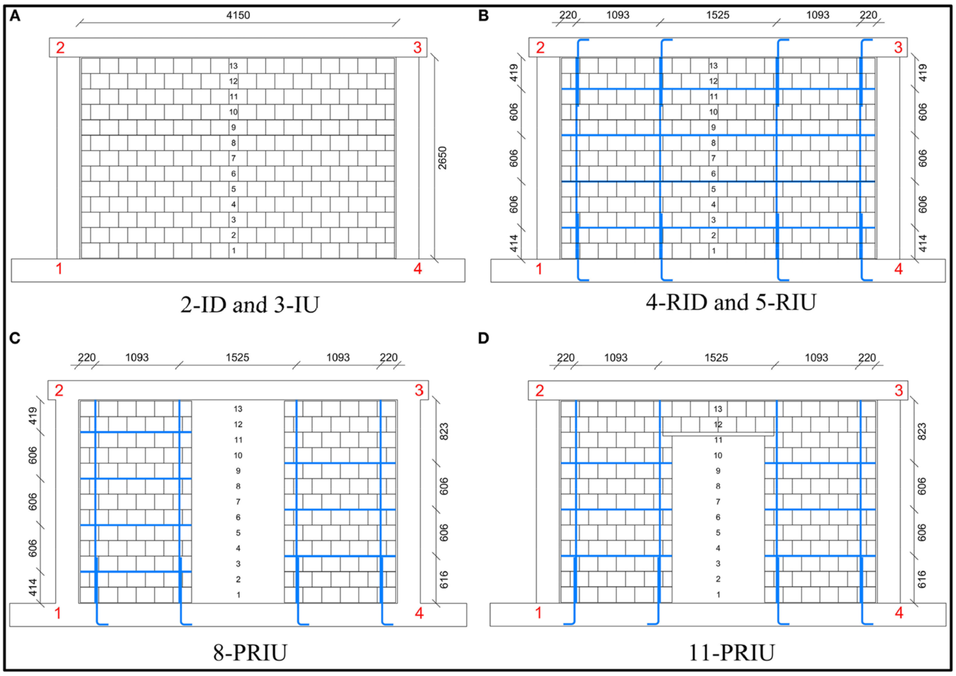
Building materials

Bricks

Brick is one of the oldest building materials used for construction purposes—bricks for constructing shelter dates back to 7000 B.C. Since then, bricks have been the most famous building material till today. Bricks (Fig. 3) the material manufactured artificially using natural resources such as clay heated and moulded in uniform shape and size “Bricks and blocks,” (2019).

The brick consists of a small cavity on one of its surfaces called the frog, whose depth is about 10 mm, provided for the excellent binding with the mortar. There are four classes of bricks based on the water absorption capacity and its strength. The details of these classes of bricks are as follows. A summary table (Table 1) for the same is prepared to comprise the elements apropos the classification of bricks (Fig. 4).

Fig. 2 Filled frames with unreinforced masonry (**A**); filled frames with reinforced masonry (RM) (**B**); partially RM filled the frame with the opening (**C**); partially RM filled the frame with door and lintel (**D**). da Porto et al. (2020)



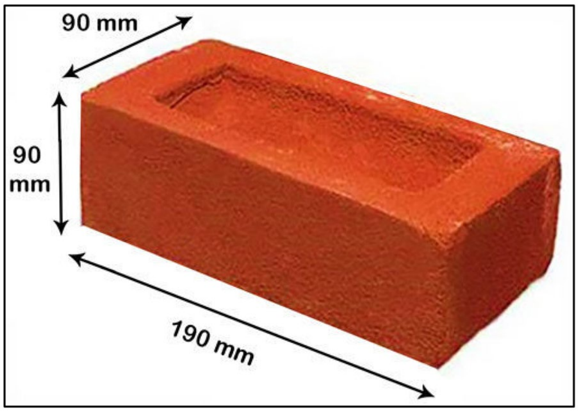


Fig. 3 Dimension of brick

Composition of bricks

Bricks are not naturally available material. The manufacturing takes place artificially, either manually or mechanically. Later, fire bricks were invented in 3500 B.C by Romans. They just eliminated the long and tedious process of hardening the bricks under warm temperatures and manufactured bricks in different shapes according to the requirement in wooden moulds. In the medieval period, clay became the most crucial ingredient in the making of bricks. In 1666, the city of London was majorly decorated with brickwork structures. The majority of the skyscrapers in the United States of America use bricks or terracotta, “Bricks and blocks,” (2019).

The bricks consist of primarily five constituents, namely silica, alumina, lime, iron oxide and magnesia in different proportions. Each component has another purpose that forms the end product brick. Hence, it can be a great brick if its excellent properties such as the shape and size of the brick are uniform with straight and sharp edges, deep red with the surface texture being rough so that binding action with the mortar will be proper. The hardness should be so that no mark should be visible if nails scratch the brick, and it should make a clear metallic sound it pounded on each other, which indicates the soundness of the brick. Most

Table 1 Summary of classification of bricks

Class	Crushing strength (N/mm^2)	Water absorbtion (%)	Colour	Uses
Class I	≥ 10	12 to 15	Deep Red	Load-bearing masonry structures
Class II	≥ 7	16 to 20 (22 max.)	Reddish Orange	Exterior walls and flooring
Class III	3.5 to 7	22 to 24 (24 max.)	Reddish Yellow	Partition or parapet walls
Class IV	≤ 3.5	No limit	Dark Reddish Brown	Temporary structures

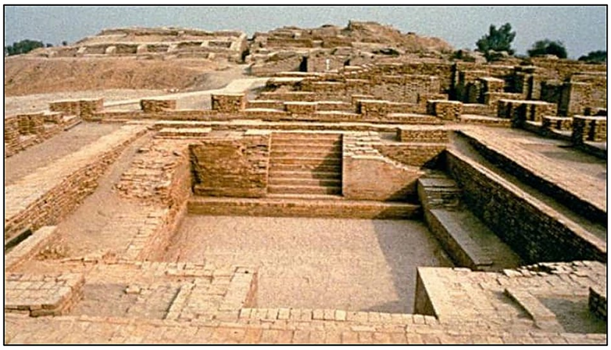


Fig. 4 Mud bricks used in Mohenjo-Daro

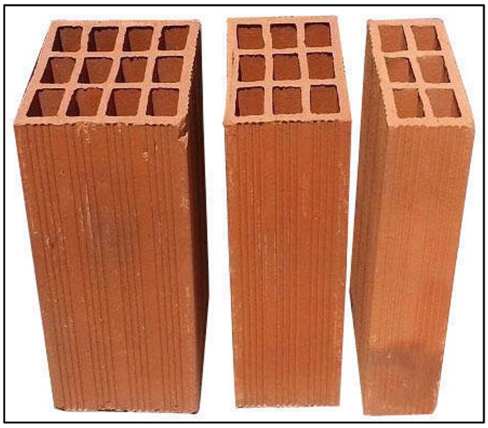


Fig. 5 Porotherm clay hollow blocks ("Bricks & blocks", 2019)

importantly, the brick should not contain any impurities in the form of stones or grits, etc (Fig. 5).

Special types of bricks

The most common type of bricks for construction purposes are burnt clay bricks. Other types include fly ash bricks, solid concrete blocks, hollow blocks, heavy-duty bricks, perforated bricks, lightweight bricks and refractory bricks. The application of these bricks includes abutments, construction of bridges, heavy types of equipment works, etc. "The history of bricks and brickmaking," (2017).

Porotherm clay hollow blocks are easy to use to construct partition walls or mainly for masonry infill walls consisting of clay, concrete, and coarse aggregates as components. Its crushing strength is about 4 N/mm^2. It is available in different dimensions ranging from 4 to 8 inches. Compared to solid concrete blocks, Porotherm blocks are of 60% less weight and provide superior thermal insulation, BIS (1988).

Masonry construction

Masonry is a process of construction that utilises singular units, similar to brick and stone, bound along with mortar. Even though it is amazingly durable, masonry does, in any case, wear out after some time and is regularly needing repair or restoration.

Types of masonry construction

Masonry wall construction is of two types based on their function. They are load-bearing walls and non-load bearing walls. The walls that support no imposed load, i.e., vertical load except gravity loads, are called non-load bearing walls primarily used as interior partition walls (Fig. 6a). The walls designed to carry the superimposed load, including their self-weight, i.e., dead load, are load-bearing walls. These walls are generally helpful as exterior walls (Fig. 6b).

Functional requirement

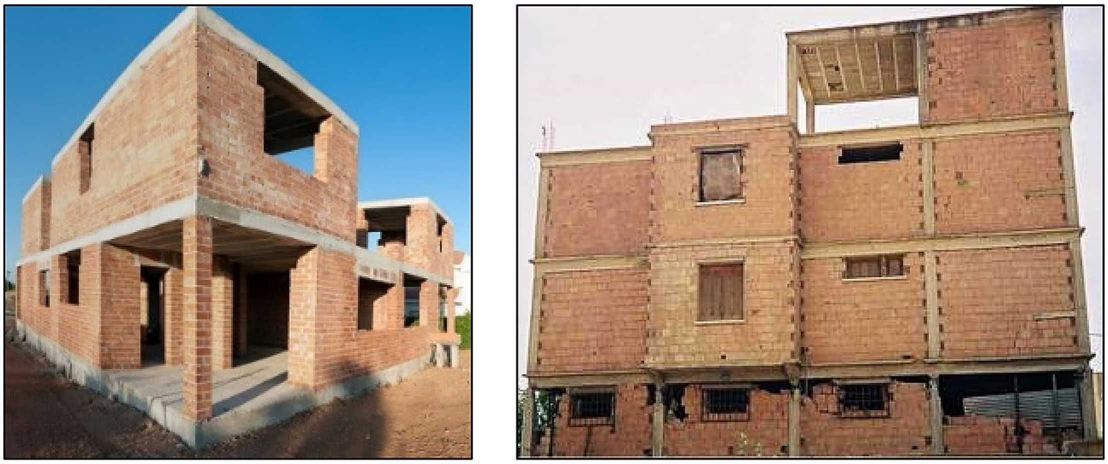
A wall is used to enclose a space to provide privacy and good communication inside a house. Along with this, their secondary purposes include supporting the weight of the top storeys, providing security and protection against the weather. Walls can be classified based on their functions and placement in a building. Depending on the motor mix materials, there are various types of masonry walls used in building constructions as follows:

a) Load-bearing masonry wall.
b) Reinforced masonry wall.
c) Hollow/Cavity masonry wall.
d) Composite masonry wall.
e) Post-tensioned masonry wall.

However, not going deep inside these details, the typical primary concern regarding any wall might be the failure under different loading conditions. The primary function of a non-load bearing wall is to carry the gravity loads, but instances occur where lateral loads act on these walls. In such circumstances, the walls will become vulnerable and might collapse drastically. As discussed in the following sections, the walls can be seismically strengthening or protected against lateral loads to prevent the walls from these failures.

Prevention of failures

The fundamental purpose of seismic strengthening is to enhance the overall structural performance and increase the resistance to deformation when subjected to lateral loadings.



a Load-bearing wall **b** Non-load-bearing wall

Fig. 6 **a** Load-bearing wall. **b** Non-load-bearing wall

There are two safeguarding strategies for the masonry system against the effect of the earthquake. One is to protect the structure from the seismic forces, and the other is to enhance the strength of the existing systems to withstand seismic loads. The two ways of retrofitting a structure are by using additional components and additional adhesives.

Seismic analysis of the existing structure is proper if the soil under the construction is solid and stiff enough; then only, fewer seismic forces will transfer to the network.

Estimating the capacity of structure for strengthening is estimated by the structural engineers by considering the type of construction materials, loads acting on the structure and the geometric aspects of deteriorated structures. All kinds of failure modes must be in consideration during the strengthening process.

The selection of strengthening technique should be according to the design and condition of the existing structure, knowing the overall characteristics of the system in detail for the selection process of a particular strengthening method. The basic parameters such as deformation capacity, dissipating energy capacity, shear capacity, stiffness and strength properties are considered.

In addition to all these mentioned, other details include the foundation design, seismic zone and earthquake records in that zone.

Seismically strengthen the structure

Seismically strengthening the structure represents improving each member's strength, such as beam, columns and walls individually. There are various techniques to retrofit these members. The strengthening methods are two types based on the location of the strengthening material on the MIW: intrinsic and extrinsic. The former consists of dowel bars, vertical and horizontal reinforcement, and the centre core technique. In contrast, the latter consists of various methods such as Welded Wire Mesh (WWM), Fibre Reinforced Polymer (FRP) jacketing, Steel Bracing and Textile Reinforced Concrete (TRC). In this paper, retrofitting techniques for infill walls are discussed. The methods involved in retrofitting walls include structural fuse, repointing technique, centre core technique, Fibre Reinforced Polymer (FRP) and Textile Reinforced Mortar (TRM).

Repointing technique

This repointing technique is the most popular in the masonry wall field among the available traditional retrofitting infill walls. This method's general procedure follows to eradicate the defective portion and substitute those with similar elements to rehabilitate the previously lost strength of the wall. In such cases, this method is more productive when the mortar gets eroded over time or notches included in the bonds, Jaime et al. (2019).

The filling of the bed joint between the bricks in a brick wall is called the pointing method. This method accomplishes the ongoing work by disseminating the mortar in the bed joint with the masonry wall face or separately when the exterior part of the mortar in the bed joint was left broken. The primary factor contributing to the brick wall's aesthetic appearance is the pattern of the mortar joints, uniformity and the sequence of laying, significantly when the sizes of the bricks vary. The mortar joint contributes to the aesthetic aspect of a masonry wall. It favours keeping the structure dry mainly in two ways, i.e., by not letting the atmospheric moisture penetrate through the wall and allowing the already present humidity inside the wall to dissipate into the dry weather. There is the possibility that rainwater may penetrate the wall through the tiny cracks between the mortar joints and the bricks. The water must escape back into the environment after the rain stops to avoid moisture entering the wall. The best way to achieve this is through permeable mortar bed joints. If hardened cement mixes with the mortar, it may not release the moisture, and it may stagnate in the bricks, which hikes the chances of damage caused due to crystallisation of soluble salts, Chuang and Zhuge (2005).

The process of filling the exterior part of the bed joints where the old mortar should have got weathered out or become unsuitable is a repointing process. Repointing can improve the aesthetic appearance as well as the durability of the brick masonry. It may affect the brickwork if it is not done correctly, sometimes leading to unrecoverable damage. It is needed most on the exposed face of the brick wall of the structure. The principle of the repointing technique is that the bed joint mortar should be a little weaker than the bricks. Suppose the mortar is more complicated than the brick masonry as such in cement mortars. In that case, the wall is in the danger zone where the permeability is allowed correctly, preventing the moisture content from drying out through the bed joints. Due to this, cement-based mortars started declining; instead, lime-based mortars can be beneficial, strictly following the principle. The types of mortars that can be advantageous for the repointing techniques are lime-based mortars and cement-rich mortars. Two types of lime are easy to use in mortars, i.e., non-hydraulic lime and natural hydraulic lime. After completing the repointing process (Fig. 7), the wall is safeguarded from temperature variations such as rain, sunlight, and heavy winds to prevent any damage. It should be maintained under damp conditions using jute bags or thick mats for allowing the mortar to set. Finally, the cannon is ready for the final step, finishing while still in damp condition. Proper maintenance is necessary until the curing of mortar is complete enough to resist any damage by the variation in temperature.

Fig. 7 Repointing Technique

Centre core technique

This technique follows a method in which holes (cores) are drilled vertically along the height through the already built masonry brick wall through which reinforcement bars are embedded through the brick wall into the basement of the wall as shown in the Fig. 8. The diameter of this core varies between 100 to 150 mm depending on the type and size of the wall. The centre is made using the oil-well drilling technique. This dry process may release large debris that can be removed manually or using any mechanical instrument such as a vacuum cleaner. The most common reinforcement used is solid steel bars placed at the centre of the drilled hole and usually filled with a pump using sand-grout throughout the cavity under pressure. This technique will help in filling out the voids along with the height of the drilled core. The bonding between the inner surface of the grout with the rebar and the outer surface of the grout to the masonry makes it

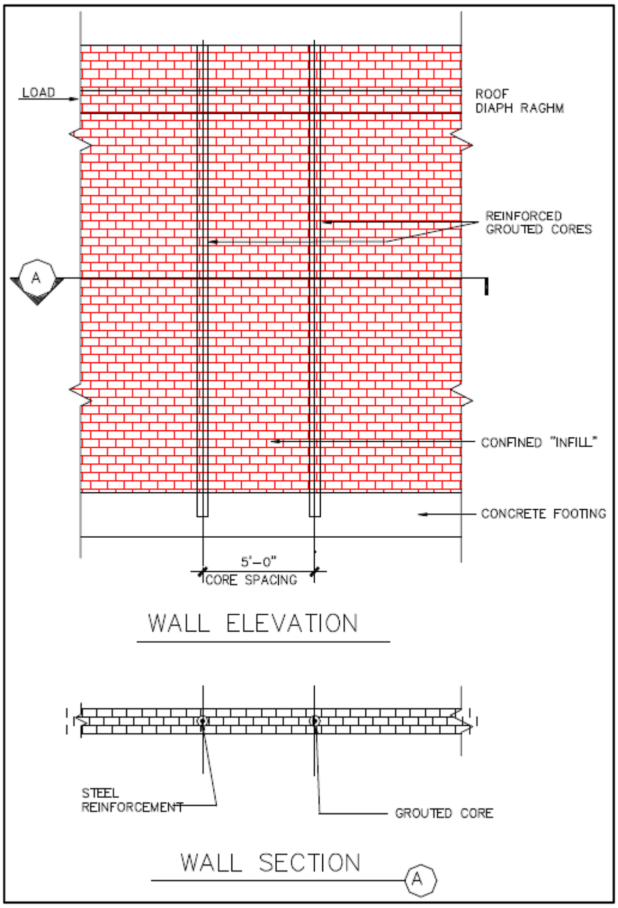


Fig. 8 Centre core technique (Breiholz, 2000)

a homogeneous compound better than the core itself. This method helps the masonry infill wall to resist both the in-plane loading and the out-of-plane loading. This method has many advantages rather than disadvantages; for example, this process creates a minimum amount of disturbance during the process. The geometry of the wall is not changed overall since it is one of the non-destructive testing methods (Breiholz, 2000).

Fibre reinforced polymer (FRP)

Many existing structures built with masonry are vulnerable to seismic forces in the in-plane and out-of-plane directions. Hence, these structures need retrofitting to resist these loads to avoid damage or collapse, resulting in property loss or life loss. Available techniques for strengthening masonry infills are more often uneconomic as well as time-consuming. All these limitations led to developing other methods such as fibre reinforced polymer (FRP) strengthening material. Due to its light-weight nature and minor time-consuming procedure, it has gained significant popularity. FRP is available in many types and many forms as well. The different fibres available are carbon fibre, glass fibre, basalt fibre in various forms, such as chopped fibres and woven fibres, ("SHODHGANGA—Chapter 1—Adhesive" xxxx).

Fibre Reinforced Polymers (FRP) has broad applications, including aerospace, automotive, marine, and construction industries. FRP is a composite material made of a polymer matrix reinforced with fibres. The fibres are usually glass, carbon, or aramid, although other fibres such as paper, wood, or asbestos were sometimes functional. The polymer is usually an epoxy, vinyl ester or polyester thermosetting plastic, and phenol–formaldehyde resins are still available. As shown in Fig. 9 the applicability of FRP to concrete or masonry structures as a substitute for steel bars or pre-stressing tendons has been actively studied in numerous research laboratories and professional organisations worldwide. FRP strengthening offers several advantages as follows: corrosion resistance, nonmagnetic properties, high tensile strength, lightweight and ease of handling. However, they generally have a linear elastic response in tension up to failure (described as a brittle failure) and a relatively inferior transverse or shear resistance, "Bricks and blocks," (2019). They also have poor resistance to fire and when exposed to high temperatures. They lose significant strength upon bending, and they are sensitive to stress-rupture effects. Moreover, their cost, whether considered per unit weight or based on force carrying capacity, is high compared to conventional steel reinforcing bars or pre-stressing tendons. One of the disadvantages of using FRP solutions is the high costs associated, which turns this solution impracticable for the large majority of the building's owners, Shrivastava and Gupta (2009).

Textile reinforced mortar (TRM)

It is known as Textile Reinforced Mortar (TRM) or [Fiber Reinforced Cementitious Matrix (FRCM) or Textile Reinforced Concrete (TRC), in International Literature (Fig. 10)]. It is a newly developed material in which multi-axial fabrics are helpful in combination with fine-grained concrete. The new FRCM externally bonded Composite Strengthening System combines high-performance sprayable mortar with any fibre grid that creates a thin structural layer without significantly increasing the structure's weight or volume (Naaman, 2010).

TRC is being built as a revolutionary alternative to the steel skeleton, giving Reinforced Concrete (RC) stability. Carbon fibres are too soft to add directly to concrete, so they apply a coating to stiffen after being woven together.

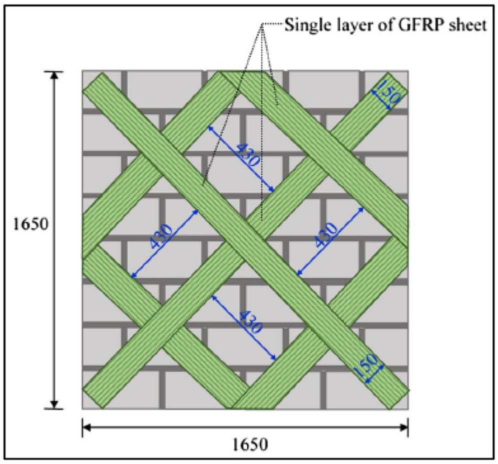


Fig. 9 FRP wrapping around MIW (Elsanadedy et al., Dec. 2016)

Fig. 10 TRM wrapped around MIW Koutas and Bournas (2019)

The fibres in the weave are adjusted for maximum tenacity to perform optimally in the concrete. These individual fibres form the basis of the concrete: up to 50,000, are combined to create a yarn. It is then processed on an automated loom to produce woven mesh. The new concrete's textile interior emerges from a myriad of fine threads. Another coating is put into the mesh that increases stability. After few minutes, the piece is cut to the required length (Naaman, 2010).

Earthquake-resistant structures are structures designed to protect buildings from earthquakes. While no structure can be entirely immune to damage from earthquakes, the goal of earthquake-resistant construction is to erect structures that fare better during seismic activity than their conventional counterparts. According to Code and Commentary IS: 1893 (Part 1) (1893), masonry infills hold considerable in-plane stiffness and strength and contribute to the overall stiffness and stability. The infills show a lesser effect on the structure if openings are present. However, these infills pose the hazard of out-of-plane collapse, which means the loss of life should be minimal by preventing the destruction of the buildings for rare earthquakes, while the loss of functionality should limit to more frequent ones. Strengthening RC frame structures generally increases the resistance and deformation capacity of the frame itself for the system to satisfy the levels of performance according to the codal provisions. Another possible way to improve the resistance of existing structures under lateral loads is to convert the infill walls into a more stable source of resistance over the whole spectrum of structural response through a significant and indemnified contribution to the structure's strength/stiffness (Curbach & Jesse, 2018).

Research and development on masonry structures

Research on masonry infill walls is not a contemporary topic as it was started a few decades back and is still continuing (Table 2).

Dividing the broad area of masonry

The construction of masonry walls is in two different ways. One method includes filling up the space between columns with walls in which openings such as doors, windows or ventilators are optional. This method is known as masonry infill walls (Fig. 11). In the second method, the brick wall is constructed first by leaving some gap to construct vertical compression members, called tie columns joined with tie beams. The second method of construction is known as confined masonry walls (Fig. 12). In this article, the research and development of masonry infill walls are discussed in the following sections (Table 3).

Experimental work

Researchers performed and are still performing several experiments to investigate the effect of numerous parameters on the performance of reinforced concrete masonry infill frames. Fifty references are considered and segregated year-wise, from recent publication to the oldest (1979 to 2021) and summarised in tabular form as given in Table 4.

Sinha et al. (1979) (Lateral strength o f model brickwork panels) conducted tests on brickwork panels with various aspect ratios ($L/H = 0.5–2$), boundary conditions supported on top and bottom and continuous on one or both ends. They also investigated the elastic properties that confirmed the nature of brickwork is orthotropic. In addition, results suggested that the flexural capacity of brickwork increases up to 44% by vertical joint filling. The two loading directions are shown in Fig. 13.

Drysdale' and. Essawy, (1988) tested 21 full-scale MIW with concrete blocks by applying UDL perpendicular to the wall plane with simple support conditions on four sides of the border, i.e., on bottom and top on base and two sides, only on two sides. The bending strength used was extracted from the results of the tests in which bending strength used was removed from the test performed on masonry assemblages. Load for initial cracking and failure load were examined. Both the elastic finite-element plate analysis and the yield-line analyses provide quite good predictions of failure pressure. Figure 14a shows the stack-bonded prism for flexural tests normal to the bed joint using Bond wrench test setup as shown in Fig. 14b.

Ehsani et al. (1999) investigated 3 URM infill walls retrofitted with composite strips with five reinforcement ratios & 2 different glass fabric composite densities by applying OOP cyclic loading. When widens and lighter blended fabrics are helpful, tensile failure controls the mode of failure, whereas stronger ones are fruitful, governed by delamination. Results concluded that URM walls retrofitted with composite strips are effective alternate strengthening techniques. Papanicolaou et al. (2008) compared the performance of TRM overlays and FRP overlays as a strengthening material or NSM reinforcements. Many studies in the past considered parameters such as motor-based vs resin-based matrix materials, the number of layers of TRC, the orientation of moment vector concerning bed joints and concluded that TRM is advantageous over FRP in terms of strength & deformability. In other words, TRM is a promising solution for strengthening MIW under OOP. The testing frame consisted of two similar loading frames, one in the north face and the other in the south face. The tensile failure observed during the experiment can be seen in Fig. 15a and the delamination in Fig. 15b.

Hak et al., (2014) constructed an external MIW with tongue and groove clay block to understand the seismic

Table 2 Summary of the literature review on the experimental study on MIW carried out by researchers

Authors	Brick unit used	Details of Strengthening material	Parameters considered	Strengthening contribution	Failure mode	Year
Sinha et al. (Lateral strength o f model brickwork panels”. 1979)		Filling of vertical joints	Different aspect ratio	Increase in flexural capacity		1979
By Drysdale and Essawy (1988)	Concrete block		Simple support conditions on all four boundaries		Initial cracking	1988
By Ehsani et al. (1999)	Unreinforced brick walls	Vertical composite strips	Reinforcement ratios and different glass fabric composite densities	Capable of dissipating some energy	Tensile failure, delamination	1999
Murty, Jain (Papanicolaou et al., 2008)	Masonry with and without reinforcement		Effect of brick size on the hysteretic response	Improve the out-of-plane response		2000
Yaw-Jeng Chiou et al. (Hak et al., 2014)		Discontinuous deformation analysis (DDA)	Tensile failure and shear failure	Increases the stiffness	Short column effect and leads to a severe loss of column	2000
Mohamed Elgawady	Half-scale hollow clay brick units	FRP-aramid, glass, carbon, hardwire post-tensioning	With and without retrofitting	Improved the lateral resistance of the URM walls		2004
Panka J Agarwal and S. K. Thakkar		Strengthening measures and retrofitting measures	Different strengthening and retrofitting measures	Horizontal bond beam at the lintel—reduce the cracking above the lintel level. Insertion of an additional sill-band reduces the cracking in walls. Epoxy sand mortar technique restore the initial strength, stiffness and deformation capacity		2004
Catherine G. Papanicolaou et al.	Fired clay brick, ridge-faced, 6-hole, horizontally perforated clay bricks	NSM CFRP strips per side	Mortar-based versus resin-based matrix materials, the number of layers, the orientation of the moment vector with respect to the bed joints and the performance of TRM or FRP jackets in comparison to NSM strips	TRM overlays provide a substantial gain in strength and deformability	Damage in the masonry	2008
Sigmund, Zovkić, Sigmund	Strong, medium strong and weak infill		Types of infill	Enhances the initial stiffness, increase the load-carrying capacity	Cracking in the infill,	2012
Zovkić, Sigmund and Guljaš	High strength, medium-strength hollow clay brick blocks and low strength lightweight AAC blocks			Masonry infill strength influenced the maximum lateral load and energy dissipation capacity	Not much severe damage to the frame columns	2012

Table 2 (continued)

Authors	Brick unit used	Details of Strengthening material	Parameters considered	Strengthening contribution	Failure mode	Year
Andrew Kauffman, Ali M. Memari	Concrete masonry units and AAC blocks	Structural fuse	Replacement of conventional brick types	Brittle failure of the infill walls or frame elements is prevented, increase the in-plane stiffness		2014
Marin Grubišić, Vladimir Sigmund	Hollow and solid clay masonry units			Achieve both strength and flexibility at the same time, enhances the maximum load-carrying capacity		2014
Sanja Hak, Paolo et al.	Clay masonry, clay block masonry units with tongue and groove				Out-of-plane failure mechanism	2014
Saman Babaeidarabad et al.	Clay brick	FRP, FRCM	Strengthening material	Flexural capacity and stiffness	Flexural failure and shear failure in the substrate material	2014
Lila M. Abdel-Hafez et al.		GFRP sheets, steel rebar impeded in frame, plastering and ferrocement meshes		GFRP increases ultimate load-carrying capacity; ductility increased with ferrocement,	GFRP reduces its ductility	2014
Sadeghi Marzaleh, Abdollah	Solid clay bricks	Post-tensioning	Aspect ratio of the walls	Increase in the shear resistance	Rocking failure mode, ductile rocking mode to a brittle diagonal cracking	2015
Elsanadedy et al.	Hollow concrete block	FRP, GFRP	FRP reinforcement ratio and stiffness	Upgrading the load-carrying capacity, enhancing the ductility capacity	FRP debonding	2016
Najif Ismail, Jason M. Ingham	Vintage solid clay bricks	Two types of TRM polymer	Perforated and non-perforated URM wall	Strength increment, increment in deformation capacity and ductility	Polymer textile ruptured in a brittle manner	2016
Leal et al.		Confining elements horizontal reinforcement	Wall/frame stiffness ratio, the use of confining elements and the use of horizontal reinforcement	Enhance the OOP stability of the wall and the contact conditions between the wall and frame	Sliding mode failure	2017
Arash Rahgozar, Abdollah Hosseini	Low strength clay bricks		Ancient mortars of mud, lime-mud, and lime-sand		Failure occurs partially in the interface of brick and mortar	2017
Natalino Gattesco, Ingrid Boem	Solid brick, 250 mm thick, rubble stone and cobblestones, 400 mm thick	GFRP meshes	Types of masonry and failure mode	Resist out-of-plane bending moments almost 4–5 times greater than those of plain specimens	Collapse occurred abruptly, almost at mid-height of the sample, at the interface between mortar joint and masonry units	2017

Table 2 (continued)

Authors	Brick unit used	Details of Strengthening material	Parameters considered	Strengthening contribution	Failure mode	Year
Shermi C., R.N. Dubey		WWM		Enhanced the flexural strength and ductility of masonry	Flexure cracks, ductile failure	2017
Kariou, Triantafyllou, Bournas, Koutas		TRM	Textile reinforcement ratio, the textile material, the coating of the textile reinforcement with epoxy resin, and the wall thickness	Increase the load-bearing capacity		2018
André Furtado et al.			Geometric dimensions, material and mechanical properties, test setups and loading protocols			2018
Claudio D'Ambra et al.	Clay brick	Composite basalt grid with inorganic matrix FRCM	Damaged wall and not predamaged wall	Prevent a brittle failure, ultimate load doubled	Shear sliding at higher displacement levels	2018
Mario Fagone, Giovanna Ranocchiai		CFRP Composite Materials	Influence of spike anchors on the load-bearing capacity and dissipation the capability of the reinforcements	Increase of F_1 and F_{max}, spike anchors effectively increase strength and dissipative power of CFRP reinforcement sheets	Cracks the pattern in the central portion and failed because of masonry compressive failure, detachment of the rein from the substrate	2018
Padalu et al.		WWM reinforcement	Loading direction, reinforcement ratio and effect of shear span	Enhances the flexural strength of the wallets deformability and energy absorption capacity	Failure of URM wallets is sudden and brittle, debonding of bed-joints at the interface with mortar	2018
Di Domenico et al.			Different slenderness ratios, the gap between frame and wall		Brittle failure due to masonry crushing soon after the attainment of peak load	2018
Ismail1 et al.		FRCM basalt, glass, and carbon fabrics	Masonry type, the FRCM fabric material, and the number of FRCM layers	Shear strength increase, increase in the ductility and energy dissipation capacity	From brittle bed joint sliding to a more gradual distributed diagonal cracking and toe crushing	2018
Farhad Akhoundia et al.	Traditional brick infills	TRM		Improving the lateral strength and by reducing significantly the damage of the brick infill walls		2018
Thi-Loan Bui et al.	Clay solid brick	TRC		Residual strength and deformation ability	Reduce the risk of out of plane failure	2018
Ismail, El-Maaddawy, Khattak	Hollow concrete masonry	FRCM glass, carbon and basalt fabrics		Improving the seismic performance	FRCM deboning	2018

Table 2 (continued)

Authors	Brick unit used	Details of Strengthening material	Parameters considered	Strengthening contribution	Failure mode	Year
Ali M. Memari and Mohammad Aliaari		Structural fuse		Structural fuse elements as sacrificial components in masonry construction	Effect of frame joint stiffness on the overall mode of behaviour is not as much as the stiffness of the frame members	2018
Saeed Pourfalah, Demetrios M Cotsovos		ECC layers fully bonded to the surface of the masonry		More ductile performance	Localized cracking exhibited by the ECC layer, premature failure	2019
Zuhair Al-Jaberi et al.	Fully grouted concrete masonry units	FRP, EB—wet layup GFRP sheet and prefabricated CFRP laminate		Enhancing the flexural capacity, out-of-plane flexural capacity and pre-yield stiffness remarkably increased	Compressive concrete crushing failure, FRP rupture, shear failure, and debonding from the masonry substrate	2019
Gerardo M. Verderame et al.		FRCM and FRP	Unreinforced and reinforced one-way spanning masonry infills	Increment of the out-of-plane strength	Combined flexural and arching mechanism	2019
Mahmoud R. Maheri et al.	Concrete block masonry	Reinforced concrete layers	Different aspect ratios and boundary conditions	Enhancement in-wall capacity and ductility	Stepwise diagonal cracking through the mortar bed joints	2019
Arton D. Dautaj et al.			Varying degrees of separation between upper and lower portions		Split in the masonry infill, displacement damage	2019
Ehsan Nasiri	Concrete Masonry Units (CMUs)		Infill opening, interfacial gaps, and prior in-plane damage on the out-of-plane behaviour and strength of infilled RC frames		Prior in-plane damage	2019
Alireza Namayandeh Niasar et al.		ECC	Retrofitted undamaged and damaged wall	Increase in energy dissipation capacity and lateral strength	Rocking (flexural behaviour) failure mode	2020
Francesca da Porto et al.	Robust clay masonry	Vertical and horizontal reinforcement	Presence of a central opening, effect of a lintel	Reduces the IP damage and increases the IP strength	Vertical reinforcement – worsen the behaviour of the infill masonry system	2020
Filip Ani et al.		Non-contact optical techniques to measure contour strains and deformations	With and without window and door openings	High stability, no cracks occurred in the frame, except in the infill wall and the lower beam	Debonding of the infill from the frame, fall out of parts of infill walls due to inertia	2021
Xiao Lu, Shumin Zha	Resilient Infill Wall (RIW)	Setting of gaps and metal connectors	Damage evolution and hysteric performance	Initial stiffness increased, great improvement in seismic performance and hysteresis characteristics	Large residual deformation in the metal connectors	2021

Fig. 11 Masonry Infill Wall

Fig. 12 Confined Masonry Wall

performance in the OOP orientation, mainly in terms of failure, mechanical and damage propagation and OOP strength. The masonry unit used in the experimental tests is shown in Fig. 16, along with the dimensions. It has been determined that resistance mechanism formed with respect to two-directional arching action.

Babaeidarabad et al., (2013) conducted OOP experimental tests on nine clay brick MIW in which three specimens were without strengthening and six were with strengthening, with FRCM having one and four reinforcement fabrics (Fig. 22a–c), which proved that it strengthened walls. The behaviour of the infill wall both in terms of stiffness and flexural capacity was in significant improvement. Also neglecting the arching effect, an analysis was carried out, and the output was compared with experimental data. Elsanadedy et al., (2016) conducted experimental and analytical study on the OOP flexural performance of URM infill walls externally bonded with GFRP composites. For this study, six hollow concrete block-cyclic walls were loaded to failure using an airbag and a loading frame to obtain uniform loading by considering FRP reinforcement ratio and stiffness as main parameters. The conclusion derived was that FRP effectively enhances the load-carrying capacity, the load-carrying capacity,and the OOP deformation capacity of URM walls (Fig. 17).

Gattesco and Boem (2017) examined the OOP bending effectiveness of GFRP meshes applied on both faces of the existing MIW by carrying out both experimental and numerical studies. For this, 4-point bending load was used on the full-scale MIW as shown in Fig. 18a and b. Constructing three masonry types is solid brick, rubber stone, cobblestones. The conclusion stated that the strengthening technique enhanced the OOP bending moments by 4–5 times the specimen without strengthening. Moreover, numerical results were in good agreement with the experimental results that determined the accuracy of the simulations.

In Fig. 19, the numerical results of RM specimens are plotted in addition to the experimental curves referred to as both RM and URM specimens. Both the first cracking and the GFRP wire's rupture occurred at the height of the upper horizontal force. In solid brick (Fig. 19b) and rubble stone (Fig. 19c) RM cases, the cracking and the ultimate resistance points were estimated accurately. Also, the cobblestones RM specimen (Fig. 19d) evidenced a trend like the experimental one up to the occurrence of the first crack, but then the numerical curve prosecuted with a lower slope and a lower value of maximum load was reached. This aspect is probably due to the marked irregularity of the coating thickness. The cobblestone masonry surface was significantly uneven due to the round and irregular shape of the stone units. This aspect may alternate the tension stiffening effect of the mortar between cracks. Shermi and Dubey (2017) tested 6 URM walls & 18 reinforcements masonry panels applying 3-point loading as per ASTM E518-10 to investigate OOP performance of both URM and WWM URM were strengthened using high strength mortar (1: 4), low strength (1: 6) and WWM of different spacing (25, 38, 50 mm) WWM increased the flexural strength & ductility of masonry. Kariou et al., (2018) suggested TRM has a significant effect on the load-carrying capacity of MIW by testing 18 specimens divided in equal numbers into single-wythe and double-wythe walls, investigating key parameters such as textile reinforcement ratio, textile material, and textile material coating of textile reinforcements with epoxy resin and the wall thickness. The different textiles used for this study is shown in Fig. 20.

Furtado et al., (2018) presented a systematic review of the experimental OOP tests grouped into the following three categories: built specimens, specimens within plane damage and retrofitted specimens. According to the masonry

Table 3 Summary of the literature review on the numerical study on MIW carried out by researchers

Authors	Brick unit used	Details of Strengthening Material	Parameters considered	Strengthening contribution	Failure mode	Year
Dawe and Seah	Concrete blocks		Compressive, shear and tensile strength, elastic and shear modulus		Diagonal tensile cracking as well as crushing	1989
Madan et al.	Clay bricks		Drift analysis and base shear		Cyclic lateral loading	1997
Armin B. Mehrabi, P. Benson Shing	Hollow and solid concrete masonry blocks		Compressive, shear and tensile strength, elastic and shear modulus		Lateral and horizontal loads	1997
Hemant B. Kaushik et al.	Burnt clay solid bricks		Compressive, shear and tensile strength, elastic and shear modulus		Crushing failure	2007
Ghassan Al-Chaar et al.	Hollow concrete blocks		Compressive, shear and tensile strength, elastic and shear modulus		Cyclic lateral loads	2008
Saedi Daryan et al.	Concrete blocks	Link Beams	Compressive, shear and tensile strength, elastic and shear modulus	Dissipation of a large amount of energy during earthquake	Dynamic loading	2009
Andreas Stavridis and P. B. Shing	Empty frame, hollow and solid concrete masonry blocks		Compressive, shear and tensile strength, elastic and shear modulus	Increase in strength	Horizontal sliding, diagonal crack, panel crushing	2010
Vladimir G. Haach et al.		Prefabricated Steel Truss Reinforcement	Compressive, shear and tensile strength, elastic and shear modulus		Shear-flexure failure	2010
Ioannis Koutromanos et al.			Drift analysis and base shear		Lateral loading	2011
Nishant Kishore Rai et al.	Burnt clay bricks		Compressive, shear and tensile strength, elastic and shear modulus	Response of the system gets reduced	Seismic failure	2011
Meillyta	Clay brick and concrete blocks		Compressive, shear and tensile strength, elastic and shear modulus		Shear failure	2012
Torrisi et al.			Compressive, shear and tensile strength		Lateral loading	2012
Changhai Zhai et al.	Concrete blocks		Compressive, shear and tensile strength, elastic and shear modulus		Dynamic loading	2012
Ray Kai Leung Su And Chien-Liang Lee		A coefficient based method will be used for the design	Peak ground accelerations	Technique used can be suitably adopted	Seismic failure	2013
Alireza Mohyeddin et al.			Compressive, shear and tensile strength, elastic and shear modulus		Dynamic loading failure (in plane and out of plane)	2013

Table 3 (continued)

Authors	Brick unit used	Details of Strengthening Material	Parameters considered	Strengthening contribution	Failure mode	Year
Xi Chen, Yi Liu			Compressive, shear and tensile strength, elastic and shear modulus		Diagonal tensile cracking as well as crushing	2014
Mohammed Ashraf Nazief	Hollow concrete blocks		Compressive, shear and tensile strength, elastic and shear modulus		Sliding shear failure	2014
Amir Hossein Karimi, Mohammad Saeed Karimi	Clay bricks		Compressive, shear and cyclic loading		Seismic failure	2016
Wang Guojue et al.	Solid clay bricks	Precast concrete columns and beams	Compressive, shear and tensile strength, elastic and shear modulus	Increase in strength	Shear failure	2016
Maidiawati and Yasushi Sanada			Compressive, shear and tensile strength, elastic and shear modulus	Increased survival time during ground motion	Seismic loading	2016
Hongyu Deng, Baitao Sun			Shear strength parameters	Increased survival time of the structure	Seismic failure	2016
Chungman Kim et al.	Concrete bricks		Compressive, shear and tensile strength, elastic and shear modulus		Diagonal cracking	2016
Arash Rahgozar, Abdollah Hosseini	Clay bricks	Mortars including mud, lime–mud, and lime–sand	Compressive, shear and tensile strength, elastic and shear modulus	Improved structural performance	Shear failure	2017
Maria Teresa De Risi et al.	Clay bricks		Lateral and horizontal loads, displacement	Technique used can be suitably adopted	Shear failure	2017
Ali.Laftah.Abbas And Maan. H. Saeed			Lateral and horizontal loads, displacement		Dynamic loading failure	2017
Anoj Khatiwada, Huanjun Jiang			Compressive, shear and tensile strength, elastic and shear modulus			2017
Ehsan Nasiri, Yi Liu			Compressive, shear and tensile strength, elastic and shear modulus		Seismic loading failure	2017
Saif Adil Shawkat, Ammar A. Abdul Rahman	Concrete masonry blocks		Compressive, shear and tensile strength, elastic and shear modulus		Seismic loading	2017
Alessandra De Angelis, Maria R			Dynamic testing		Dynamic loading	2018
Laura Liberatore et al.	Hollow and solid brick blocks		Cyclic loading test		Seismic failure	2018

Table 3 (continued)

Authors	Brick unit used	Details of Strengthening Material	Parameters considered	Strengthening contribution	Failure mode	Year
Hadi Baghia et al.	Ceramic bricks		Lateral loading, compressive, shear and tensile strength, elastic and shear modulus		Seismic failure	2018
Ehsan Nasiri, Yi Liu	Concrete masonry blocks		Dynamic loading tests		Dynamic loading failure	2018
André Furtado et al.	Clay bricks and concrete blocks	Joint reinforcement	Lateral loading, compressive, shear and tensile strength, elastic and shear modulus	Improved structural performance		2018
Kalman Šipoš et al.			Compressive, shear and tensile strength, elastic and shear modulus	Increase in strength	Seismic failure	2018
Pantòa et al.	Commercial vertical perforated masonry	Commercial vertical perforated masonry	Lateral loading, compressive, shear and tensile strength, elastic and shear modulus	Improved structural performance	Seismic failure	2019
Mahmoud R. Maheria et al.	Hollow concrete masonry blocks		Compressive, shear and tensile strength, elastic and shear modulus		Diagonal shear failure	2019
Ebrahim Khalilzadeh Vahidi, Reza Moradi			Compressive, shear and tensile strength, elastic and shear modulus		Seismic failure	2019
Gerardo M. Verderame et al.	Hollow clay bricks	FRP’s and CFRP’s	Lateral loading, compressive, shear and tensile strength, elastic and shear modulus	Improved structural performance	Dynamic loading	2019
Mariano Di Domenico et al.	Hollow clay masonry blocks		Lateral loading, compressive, shear and tensile strength, elastic and shear modulus		Seismic failure	2020
Laura Liberatore et al.	Solid or hollow clay bricks		Lateral loading, compressive, shear and tensile strength, elastic and shear modulus		Seismic failure	2020
Ehsan Nasiri, Yi Liu	Concrete blocks		Compressive, shear and tensile strength, elastic and shear modulus		Dynamic loads	2020
Mohammad Yekrangnia, Panagiotis G. Asteris			Compressive, shear and tensile strength, elastic and shear modulus	Improved structural performance		2020
Ali Jalaeefara, Azam Zargar			Compressive, shear and tensile strength, elastic and shear modulus		Seismic failure	2020
Lihua Niua et al.	Sintered ordinary brick		Lateral loading		Seismic loading	2020
Sandy Nyunna et al.			Lateral loading		Column failure at corner and exterior region	2020

Table 3 (continued)

Authors	Brick unit used	Details of Strengthening Material	Parameters considered	Strengthening contribution	Failure mode	Year
Laura Liberatore, Omar Alshawa	Clay bricks and concrete blocks		Compressive, shear and tensile strength, elastic and shear modulus		Seismic failure	2021
Xiao Lu, Shumin Zha	Hollow concrete bricks		Cyclic loading tests		Drift	2021
Filip Ani et al.	Hollow clay masonry blocks		Cyclic, quasi-static IP tests		Seismic failure	2021

and in-plane drifts, to predict the OOP capacity of the infill panel, empirical equations were proposed. The parallel flexural strength parallel to the horizontal bed joints increases the OOP capacity by five times. D'Ambra et al., (2018) performed experiments on full-scale clay infill wall strengthened with basalt grid with inorganic matrix (FRCM) used to strengthen pre-damaged walls and constructed walls to study the effectiveness of FRCM to regain the capacity of pre-damaged wall and to enhance the overall performance of a non-damaged wall. Fagone and Ranocchiai (2018) described the mechanical performance of MIW strengthened with CFRP sheets, subjected to OOP loads, particularly the effect of spike anchors on the reinforcement's load-bearing capacity and energy dissipation capacity which significantly increased. Padalu et al., (2018) tested 8 URM and 28 strengthened wallets using WWM in perpendicular orientation under 2-point OOP loading. The parameters considered are loading direction, i.e., perpendicular and parallel to the bed joints (Fig. 21), reinforcement ratio and effect of shear span. The results displayed that the WWM increases Wallette's flexural capacity by 9.4 times, over by 61 times and energy absorption capacity by 1024 times compared to URM wallets without strengthening. Di Domenico et al. (2020) presented the OOP response of URM walls by conducting pseudo-static tests to observe the effects of BC in terms of stiffness, strength & displacement capacity with one specimen being mortared on four edges to the bounding RC flame, another model with a gap of 2 mm between the upper edge & beam & the other final one being restrained to the bounding frame only on the upper & lower edges. OOP response during the test experienced also vertical arching.

Pourfalah and Cotsovos (2020) ECC to enhance the out of plane strength of URM walls subjected to impact loading, ECC layers were fully bonded to the surface. The results revealed that the application of ECC increased the out of a plane performance of MIW subjected to blasts or impact loads and enhanced the strength, ductility and deformability of the MIW by acting as a mesh to prevent debris due to impact load. Al-Jaberi et al., (2019) tested 12 reinforcements MIW constructed with fully grouted concrete masonry units with different amounts of steel reinforcement strengthened with wet layup GFRP and prefabricated carbon FRP and showed the efficacy of FRP as an externally bonded strengthening material in increasing the capacity of MIW in flexure. Verderame et al., (2019) performed experiments on URM and RM infill frames by using OOP lateral loading. These specimens are compared with the other two models, which were strengthened using FRCM and FRP. The results showed that the FRCM boosted with FRCM gave three times the strength, whereas FRP gave two times the strength of the specimen without supporting. da Porto et al. (2020) examined eight whole scales, one bay, one storey MIW RC framed under combined IP/OOP tests conducted

Table 4 Analytical prediction of lateral resistance and stiffness

S. no	Failure mechanisms	Force diagrams	Lateral resistance		
1	Figure 40(1)	Figure 41	$V_{u1}=V_{wr}+F_{cc}+F_{ct}$	$F_{cc}=\frac{4M_{pc}}{h}$, $F_{ct}=\frac{4M_{pct}}{h}$	
2	Figure 40(2)	Figure 42	$V_{u2}=V'_{wr}+F_{cc}+V_{ct}$	$V'_{wr}=A_w\frac{\frac{\mu_r P}{A_w+2A_{ceq}}}{1-0.5\mu_r\frac{h}{L}}$, $V_{ct}=0.8V_{cs}+V_{cc}$	
3	Figure 40(3)	Figure 43	$V_{u3}=\mathrm{yf'_m t}=m_c f'_m th_c$		$m_c=\sqrt{\frac{4M_p}{f'_m th_c^2}}$ $y=\sqrt{\frac{4M_{pc}}{f'_m t}}$
4	Figure 40(4)	Figure 44	$V_{u4}=0.67\ f'_m\ t\alpha h+2\ F_c=$ $(m_c^2+0.67\alpha-0.5\alpha^2)\ f'_m\ th$		$\alpha h=\pi\sqrt[4]{\frac{E_c I_c h}{4E_w t\sin 2\theta}}$
5	Figure 40(5)	Figure 45	$V_{u5}=V_{wr}+F_f$	$F_f=\frac{4M_{pc}}{h}$	

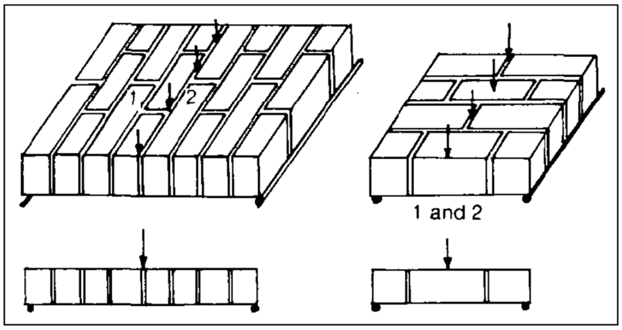
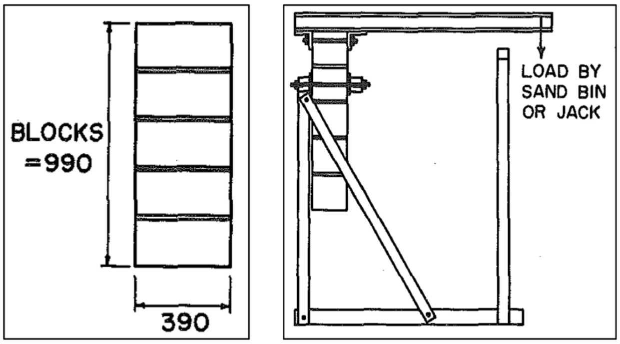


Fig. 13 Test arrangements for the determination of flexural strengths in two directions ("Lateral strength o f model brickwork panels". 1979)



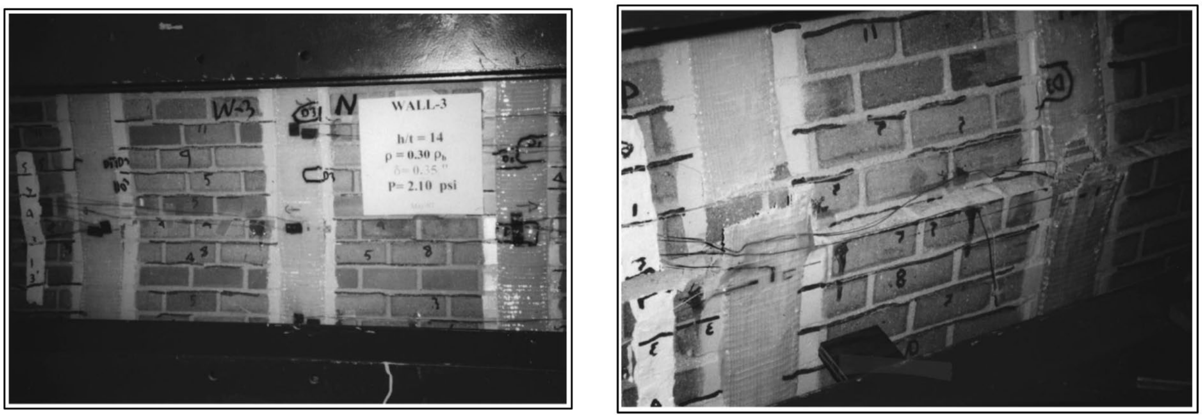
a Specimen; **b** Bond Wrench Test Setup

Fig. 14 Flexure normal to bed joint (Drysdale' & Essawy, 1988)

on robust clay infill frames and presented the overview of the results obtained from the same. Among eight frames, in four cases, two were constructed of URM and the other two were of RM, i.e. both horizontal and vertical reinforcements. In addition, other four instances of the same configuration, but with openings at the centre and one with lintel, were considered. Further, analytical models were also carried out based on the arcing mechanism. Anić et al. (2021) used non-contact optical techniques for measuring the contour strains and deformation of RC Frames with MIW with and without openings subjecting it to cyclic OOP lateral load for the investigation. The results showed that neither the infills nor the spaces affected the specimen's overall behaviour. However, it was also found that infills were damaged with storey drift of 1.25–2.5%, which imparts the risk to the occupants' life. Also, infills with eccentric openings suffered further damage than full infill frames without frames' opening. Finally, the presence of infill could influence the overall combined in-plane performance of the structure.

When subjected to seismic loads, RC frames with brick infill display undesirable failures such as short-column, soft-storey, torsion and out-of-plane collapse. To overcome these effects, C. Murty and Jain (2000) have carried out experimental tests on RC frames subjected to cyclic tests and concluded that infills increase the lateral stiffness, strength, ductility, and energy dissipation capacity. The test setup adopted by the authors is shown in the Fig. 22.

Chiou et al., (2000) tested three full-scale specimens—a bare RC frame, an RC frame constructed with partial infill and an RC frame filled with brick wall subjecting them to in-plane monotonic loading and carried out the numerical study using DDA considering the concrete and mortar failure to investigate both tensile and shear failure where the latter is assumed to follow Mohr–Coulomb criterion. Observations put forth that the partial infill wall induced a short column effect and was the reason for severe column failure. However, the filled wall helped in increasing the stiffness of the structure. Elgawady (2004) FRP is a technique to strengthen the MIW instead of approaching conventional methods due to its apparent advantages such as economic, less specific weight, no corrosion and high tensile strength. They focussed on the in-plane performance of URM walls retrofitted with FRP. Different parameters considered were another effective moment or shear ratios of 0.5, 0.7 and 1.4, fibre type considered are aramid, glass, carbon hardwires,



a Cracking and Delamination Pattern at Failure on North Face

b Tensile Failure of GFRP Strips on South Face [23]

Fig. 15 **a** Cracking and delamination pattern at failure on north face. **b** Tensile failure of GFRP strips on south face (Papanicolaou et al., 2008)

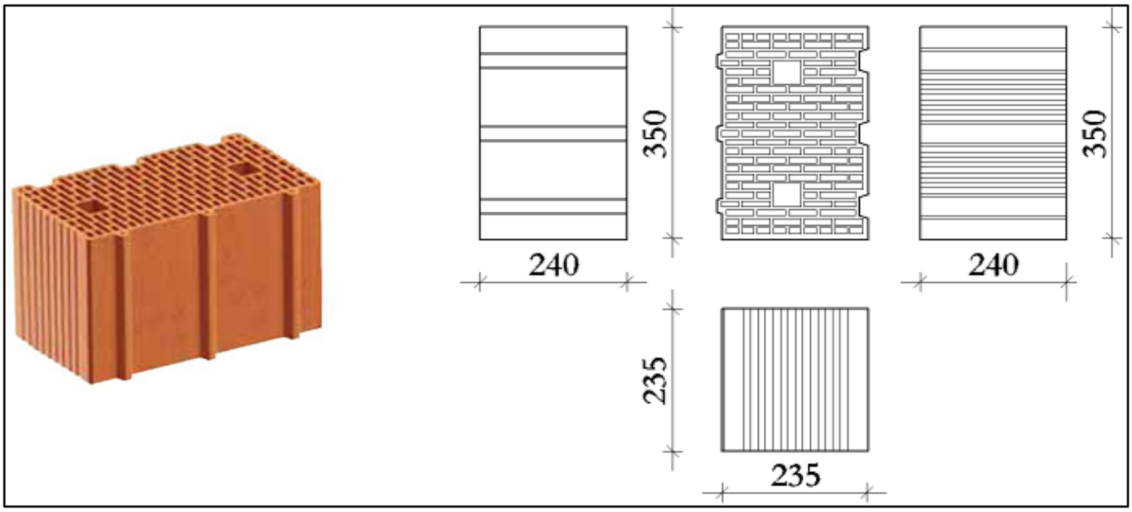


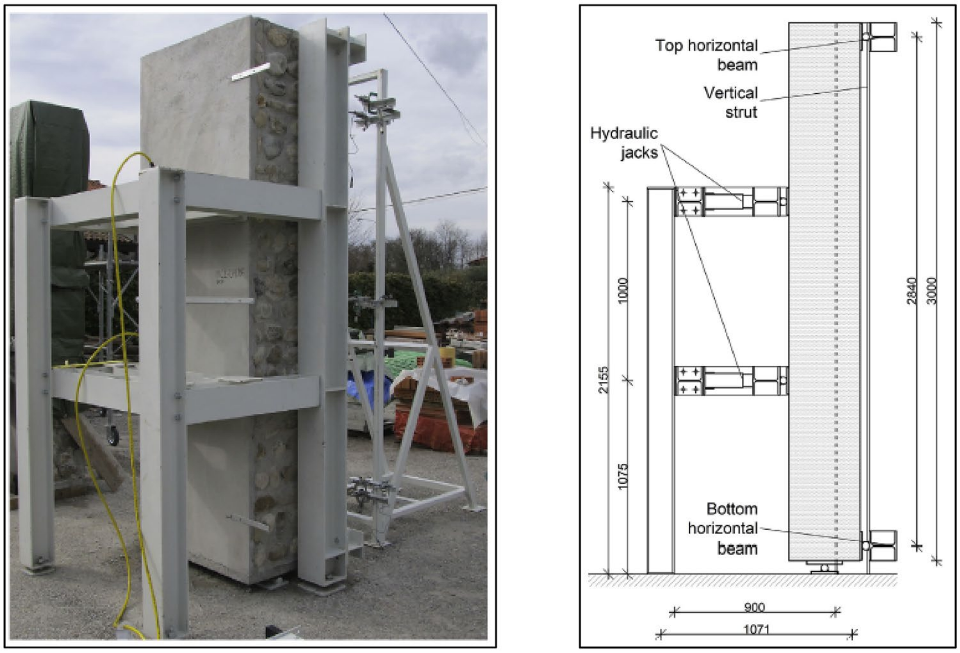
Fig. 16 Tongue and groove clay masonry blocks (Hak et al., 2014)

reinforcement ratio from 0.07% to 0.28% fibre. Results displayed that the lateral resistance depends on reinforcement ratio, specific aspect ratio and fibre characteristics. In contrast, the ultimate drifts were independent of reinforcement ratio and reinforcement type but dependent on aspect ratio and retrofitting configuration. Since past earthquake events in Turkey have damaged many reinforced concrete structures, investigations on strengthening methods for MIW have increased. Two strengthening methods were adopted by the Erdem et al., (2006) in this study: one of the frames was strengthened with reinforced concrete infill, and the other was an RC frame using hollow clay blocks (Fig. 23) strengthened with CFRP considering Strength, stiffness, and storey drifts of the test specimens as variables. Observations concluded that both the strengthening techniques were performed when subjected to reversed cyclic lateral loading.

The bare frames were strengthened with partial infills and tested under lateral cyclic loading considering the parameters such as the aspect ratio of the infill wall and the configuration placement. The test output concluded that the frame with partial infills exhibited higher ultimate strength and initial stiffness than the bare frame. Also, both the lateral capacity and the rigidity were increased with the increase in the aspect ratio of the infill wall. In addition to that, the connection between column and beam to the partial infill wall exhibited the best behaviour Anil and Altin (2007). One-storey, one bay 1/3rd scale masonry infill RC frames constructed with perforated clay brick infills have

a The first layer of mortar **b** Pre-cut carbon fabric **c** The second layer of mortar

Fig. 17 Application of FRCM onto the masonry infill wall S. Babaeidarabad et al. (2013)

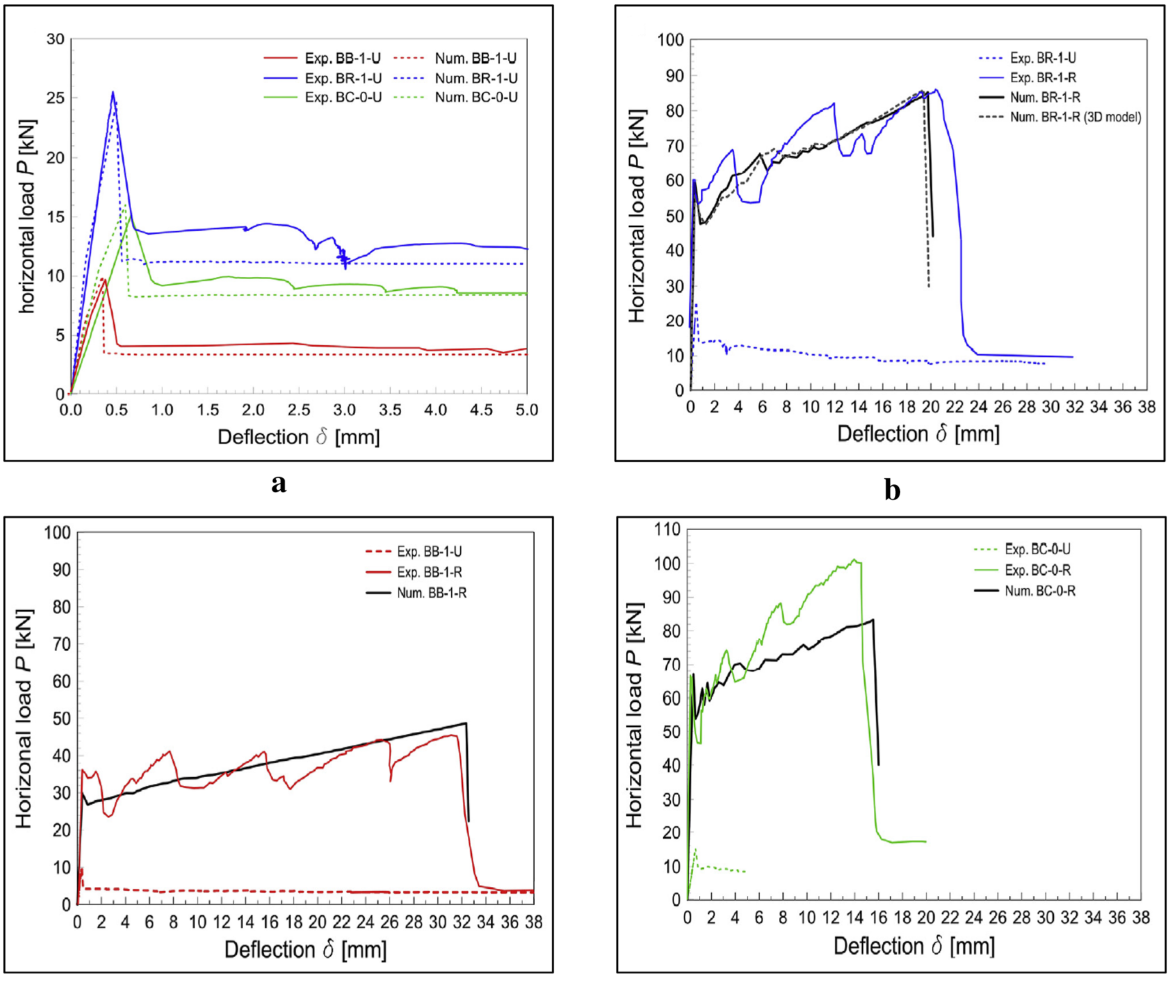


a Global view **b** Vertical section

Fig. 18 Experimental apparatus for bending tests (Elsanadedy et al., 2016)

been strengthened using CFRP strips and subjected to lateral cyclic loading to investigate the same performance. The adopted aspect ratio for the frame is 1.73. The CFRP is placed in three different arrangements. They are on both sides of the wall, on the walls' interior side and exterior side. The parameters studied are the additional width of CFRP (Fig. 24) and the arrangement on the MIRCF. CFRP considerably increased the strength and stiffness of the perforated clay brick infill wall. Those symmetrically strengthened specimens showed better performance in terms of lateral stability and stiffness; Altin et al., (2008).

Agarwal and Thakkar (2004) used a different strengthening approach and retrofitting method to study the performance of MIW under quasi-static cyclic loading test. The strengthening technique used is the horizontal bond beam placed at the sill and lintel levels combined with vertical reinforcement at corners and openings. The retrofitting methods used are epoxy-sand-mortar and cement-grout

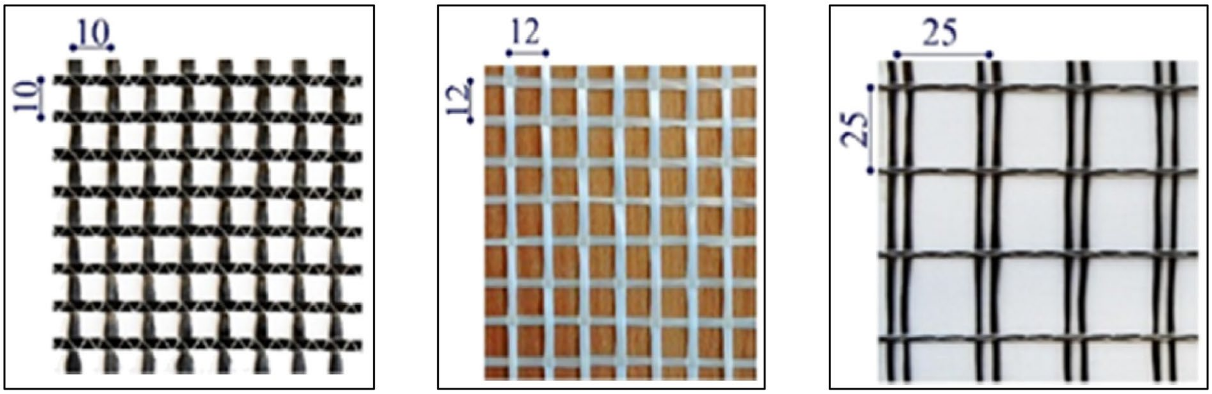


a **b**

c **d**

(a) URM
(b) Solid brick
(c) Rubble stone
(d) Cobblestones

Fig. 19 Out of plane bending tests: horizontal load, P against deflection d curves of (Gattesco & Boem, 2017)



a Carbon **b** Glass **c** Coated Basalt

Fig. 20 Textiles used in this study (Kariou et al., 2018)

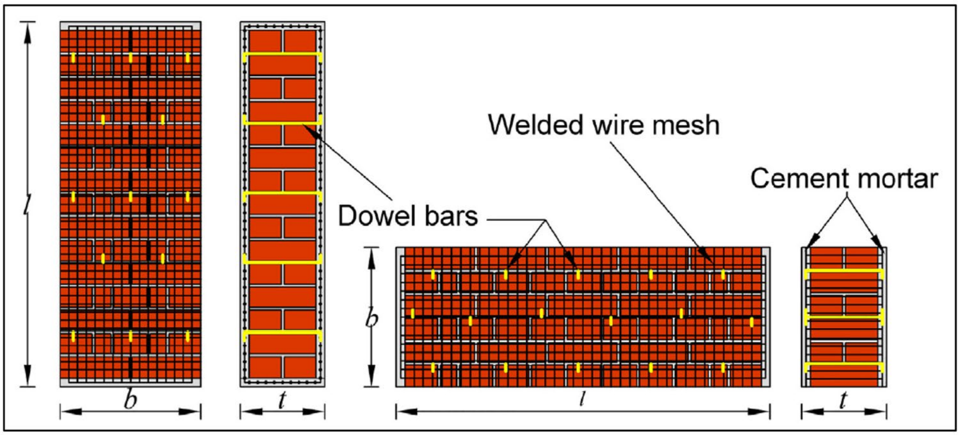


Fig. 21 Details of specimen geometry and strengthening components: strengthened Wallette—bending tension perpendicular to bed joints and parallel to bed joints (Padalu et al., 2018)

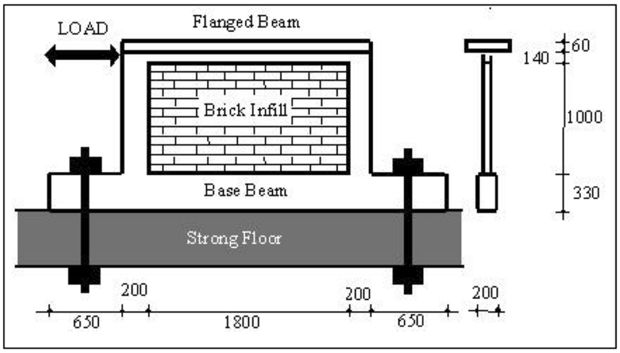


Fig. 22 The geometry of frames tested, Murty and Jain (2000)

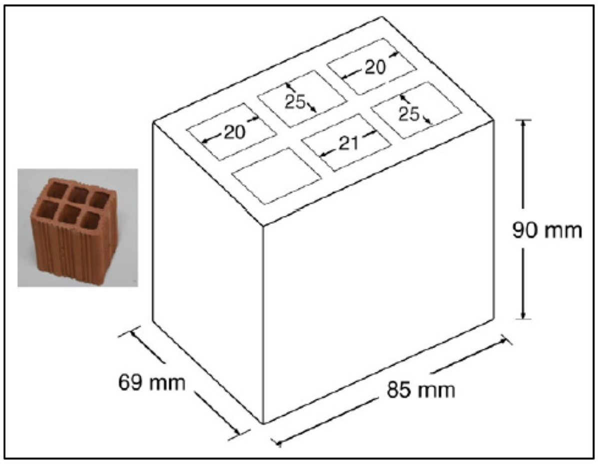


Fig. 23 Dimensions of the hollow clay block (Erdem et al., 2006)

injection with WWM in the cracked region. The retrofitting technique for cracked areas was effective to regain initial strength, stiffness and deformation capacity. The use of WWM helped in recovering the ultimate strength; however, we can observe brittle failure. Altin et al., (2010) added a plaster layer with mesh reinforcement to strengthen the masonry infill to one face of the wall and studied the same performance. Studies showed a satisfying increment in terms of lateral strength and stiffness. However, premature failure occurred in one of the specimens due to the dowel bars' inadequate bonding to transfer shear loads from the frame to the plaster. The best lateral performance was attained from the test specimen in which a mesh-reinforced high-strength plaster layer was applied. Sigmund et al., (2010) put forward the results depicting the relation between the drift capacity and the wall-frame system properties controlling the drift capacity by modelling frames according to EC-8, in a scale of 1:2.5, constructed with three masonry types with standard materials and procedures followed in Croatia subjected to constant vertical and cyclic horizontal loading which concluded that the load-carrying capacity of the structure depends on the type of infill that brings on the increment of 5 to 25%. Zovkić et al., (2013) constructed in full 10 RC infill frames with different types of masonry blocks, among which three frames erected with high strength hollow clay blocks, three shelves with medium strength HCB, three shelves with low strength lightweight AAC blocks and one additional being bare RC frame, all of which were subjected to constant vertical and constant lateral loading. The final results displayed a significant increase in the energy dissipation capacity and maximum lateral load-carrying capacity. However, the deformation capacity remained the same. Grubišić and Sigmund (2014) studied the contribution of strengthening methods of the MIW weak and strong frames on which researchers concentrated less. These MIW were constructed using two kinds of infills, i.e., solid and hollow block units with other properties similar to Croatia. Observations have shown that, under cyclic excitation, the displacement and stiffness response is directly affected by the presence of infill walls. The strengthening technique moderately increases the maximum load-carrying capacity and has a rare loss in the lateral stiffness in the high deformation vicinity. Finally, the infills with solid bricks have much

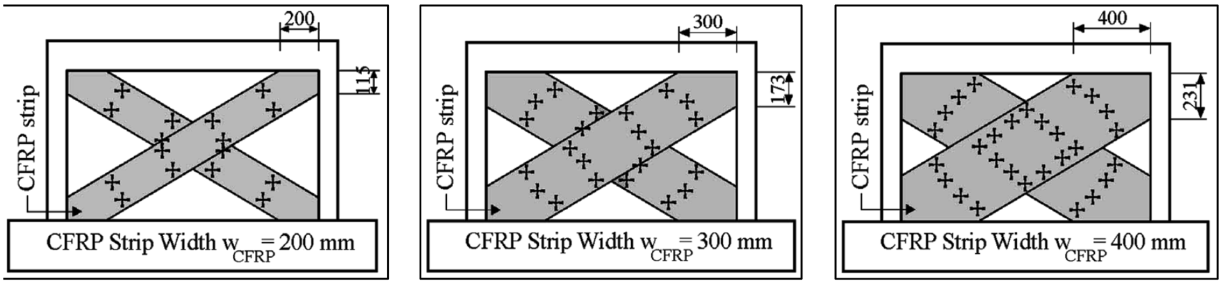


Fig. 24 CFRP strip configuration used in specimens (Altin et al., 2008)

higher energy dissipation than the infills with hollow bricks. Kauffman and Memari (2014) studied the performance of structural fuse with various masonry materials subjected to cyclic loads applied by displacement-controlled loads at the first three storeys of 2 bay, three-storey steel frame with infill brick walls, and 1st mode response in the system quasi-static load was used. The parameters considered were bricks used for infills for concrete masonry units, and autoclaved aerated concrete blocks. Sadeghi Marzaleh (2015) studied the use of a post-tensioning system for residential masonry as a seismic rehabilitation method against seismic events. Also identified the lack of shear resistance in URM walls and implemented post-tensioning to overcome it following the Merkblatt SIA 2008 "Assessment of existing". Abdel-Hafez et al., (2015) used GFRP sheets steel rebar impeded in frame, plastering and ferrocement as strengthening material to improve the behaviour of URM tested under in-plane lateral load. This MIW improved characteristics such as drift toughness ductility and failure load. They recommended the ferrocement method for the improvement of ductility and ultimate failure load of existing frames.

Jiang et al., (2015) performed full-scale reversed cyclic in-plane and oop test on URM walls strengthened with polymer TRM, which were constructed using vintage solid clay bricks and low-strength hydraulic cement mortar to repeat the similar properties of ancient masonry material. The observations concluded that the strength increased up to 128% to 136% when URM was tested in-plane loads and 575% to 789% under OOP loading. Ismail and Ingham (2016) examined the in-plane responses of masonry prisms constructed using cement lime mortars (bastards) by conducting compression, shear and tension test. In addition, experiments and numerical investigation were carried out to study the in-plane characteristics of BM prepared with ancient motors, which includes mud, lime- mud and land-sand; Abaqus FEM was used to model the old masonry structure were the results displaced in unity with the test. Rahgozar and Hosseini (2017) conducted experiments on MIRCF with 1:2 scale considering variables such as wall/frame stiffness ratio, use of configuration elements and horizontal reinforcement and found out that the cracking strength of the wall and the maximum shear strength of the structure is affected by the wall/ frame Stiffness ratio. The effect of horizontal reinforcement is dependent on the stiffness ratio. The final parameter confining elements does not contribute much to the lateral strength or displacement. However, the structure's capacity increases the oop stability of the wall and the bond between wall and frame. Leal et al., (2017) presented a literature survey on the performance of MIW during seismic actions. If the gaps are not provided between the frame and the wall, the stiffness will be high. If the holes are present, damage probability considerably reduces; however, the benefit of increment in strength and stiffness of the infill wall will be lost. Ismail et al., (2018a) tested the performance of 9 2/3 rd scale non—ductile reinforced infill frames with hollow concrete masonry infill strengthened with FRCM subjecting it to cyclic in-plane loading one specimen built without infill and second specimen made with infill but without reinforcing. All models were retrofitted with three different fibre grids, namely basalt, glass and carbon, and three different configurations for retrofitting. A full-scale diagonal band with varying widths finally indicated that frames strengthened with diagonal bars were most effective. In contrast, carbon fibre possessed greater strength than other fabrics, but carbon exhibited the lowest strength for RCFMI. Carried out surveys in China on Wenchuan Eq. (2008) and Dushan Eq. (2013) and provided details on the failure modes of MIW exposed to the equation and sudden damage of MIW due to unplanned arrangement in a building. They also concluded elastoplastic—time—history analyses for ten models based on damaged structures in the Wenchuan equation, concluding that the analytical results match the original failure of the building; however, the work was varying when the vibration period was reduced due to the increase in the stiffness of the structure contributed by MIW. F. Akhoundi, G et al. (2018) (2018) conducted experiments on 7 MIWs subjecting them to in-plane static tests to observe the cyclic -in-plane behaviour of convectional brick infills constructed in Portugal, ultimately arriving at the conclusion stating the infills present inside the bare frame increased both the in-plane systems and resistance and TRM improved the lateral strength and reduced the damage of MIW. Ismail et al. (Ismail et al., 2018b) presented an overview expertly conducted on the efficiency of three kinds of FRCM, namely basalt, carbon and glass, to resist the critical shear damage in unreinforced Hollow Concrete Block (HCB) masonry of two types (200 mm and150 mm thickness) which altered the failure mode from sliding bed joint brittle mode to gradual diagonal cracking on toe crushing. Observations indicated that FRCM rupture and debonding did not occur. In addition, other parameters such as shear strength, toughness modulus and energy deformation capacity considerably increased with FRCM. Nasiri (2019) investigated experimentally and numerically the in-plane and out of plane performance and strength of MIW and advanced simulation using finite element technique and provided a rational design method for out of plane behaviour of MIW; however, significant residue can be observed damaged infill that touched the peak in-plane capacity. C. Liu et al. (2019) recycled concrete hollow block (RCHB) to be used for the masonry structure with seismic requirements considering the primary parameters such as the effect of the axial compression stress, aspect ratio, and the materials of structural columns on the seismic performance. Results concluded that with the increase of aspect ratios, the ductility of RCHB masonry walls increased, but the horizontal bearing capacity and energy dissipation of RCHB masonry walls decreased. Dautaj et al. (2019) carried out an experimental study on five MIRC frames with different upper and lower storey heights of MIW to determine the shear resistance capacity using a newly proposed method which offers a promising approach to design RC infill frames. Maheri et al. (2019) used results of in-plane tests conducted on URM constructed by replacing conventional bricks with hollow concrete block masonry with RC layers to carry out pushover analysis which revealed that the response has the effect of Boundary Conditions. Niasar et al. (2020) tested the efficacy of ECC on URM under in-plane loading by constructing three specimens among which the first one is reference wall, second one is strengthened with ECC, and the third was damaged and then retrofitted with ECC as in the case of the previous specimen and observed a hike in terms of energy dissipation capacity and shear strength in the second specimen and 115% and 330% in the third specimen. Lu and Zha (2021) constructed Resilient Infill Wall (RIW) as shown in Fig. 25 whose performance was enhanced by using metal connectors and conducted cyclic in-plane tests to compare the damage evolution and hysteric performance of the same and successfully concluded that the understanding of RIW is much better in terms of initial stiffness, storey drift ratios and has been shown deterioration of strength.

Numerical work

Several numerical investigations were performed to investigate the effect of numerous parameters on the performance of reinforced concrete masonry infill frames. The references are segregated year-wise, from recent publication to the oldest (1987 to 2021) and summarized in tabular form in Table 5.

Madan et al., (1997) the development of the hysteretic model and the definitions of the control parameters, which can be determined using any suitable theoretical model for masonry infills, has been done. The proposed macro-model is better suited for representing the behaviour of infills in nonlinear time history analysis of large or complex structures with multiple components, particularly in cases where the focus is on evaluating the inelastic structural response. The stress–strain relationship for masonry in compression, as shown in Fig. 26, used to determine the strength envelope of the equivalent strut, can be idealized by a polynomial function.

Mehrabi and Benson Shing (2003) the experimental results are concisely summarized, and a constitutive model is presented for general modelling of masonry mortar joints and cementitious interfaces. The models eventually can be

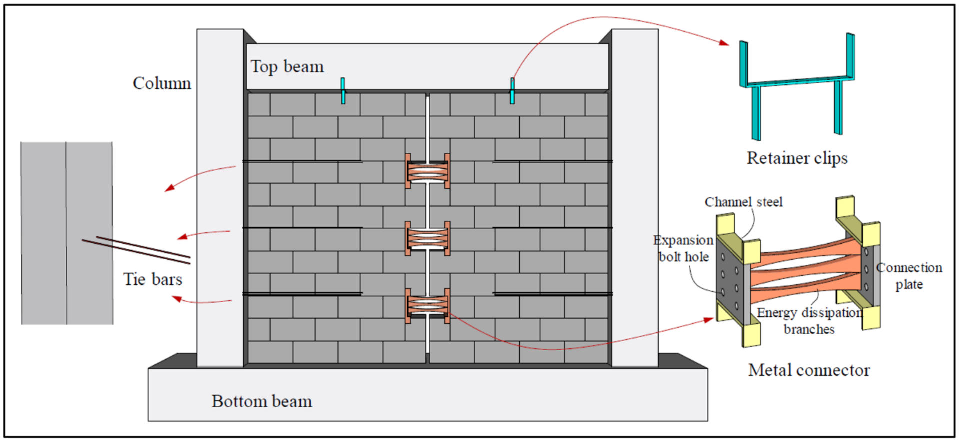


Fig. 25 Sketch of the proposed RIW Lu and Zha (2021) (2021)

Table 5 Summary of the literature review on the analytical study on MIW carried out by researchers

Authors	Brick unit used	Details of strengthening material	Parameters considered	Strengthening contribution	Failure mode	Year
Mallick			Lateral stiffness of infilled frames		The best door opening position can be best located in the centre of the lower half of the panel and to the centre from the window	1971
Abolghasem Saneinejad and Brian Hobbs			In-plane forces		Analysis of multi-storey infilled frames as braced frames	1995
Jack P Moehle			Probabilistic approach		Uncertainties in estimating the capacity and demands	1996
Madan, Reinhorn			Non-linear analysis		Influence of masonry infill frames	1997
By Yaw-Jeng Chiou et al.	Brick		In-plane monotonic loading		Entire filled masonry walls show high stiffness, whereas the adjacent column fails with nearly uniform cracks	1999
Kevin T Doherty et al.			Collapse behaviour of unreinforced masonry walls		Comparison of displacement based analysis with time history analysis is made	2000
Francisco J. Crisafulli et al.			Non-linear behaviour		The advantages and disadvantages of each of the methods are studied	2000
Doherty et al.			Seismic assessment		One-way vertical bending for application to walls in two-way bending is done	2002
Wael W. El-Dakhakhni et al.			Lateral stiffness and lateral load capacity			2003
Marc D. Kuzik et al.		GFRP Masonry walls	Out of plane behaviour		Simple model behaviour is taken for evaluation for strength and deformation characteristics	2003
Ahmed H. Alwathaf et al.	Masonry blocks		Conventional mortared and non-conventional mortar		Different analytical methods for masonry joint analysis are reviewed	2003
Armin B. Meharbi et al.			Seismic performance		Response spectrum analysis is performed on the masonry structure, and results are evaluated	2003

Table 5 (continued)

Authors	Brick unit used	Details of strengthening material	Parameters considered	Strengthening contribution	Failure mode	Year
Can C. SIMSIR et al.			Out of plane behaviour		Experimental results are compared with SDOF and MDOF. Two degrees of freedom is considered for dynamic stability	2004
Kiang Hwee Tan et al.		Fiber-Reinforced Polymers	Three anchorage methods		Results were compared well with the analytical predictions	2004
Milani,Lourenço, Tralli			Out-of-plane loading		Efficient results are found in all the cases, indicating the proposed simple technique is sufficient for safety assessment for out-of-plane loaded masonry panels	2006
Matjaz Dol ˇ sek et al.			Response spectrum method		The provision of infills helps in resisting the loads and does not cause the failure of the columns	2007
Amato et al.			Infill behaviour switches from a strut element to plate shell		Lateral stiffness of infill frames is evaluated	2008
Asteris			Lateral load		The difference in magnitude and contact lengths has been clearly shown for different frame members	2008
Hemant B. Kaushik et al.			Linear and nonlinear analysis		The single strut model can be effectively used when masonry is discontinued in the first storey for parking space	2008
Stavridis, Andreas			Shake table test		The approach can be further used to construct simple struts in the construction of the entire structure	2009
Hugo Rodrigues et al.			Bi-diagonal compression strut model		Single bay and double bay are tested in different laboratories, and a comparison is made	2010
Panagiotis G. Asteris et al.			Diagonal struts are provided		Validity of the proposed equations is verified by comparing the work done results by researchers against the achieved results	2011

Table 5 (continued)

Authors	Brick unit used	Details of strengthening material	Parameters considered	Strengthening contribution	Failure mode	Year
Alireza Mohyeddin-Kermani			Earthquake loads behaviour		In-plane and out-of-plane for different drifts to check the behaviour of the buildings	2011
Ray Kai Leung Su et al.			Seismic fragility and spectral displacement		Spectral displacements are found to be within limits for low-rise buildings	2013
Asteris et al.			Micro models are considered		Both advantages and disadvantages of each of the considered models are evaluated	2013
Ivo Caliò et al.			Plasticity beam-column elements		This approach is evaluated by Non-Linear analysis performed on Infilled structures	2014
Yuen et al.			In-plane and out of plane loading		By providing anchorage, it stabilizes the forces against buckling	2014
Nitin Kumar et al.			Plasticity-based interface model		The results are validated by comparing with literature review with the experimental results	2014
Kiarash M. Dolatshahi et al.			Seismic loads		The curve is further used for the preliminary evaluation of URM walls for bidirectional loading	2015
Marina L. Moretti			Experimental, analytical and code provisions		Different approaches for single strut members are made, and results are tabulated	2015
Kuang and Yuen			Damage based modelling		Non-Linear behaviour of infilled frames was conducted by combining in-plane and out of plane loading	2015
Ganesana et al.			Infills are main factors		The effectiveness of the cork is interface material is studied, and adaptive infilled frames are adapted	2015
Natalino Gattesco et al.		GFRP	Diagonal compression and plane behaviour		The tensile strengths are compared with experimental results and from an analytical formulation	
Kiarash M. Dolatshahi et al.			In-plane or out of plane behaviour		The analysis was carried using TNO DIANA and ABAQUS software	2015

Table 5 (continued)

Authors	Brick unit used	Details of strengthening material	Parameters considered	Strengthening contribution	Failure mode	Year
Kun Lin et al.			Dry stacked panel (DSP) semi-interlocking masonry (SIM)		Constant friction part is verified to provide substantial energy dissipation and benefits such as ductility of the structure	2015
Miglietta et al.			Cyclic behaviour		Y-Brick is also shown to identify the position of the cracks that form in the structure	2017
Monica Pasca et al.			Seismic loads		A comparison between experimental and analytical values is made	2017
Kurdo F. Abdulla et al.			Monotonic in-plane, out-plane and cyclic loads		Abaqus software is used for the analysis, followed by a numerical algorithm, i.e., the newton Raphson method for employing user-defined subroutines	2017
Idan E. Edri et al.			Out of plane loading		The two experimental results, when subjected to lateral loading, are compared with analytical model predictions. In both cases, results are within the limit and safe	2017
Arton D. Dautaj et al.			Cyclic loading		The model is used to predict the failure patterns of infilled RC frames	2018
Fabio mazza et al.			Out-of-plane and in-plane model		Different displacement history is considered, such as i) OP loading faster than IP, at the sixth storey; ii) equal IP and OP loading, at the third storey; iii) IP loading faster than OP, at the first storey	2018
Bharat Pradhan			Seismic action		The feasibility of the 3D frame structure is checked and adapted	2018
Peter B. K. Mbewe			Pushover analysis		The results show a good correlation between experimental data and the proposed model	2019

Table 5 (continued)

Authors	Brick unit used	Details of strengthening material	Parameters considered	Strengthening contribution	Failure mode	Year
Konstantinos Kostinakis et al.			Seismic loads		It is concluded that the irregular placement of infill frames in the structure leads to severe seismic damage	2020
Jorge Varela-Rivera et al.			Out of plane behaviour	Failure of the walls was from crushing of masonry is found by yield line	It is concluded that the bidirectional strut method is the best choice	2020
Xiaomin Wang et al.			Bidirectional seismic behaviour		For stability is obtained by reducing stiffness and strength in OOP	2020
Mohammad Yekrangnia et al.			Simulating overall force–displacement behaviour		A reduction factor is proposed for better strength and stability	2020
Da pohoryles et al.		Composite materials	Stiffness of the material and angle		The comparison between experimental and obtained strain is assessed using an empirical formula	2020
Gerson Moacyr Sisniegas Alva et al.			Seismic response		The use of participating masonry walls to be considered by engineers for better efficiency under seismic loads	2021

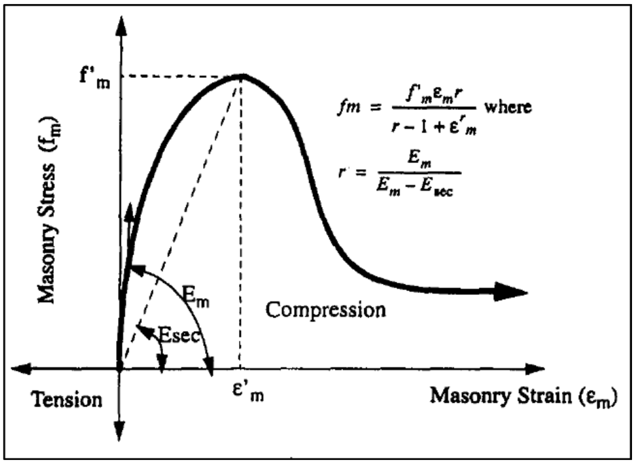


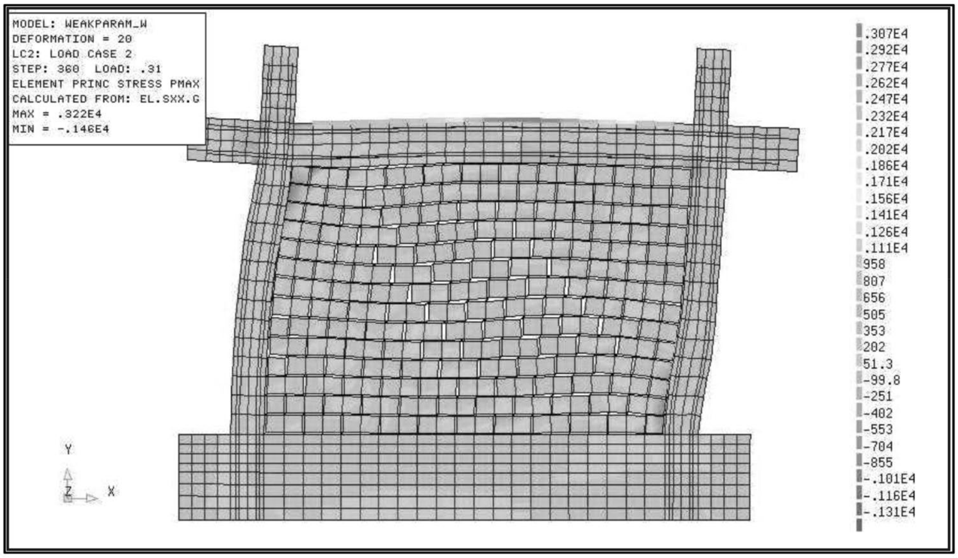
Fig. 26 Adopted constitutive model for masonry Madan et al. (1997)

used for numerical parametric studies to extrapolate existing experimental results to develop comprehensive design guidelines. Kaushik et al. (2017) adopted a linear regression analysis; an elementary analytical model has been suggested for accessing the stress–strain curves for masonry that can be adopted in the research and design procedures. The governing points attained from the analysis can be utilized to limit states for masonry material and members. Al-Chaar (2008) proposed the mode of infilled frames is summarized to actuate essential conditions that must be deliberated and considered. In any case, it is implied that for the successful operation of any F.E. program to infilled frames, the model properties must be evaluated using appropriate material level and structural-level experimental results. Author et al. (2009) proposed a proper model be invented using explicit FEM to study the behaviour of EBFs (Eccentrically Braced Frames) with an infilled masonry wall. The single brick wall and EBF with infilled wall were made, and these models (Fig. 27) were analysed by the explicit finite element method. The software used in this study was Diana. Three different models were examined, by maximizing kinetic energy. The stifness of the braced frames with infill walls showed better yield strength but on the other hand the frame deteriorated due to plastic behaviour (Table 6).

Haach et al. (2010) proposed an innovative system for reinforced concrete masonry walls based on the combination of vertical and horizontal trussed reinforcement is proposed. The mechanical characterization of the seismic behaviour of such reinforced masonry walls is based on static cyclic tests carried out on panels with appropriate geometry. The results stressed that the increase in the pre-compression level leads to a stiffer and more brittle lateral behaviour of the masonry walls (Fig. 28).

Stavridis and Shing (2010) proposed the initiation of nonlinear FEM models for determining the seismic performance of these structures has been dealt with in this. The suggested modelling technique can apprehend the different failure mechanisms and also the load–displacement responses displayed by infilled R.C. frames. Koutromanos et al. (2011) in this study, nonlinear finite element models have been used to simulate the behaviour of masonry infilled reinforced concrete frames under cyclic lateral loading. The finite element models presented here can accurately reproduce the infilled frames' load–displacement response, crack patterns, and failure mechanisms. Smeared-crack elements have a stress locking issue that does not permit appropriate shear cracks displaying and can prompt un-conservative outcomes. This issue can be evaded using zero-thickness cohesive interface elements to display shear cracks in a discrete design. To accomplish the

Fig. 27 Deformed shape and stress contour for frame with weak infill, analysis using Al-Chaar (2008) (2008)



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MODEL: WEAKPARAM_W
DEFORMATION = 20
LC2: LOAD CASE 2
STEP: 360  LOAD: .31
ELEMENT PRINC STRESS PMAX
CALCULATED FROM: EL.SXX.G
MAX = .322E4
MIN = -.146E4
```

Table 6 Summary of the literature review on the fragility functions for MIW carried out by researchers

Authors	Brick unit used	Details Of strengthening material	Parameters considered	Strengthening contribution	Failure mode	Year
Marin Grubišić et al	Not specified	RCC frames	Pushover analysis on frames with and without masonry infills	Increase in the time take for collapse	Light, moderate, extensive and partial collapse	2013
Ray Kai Leung Su et al.		Masonry infilled RCC frames	Coefficient based method utilized for obtaining spectral accelerations	Increase in the lateral stiffness and capacity of the structure		2013
Arash Nassirpour et al.	Clay bricks	brick-infilled steel frame with and without opening	Pushover analysis on masonry infills with different end conditions	Increase in the lateral stiffness and capacity of the structure	Compression failure	2014
Donatello Cardone et al.	Hollow clay bricks	RC frames with and without openings	Peak floor acceleration to identify out of plane behaviour of infilled walls	Increase in the resistance to drift	Light cracking, corner crushing, extensive cracking and collapse	2015
Jong-Su Jeonl et al.	Hollow or solid brick	Masonry infilled RCC frames	Non-linear pushover analysis	Increase in the lateral stiffness and capacity of the structure	sliding shear, diagonal cracking, and corner crushing	2015
Kathy Sassun et al.	Solid and hollow clay brick or concrete block	Masonry infilled RCC frames	Non-linear structure analysis	Increase in the lateral stiffness and capacity of the structure	Combination of different failure mod horizontal slip, diagonal cracking, corner crushing	2016
Eduardo Charters Morais et al.	Clay bricks	Unreinforced masonry infilled wall	Incremental dynamic analysis to simulate the in-plane shear behaviour pf masonry infilled wall		Compression failure	2016
Carlo Del Gaudioa et al.	Hollow clay bricks	Masonry infilled RCC frames	In-plane behaviour analysis of infilled walls	Increase in the lateral stiffness and capacity of the structure	Combinations of various failures	2017
Andrea Chiozzi et al.	Solid, hollow clay bricks and concrete blocks	Masonry infilled RCC frames	In-plane behaviour analysis of infilled walls	Increase in the lateral stiffness and capacity of the structure	Combinations of various failures such as small hairline cracks in masonry up to 2 mm, beginning of significant cracks, more than 2 mm wide, development of wide diagonal cracks (usually larger than 4 mm)	2017
Gianni Blasi et al.	Clay and concrete blocks	Masonry infilled RCC frames	Fragility functions for the in-plane performance of masonry infills using incremental dynamic analysis	Increase in the lateral stiffness and capacity of the structure	Flexure and shear failures	2017
Maria Teresa De Risi et al.	Hollow clay bricks	Masonry infilled RCC frames	In-plane behaviour of frame under lateral load	Increase in the lateral stiffness and capacity of the structure	Sliding Shear, diagonal cracking, diagonal compression, corner crushing	2018

Table 6 (continued)

Authors	Brick unit used	Details Of strengthening material	Parameters considered	Strengthening contribution	Failure mode	Year
Hossameldeen Mohamed et al.		Fully and partially infilled masonry RCC frames with and without openings	Non-linear dynamic analysis	Increase in the lateral stiffness and capacity of the structure		2018
Dipendra Gautam et al.	Stone masonry	Masonry infilled walls without any reinforcement	Peak ground acceleration and ground acceleration		Combinations of various damages observed	2018
Carlo Del Gaudio et al.	Clay and concrete bricks	Masonry infilled RCC frames	Damage and loss analysis due to drifts and seismic activity	Increase in the lateral stiffness and capacity of the structure	Combinations of failure according to the type of damage	2018
Trishna Choudhurya et al.		Fully and partially infilled masonry RCC frames	Non-linear time history analysis	Increase in the lateral stiffness and capacity of the structure	Failure possibilities according to the type of damage	2019
Carlo Del Gaudio et al.					Failure possibilities according to the type of damage	2019
Xianxin Xie et al.	Clay and concrete bricks	Masonry infilled RCC frames	Maximum crack widths, skeleton curve-based and phenomena based method	Increase in the lateral stiffness and capacity of the structure	Combinations of failure according to the type of damage	
Di Trapani et al.		Unreinforced masonry infilled wall	Incremental dynamic analysis to determine out of plane behaviour of masonry infilled wall		Failure occurred according to damage conditions	2020
Muhammad Waleed Khan et al.		Masonry infilled RCC frames	Nonlinear static and dynamic analyses	Increase in the lateral stiffness and capacity of the structure	Failure occurred according to damage conditions	2021
Marco Nale et al.		Unreinforced masonry infilled wall	Multiple strip analysis for determining the out-of-plane behaviour		Out of plane local failure	2021
Dipendra Gautam et al.		Masonry infilled RCC frames	Fragility analysis was conducted based on in plane and out of plane damages	Increase in the lateral stiffness and capacity of the structure	Failure occurred according to damage conditions	2021
Bharat Pradhan et al.		Masonry infilled RCC frames	Out-of-Plane fragility functions are developed by probabilistic approach based on Monte Carlo simulations employing a numerical macro-element model for the evaluation of the out of plane capacity of infills	Increase in the lateral stiffness and capacity of the structure	Out of plane failure	2021

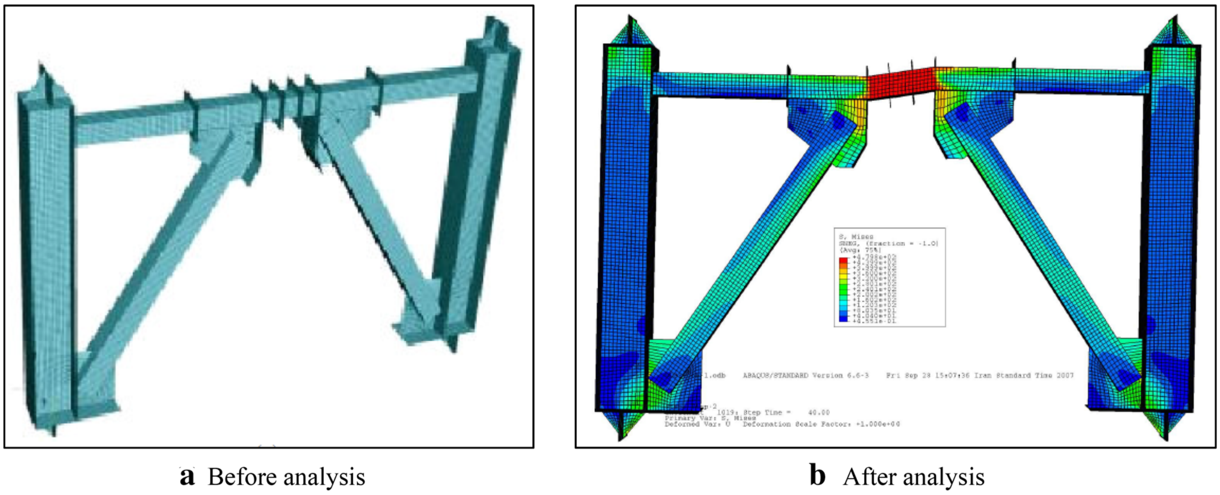

a Before analysis **b** After analysis

Fig. 28 Finite element model of the eccentrically braced frame (Author et al., 2009)

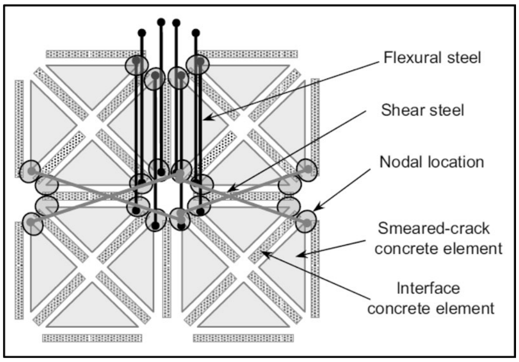


Fig. 29 Finite-element discretization of RC members, Koutromanos et al. (2011)

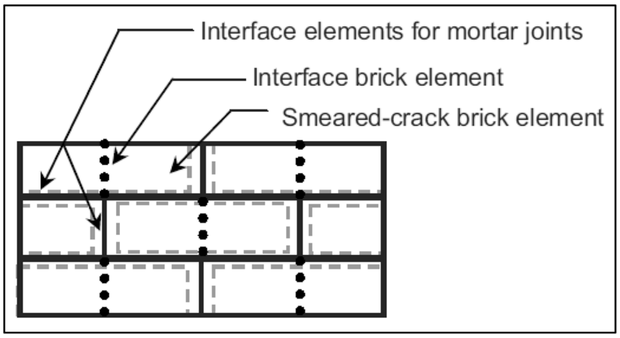


Fig. 30 Finite-element discretization of masonry infill, Koutromanos et al. (2011)

mentioned issue without prior information of the areas and directions of the breaks, every quadrilateral component can be supplanted with a module of four triangular smeared-crack elements associated with four, diagonal set, twofold noded, interface components, as outlined in Fig. 29. Each module is associated with the adjoining modules with level and vertical interface components. With this lattice, discrete breaks can create at points of 0°, 90°, and ± θ, where θ can be near 45° to address askew shear breaks. The presentation of discrete breaks does not just eliminate the undesired stress locking under shear yet in addition mitigates the mesh-size sensitivity problem, which is notable for smeared-crack models. A discretization model based on the above discussion is shown in Fig. 30 in which each masonry unit is modelled with two rectangular continuum elements that are interconnected with a vertical interface element. The latter allows for the tensile splitting of the brick units and the relative sliding motion in a fractured unit (Figs. 31, 32, 33).

Rai et al. (2011) proposed an existing masonry infilled R.C. framed structure that can be retrofitted for better rendering under seismic loading by the structural response control methodology using tuned sloshing water dampers (TSWDs) (Fig. 34, 35). The advised retrofitting system will ensure a more regular masonry infilled R.C. structure during ground motion. The mass, stiffness and damping ratio of the structure vary depending on various factors such as constructional and utility, cross-sectional and elastic properties of the construction material and the nature of loading and deformation. These approximations are carried over to the structure's estimated response, leading to an inaccurate design of TSWD (Figs. 36, 37). This complication may be lectured by amplifying the concept of multiple mass dampers (MMDs) to TSWD (Fig. 38).

Crisafulli et al., (2000) represented a masonry panel using six strut members located in the panel's diagonal direction, whereas the R.C. members are embraced with a column macro-element. The main advantages of the model are the

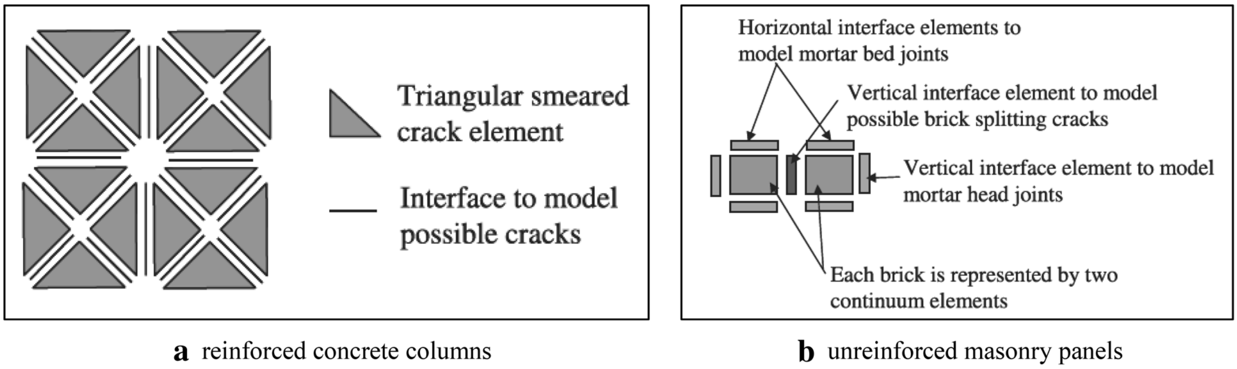


Fig. 31 Discretization scheme employed in finite element models, Koutromanos et al. (2011)

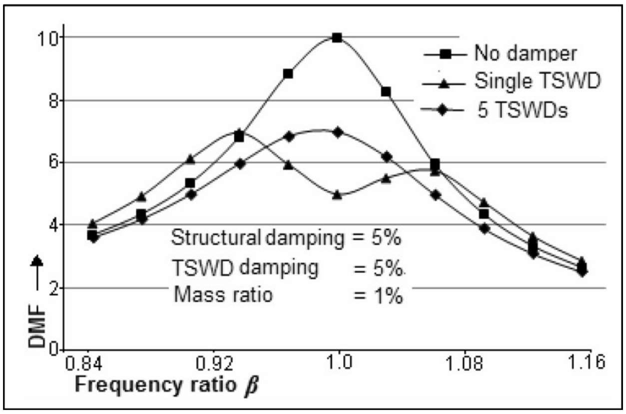
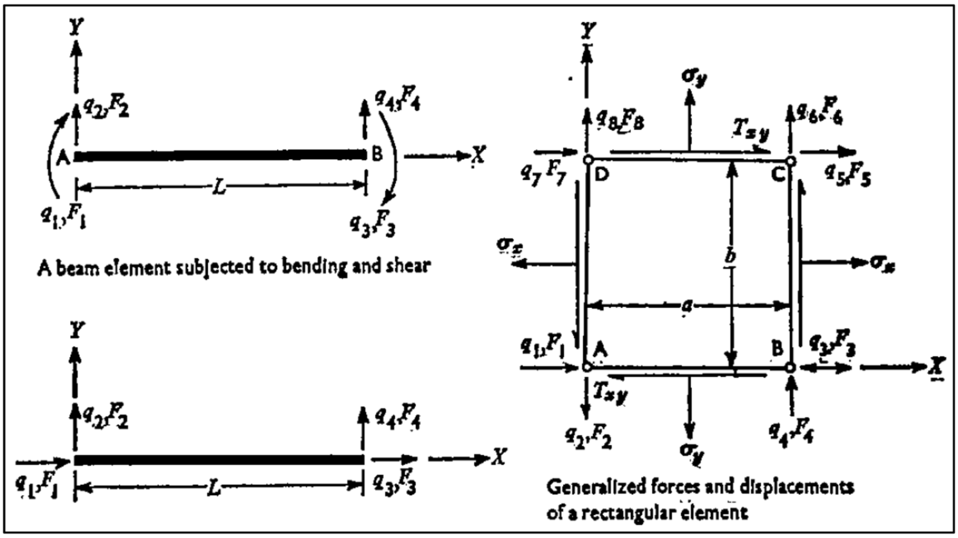


Fig. 32 Dynamic magnification factors for single and multiple TSWDs Rai et al. (2011)

capacity to predict not only the stiffness and strength of the structure but also to represent the influence of the masonry panel on the surrounding frame. Zhai et al. (Zhai et al., 2012) (Torrisi & Crisafulli, 2011) proposed an isolated F.E. model for the investigation of out of plane code of the infill wall is established using 3-D elements with deterioration plasticity material model and the surface-dependent contact cohesive cooperation model simulating the assemblage between blocks. Meillyta (2012) aimed to investigate the behaviour of URM wall with openings when horizontal load acted on it and developed load–drift relationship of the wall. The finite element (F.E.) method was chosen to simulate the behaviour of URM with openings numerically. Results showed that the finite model could well capture the behaviour of the URM wall with doors. (Fiore et al., 2012) (Meillyta, 2012). This finite element analysis is performed comparing the results to the experimental data to evaluate the local effects on the frame and underline the influence of the Coefficient of friction at the infill frame interface. In high seismicity, the method is reliable since the increasing horizontal load does not significantly influence the position of the resultant contact forces at each interface (Kai et al., 2013) (Fiore et al., 2012). Robust seismic analysis and optimum spectral displacement assessment of low-rise

Fig. 33 A beam element subjected to shear and axial deformation (Mallick and Garg 1971))



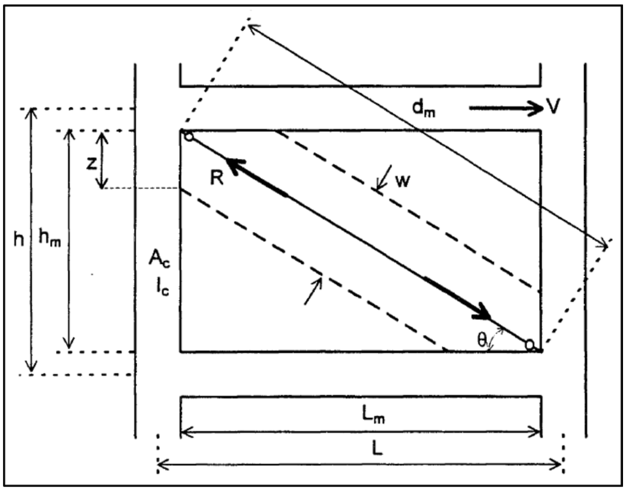


Fig. 34 The effective width of the diagonal strut (Crisafulli et al., (2000) (Rodolico, 1985))

masonry infilled reinforced concrete buildings presented a coefficient-based method. The coefficient-based process does not require a FEM analysis. It is a favourably simplified, quick non-automatic procedure for evaluating buildings' spectral accelerations and displacements for a given inter-story drift ratio. Mohyeddin et al. (2013) (Kai et al., 2013) proposed a detailed presentation of a generic three-dimensional discrete finite element model that has been constructed for reinforced concrete frames with masonry infill using ANSYS has been done. The proposed strut model would apply to the analysis of infill-frames well beyond the very early stages of lateral loading. Nazief (Mohyeddin et al., 2013) proposed a finite element (F.E.) technique to model masonry infilled frames using the simplified micro modelling approach. From this, it is

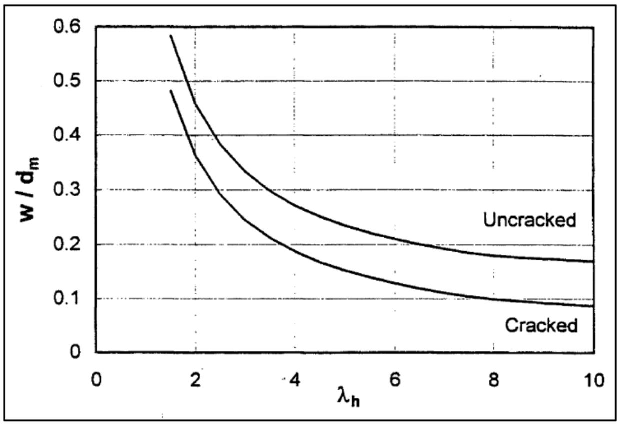


Fig. 36 Ratio w/d_m for framed masonry structures

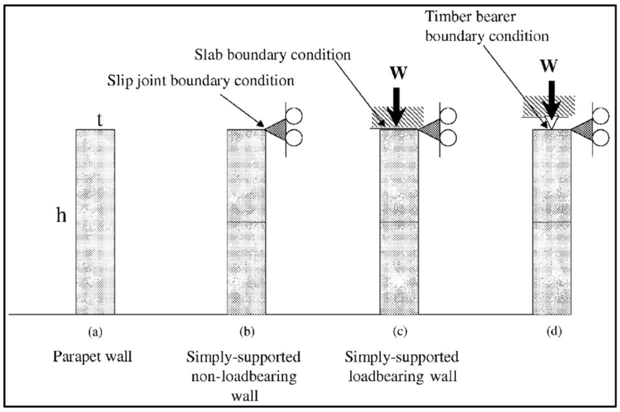
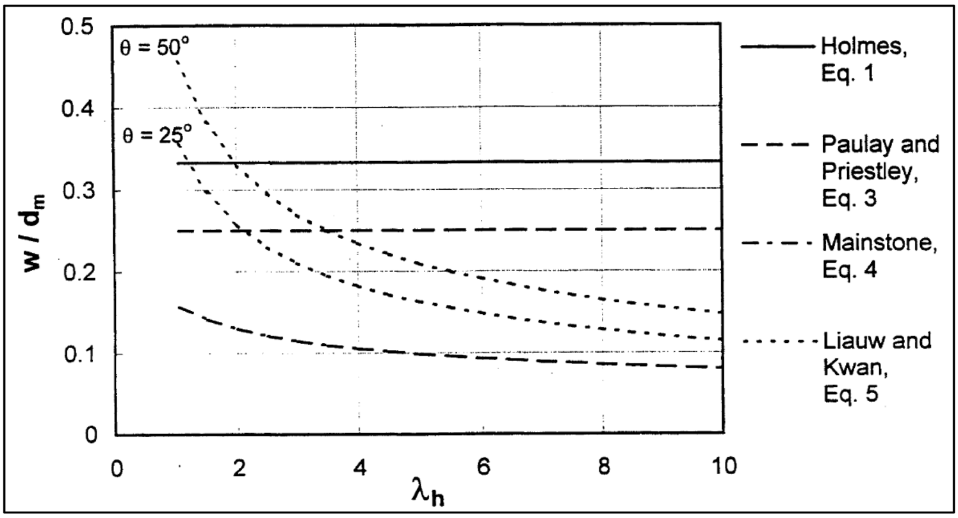


Fig. 37 Unreinforced masonry wall support configurations Doherty et al. (2000) (Crisafulli et al., 2000)

Fig. 35 Variation of the ratio w/d_m for infilled frames as a function of the parameter λ_h



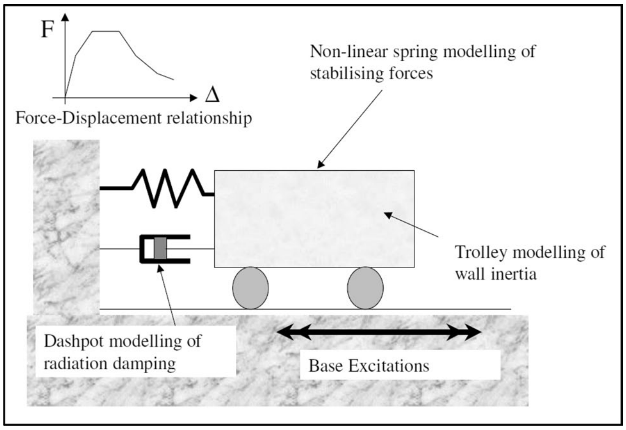


Fig. 38 Idealized non-linear single-degree-of-freedom model Doherty et al. (2000) (Crisafulli et al., 2000)

observed that the best location for an opening in an infill wall is where the interference with the developed compression strut is minimum. Chen and Liu (2015) (Nazief, 2014) executed to investigate the in-plane behaviour of masonry infills constrained by steel frames, focusing on the infills with openings. It came out that the model used as a single-frame configuration, its applicability to multi-storey multi-bay infilled frames needs further investigation. Karimi et al. (2016) (Chen & Liu Jan., 2015) in this learning, an infilled masonry wall and an arched masonry wall with clay bricks and clay and gypsum mortar are correlated. Their seismic behaviours are verified under cyclic loading. The results from the analysis illustrated that the concrete damaged plasticity model could simulate the cyclic behaviour of masonry walls. Chungman et al. (2016) (Karimi et al., 2016) in this research, F.E. analyses of masonry infilled frames using a general-purpose F.E. program, ABAQUS, were performed. Analysis models comprised of the bare frame infilled structures with masonry wall thickness. Deng and Sun (2016) (Chungman et al., 2016) proposed a finite element simulation method by ABAQUS is used to ascertain an empirical formula to examine the behaviour of equivalent bracing walls and the frame columns. It was denoted through the outcomes that the reliable finite element method was consistent with the actual empirical data (Maidiawati and Sanada 2017) (Deng & Sun, 2016). The intended analytical model put back masonry infill with a diagonal compression strut, delineating distributed compression assigned between frame and infill interfaces. The brick infill notably amplified the strength of the surviving building and may have averted its total disintegration during the earthquakes. Wang et al. (2016) (Maidiawati & Y. Sanada, 2017) proposed an investigation to experimentally demonstrate the performance of masonry walls with conventional concrete columns & FEM models prepared to know the seismic response. It was instituted that FEM simulations cannot replace laboratory testing.

Nasiri and Liu (2017) (Wang et al., 2017) proposed an attributed study concerned with developing a numerical model for simulating the nonlinear behaviour of the concrete masonry infilled R.C. frames subjected to in-plane lateral loading. The ABAQUS FEM software was incorporated in the modelling. FEM results of this study conveyed that the dilatancy of mortar should be considered in the numerical models. Shawkat and Rahman (2017) (Nasiri & Liu Jul., 2017) focused on the evaluation of infill walls' contribution to the seismic performance of R.C. frames. A numerical model of the infill wall is developed to evaluate its contribution to the seismic performance of the R.C. frame under earthquakes. The finite element model proposed in this work using the elements of ABAQUS with the micro-modelling of the infill wall accurately predicted the behaviour and damage sequence of the R.C. frame and the infill walls under earthquake. Khatiwada and Jiang (Shawkat & Rahman, 2017) utilized the commercialized software ABAQUS to simulate the in-plane seismic behaviour of infilled R.C. frame and validated using the available experimental results. Simulated force–displacement curve and crack patterns displayed satisfactory consensus with the practical work. Abbas and Saeed (Abbas & Saeed, 2017) (Khatiwada & Jiang, 2017) the main objective of this research assesses masonry wall modelling using the representation techniques acquired and use the suitable approach to exhibit masonry room using the ABAQUS software under the seismic load. The use of macro modelling is used in large scale models to save time and effort. Its result is definitive for its excellent approximation with micro modelling and uncomplicated micro modelling. Rahgozar and Hosseini (2017) proposed the in-plane responses of these masonry prisms are regulated through various tests. The compressive results marked that the interface element performance is designated up to the mark, and the model appropriately predicts the complex failure behaviour of brick masonry structures. Šipoš et al. (2018) (Abbas & Saeed, 2017) Analytical and experimental data were used to inspect the association between drift and damage of masonry infilled frames. The implementation of standards and design process for RCC structures in the current practice disregards the impact of masonry infill framed structures. Baghi et al. (2018) (Šipoš et al., 2018) studied the existing model to create a numerical tool to study the behaviour of frame infill separation, and non-linear analysis of was performed with Eigen value consideration subjected to cyclic loading. It is further concluded that both experimental and analytical results is matching to each other with respect to initial stiffness, cracking patterns and maximum shear capacity. In Liberatore et al. (2018) (Baghi et al., 2018), the effectiveness of masonry infill wall on the behaviour of a Reinforced Concrete (R.C.) frame subjected to a column failure is studied experimentally. This model can predict the load–deflection with reasonable accuracy. De Angelis and Pecce (2018) (Liberatore et al., 2018) the proposed strut model incorporates the error terms and the interaction matrix among errors that can be successfully occupied in risk measurement to consider the model uncertainty on the structural response. Khalilzadeh Vahidi and Moradi (2019) (Angelis & Pecce Oct., 2018) the primary purpose of this document is to show an organized survey of experimental studies related to infill masonry walls out of plane action. The use of joints reinforcement is marked as an explanation for wellbeing since it furnishes deformation capacity to the panel. Maheri et al. (2019) explored seismic criterion, ultimate tensile damage, and force transfer mechanisms in an RCC structure under plan load. The infilled walls in the concrete frame wield much compression on the base beam that they are preeminent to split the beam–column joint. The further the enhancement in opening size, the less the compression on the base beam. Nasiri and Liu (2019) (Khalilzadeh Vahidi & Moradi, 2019) This numerical study on the in-plane shear capacity of full-scale unreinforced concrete block masonry walls, externally retrofitted by reinforced concrete layers, is presented. The simplified micro modelling adopted for numerical analyses proved to predict reasonably well the actual in-plane nonlinear static (pushover) response of both the URCBM and RCBM walls. Pantò et al. (2019) (Nasiri & Liu, 2019) handled the analytical simulation of brick infill walls subjected to OOP conditions. The numerical simulation results proved to appraise the satisfactory conduct of the macro modelling advent in simulating failure mechanisms.

Nyunn et al., (2020) (Pantò et al., 2019) in this analysis, bare and infill-wall R.C. frames are reviewed by considering column failure at the corner and outer region. The results demonstrated that as the number of corrosion cycles boosts up, the bearing capacity of wall specimens decreased. Niu et al. (2020) (Nyunn et al., 2020) inspected deals with the response of infill walls on the action of R.C. special moment frames subjected to numerous seismic activities. As the sum of stories upsurges, displacement and rotational ductility are reduced. Kostinakis and Athanatopoulou (2020) (Niu et al., 2020) aimed to propose a multi-strut large-scale model suited for simulating the long-term force–displacement behaviour of infilled frames with various opening configurations. The outcomes show that the extent and spot of the opening have a considerable repercussion on both the inclination and the effective width of the struts. Jalaeefar and Zargar (2020) (Kostinakis & Athanatopoulou, 2020) in this investigation number of experimental tests, data is collected with the focus of examining and determining the vital components of the infill and judging the convenience system proposed. Yekrangnia and Asteris (2020) (Jalaeefar & Zargar, 2020) in this analysis, various tests are operated to weigh the I.P. damage effects on the OOP response of square URM infills with a relatively low slenderness ratio in RCC frames. Tests results enrich the stiffness reduction as a function of geometric properties of the infill (namely, the slenderness ratio and the aspect ratio) and the I.P. displacement demand. Liberatore et al. (2020) (Yekrangnia & Asteris, 2020) Results showed a study on the out of plane behaviour and strength of concrete masonry infills vaulted by R.C. frames before plane damage. The equations were submitted and verified with limited test results. Di Domenico et al. (2021) (Liberatore et al., 2020) aims at enhancing the seismic performance of the infill wall by an alternative method. The results manifested that the seismic performance of the RIW has been adequately progressed. The initial stiffness is lowered by 31%, and the strength depreciation is much retarded than that of the OIW specimen. Nasiri and Liu (2020) (Domenico et al., 2021) deal with the progress of an experimental campaign to probe the cyclic out of plane behaviour of RCC frames enclosing masonry infill walls adopting non-contact optical means to part contour strains and deformations. It was established that neither the infill walls nor the openings compellingly alter the entire behaviour of the specimens. Liberatore and AlShawa (2021) (Nasiri & Liu, 2020) adopted the yield line theory for evaluating the out of plane infill strength is inspected. The equations furnish their OOP strength to be serviced in the local appraisal of infills in both recent and extant buildings.

Analytical work

Mallick and Garg (Liberatore & AlShawa, 2021) has considered the effect of most probable positions of openings on the lateral stiffness of infilled frames. It is recommended that the best position of door opening can be best located in the centre of the lower half of the panel and to the centre from the window. Using FEM stiffness has been calculated for MIW with openings. To derive the stiffness matrices, using Airy's stress function that fulfils biharmonic equation with B.C. was introduced. By minimizing the energy for linear edge displacement, the stress pattern obtained is

$$\left.\begin{aligned} X &= A_1 + A_2Y + A_3X \\ Y &= A_3 + A_4X + A_5Y \\ XY &= A_5 - A_6Y - A_7X \end{aligned}\right\} \tag{1}$$

Stress components having seven coefficients for accuracy of the solution is of the form

$$\left.\begin{aligned} U &= B_1 + B_2X + B_3Y + B_4XY \\ V &= B_5 + B_6X + B_7Y + B_8XY \end{aligned}\right\} \tag{2}$$

The stiffness matrix of a beam element subjected to shear and axial deformation

$$K'B = \begin{pmatrix} \frac{12EI}{l^3} & & \mathit{Symmetrical} & \\ 0 & \frac{AE}{l} & & \\ \frac{-12EI}{l^3} & 0 & \frac{12EI}{l^3} & \\ 0 & \frac{-AE}{l} & 0 & \frac{AE}{l} \end{pmatrix} \tag{3}$$

Smith's formula was used to determine the length of contact for frame without shear connectors

$$\frac{\beta}{l} = \frac{\pi}{2\lambda l}\text{where}\lambda = 4\sqrt{\frac{E_o t}{4EIl}} \tag{4}$$

The stiffness of masonry infill wall with shear connectors can be derived using

$$K_o = 2\left(\frac{V_m}{u_m}\right) \tag{10}$$

$$V_y^+\left(V_y^-\right) = \frac{V_m - \alpha K_o u_m}{(1-\alpha)} \tag{11}$$

$$u_y^+\left(u_y^-\right) = \frac{V_m - \alpha K_o u_m}{K_o(1-\alpha)}, \tag{12}$$

where K_o is the stiffness of the wall, V_m and U_m is Maximum lateral force and displacement.

$$S = \frac{A+B+C}{C+(A+B)}\text{where } A = \frac{h\tan^2\alpha}{aE_s}, B = \frac{d}{WtE_s\cos^2\alpha}, C = \frac{h^3(3h+21)}{\left(2E_sI(6h+1)\right)} \tag{5}$$

where h is the height of the wall, W is the weight, t is the thickness, E_s is the modulus of elasticity.

Saneinejad and Hobbs (Mallick & Garg, 1971) has considered a new analysis method of steel frames with concrete masonry infill walls subjected to in-plane forces. Further model is analysed for multi-storey infilled frames as braced frames. "A3—Displacement based seismic design criteria" (Saneinejad & Hobbs, 1995) seismic performance is considered to produce structures that satisfy the specific performance of the objectives. The probabilistic approach should be used to deal with the uncertainties in estimating the capacity and demands. Madan et al. (1997) an equivalent strut approach is considered, and hysterical modelling is proposed for masonry infill panels in the non-linear analysis of frame structures. Dynamic analysis is done for a light reinforced concrete structure to find the influence of masonry infill frames.

The stiffness loss due to deformation is an important property of the hysteric model, including the control parameter η for Z, hysteric parameter

$$dZ_i = \left\{A\left|Z_i\right|^n\left[\beta\text{sgn}\left(d\mu_i Z\right) + \Upsilon\right]\right\}\frac{d\mu_i}{\eta_i} \tag{13}$$

$$\text{where } \eta_i = \left[s_k + a(\mu_i - 1) + 1\right]/\left[s_k + \mu_i\right] \text{ for } \mu_i \geq 0 \tag{14}$$

The strength degradation is modelled reducing the yield force V_y from

$$V_y^k = V_y \geq (1 - DI) \text{ where} \tag{15}$$

$$DI = \frac{\mu_{\max} - 1}{\mu_c - 1}\left[1 - 0.25s_{pl}\int\frac{V}{V_y}\frac{d\mu}{(\mu_c - 1)}\right]^{-sp_2} \tag{16}$$

$$\text{Maximum lateral force } V_m = V_m^+\left(V_m^-\right) \leq A_d f_m' \cos\theta \leq \frac{vtl'}{(1 - 0.45\tan\theta)\cos\theta} \leq \frac{0.83tl'}{\cos\theta} \tag{6}$$

$$\text{Displacement } u_m = u_m^+\left(u_m^-\right) = \frac{\in'\, mL_d}{\cos\theta} \tag{7}$$

$$\text{Where } A_d = (1-\alpha_c)\alpha_c th'\frac{\alpha_c}{f_c} + \alpha_b tl'\frac{\tau_b}{f_c} \leq \frac{0.5th'\frac{f_a}{f_c}}{\cos\theta} \tag{8}$$

$$L_d = \sqrt{\left(1-\alpha_c\right)^2 h'^2 + l'^2\}} \tag{9}$$

Where V_m is the maximum lateral force, U_m is the displacement, L_d is the lateral length.

The initial stiffness of the wall can be determined by.

Crack slip model $\mu = \mu_1 + \mu_2$ where μ_2 is displacement ductility component given by

$$d\mu_2 = af(z)dz \tag{17}$$

$$f(z) = \exp\left(-\frac{[z - n]^2}{Z_x^2}\right)\text{where} - 1 \leq z, \breve{z} \geq 1 \tag{18}$$

$$\frac{dZ}{d\mu} = \frac{(A - Z^n\{\beta\text{sgn}(d\mu z) + \lambda\})}{\eta\left[\left[1 + a\exp(-\frac{\left[z-\breve{z}\right]^2}{Z_x^2}\right)(A - |Z|^n\{\beta\text{sgn}(d\mu z) + \lambda)\right]} \tag{19}$$

Priestley and Kowalsky (2020) a full-scale test verifies in-plane monotonic loading. Finally, after the analysis is completed, full-filled masonry walls show high stiffness, whereas the adjacent column fails with nearly uniform cracks. A complete first-order polynomial is chosen as displacement function for 2D block

$$\begin{Bmatrix} u \\ v \end{Bmatrix} = \begin{matrix} 1 & 0 & -(y-y_o) & (x-x_o) & 0 & \frac{(y-y_o)}{2} \\ 0 & 1 & (x-x_o) & 0 & (x-x_o) & \frac{(x-x_o)}{2} \end{matrix} \begin{pmatrix} u_o \\ v_o \\ r_o \\ \varepsilon_x \\ \varepsilon_y \\ \Upsilon_{xy} \end{pmatrix} \tag{20}$$

$$\begin{Bmatrix} u \\ v \end{Bmatrix} = \left[T_i\right]\left[D_i\right], \tag{21}$$

where u and v are the lateral force and displacement, respectively.

The failure criteria for mortar are

Tensile failure—

$$\sigma \geq \sigma_t \tag{22}$$

$$dK^n \geq \sigma_t 1 \tag{23}$$

Where, σ is the tensile stress and σ_t is the failure tensile stress.

Shear failure—

$$\tau_f = \tau_o + \sigma_n \tan\varphi \tag{24}$$

Rodolico (1985) (Of et al., 1999) carried out at the University of Adelaide and the University of Melbourne. The main objective of the research was to find the collapse behaviour of unreinforced masonry walls. Finally, the comparison of displacement-based analysis with Time History analysis is made. The natural, highly non-linear system should be modelled as a primary linear single degree of freedom (SDOF) oscillator to apply THA to predict the semi-rigid rocking response of a URM wall. Doing this allows the utilization of time-stepping integration procedures, such as the Newmark constant-acceleration approximation. The modelling change is accomplished by correlation of the individual framework dynamic equations of motion. Equation Arora (2010) (Elouali 2008) addresses the generally acknowledged dynamic equation of action for a primary linear SDOF oscillator exposed to base excitation $\ddot{a}g$ where C is the corresponding damping coefficient, M the framework mass, v (t) the relocation reaction and ω the framework average precise recurrence. Since for the SDOF oscillator, the framework recurrence ($f = \omega/2\pi$) is consistent. The single condition can portray assertive conduct. For semi-inflexible URM walls with the tri-straight ($F - \Delta$) rearrangements used to show the genuine non-direct bend, three states are needed to depict the unique behaviour with changing straight firmness segments. Conditions (Hak et al.–Gattesco and Boem), (Furtado et al., 2018; Kariou et al., 2018; Shermi & Dubey Jul., 2017) hence address the dynamic equation of motion where v (t) is the removal reaction at either the mid-stature of a SS wall or at the wall top of a free-standing parapet wall.

$$\ddot{v}(t) + \left[\frac{C}{M}\right]_{SDOF}\dot{v}(t) + \left[\omega^2\right]_{SDOF}v(t) = -\left[\ddot{a}_g\right]_{SDOF} \tag{27}$$

$$\ddot{v}(t) + \frac{3}{2}\left[\frac{C}{M}\right]_{EXP}\dot{v}(t) + \frac{3}{2}\left[\left(\frac{\mathrm{Re}(1) + Ke(1)uy(2)}{Muy(1)}\right)\right]_{EXP}v(t) = -\frac{3}{2}\left[\ddot{a}_g\right]_{EXP} \text{ for } v(t) < uy(1) \tag{28}$$

$$\ddot{v}(t) + \frac{3}{2}\left[\frac{C}{M}\right]_{EXP}\dot{v}(t)\frac{3}{2}\left[\left(\frac{\mathrm{Re}(1) + Ke(1)uy(2)}{Mv(t)}\right)\right]_{EXP}v(t) = -\frac{3}{2}\left[\ddot{a}_g\right]_{EXP} \text{ for } uy(1) < v(t) < uy(2) \tag{29}$$

$$\ddot{v}(t) + \frac{3}{2}\left[\frac{C}{M}\right]_{EXP}\dot{v}(t) + \frac{3}{2}\left[\left(\frac{\mathrm{Re}(1) + Ke(1)v(t)}{Mv(t)}\right)\right]_{EXP}v(t) = -\frac{3}{2}\left[\ddot{a}_g\right]_{EXP} \text{ for } v(t) > uy(2) \tag{30}$$

$$\tau \geq \tau_o \pm \sigma_n \tan\varphi \tag{25}$$

$$s.K_s \geq \tau_o l \pm dK_n \tan\varphi, \tag{26}$$

where τ_f is the shear failure and σ_n is the normal tensile stress

$$f_{SRR} = \frac{\sqrt{\frac{3}{2}\left[\left(\frac{\mathrm{Re}(1)+Ke(1)uy(2)}{Mv(t)}\right)\right]_{SRR}}}{2\pi} uy(1) < v(t) < uy(2) \tag{31}$$

Crisafulli et al. (2000) (Rodolico, 1985) It is seen that modelling a masonry structure is a complex issue because it shows a high non-linear behaviour. Different methods are considered, and further advantages and disadvantages of each of the methods are studied.

The first approximation to calculate the width of the equivalent strut in the lack of experimental data, assuming that

$$w = \frac{d_m}{3}, \tag{32}$$

where d_m is the diagonal length of the panel. Additional experimental information ("Lateral strength of model brickwork panels" 1979; Koutas & Bournas, 2019) allowed a more refined evaluation of w, considering the ratio h_n/L_m, and a dimensionless parameter A_i (which takes account of the relative stiffness of the masonry panel to the frame) defined as follows:

$$\lambda_h = h^4\sqrt{\frac{E_m t \sin 2\theta}{4E_c I_c h_m}}, \tag{33}$$

where t and h_m are the thickness and the height of the masonry panel, respectively, θ is the inclination of the diagonal of the panel, E_m and E_c are the modulus of elasticity of the masonry and the concrete, respectively, and I_c is the moment of inertia of the columns. The equation which is recommended for a lateral force level of 50% of the ultimate capacity is given by

$$w = 0.25d_m \tag{34}$$

Figure 36 illustrates the variation of the ratio w/d_m according to the previous expressions.

Two sets of equations were proposed considering different states of the masonry infill.

Uncracked panel:

$$\left.\begin{array}{l} w = \left(\frac{0.748}{\lambda_h} + 0.085\right)d_m \text{ if } \lambda_h \le 7.85. \\ w = \left(\frac{0.393}{\lambda_h} + 0.130\right)d_m \text{ if } \lambda_h > 7.85 \end{array}\right\} \tag{35a}$$

Cracked panel:

$$w \left.\begin{array}{l} = \left(\frac{0.707}{\lambda_h} + 0.010\right)d_m \text{ if } \lambda_h = 7.85 \\ w = \left(\frac{0.470}{\lambda_h} + 0.040\right)d_m \text{ if } \lambda_h > 7.85 \end{array}\right\} \tag{35b}$$

The modulus E_m calculates parameter A.11, corresponding to the considered state (uncracked or cracked masonry). These equations are plotted in Fig. 37 as a function of the parameter λ_h. The principal advantage of the approach is the distinction between the uncracked and cracked stages. The comparison of Eqs. 35a and 35b indicate that w reduces significantly after cracking to a value ranging from 50 to 80% of the initial width. The higher reductions occur for large values of the parameter ′′′h because the influence of the infill panel in the system's response is more remarkable in these cases. Doherty et al. (2002) (Crisafulli et al., 2000) a newly developed displacement-based method for the seismic assessment of URM walls in one-way vertical bending for application to walls in two-way bending is done the results are tabulated. The single-degree-of-freedom idealization of URM walls is.

The computed displacement, velocity and acceleration of the lumped mass are defined as the effective displacement, velocity and acceleration, respectively. The equation of motion of the lumped mass SDOF system can, therefore, be expressed as follows:

$$M_e a_e(t) + Cv_e(t) + F\left(\Delta_e(t)\right) = -M_e a_g(t), \tag{36}$$

where a_e (t) is the effective acceleration, a_g (t) the acceleration at wall supports, $v_e(t)$ the effective velocity, Δ_e (t) the effective displacement, C the viscous damping coefficient and $F(\Delta_e(t))$ the non-linear spring force which can be expressed as a function of Δ_e (t) [NB: $F(\Delta_e(t))$ is abbreviated hereafter as $F(\Delta_e)$].

The effective modal mass (M_e) is calculated by dividing the wall into several finite elements, each with mass (m_i) and displacement (δ_i) and applying Eq. (2) which is defined as follows:

$$M_e = \frac{\left(\sum_{i=1}^{n} m_i\delta_i\right)^2}{\sum_{i=1}^{n} m_i\delta_i} \tag{37}$$

The effective mass for a wall with uniformly distributed mass for parapet walls and walls supported at their top and bottom has been calculated to be three-fourths of the total mass, based on standard integration techniques (Figs. 39, 40). Thus,

$M_e = 3/4M$ here M is the total mass of the wall.

A similar expression, Eq. (4), also derived using standard modal analysis procedures, defines the effective displacement (Δe).

$$\Delta_e = \frac{\sum_{i=1}^{n} m_i\delta_i^2}{\sum_{i=1}^{n} m_i\delta_i} \tag{38}$$

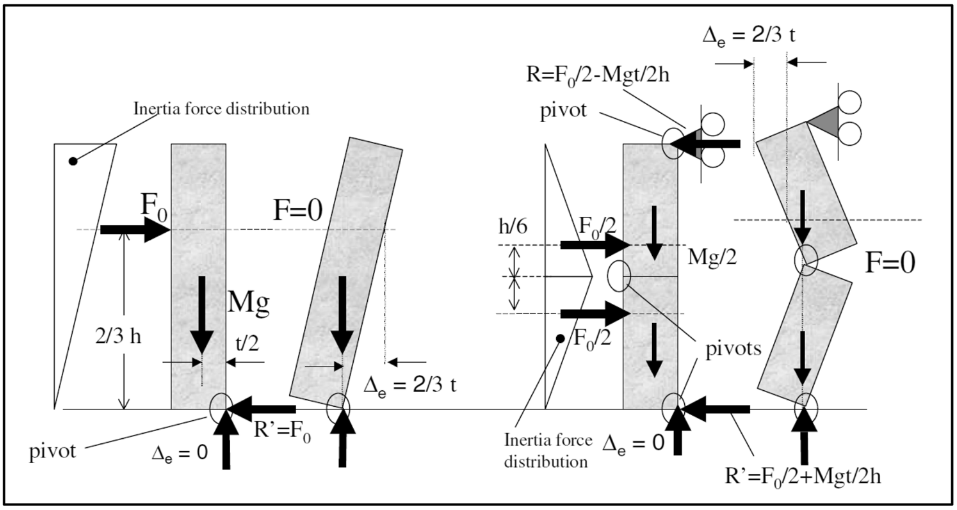
It can be seen from Eq. (4) that.

$$M_e = 2/3\Delta_t \text{ for a parapet wall and} \tag{39a}$$

$$M_e = 2/3\Delta_m \text{ for a simply support wall and} \tag{39b)}$$

where Δ_t and Δ_m are the top of wall and mid-height wall displacements, respectively.

Fig. 39 Inertia forces and reactions on rigid URM walls. **a** Parapet wall at incipient rocking and point of instability. **b** Simply supported wall at incipient rocking and point of instability



(a) (b)

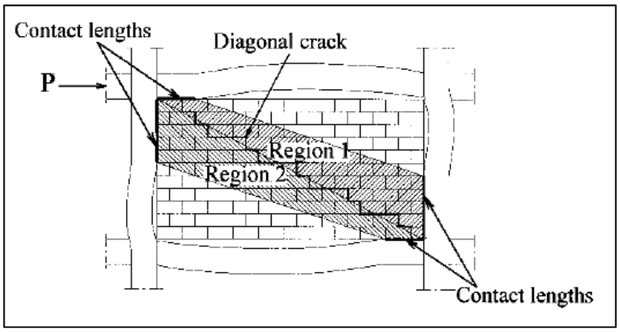


Fig. 40 Infill panel separation into two diagonal regions (El-Dakhakhni et al., 2003)

El-Dakhakhni et al. (2003) (Doherty et al., 2002) Masonry infill frames are known for their stiffness, ductility and strength of structure; in this paper, lateral stiffness and lateral load capacity of concrete frame structures. This method can further be used in computer modelling, and non-linear analysis can also be performed. In the case of an unconfined panel, immediately after diagonal crack develops within an infilled panel, the panel assumes itself confined inside the bounding frame and bearing against it over contact lengths, as shown in Fig. 41.

The total diagonal struts area, A, is to be calculated by

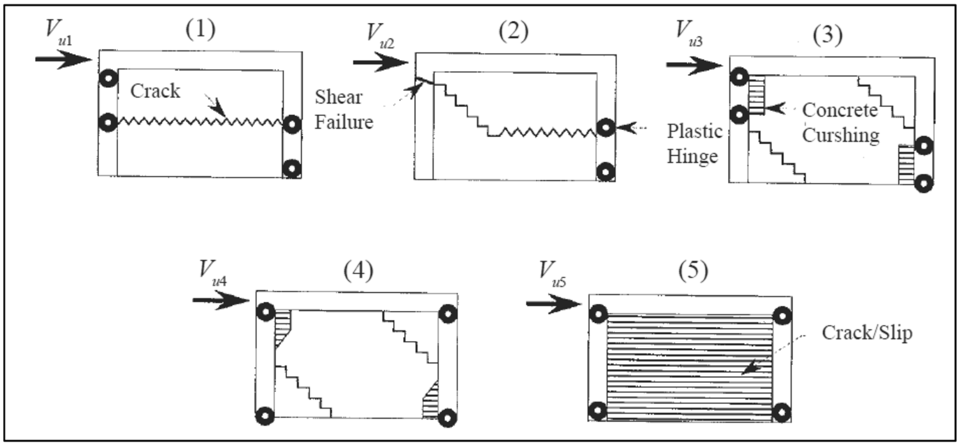
$$A = \frac{\left(1 - \alpha_c\right)\alpha_c ht}{\cos\theta} \tag{40}$$

The Young's modulus, E_u, of the panel in the diagonal direction using the following equation:

$$E_\theta = \frac{1}{\frac{1}{E_o}\cos^4\theta + \left[-\frac{2\nu_{o-90}}{E_o} + \frac{1}{G}\right]\cos^2\theta\sin^2\theta + \frac{1}{E_{90}}\sin^4\theta} \tag{41}$$

Kuzik et al. (El-Dakhakhni et al., 2003) has studied the out of plane behaviour of masonry walls reinforced with

Fig. 41 Selected failure mechanisms



GFRP and subjected to cyclic loading. Simple model behaviour is taken for evaluation for strength and deformation characteristics. The amount of GFRP sheet reinforcement can be expressed as a reinforcement ratio (ρ_{GFRP}) in terms of the transformed section area as

$\rho_{\text{GFRP}} = \frac{A_{GFRP}E_{GFRP}}{A_e E_m}$, where

A_{GFRP} = area of the GFRP sheet reinforcement on one side of the wall.

E_{GFRP} = modulus of elasticity of the GFRP sheet reinforcement on one side of the wall.

E_m = prism modulus of elasticity of the masonry.

Figure 46 shows the regression line plotted through the data and the resulting linear equation relating the two ratios.

The cracking moment can be explained to consider for axial forces as

$$M_{cr}^{f} = \left(f_t + \frac{P}{A_e}\right)\cdot\left(\frac{2I_g^f}{h}\right), \qquad (42)$$

where P is axial compressive force; A is effective area of an uncracked cross-section; h is the total depth of the cross-section.

Alwathaf et al. (2003) (Kuzik et al., 2003) there is a various numerical method in the world. The author has reviewed conventional mortared and non-conventional mortarless interlocking blocks masonry. Also finally, different analytical methods for masonry joint analysis is reviewed. Sobaih and Abdin (1988) (Alwathaf, et al., 2003) simple techniques which can be used to evaluate the seismic performance of masonry-infilled reinforced concrete frames is presented. Response spectrum analysis is performed on the masonry structure, and results are evaluated. The selected failure mechanisms are displayed in Fig. 42.

Aschheim and Abrams (Sobaih & Abdin, 1988) out of plane behaviour of unreinforced masonry structure is taken into consideration. Experimental results are compared with SDOF and MDOF. Two degrees of freedom is considered for dynamic stability. Hwee Tan and Patoary (Aschheim & Abrams, 2004) thirty masonry walls were strengthened using three different fibre-reinforced polymers, with three anchorage methods, was fabricated and tested under a concentrated load over a 100 mm square area. The test results were compared well with the analytical predictions. Milani et al. (2006) (Hwee Tan & Patoary, 2004) the usage of a simplified homogenized technique is used for the analysis of masonry subjected to out-of-plane loading. Efficient results are found in all the cases, indicating the proposed simple technique is sufficient for safety assessment for out-of-plane loaded masonry panels. Fajfar (2008) (Milani et al., 2006) Four storeys reinforced concrete frame structures has been analysed using the response spectrum method by inelastic approach. The provision of infills helps in resisting the loads and does not cause the failure of the columns. Amato et al. (Fajfar, 2008) due to masonry infills in the frame structure, infill behaviour switches from a strut element to a plate shell. The lateral stiffness of infill frames is evaluated. "Finite Element Micro-Modeling of Infilled Frame." (Amato et al., 2008) A different computer-based programming method is done to analyse single bay single storey masonry infilled RC frame when subjected to Lateral load. The difference in Magnitude and contact lengths has been clearly shown for different frame members. Kaushik et al. (2008) (Asteris, 2008) A comparative study was carried out considering different models. After linear and non-linear analysis, it is found that the 3-strut model can estimate the force resultants in RC members with accuracy. Also single strut model can be effectively used when masonry is discontinued in the first storey for parking space. Date (2009) (Kaushik et al., 2008) Unreinforced masonry panels are used for exterior or interior partitions in concrete frames, which is further subjected to shake table test (Figs. 43, 44, 45, 46). This approach can be further used for construction of simple struts in construction of the entire structure. Rodrigues et al. (2010) (Date, 2009) when the structure is subjected to earthquake loads the behaviour of infill frames will be affected. So, in this paper bi-diagonal compression strut model is considered

Fig. 42 Force diagrams for mechanisms 1

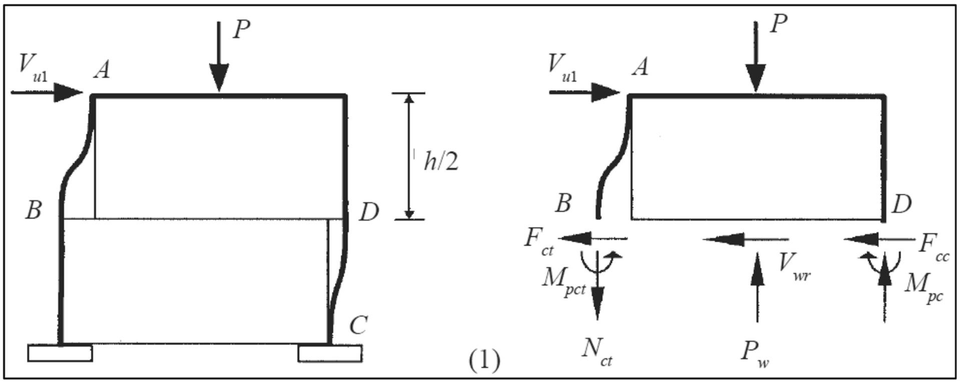
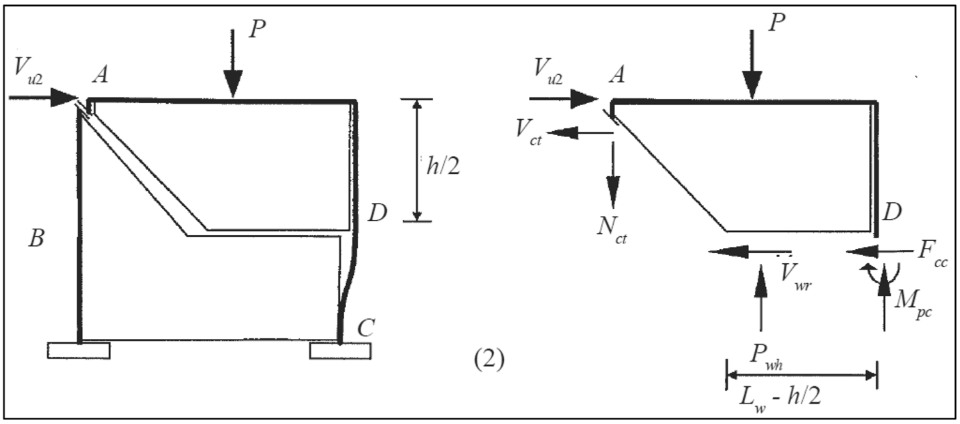


Fig. 43 Force diagrams for mechanisms 2



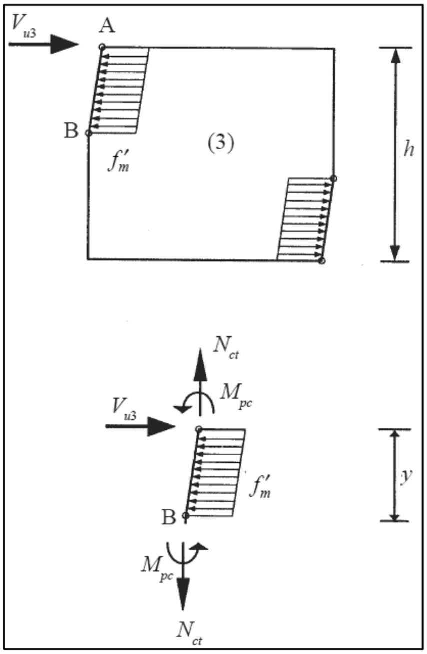


Fig. 44 Force diagrams for mechanisms 3

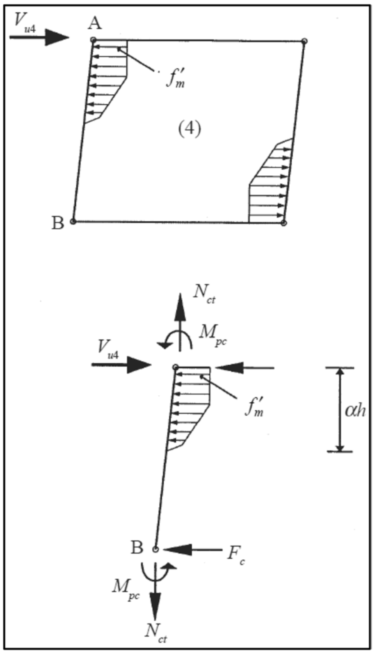


Fig. 45 Force diagrams for mechanisms 4

for the analysis. Single bay and double bay is tested in different laboratories and comparison of the results is done. In the proposed infill board model, every masonry panel is basically characterized by considering four support strut-elements, with rigid behaviour and a centre swagger component, where the nonlinear hysteretic conduct is concentrated (Fig. 47a). The stresses created in the focal component are simply of tensile or compressive nature.

Nine parameters characterize the nonlinear behaviour by a multi-linear envelope curve (Fig. 47), representing the following:

(i) cracking (cracking force, F_c; cracking displacement, d_c);
(ii) yielding (yielding force, F_y; yielding displacement, d_y);
(iii) maximum strength, corresponding to the beginning of crushing (F_{cr}; and corresponding displacement, d_{cr});
(iv) residual strength (F_u) and corresponding displacement (d_u);
(v) the fifth branch of the behaviour curve is defined by its stiffness (K_4).

A different behaviour curve can be defined for each loading direction, which allows for the consideration of non-symmetrical behaviour.

Asteris et al. (2011) (Rodrigues, et al., 2010) for achieving higher stiffness in the infilled frames, diagonal struts are provided. After the analysis, the validity of the proposed equations is verified by comparing the work done results

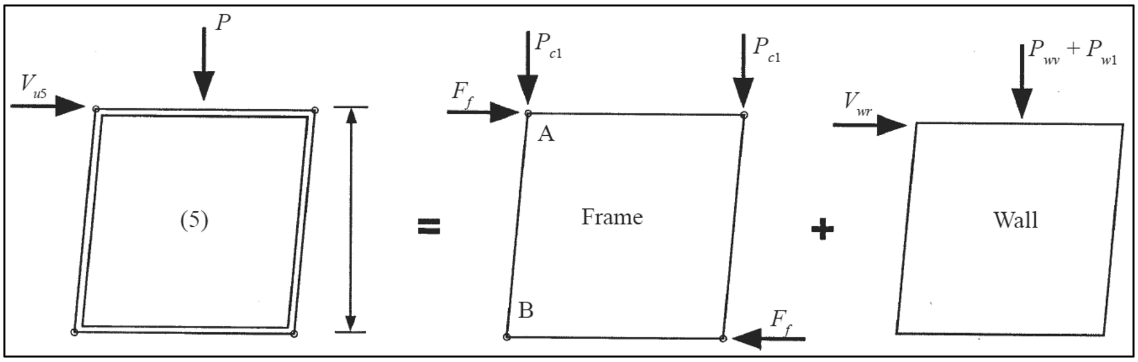


Fig. 46 Force diagrams for mechanisms 5

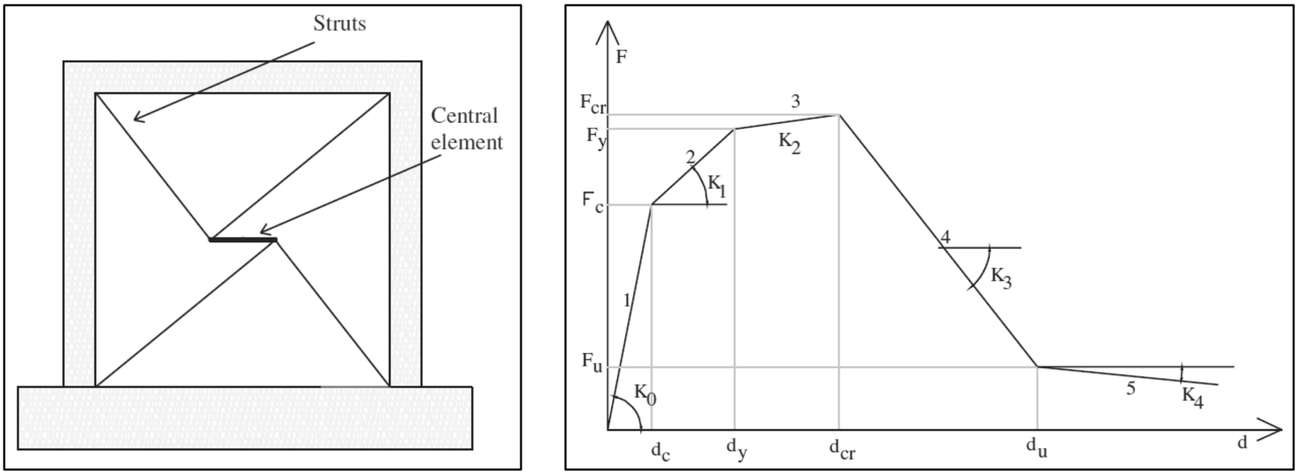


Fig. 47 Macro-model for the simulation of an infill masonry panel and force–displacement monotonic behaviour curve

by researchers against the achieved results. A. Mohyeddin-kermani (2011) (Asteris et al., 2011) the exterior and interior walls are constructed using infill frames. When subjected to earthquake loads behaviour of such frames are evaluated. The structure is analysed by using Ansys software. The structure is analysed both in-plane and out of a plane for different drifts to check the behaviour of the buildings. Su and Lee (2013; Mohyeddin-kermani, 2011) seismic fragility and spectral displacement are the parameters that are considered for Low rise and RC buildings. Coefficient-based methods obtain fragility curves after the shake load test. Spectral displacements are found to be within limits for low rise buildings. Asteris et al. (2013) (Su & Lee, 2013) since the behaviour of infilled frames under earthquake loads is different in each case, different micro models are considered for the analysis in this paper. Both advantages and disadvantages of each of the considered models are evaluated. Caliò and Pantò (2014) (Asteris et al., 2013) macro modelling technique is implemented, lumped plasticity beam-column elements model the frame members. This approach is evaluated by Non-Linear analysis performed on Infilled structures. Yuen and Kuang (2014) (Caliò & Pantò, 2014) the response of in-plane and out of a plane is usually analysed separately. The masonry infills, when subjected to out of plane loading, are provided with diagonal thrust. Also, in-plane loading reduces the load capacity of the RC frame by 50%. Also, by providing anchorage, it stabilises the forces against buckling. N. Kumar et al. (2014) (Yuen & Kuang, 2014) plasticity-based interface model is considered for masonry structure. The structure is further analysed using ABAQUS software, and the results are validated by comparing with literature review with the experimental results. Dolatshahi et al. (2015) (Kumar et al., 2014) different types of macro-elements are considered in unreinforced masonry structures and evaluated under seismic loads. After the analysis, the derivation curve is compared with non-linear FEA. This curve is further used for the preliminary evaluation of URM walls for bi-directional loading. Moretti (2015) (Dolatshahi et al., 2015) for the analysis of masonry structure is done by considering experimental, analytical and code provisions. Different approaches for single strut members are made, and results are tabulated. Yuen and Kuang (2015) (Moretti, 2015) a unified analysis method with the damage based modelling technique is proposed for numerical simulations of masonry-infilled reinforced concrete frames failure. Non-Linear behaviour of infilled frames was conducted by combining in-plane and out of plane loading. Thirumurugan et al. (2015) (Yuen & Kuang, 2015) properties of frame, infills are the main factors of an infilled frame. Different members of different sizes are taken along with one 3D. The effectiveness of the cork is interface material is studied, and adaptive infilled frames are adapted. Gattesco and Boem (2015) (Thirumurugan et al., 2015) the diagonal compression tests are compared with the in-plane behaviour of unreinforced masonry walls with GFRP coated structures. The tensile strengths are compared with experimental results and from an analytical formulation. Dolatshahi and Aref (2015) (Gattesco & Boem, 2015) the infilled structures are analysed by various numerical procedures and limited to in-plane or out of plane behaviour of masonry walls. In this paper, the experiment is done by considered extreme loading to address the gaps. The analysis was carried using TNO DIANA and ABAQUS software. Lin et al. (2016) (Dolatshahi & Aref, 2015) since there will be a decrease in the energy of masonry infilled frames, a new dry-stacked panel (DSP) semi-interlocking masonry (SIM) infill panel has been provided. The constant friction part is verified to provide substantial energy dissipation and benefits such as ductility of the structure. Miglietta et al. (2017) (Lin et al., 2016) a branch of the FDEM software was developed at the University of Toronto and called it Y-Brick. It is presented and validated as a reliable tool to model the reverse cyclic behaviour of masonry structures by varying levels of complexity. Y-Brick is also shown to identify the position of the cracks that form in the structure.

Pasca et al. (2017) (Miglietta et al., 2017) the out-of-plane response of infilled frames is considered for damage assessment of RC and steel buildings when subjected to seismic loads. After the analysis, the comparison between experimental and analytical values is made. Abdulla et al. (2017) (Pasca et al., 2017) has chosen extended Finite element analysis, he has approached three-dimensional nonlinear behaviour of masonry under monotonic in-plane, out-plane and cyclic loads. Abaqus software is used for the analysis, followed by a numerical algorithm, i.e., the Newton Raphson method for employing user-defined subroutines. Edri and Yankelevsky (2017) (Abdulla et al., 2017) URM structures, when subjected to out of plane loading, incorporates large deflection and strains. A master has considered which has suitable geometry and material nonlinearity. The two experimental results, when subjected to lateral loading, are compared with analytical model predictions. In both cases, results are within the limit and safe. Dautaj and Kabashi (2018) (Edri & Yankelevsky, 2017) 7 RC frames with masonry infills are tested under cyclic loading. Based on the results achieved, a new macro model is framed to analyse the infill RC frames. Further, the model is used to predict the failure patterns of infilled RC frames. Mazza and Donnici (2018) (Dautaj & Kabashi, 2018) Four diagonals out of plane nonlinear beams and one horizontal in-plane truss are taken into account. After analysing the numerical results of the out-of-plane and in-plane models, cyclic tests for six-storey RC framed buildings are compared. Different displacement history is considered, such as (i) OP loading faster than IP, at the sixth storey; (ii) equal IP and OP loading, at the third storey; (iii) IP loading faster than OP, at the first storey. Pradhan (2018) (Mazza & Donnici, 2018) a master macro model unreinforced masonry infill is considered under seismic action. Existing macro models is analysed, and their advantages and disadvantages are reported. Using diagonal struts is complex for structural engineers to obtain the desired efficiency. The feasibility of the 3D frame structure is checked and adapted. Mbewe and van Zijl (2019) (Pradhan, 2018) Seismic analysis Infilled structures using strut models and pushover analysis has gained popularity. The results show a good correlation between experimental data and the proposed model. Kostinakis and Athanatopoulou (2019) (Mbewe & Zijl May, 2019) the presence of infill frames in the masonry structure in RC buildings behave feasibly under seismic loads. But the position of infilled frames irregularly in the structure results in adverse effects. Finally, it is concluded that the irregular placement of infill frames in the structure leads to significant seismic damage. Eng et al. (Kostinakis & Athanatopoulou, 2019) the experimental study of out of plane behaviour of confined masonry walls is studied. 4 walls with different aspect ratio is considered for study and further tested in the laboratory. Failure of the walls was from crushing of masonry is found by yield line, failure line and bidirectional strut method. It is concluded that bidirectional strut method is best choice. Wang et al. (2020) (Eng et al., 2019) conducted Bidirectional seismic behaviour of masonry infill walls. After the analysis, comparison of experimental and analytical data is done to predict the failure modes. Further, based on slenderness ratio, masonry strength on the out of the plane (OOP), Response of infill walls within the plane damage is explored. Finally for stability is obtained by reducing stiffness and strength in OOP. Yekrangnia and Asteris (2020) has chosen multi strut macro model, which is capable of simulating overall force–displacement behaviour of infilled frames with different configurations. Model is analysed for different parameters and varying characteristics such as position, opening height to length ratio, etc. A reduction factor is proposed for better strength and stability. Pohoryles and Bournas (2019) (Wang et al., 2020) using composite materials for in-plane retrofitting will reduce the risk of collapse of the infills. The stiffness of the material and angle is considered as the crucial factors. The comparison between experimental and obtained strain is assess using empirical formula. Moacyr and Alva (2021) (Pohoryles & Bournas, 2019) seismic analysis is performed on RC building with masonry walls is considered. Equivalent strut on the seismic response is found which eases the complexity on the structural engineers. Finally, the use of participating masonry walls to be considered by engineers for better efficiency under seismic loads.

Concerning Table 5.3, the analytical studies carried out on masonry infill panels are summarized. For demonstrating infills, a few strategies have been created. They are classified into following two principal classes: macro-models and micro-models. The first depends on the equivalent strut method, and the second depends on the finite element method. The principle benefits of macro-modelling are computational effortlessness and underlying mechanical properties from masonry tests since the brickwork is a heterogeneous material. The dispersion of material properties of its constituent components is hard to anticipate. The single strut model is most generally utilized as it is essential and most appropriate for large structures.

Consequently, R.C. frames with masonry infilled walls can be demonstrated as comparable supported casings with infill dividers supplanted by an identical corner to corner swagger, which can be utilized in a thorough nonlinear sucker investigation. The fundamental boundary of these struts is their equivalent width, which influences their stiffness and strength. There are new bricks known as Porotherm bricks developed considering the weight of the overall structure, economic point of view, especially in new masonry constructions. Still, there is secondary research to characterize the infill panels' behaviour with these masonry units.

The popular strengthening material for MIW GFRP is widely used on the MIW to increase the lateral resisting capacity against horizontal loads. As suggested by Gattesco and Boem (2015), the principal tensile strength f_t at the centre of a sample square subjected to diagonal compression is calculated by using the following formula:

$$f_t = \alpha \frac{P_{\max}}{b.t}$$

$P_{\max}$ is the maximum load attained in the test, t and b are the thickness and the width of the specimen, respectively, and a is a coefficient assumed equal to 0.5. Then, a modification factor (β) is defined as the ratio between the experimental resistance of RM wallets $P_{\max(R)}$ and the preliminary analytical prediction ($P_{\max(U)} + P_c$).

$$\beta = \frac{P_{\max\ (R)}}{P_{\max\ (U)} + P_c}$$

Also, it is seen that masonry with similar mechanical characteristics and the coating is tested for the mortar range. The coefficient β is assumed as a linear trend function of the tensile strength of the mortar, with values decreasing as the mortar strength increases. From tendency curves, the values of the modification factor are calculated for each masonry type of structure. The relation of the resistance of RM specimens and the mortar coating resistance was derived analytically through the relationship as shown below

$$P'_{\max(R)} = \beta'.\left(P_{\max(U)} + P_c\right)$$

Fragility functions for masonry infills

Grubišić et al. (2013) (Grubišić & Sigmund, 2014) conducted deals with the seismic assessment of the masonry infilled walls with different infill conditions by utilizing fragility curves which gives the assessment of the vulnerability of the structure during seismic activity. Results showed that the type of infill considerably affected the seismic response of frame with the lowest probability of failure belonging to fully and partially infilled frame as compared to bare frame. Su and Lee (2013) analyzed masonry infilled RCC frames for spectral acceleration and displacement under seismic action using coefficient-based method (CBM). The CBM is more advantageous than finite element method (FEM) in terms of complexity. The frames analyzed using CBM obtained fragility results which were in validation with the previous studies. Nassirpour and D'Ayala (2014) considered infilled frames with steel frames with different end conditions in order to determine their seismic response using fragility analysis. The results pointed out that the infilled frames with steel bracing performed better under simulated earthquake vibrations as compared to the bare frames with steel bracings. Cardone and Perrone (2015) evaluated the damage potential of the non-structural component of the masonry infilled RC frames with and without opening through fragility functions by utilizing the experimental results of previous studies. Further, the damage quantification was performed and the remedial measures were given based on fragility curves which indicated that the results can be directly incorporated performance assessment calculation tool. Jong-Su Jeonl et al. (2015) (Blasi et al., 2018) estimated the seismic vulnerability of the lightly reinforced masonry infilled wall through fragility analysis. The simulation was conducted by taking into account a non-linear push over analysis. The masonry unit that was taken into account was either hollow or solid. The results concluded that RC frames with masonry infill improved the seismic response of the frames. Sassun et al. (2016) conducted examined the in-plane seismic performance of the masonry infilled RC or steel frames. A non-linear analysis was implemented to obtain the results which concluded that low drift values such as 0.2% did not caused any serious damage to the structures until the drift values were as high as 2%. When the repair cost analysis was executed, it was concluded from the results that there is reasonable correlation between Italian masonry infill repair cost estimates obtained using costing manuals and those obtained through consultation with the industry. Eduardo Charters Morais et al. (2016) (Papanicolaou et al., 2008) The probabilistic damage state estimation of unreinforced masonry infilled walls made with clay bricks in case of occurrence of an earthquake using dynamic structural analysis was performed. The earthquake intensities were obtained through 50 selected seismic data matching the Komárom historical earthquake and incremental dynamic analysis was implemented. The results concluded that that peasant houses were probably not made of clay masonry when the 1763 Komárom historical earthquake occurred, and possibly made of adobe or srfal.

Del Gaudioa et al. (2017) (Xie et al., 2020) conducted experimental investigation of RC frames infilled with clay brick masonry under seismic activity was executed and the results were then correlated with previous studies to obtain the fragility functions. Chiozzi & Miranda (2017) (Sassun et al., 2016) performed in the study deals with the development of fragility functions by incorporating 152 different masonry units from previous works which were strengthen with RCC or steel and infilled with either solid/hollow clay bricks or concrete blocks. The failure modes were identified according to the previous literature considered in the research. The results concluded that the type of masonry did not have any significant effects on fragility analysis. However, the compressive strength of the masonry influenced the performance of the building under seismic activity. Blasi et al. (2018) (Di Trapani et al., 2020) evaluated the seismic performance of the RC frames infilled with clay and concrete blocks using incremental dynamic analysis to develop fragility functions for in-plane behaviour of the structure. The results concluded that seismic retrofitting techniques needed to be employed in order to prevent the seismic failure of the structures. De Risi et al. 2018) carried out discussed the in-plane behaviour of the RC frames infilled with hollow clay bricks under earthquake activity. The analysis was conducted both experimentally and analytically to develop fragility functions and a new model is proposed. The results concluded that the proposed model was reliable in determining the key points at which losses occur during earthquakes. Mohamed and Romão (2002) conducted encompasses the non-linear dynamic analysis of the partially and fully infilled and soft-storey RC framed structures with and without openings to develop fragility functions to evaluate seismic stability. A bare frame model was also analyzed for reference purposes. For the first three damage states i.e., slight, light and moderate damage the bare frame and soft storey had a close performance while the performance of the partially infilled framed structure was closer to that of the fully infilled framed structure. Gautam (2018) executed determined the seismic vulnerability of the stone masonry houses in the village affected by the 2015 Gorkha earthquake sequence of Nepal. The fragility curves for seismic analysis were obtained from the 665,515 damage state conditions of the houses built in Nepal. The results highlighted that stone masonry houses in Nepal were highly vulnerable even in the case of low to moderate seismic activity. Del Gaudio et al. (2018) (Gaudio et al., 2019) found its background from the seismic events that occurred in the Mediterranean region. These regions are of high economic and social importance. The study executed analyzed Masonry infilled RCC frames. The masonry units used were clay and concrete type blocks. The damage quantification was conducted concerning drift and seismic activity and the fragility curves were obtained. The results concluded that concrete blocks filled masonry frames performed better as compared to clay block infilled masonry in case of drift capacity and seismic activity.

Choudhury and Kaushik (2019) investigated the seismic stability of the RC frames with partially and fully infilled conditions. A non-linear time history analysis was performed to develop fragility curves. The results showed that the epistemic uncertainty is significant only for higher damage states in any type of RC frame. On the other hand, the ground motion variability was found to be the major contributor to the total uncertainty in all the frames. Del Gaudio et al. (2019) evaluated structural and non-structural damage of the structures conducted by post-earthquake survey following the L'Aquila earthquake. For the analysis, a database of 32,520 residential masonry buildings was taken into account. The analysis showed that vulnerability was strongly related to the quality of the masonry units and the type of connections provided. Xie et al., (2020) (Nale et al., 2021) conducted on nine fully infilled masonries infilled RCC frames subjected to quasi-static loading to develop their fragility functions and corresponding fragility curves. The results showed that maximum crack widths gave the smallest dispersion, whereas the skeleton curve-based methods generated excessive dispersions and the phenomena-based method was shown to be self-contradictory in certain circumstances. Di Trapani et al. (2020) conducted on unreinforced masonry infilled units that were not subjected to prior in-plane damage to develop their fragility curves. An incremental dynamic analysis was performed for assessing the out-of-plane behaviour of masonry infilled units based on 26 seismic data. The outcomes showed fragility curves which were representing the possibility of exceedance of out-of-plane failure at a given ground vibration as a function of a different combination of geometrical and mechanical parameters, in-plane damage level and supporting conditions. Muhammad Waleed

Khan et al. (2021) (Choudhury & Kaushik, 2019) aimed at performing fragility assessment of RCC frames infilled with masonry blocks using linear and non-linear static and dynamic analysis. All the models were analyzed for plastic behaviour. The results concluded that the probability of exceedance of collapse for specific damage was under the limit. Nale et al., (2021) was implemented to evaluate the out of plane failure mechanism of the unreinforced masonry infilled walls by developing the fragility curves using the multiple strip analysis method. The results concluded that the fragility functions developed in the study will help assess the damage conditions of unreinforced masonry units as well as the economic losses. Gautam et al. (2021) (Del Gaudio et al., 2019) concentrated on developing the fragility functions of the RCC framed infilled bricks walls affected by the Gorkha earthquake that occurred in Nepal in 2015. For the analysis purpose, 2196 damage data of the structures were collected based on a global and local level. The damage states were categorized into three types which were minor, major and collapse. The conclusion which was arrived at from the fragility analysis was that even the moderate-intensity earthquake can cause serious damage to RC framed structures of Nepal which will lead to collapse. Pradhan et al. (Pradhan et al., 2021) (Khan et al., 2021) conducted developed a procedure to derive the fragility functions of the low rise RC framed structures. The out of plane fragility functions were developed using a probabilistic approach based on Monte Carlo Simulation. The results indicated that the out of plane fragility of the infill walls increased as the level of in-plane damage increased.

From the literature carried out, it is clear that strengthening of masonry infill wall is necessary to prevent the failure of the wall against earthquake forces. There are various strengthening techniques available to fulfil the functional requirement. The popular approach is to provide reinforcement either in the vertical and horizontal direction or in both directions depending on the severity of the seismic attacks. The reinforcement bars are inserted into the base of the wall at the bottom and the beam on the top for vertical reinforcement and column-to-column for horizontal reinforcement. An alternative method is to provide perforated steel plates or steel braces on the surface of the wall. This method unintentionally added extra weight to the existing structure, which also increased the overall cost of the whole system. The dowel bar system was then implemented, consisting of steel round bars inserted inside the wall so that half-length of the bar is penetrated inside the bounding frame. The remaining portion is inserted into the wall connecting both the structure and infill wall. This method has the disadvantage that the bar has more stiffness than the wall system, due to which cracks start propagating on the wall, which reduces the performance of the wall itself. The welded wire mesh, popularly known as ferrocement, was weightless and advantageous compared to previous methods. But the only disadvantage was the corrosion aspect as the mesh is mainly made up of steel. However, WWM is recommended for the improvement of ductility and ultimate failure loads of existing frames. Later, epoxy materials started gaining recognition as Fiber Reinforced Polymer (FRP) overcame all these disadvantages. The various types of FRP's are carbon, basalt and glass. Still, this method does not perform satisfactorily under elevated temperatures or aggressive environments. The experimental results showed that the lateral resistance of the infill wall increased when FRP was wrapped around MIW in any pattern. However, the experimental results displayed that the lateral resistance depends on the reinforcement ratio, specific aspect ratio and fibre characteristics.

In contrast, the ultimate drifts were independent of reinforcement ratio and reinforcement type but dependent on the aspect ratio and the retrofitting configuration. The most recent upcoming strengthening material is a textile reinforced mortar (TRM) that displayed better performance under elevated temperature, UV radiation and was used where vapour permeability is required. The same types of fibres are present in TRM, too, but the manufacturing and implementation method differentiates both. The TRM is recommended to strengthen the newly constructed walls as well as repairing the pre-damaged wall. FRCM helps regain the capacity of pre-damaged walls and enhance the non-damaged wall's overall performance. According to Papanicolaou et al. (2008), TRM had the upper hand over FRP in strength and deformability, i.e. TRM is a promising solution for strengthening MIW under out-of-plane loading conditions.

In addition to the strengthening material used, the type of masonry unit with which the wall is constructed also influences the overall performance of the infill system. The oldest known commonly used brick type is the burnt clay bricks, famous in many developing countries. Other types of bricks used to erect masonry infill walls are solid/hollow concrete blocks, Autoclaved aerated Blocks, interlocking blocks and Porotherm bricks (for which research needs to be carried out). Considering the brittle nature of the infill materials, the tensile capacity should be enhanced by using additional materials or techniques that have been summarized in the above sections. In alternate cases, a small gap is provided between the infill walls and the bounding frame so that the deflection of the structure once loaded does not show more impact on the infill wall as in the case without the gaps being provided. The use of similar techniques is also allowed for different materials. Still, it is necessary to determine the perfect method to safeguard the infill wall through experimental tests or numerical simulations.

Conclusion

This article aims to cover the general review of the complete evolution of masonry as a building construction material from the past to the present. The different kinds of material used to construct a masonry infill wall are elaborated, and the pros and cons are discussed. The performance of masonry infill walls under seismic loading, and the different failure modes are mentioned. To accomplish this, a systematic review methodology was implemented to segregate only the works in which the scope of the present research is in accordance. The performance of masonry infill walls under seismic loads is not satisfactory as it is brittle. Being vulnerable to the lateral loads, additional strengthening materials and methods are adopted to increase the in-plane and out-of-plane resistance. The intricacy essential to the out-of-plane conduct of these components is reflected by the measure of parameters considered through the tests investigated, like the board calculations, masonry units, openings, line compels, gravity load, past in-plane collapse, and past in-plane descent, and retrofit procedures.

The main findings obtained from the state-of-the-art review of masonry infill walls' seismic performance are that the type of infill blocks used influences the version of the overall structure. The infills reduce the shear failure occurrence in the RC beam-column joints. Porotherm bricks, a new kind of brick masonry infill, is introduced. As masonry is a brittle material, to increase its lateral load resistance, the usage of external strengthening materials are recommended, among which TRC proved to be beneficial. A balanced amount of literature on in-plane and out of plane loading is considered. Apparent differences in the performance of the wall were found regarding the strengthening material. Cracking criteria depends on the aspect ratio of the specimen. Comparatively, the compression strength of the masonry has more impact on the arching mechanism than tensile capacity. The performance of TRC as a retrofitting material used on the pre-damaged wall is better in terms of strength increment.

Finally, various strengthening and retrofitting systems were embraced in the literature to develop the board in-plane further and out-of-plane execution. The utilization of textile reinforced mortar (TRM) is an answer with great productivity since giving deformability to the board. Other arrangements, for example, the repointing technique, are additionally considered a method with excellent outcomes. The association between the brick infill and the mortar is one of the detailed perspectives that restricted the presentation of these arrangements. To supplement the current examination, what's more, the worldwide discoveries, the assessment of the contrasts between the full-brick wall width and half-brick width ought to be investigated later on. As masonry bricks are cheaper and popular in most countries, these are in great demand for construction and should be safeguarded against lateral load actions such as earthquakes. The research and development on this construction material are being carried out for decades and continue in the years to come. The study should be oriented to help enhance the strength, durability, and performance against seismic actions without increasing the overall weight and any deterioration to the material used. The following variables can be taken into account:

- Type of brick infills used to construct the wall influences the performance under loading conditions.
- The type and amount of strengthening material used to increase the masonry infill wall's lateral resistance significantly affect the infill wall's performance enhancement aspect.
- Boundary conditions have a significant impact on the seismic performance of the infill wall.
- Different reinforcement ratios of the strengthening material can be studied concerning the economic, overall weight, functional and aesthetic point of view.
- Openings in a wall and their location have a critical effect on the overall performance of the infill structure.

Acknowledgements The authors thank Birla Institute of Technology and Science, Pilani Campus, for this research work's financial and moral support.

Author contributions All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by JKB, and DB. The first draft of the manuscript was written by JKB, KJ and AS and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

Funding This work was supported by Birla Institute of Technology and Science.

Declarations

Conflict of interest The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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