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Shear Walls against Lateral Loads: A Review

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ABSTRACT

The consequences of lateral loads like earthquake loads and wind loads are achieving utmost concern nowadays. Imparting sufficient strength and stability in counter to the lateral loads is one of the major challenges faced by every designer. Therefore Proper understanding of the Seismic performance of different types of shear walls is necessary for structural engineers so as to safeguard the structure against lateral loads. Performance-based seismic design requires extensive research for capacity evaluation and development of reliable nonlinear models. Shear walls are the ideal choice to resist lateral loads in tall RC buildings. They provide large strength and stiffness to buildings in the direction of their orientation (in-plan), which significantly reduces lateral sway of the building.

1. Introduction

Many initiatives are taken in nations with modest seismic exposure to better understand seismic dangers, such as increasing awareness of analysing structures that are not constructed to handle seismic work. Experiments not only give physical insight into force-resisting mechanisms for model creation, but also the data needed to calibrate them, allowing for safe and efficient evaluation procedures.

There is an engineering definition for the term reinforced concrete shear walls, which are structural systems resistant to lateral load that are widely used in seismic areas worldwide. The use and construction of these reinforced concrete walls began in the sites in the fifties and sixties of the twentieth century, as they were used in those urban areas with a high seismic nature of medium buildings as well as high-rise buildings. Over the last 50 years, research has produced in considerable advancements in the performance of extremity wall structures, as well as a better understanding of seismic behavior. Where previous experiments showed that elderly structures are more vulnerable to severe damage during medium and large earthquakes, and that this is attributable to their ineffective design. For example, this case has been illustrated by separating these old walls with very large distances between stirrups and inadequate flexural reinforcement, which in turn makes them more susceptible to no any flexible behavior and potentially catastrophic damage in severe earthquake situations. The common structural deficiencies associated with those old wall structures also include insufficient in-plane stiffness, flexibility and flexural

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strength. There are many modern techniques that can be used to address these deficiencies as well as to improve the performance of old wall structures to ensure their safety under the loads caused by earthquakes.

According to Canadian Standards Association (CSA) A23.3 (2004), RC walls are classed as bearing walls, non-bearing walls, shear walls, flexural shear walls, and squat shear walls. Vertical loads, bending moments around the strong axis of the wall and shear forces parallel to the wall's length can all be absorbed by shear walls. Shear walls are widely used in mid- to high-rise structures to offer the necessary strength and stiffness to withstand external forces such as wind loads and earthquakes., provided that the work is done with an appropriate design that takes care of each of the strength wall and flexibility. Significant effort has been made in recent years to construct analytical models capable of simulating the real behaviour of RC elements., and the shear walls model is one of these models. Because of the rapid development in computer processing efficiency, The researchers developed more complete models that account for a number of RC shear wall phenomena that had previously gone unnoticed because to their complexity. **Glal et al. (2008)**.

Squat and slender shear walls were characterised by the researchers based on their behaviour. They also defined the squatting wall more precisely, classifying it as a short shear wall. The phrase "squatting wall" refers to a wall whose shear forces determine its deflection and strength. Alternatively, the term "thin wall" (long shear wall) refers to a wall whose deflection and strength are determined by flexure. Squat shear walls have an aspect ratio (the ratio of height to width) smaller than the unit, whereas slender shear walls have an aspect ratio larger than 2. Transitional shear walls have median aspect ratio between 1 and 2 which flexure and shear both have a role in the failure. However, there are no universally accepted aspect ratio numbers for determining squat and slim walls. Different codes and standards have slightly different rules for identifying squat and thin walls. Also, whether the performance is squatting or slender, the axial force on the shear wall impacts its behaviour. When designing earthquake-resistant reinforced concrete shear wall structures, certain factors must be considered. The following are the performance objectives and design criteria for structural shear wall elements:

- To provide stiffness to the building, and to control deformations in the structure which may otherwise cause damage to non-structural components during low intensity earthquakes.
- To provide adequate in-plane flexural and shear strengths to prevent structural damage during moderate earthquakes.
- To prevent total collapse of the building and to minimize major structural damage by responding in a ductile manner capable of dissipating the seismic energy through hysteretic behaviour during severe intensity earthquakes. **Chao et al. (2011)**.

2. General behavior of shear wall under various loads

Thomas (2002) displayed that for shear walls with an aspect ratio of 1.0 to 1.5, the sliding shear deformation process becomes significant.

Resmi et.al (2016) examined almost different viewpoints of execution of shear wall displayed by numerous of the agents. The taking after recommendations were given to move forward the performance of shear wall:

- When considering displacement and base shear, a structure with a shear wall at the fitting area is more critical.
- The strength of shear walls with openings was reduced.
- It has been determined that a diagonal shear wall is useful for constructions located in earthquake-prone zones.
- It is not essential to elevate the shear wall to the building's full height; rather, raising it to the building's mid-height is adequate.
- It is discovered that the construction with a perimeter shear wall is more productive.

3. Effect of shear wall position on building behavior

Balaji et al. (2015) used non-linear mapping to determine the optimal shear wall placement in a multi-story building. On four models, ETABS was utilised to apply seismic loads to an eight-story building., each having the shear wall in a different location in each seismic zone. When considering displacement and base shear, push over curves were produced, and it was shown that a construction with a shear wall at an appropriate location is more relevant.

Sivabala et al. (2011) investigated the effect of structural drift and inter-storey drift on various shear wall panel configurations in high-rise constructions. The basic frame was compared to a variety of alternative configurations, including the following:

i) Conventional shear wall

ii) Alternate arrangement of shear wall

iii) Diagonal arrangement of shear wall

iv) Zig Zag arrangement of shear wall

v) Influence of lift core shear wall.

The study discovered that when compared to other types of shear walls, a Zig Zag shear wall boosted the structure's strength and stiffness. A diagonal shear wall has been discovered to be beneficial for structures located in seismically active zones.

Shahzad et al. (2013) modelled and analysed a 25-story building by varying the location of the shear wall in order to determine various parameters such as storey drift, storey shear, and displacement using (ETABS), where both static and dynamic analysis were used to determine and compare base shear compared to other models, by placing the shear wall in the centre and four shear walls parallel to the X and Y direction model. This resulted in decreased displacement and inter-story drift when the building was subjected to maximum base shear, as well as an increase in the structure's strength and stiffness.

Ehsan et al. (2012) demonstrated that altering the location of the shear wall can reduce upper floor drift, as they determined the effect of the shear wall configuration on the seismic performance of the building and obtained upper floor displacements for various configurations using the SAP 2000 system.

4. Factors affecting the response of RC shear walls

A mix of flexural, shear and axial deformations influences the behaviour of shear walls. Low-rise walls are mostly governed by shear deformations, but medium- to high-rise walls are generally flexural in nature. The nonlinear response of RC shear walls appeared to fluctuate in response to a few variables in previous tests:

1- The wall dimensions and its aspect ratio.

2- The amount of axial load applied to the wall (axial-flexure interaction).

3- The amount of reinforcement in the wall and the bond strength between the reinforcement and the concrete.

4- The wall's flexure capacity in relation to its shear capacity.

5- Contact between the wall and its foundation, as well as the rigidity of the wall foundation.

6- The wall is swaying around its foundation due to the foundation's vertical reinforcement slipping .

7- The dimensions and reinforcement of the wall border columns, if applicable.

8- The impact of the wall-connected structural elements (e.g., coupling beams, moment resisting frame, etc.).

As a result, modelling of RC shear walls should consider the preceding variables, particularly the axial-flexure interaction and the depiction of the wall boundary conditions, in order to successfully mimic the wall behaviour. The demonstration should be able to determine both the wall's monotonic capacity and its behaviour when subjected to switched cyclic loads. Other phenomena such as concrete cracking, stiffening under tension, crack opening and closing with recovery of stiffness, strength degradation under cyclic loading, and confinement effects in compression, should all be represented by the ideal numerical model. Typically, one or more of these components are omitted from the analytical model for simplicity, provided that this omission has no significant effect on the model's accuracy when simulating varied RC wall behaviours.

4.1. Wall Dimensions

The height to length ratio of a shear wall has a considerable impact on its overall behaviour. Squat or low-rise walls are shear walls having an aspect ratio less than two. Tall or flexural walls are shear walls that have an aspect ratio larger than this dividing limit. **Thomas (1975)**.

A tall shear wall carries on basically within the same way as a reinforced concrete beam and is therefore typically designed using conventional beam theory. For a shear wall with height to length ratio less than one, the conventional beam theory is not applicable because of the deep beam effect. The shear and flexural behavior of the shear wall are interrelated. The flexural and shear strengths of a low-rise wall can be determined using principles established for deep beams. Since a squat wall has a low aspect ratio, high nominal shear stresses will develop prior to the wall attaining its full flexural capacity. This not as it were makes the low-rise walls more susceptible to diagonal tension, diagonal compression and sliding shear failures, it too makes it troublesome to outlive extreme seismic tremors by not having the vital capacity to disseminate the seismic energy through ductile inelastic actions **Paulay (1980)**.

4.2. Steel Reinforcement

The flexural capacity and curvature ductility of a shear wall are related to both amount and the distribution of the vertical steel reinforcement in the wall. Concentrating the flexural reinforcement toward the extreme fibers of a shear wall, as in the case of a flanged wall, results in increased flexural capacity and curvature ductility of the wall, as long as the shear failure modes can be prevented **Paulay (1980)**.

In spite of the fact that in comparison, a shear wall with uniformly distributed flexural reinforcement includes a lower curvature ductility than a flanged wall, the uniform reinforcement distribution is favored for low-rise walls since it progresses the wall resistance to sliding shear failure **Paulay (1980)**. In expansion to the dowel action, the vertical steel makes a difference to stand up to the sliding shear movement by providing a clamping force to the concrete within the immediate vicinity of the bars **Paulay (1975)**. On the other hand, it is apparent that a drawback of the uniform distribution of the vertical steel is that this does not maximize the moment resistance given by the steel reinforcement.

4.3. Top Beams and Floor Slabs

The in-plane horizontal shear forces resisted by a reinforced concrete shear wall is ordinarily presented at the top of the cantilever wall by a floor slab or tie beam. The top beam element uniformly distributes the applied load across the entire width of the wall. This minimizes the possibility of developing diagonal tension cracks in the wall and allows the load to be transferred more efficiently to the foundation though diagonal compression **Paulay et al. (1982)**. Since the tie beam gives elective ways for the transfer of the applied shear force to the rest of the wall and in tum to the foundation, the formation of a diagonal tension crack within the wall does not fundamentally result within the loss of load carrying capacity **Paulay et al. (1992)**.

Shear walls ordinarily have generally thin webs, which make them susceptible to lateral torsional buckling failure t. In this manner, to realize the drop capacity of the wall, it is frequently essential to supply lateral out-of-plane support to the wall. The connected floor slab, which acts as a horizontal diaphragm, gives lateral support to the wall and helps to prevent lateral torsional buckling of the web.

4.4. Applied Loads

Shear walls are regularly subjected to two sorts of loads, axial compression (gravity loads) and cyclic in-plane horizontal shear (seismic or wind loads). Axial compressive forces resulting from gravity loads have several beneficial effects on the behaviour of a shear wall, which include

1-Increased shear strength **Loannis et al. (1990), Thomas (1975)**.

2- Increased sliding shear strength **Thomas (1975)**.

3- Reduced horizontal and vertical displacements **Loannis et al. (1990)**.

4- Increased flexural capacity **Loannis et al. (1990)**.

While the effects of axial compression are beneficial, the repeated load reversals of cyclic in-plane horizontal shear loading can weaken concrete's compressive and shear strength dramatically. The frequent reversals in inelastic stresses and the multi-directional cracks caused by cyclic loads are the primary causes of concrete strength degradation. **Paulay (1980)**. The wall's resistance to diagonal compression failure can be reduced if the concrete's compressive quality deteriorates **Paulay et al. (1982)**. Furthermore, cyclic loading degrades the shear friction mechanism (aggregate interlock) and the dowel shear mechanism, which are the principal methods for transferring shear stresses from the base of the wall to its foundation and preventing sliding shear failure **Paulay et al. (1992)**.

5. Factors affecting the strength of RC shear walls

Since the 1960s, a few research initiatives have concentrated on the behaviour of slender and low-rise walls when subjected to monotonic and reversed lateral cyclic stress. According to experimental studies, the aspect ratio and configuration of the wall, the axial load, the shear stress demand, and the wall reinforcement ratio all affect the behaviour of structural walls, notably their deformation capacity.

The prevalent design philosophy for concrete walls is to provide sufficient strength and stiffness to avoid or limit damage during frequent earthquakes (limited or no inelastic behaviour), while also allowing for sufficient wall deformation capacity to maintain lateral load capacity during the inelastic response expected during stronger, less frequent earthquakes **Leonardo et al. (2004)**.

According to **Pauley et al. (1982)**, structural walls must be able to release energy after yielding in order to resist considerable ground vibrations and should not break unexpectedly due to shear or local instabilities. Consideration of shear wall behaviour requires a thorough grasp of the variables that affect wall behaviour. These parameters, as well as their effect on stack resistance components and failure modes, will be explored.

5.1. Wall Aspect Ratio

The total height-to-length ratio is one of the most frequently used structural wall classifications (wall aspect ratio). The term "slender walls" refers to walls with an aspect ratio larger than two, and their behaviour is driven by flexure. Slender walls are quite common in tall buildings due to their effectiveness in resisting lateral loads and preventing lateral drift. Tall walls are used in mid- to high-rise buildings and can be treated similarly to conventional reinforced concrete cantilever beam-columns. Due to the predominance of flexural behaviour in these steel reinforced walls, achieving the desired ductility is rather straightforward.

Because shear tends to restrict the overall wall reaction, structural walls having an aspect ratio less than two are commonly referred to as "low-rise" walls. In comparison to lateral forces, such walls have a huge potential for flexural quality. Due of its diminutive stature, the base's flexural strength must be generated by typically expansive shearing stresses. As a result, low-rise shear walls are swamped by shear due to their significant influence, and hence have a harder difficulty dissipating the required energy. This is the case due to the tremendous shear forces. Squat walls are sometimes used to refer to walls with an aspect ratio less than one. Low-rise walls are utilised in a variety of applications, including residential structures, parking garages, industrial buildings, nuclear power plants, highway overpasses, and bridge abutments. Additionally, if the bending force's amplitude is reduced significantly from its maximum value at the top of the basement, low shear span-to-length ratios (shear aspect ratio,a/lw) can be found in slender basement walls of high-rise structures **Thomas (2002)**. The majorityof walls constructed in the United States and Canada are classified as medium rise walls, with typical height-to-length aspect ratios (hw/lw) ranging from 2 to 4. **Hua et al. (2010)**, The lateral response is primarily influenced by nonlinear flexural and nonlinear shear deformations.

5.2. Boundary Element

Boundary elements are widely utilised to facilitate the fastening of transverse beams. Even when no beams are present, they are typically employed to accommodate the primary flexural reinforcement, provide stability against lateral buckling, and effectively contain compressed concrete in possible plastic hinges. Boundary components include concentrated reinforcement at the ends of walls and flanged walls. When crushed, flanged walls appear to have greater ductility than web walls. The maximum width of flanged walls that can be considered viable is determined by code provisions. Meanwhile, a determined reinforcing effort is underway. Boundary elements are widely used in shear walls to limit potential instability, especially when reinforcement yield and substantial compressive loads in concrete are anticipated; for example, hinge portions at both ends of the wall.

With the shear wall, boundary elements can operate as a frame, influencing the load carrying capability, failure mode, and shear wall behaviour. This frame action was researched in order to give a gradual rather than a rapid or catastrophic mode of failure **Paulay (1977)**.

5.3. Construction Joint

Horizontal construction joints in a shear wall might become the weakest link in the resistance chain and are therefore considered to be inefficient energy dissipators. According to earlier test results, the likelihood of sliding shear failure is a characteristic of shear walls, particularly when poorly prepared construction joints are used, as significant shear forces are exchanged across the crack via shear friction. Along with shear stresses, construction joints are subjected to axial compression or tension, as well as bending moments. As a result, sufficient reinforcement across a building's join is required to ensure the structural integrity of the walls and the dissipation of energy **Paulay (1977)**.

5.4. Horizontal and Vertical Reinforcement

Although horizontal reinforcement does not add to shear strength in walls with an aspect ratio of 0.5 or less, both horizontal and vertical reinforcement are effective for creating a more distributed cracking pattern and reducing crack width, according to two different codes: CSA and ACI **Barda et al. (1977)**. Additionally, transverse reinforcement may be a critical factor in determining the web confinement of the shear wall. According to a widely regarded study, raising the transverse reinforcement ratio of limited concrete increases its strength and ductility.

5.5. Foundation of Shear Walls

The base of the wall is one of the most important basic districts of shear walls. The foundation must be strong enough to withstand the overturning moment. There are several important considerations that must be made in order to provide an acceptable plan for such enterprises.

• Shear wall anchorage: For the shear wall to survive sliding shear and overturning effects generated by lateral stresses on the wall, it must be securely linked to the foundation.

• Overturning on the foundation: this had to be considered by an overturning moment analysis using safety factors derived from dead loads and passive soil pressure.

• The foundation had to resist horizontal slide.

• A combination of vertical and moment loads results in the maximum soil pressure.

6. Behaviour of Shear Wall

When subjected to quasi-static cyclic lateral loading, shear walls respond differently than beams, columns, and deep beams. The distinction is influenced by geometry, boundary conditions, and loading. Shear walls are distinct from columns in that they are frequently thin pieces classified according to the shear span of a beam or a deep beam. Meanwhile, shear walls differ from beams and deep beams in that strains are dispersed evenly along floor lines rather than concentrated in specific locations.

6.1. Flexure Behaviour

As seen in Figure 1, the flexural behaviour of a wall under combined flexure and axial forces is determined by two equilibrium equations (Eqs. 1 and 2) and a strain compatibility relationship (Eq. 3) that may be used to compute flexural strength. The three equations generalise the concept for walls from one to n levels of reinforcement. If the neutral axis is in the web rather than the border element, the compression centre will not be in the mid-depth of a comparable rectangular compression stress block. If a significantly greater compression strain is necessary to reach a desired level of ductility, the concrete cover in the compression area must be omitted when calculating flexural strength.

$$C_c+\sum_1^n A_{si}f_{si} = p_i, \text{ where } C_c=\alpha f_c' ab \quad (1)$$

$$M_i= C_c(c-a/2) + \sum_1^n A_{si}f_{si}(c-x_i) + P_i\,(t/2-c) \quad (2)$$

$$\varepsilon_{si} = \varepsilon_{cu}(c-x_i) / c \quad (3)$$

The calculation of flexural strength of walls is more difficult than that of beams and columns since the distribution of reinforcement cannot easily be represented when commencing the design phase. As a result, design charts or a computer software are frequently used to evaluate the flexural strength of walls.

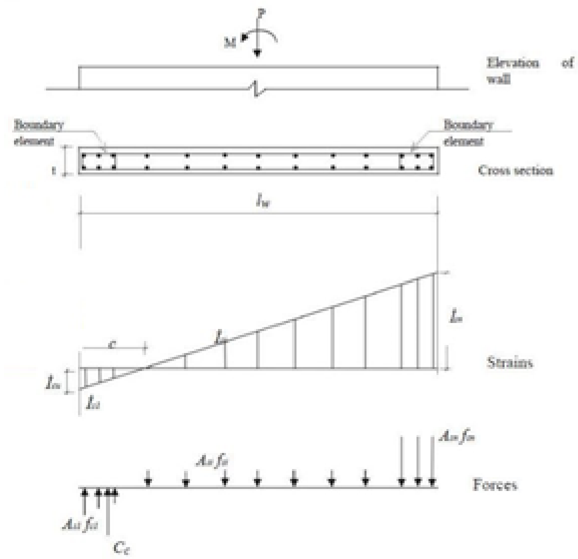

Figure 1 – Wall section equilibrium under flexural and axial loads Paulay et al. (1995).

The yielding of the flexure reinforcement is believed to be a significant source of hysteretic damping. Yielding in high-rise walls can be limited to the wall's base, which may contain a plastic hinge. On the other hand, concrete is a fragile substance that is not typically thought of as a good conductor of energy. To achieve the appropriate ductility, internal forces in the possible plastic hinge region should be allocated to the reinforcement. Figure 2a, **Paulay et al. (1995)**.

6.2. Shear Behavior

The axial tension induced by the triggered overturning moment may have a genuine impact on the shear wall's shear strength. The wall's gravity load may not be sufficient to reduce the resultant internal tension, resulting in diagonal fissures that are steeper than 45 degrees to the vertical axis of the wall. The nominal shear stress should be controlled to ensure that premature diagonal compression failure does not occur within the wall before the commencement of shear reinforcement yielding, especially where cyclic effect and ductility requirements must be considered. Figure 2b, **Paulay et al. (1995)**.

The contribution of concrete to shear strength (Vc) and the contribution of shear reinforcement (Vs) to the shear strength of a wall are calculated as follows:

$$V_n = V_c + V_s \quad (4)$$

The contribution of concrete is defined as follows:

$$Vc = vc\ b\ d \quad (5)$$

Where vc is the concrete shear stress and is calculated as follows;

$$vc = 0.27\ fc\ ' + Nu\ 4Ag \quad (6)$$

Or in plastic hinge regions as follows;

$$vc = 0.6\ Nu\ Ag \quad (7)$$

Based on truss models with a 45o diagonal strut, the contribution of shear reinforcement is

$$Vs = Av\ f\ y\ (d\ s) \quad (8)$$

Because flexural and diagonal cracks frequently mix, the diameter of the diagonal cracks widens when the vertical reinforcement yields. As a result, aggregate interlock, a key component of the concrete's shear-resisting mechanism, deteriorates, and more shear is transferred to shear reinforcement, i.e. horizontal reinforcement, as high-intensity reversed cyclic loading progresses. Plastic hinges are created at the base of the shear wall once it has reached maximum strength.

Yielding within the flexural (vertical) wall reinforcement spreads over a large height of the wall due to the combination of flexure and axial tension. Following big displacements during cyclic reversed loading can enhance yield spread. Shear resistance can be achieved following inelastic shear displacements when the next imposed displacement is greater than the largest previously encountered displacement. The negative effect of shear grows as the amplitude of the shear stresses, the axial compression on the wall decreases, and the wall's height-to-length ratio decreases.

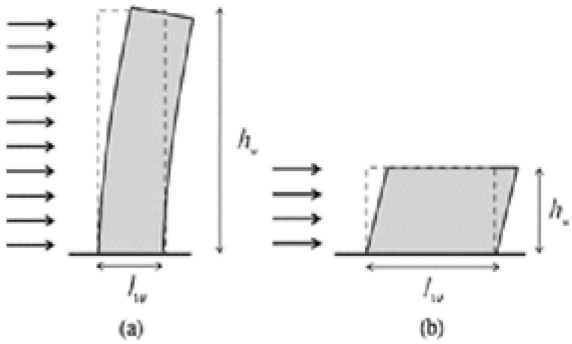

Figure 2 – a) Flexural deformation, b) Shear deformation Paulay et al. (1995).

6.3. Ductility

To minimise substantial structural damage, structures must be able to preserve a high proportion of their starting strength even when subjected to large deformations that go beyond elastic deformations, a property known as ductility. Ductility refers to a structure's ability to withstand substantial deformations and absorb energy through hysteretic behaviour when subjected to reversed loads. Limiting strength degradations associated with substantial deformations might help increase ductility, depending on the materials used in the structure. In this way, safeguards for material weakness had to be taken into account; for example, It had to be verified that no premature buckling occurred when steel was compressed. According to **CSA A23.3 (2004)**, Reinforced concrete shear walls should be designed to be ductile by ensuring that flexure failure happens earlier than shear failure owing to the yielding of the flexural steel reinforcement at the ultimate limit state. This structure is designed to sustain reversed cyclic inelastic deformations while maintaining significant strength and ductility. The terms strain, curvature (rotation), and displacement are used to describe ductility as follows:

1. Strain Ductility

Strain ductility is the most basic form of ductility, as it demonstrates the material's capacity to withstand inelastic strains without considerable stress reduction. **Paulay et al. (1995)** simply defined strain ductility as follows:

$$\mu\varepsilon = \varepsilon/\varepsilon y \qquad (9)$$

Where ε is total strain and εy is yield strain. It is obvious that unconfined concrete has extremely low strain ductility under compression; however, if concrete is confined properly, this can be greatly increased.

2. Curvature Ductility

Rotations in plastic hinge regions are the most common cause of inelastic structural deformations; detail requirements for plastic hinge regions are dependent on the curvature ductility demand. As a result, the following formula for calculating ductility in terms of section rotations per unit length (curvature) is useful:

$$\mu\varphi=\varphi m / \varphi y \qquad (10)$$

where φm is the maximum curvature expected to attain or relied on and φy is yield curvature. Because steel strain ductility capacity is normally high, the maximum curvature is controlled by the maximum compression strain at the extreme fibre. This can be represented as follows, based on **Paulay et al. (1995)**:

$$\varphi m= \varepsilon\, cm / cu \qquad (11)$$

where cu is the neutral axis depth at ultimate curvature.

When using normal strength concrete, the maximum dependable concrete compression strain in the extreme fibre of walls can be estimated to be 0.004.

The yield curvature for a typical example is the same as the initial tensile reinforcement yield, which is as follows:

$$\varphi\, y =\varepsilon y / (d - cy) \qquad (12)$$

High concrete compression strain may develop before the first reinforcement yield occurs if the section has a high reinforcement ratio. The yield curvature in this scenario should be dependent on the compression strain.

$$\varphi y = \varepsilon c / cy \qquad (13)$$

where εc is taken as 0.0015 as suggested by **Paulay et al. (1995)**.

3. Displacement Ductility

Because the displacement ductility factor characterises the structure's entire inelastic response, displacement is the most appropriate metric for evaluating the structure's capacity to produce ductility.

$$\mu\Delta = \Delta /\Delta y \qquad (14)$$

Where Δ = Δy + Δp, Δy and Δp are the yield and plastic components of the total lateral deflection, respectively.

4. Stability

Shear walls are known to be somewhat thin constructions, thus when a segment of the wall is subjected to substantial compressive loads due to out-of-plane buckling, the section faces the risk of early failure due to instability. According to **Paulay et al. (1993)**, the inelastic steel strains induced by preceding lateral displacements are the main source of instability in the compression zone of the shear wall section within the plastic hinge area. They explained that, due to unavoidable irregularities in reinforcement placement and out-of-plane inertial response, the position of the flexural compression force component may not coincide with the centroid, causing transverse curvature and bending moment at the centre of the wall, resulting in buckling failure before in-plane flexural strength could be developed, as shown in Figs. 3a and 2b. Aside from that, sliding shear displacement and possible concrete cover spalling also contribute to wall section instability.

Out-of-plane buckling could cause instability in plastic hinge zones. This flimsiness is a fundamental aspect of shear wall bendability. When building a shear wall, particularly at plastic pivot locations, this forcen is concerned with providing obstructions of least thickness of walls connected to wall tallness. In addition to the use of boundary components and rib walls, wall segments are compacted and flimsiness difficulties are reduced (Fig. 3c).

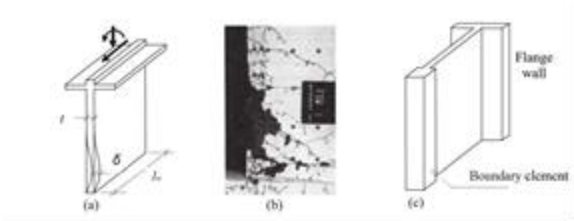

Figure 3 – Stability of structural walls (a) out-of-plane buckling (b) buckling failure in shear wall (c)wall with boundary Paulay (1980)

5. Confinement

Confining reinforcement is an excellent way to improve both the compression strain capacity and the compression strength of the concrete core in large compressive zones. High compression strains are expected in ductile seismic reaction because to the combined influence of axial force and bending moment. Spalling of concrete, followed by instability of the compression reinforcement, will cause confinement failure unless acceptable, densely dispersed, well point by point transverse reinforcement is installed, particularly in the potential plastic hinge zone **Paulay et al. (1995).**

Transverse reinforcement, in combination with longitudinal reinforcement, helps to limit the concrete's lateral expansion, allowing the compression zone to withstand higher compression loads and strains before failure.

7. Modes of Failure of RC Shear Walls

7.1. Flexural failure

During the last phases of this kind of failure, huge flexure cracks appear near the bottom of the wall's tensile zone, tensile or compression steel yielding may occur, and concrete smashing within the compression zone may occur. Furthermore, if the concrete cover within the compression zone spalled off, the compression steel could buckle. This form of failure occurs when the RC wall's flexural capacity is less than its shear capacity, which is common in high-rise walls. As illustrated in Fig. 4, the fracture pattern for a wall cracked in a flexure way. **Greifenhagen et al. (2005).**

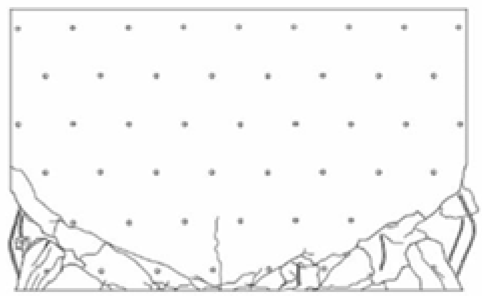

Figure 4 – Flexural failure of RC walls Greifenhagen et al. (2005)

This mode of failure was detailed within the experimental work conducted by **Loannis et al. (1990)**, **Zhang et al. (2000)** and **Perry et al. (2002)**. Larger mode effects for high-rise walls, as established by **Tremblay et al. (2001)**, result in increased shear stresses and bending moments in the wall's upper part. As a result of this, a plastic hinge would form in that place. **Bachmann et al. (1995), Michael et al. (1998), and Panneton et al. (2006)** all arrived to a similar result. As a result, existing low-rise shear walls may be required to be rehabilitated in their entirety (within the projected plastic hinge zone), whereas high-rise walls may be required to be rehabilitated in additional regions that may suffer plastic hinge formation at a higher level (due to higher mode effects that might not have been considered within the original design of the wall). To avoid wall failure at higher elevations, it is necessary to design the rebuilt wall in such a way that such behaviour is anticipated.

7.2. Shear failure

Shear walls having a low aspect ratio or insufficient shear capacity are more likely to fail in this way. Shear failure is brittle by nature, reducing the wall/energy structure's dissipation capacity when subjected to excessive ground movement. As a result, the major purpose of all seismic design codes is to avoid such a mode of failure by ensuring that the wall's shear capacity exceeds its flexural capacity. Shear failure of squat RC walls can occur in three modes, according to **Paulay et al. (1982)**: diagonal tension, diagonal compression, and sliding shear failure.

7.2.1 Diagonal tension and diagonal compression

Because of the major tensile stresses, inclined shear cracks appear, and the compression struts created between the cracks and the tension within the web reinforcement steel resist the shear force pressing on the wall. When horizontal or diagonal reinforcement is used insufficiently, diagonal tension failure occurs (yielding of shear reinforcement). High compression forces within the diagonal compression struts could cause diagonal compression failure if the shear reinforcement was insufficient to transfer high shear forces through the shear cracks. The web begins to exhibit X-shaped cracks in that form of failure and in the case of cyclic stress, followed by a brittle collapse of the concrete web. The concrete compressive strength is the most important aspect in determining the wall's potential to withstand this mode of failure. **Lopes (2001)** shear failure of an RC wall is depicted in Fig. 5(a).

7.2.2 Sliding shear failure

Sliding shear failure occurs when the wall web is sufficiently reinforced horizontally but has insufficient vertical reinforcement. In this mode of failure, a continuous horizontal crack beginning at the flexure will be shaped at the base of the wall or at the construction joint (i.e. the weak plane). In this scenario, the vertical reinforcement's dowel action and the friction between the concrete surfaces will assist the wall section in withstanding the applied shear loads. For walls with low axial load loading, the friction between the concrete layers will be minimal, and hence this form of failure may be critical. Against strengthen the resistance of RC walls to sliding, either the amount of vertical web reinforcement or the roughness of the concrete surface at construction joint points can be raised to at least 5 mm, as required by the CSA (2004). The sliding shear failure of the RC wall tested by **Riva et al. (2003)** is depicted in Fig. 5(b).

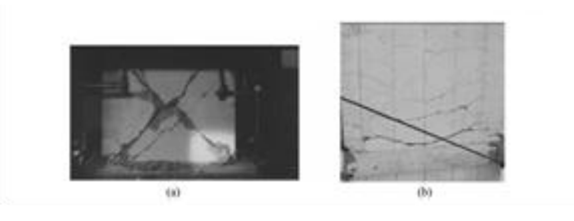

Figure 5 – Shear failure of RC walls, (a) Diagonal compression Lopes (2001), (b) Sliding shear Riva et al. (2003)

7.3. Local buckling of web (Instability of thin wall section).

Slender walls with rectangular parts are prone to this type of breakdown. To avoid this type of failure, design regulations specify a minimum wall thickness expressed as a ratio of the wall's unsupported height lu (for example, lu /10 in the CSA standard for rectangular walls). Local web buckling can also be avoided by using wall boundary features such as columns or flanges at the wall ends.

7.4. In-plane splitting failure

In-plane splitting failure was seen in lightweight RC walls when subjected to significant compression forces induced by lateral loads or increased gravity loads. Greetings, Greetings, **Mosalam et al (2003)**. This type of collapse comes suddenly and abruptly. This failure can be avoided by appropriately containing the wall.

7.5. Rocking failure

This form of failure happens when the overturning moment of lateral loads acting on the wall exceeds the stabilising moment of the axial load acting on the wall around the foundation corner. This is a common occurrence in masonry walls when the connection between the masonry blocks is broken at one plane, causing the wall to rock in the direction of the fractured plane. When the connection between the wall and the foundation is severed, this can occur with RC precast walls as well. **Taghdi et al. (2000)** discovered that after prolonged testing, RC walls can exhibit swaying behaviour. They noted that while the rocking motion would dissipate seismic energy, the wall's lateral load resistance may be insufficient to bear the lateral strains, necessitating retrofitting.

8. Finite Element modelling of RC shear wall

8.1. Finite element method of analysis

The finite element method (FEM) is the most extensively utilised technique for microsimulating the behaviour of RC elements. This technique discretizes the reinforced concrete component into a finite number of small elements (concrete and steel elements) that are connected at a certain number of nodal locations. The number of finite elements is determined by the needed level of precision and the available examination apparatus. FEM analysis can trace a member's global behaviour (for example, member forces and displacements) as it extends to its local behaviour (e.g. crack pattern, material stresses and strains). **Ngo et al. (1967)** proposed the first FE model that was used for the RC element.

The two-dimensional linear model proposed comprised constant strain triangular (CST) finite elements to replicate the concrete and steel elements, linkage elements to approximate the relationship between the steel and concrete parts, and cracking effects. Since that time, the FEM has developed into a highly effective tool for investigating RC structures, including three-dimensional and nonlinear analysis. As a result, various finite element analysis software applications have been developed and are currently being used by researchers, including: ANSYS **Desalvo et al. (1983)**, ABAQUS fig. 6 **Hibbitt (1984)**, VecTor 2 and 3 **Vecchio (1989), ADINA (1992)**.

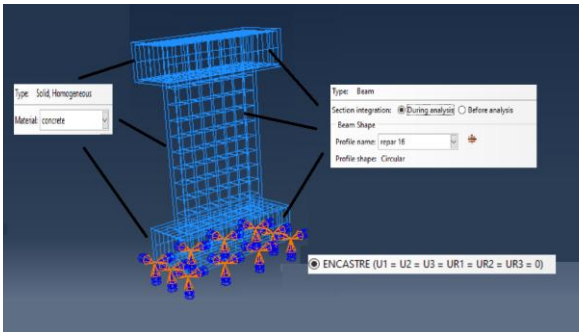

Figure 6 – Model of shear wall in ABAQUS

8.2. Fibre (layer) model

The member is divided longitudinally into many segments in this model, each of which is made up of parallel layers. The concrete material would be represented by a few layers, while the steel substance would be represented by others. In other models, as shown in Fig. 5(a), each single layer was divided into a finite number of fibres. The constitutive laws for concrete and steel materials are defined, and the member's moment-curvature relationship can be determined at each load level as a result. This model takes into account the axial-flexure interaction as well as the distribution of flexibility throughout the length of the member. The fibre model was used by **Thomas (1975)** to depict an RC member under cyclic loading. **Emori et al. (1981)** used this model for RC column members and discovered that it accurately predicted the column's inelastic zone behaviour. Within the fibre-section model, **Monti et al. (2000)** accounted for the bond-slip of the reinforcing bars (Fig. 7(a)). **Panagiotis et al. (2005)** recently used this model to mimic the behaviour of RC shear walls under dynamic excitations. The demonstration was hampered by the assumption of linear shear deformations, the difficulty of reproducing the boundary conditions, and the dismissal of the influence of bond slide. Based on studies done at the Swiss Government Founded of Innovation (ETH) in Zürich, Switzerland, **Belmouden et al. (2007)** used the layer model to predict the nonlinear behaviour of the RC shear walls under reversed cyclic stress. The wall study took into account nonlinear shear behaviour and the influence of bar slide. The layer model used by **Belmouden et al. (2007)** shown in Fig. 7(b).

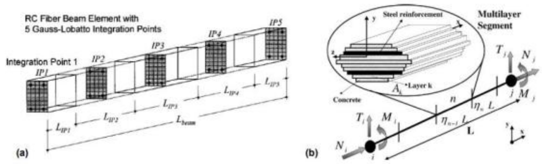

Figure 7 – (a) Fibre beam element proposed by Monti et al. (2000),(b) Multi-layer finite element model Belmouden et al. (2007)

8.3. Truss models

The truss model was used to determine the shear capabilities of RC structural elements such as deep beams and shear walls. According to this model, the wall will behave as a statically determinate truss. The model is constructed of diagonal concrete compression struts, horizontal tension ties (representing shear reinforcement), and two boundary components at the wall ends to transmit the wall's moment. The truss model used by **Oesterle et al. (1984)** to analyse the shear response of RC shear walls is shown in Fig. 8(a). Other models based on the same comparison, such as the Softened-Strut-and-Tie model illustrated in Fig. 8(b), were utilised to compute the capacity of RC walls. **Chao et al. (2011)** used the model to predict the shear capacity of RC squat walls. It's worth emphasising that, while such models can predict the capacity of RC elements, they can't account for their cyclic or hysteretic behaviour.

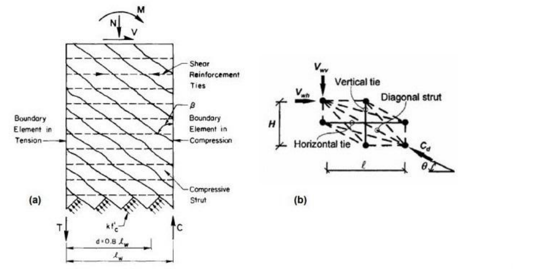

Figure 8 – (a) Truss model used by Oesterle et al. (1984), (b) Softened-strut-and-Tie model Yu et al. (2005)

9. Seismic Load on Building Using ETAB

This research studies reinforced concrete building as a typical fourteen storey flat slab-column system located in Cairo. The building is near to be square in plan with dimensions 18.6m x 19.3m. The building is designed for residential use. Typical floors plan and isometric view are presented in Fig. 9 and Fig. 10. Typical floor height is 3m. The floors are made of concrete flat slabs supported by columns. The thickness of the floor slab is 25 cm for all stores. The cross-section of the columns used to support the structure is determined as 30cm x 50cm for smallest column dimensions in the structure and as 30x140 for the largest ones. The designed system to resist the seismic forces consists of two elevator cores in both X and Y direction. Additional shear wall in X direction is also designed for seismic resistance purpose. The considered herein building structure has been designed according to the EC with specified characteristic compressive strength fcu = 25 MPa and steel reinforcement with yield strength fy = 360 MPa.

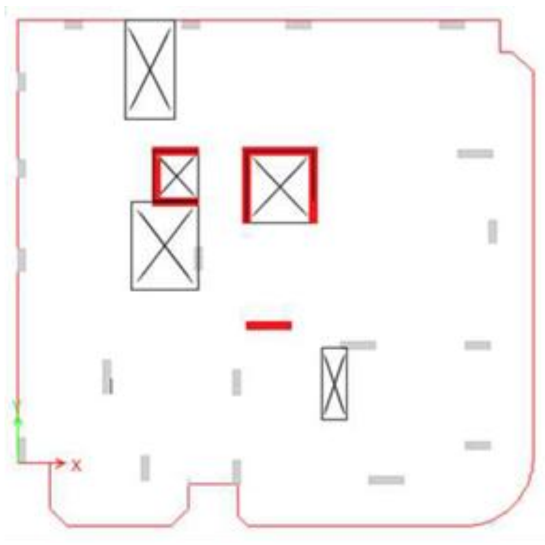

Figure 9 – Typical floors plane of the fourteen storey

The three dimensional RC multi-storey building used in this study was modelled as flat slab-column system with shear walls. For the purpose of modelling the real behaviour of the slabs, they were modelled using shell elements to ensure providing stiffness in all directions and transfer mass of slab to columns and beams. A rigid diaphragm was assumed at all floor levels. In order to account for the modal damping effect, the complete quadratic combination (CQC) technique, which takes into account the statistical coupling between closely spaced modes caused by modal damping, is used for modal combination. The first modelling step with ETABS involves defining the physical properties of the used materials. Sections for horizontal and vertical elements of the considered building are defined in terms of dimensions and material properties. Consequently the defined sections are assigned to the corresponding plane elements such as slabs and beams and the corresponding vertical elements such as columns and shear walls. Choosing the correct boundary conditions through assigning supports and connections with appropriate restraints is one of the important aspects in structural modelling. Three-dimensional analysis is carried out under static and dynamic seismic analysis in both X and Y directions, which are known to be orthogonal directions.

Figure10 – 3-D building model

Analyses of 14-storey flat slab-column building with shear walls system, designed in accordance with the EC for loads and subjected to two different approaches equivalent to earthquake loading, has been studied in both X and Y directions. The considered two approaches are the dynamic RS and static force analysis. The dynamic and static base shear in both directions of loading are computed and compared. An amplification factor has been used to scale the dynamic base shear with respect to the static one. The building's responses in terms of scaled base shear, storey deflections, storey moments, storey drifts, and torsional irregularity ratios have been calculated under the considered two methods of analysis. It is clear from the analysis that the static analysis gives higher values for maximum displacement of the stories in both X and Y directions rather than the dynamic RS analysis method, especially in higher stories. Although scaling the base shear due to RS analysis to be of equal value to the one due to ESF, it has been found that a significant increase in the dynamic shear at higher stories. However at lower stories a slight increase in the dynamic shear compared with static shear regardless the direction of loading. The dynamic RS analysis produces storey shear in both directions regardless the loading direction while the static analysis only produces storey shear in the direction of loading. Contrary to the storey shear forces, the induced storey moments under ESF and RS analysis methods are of higher values at lower stories compared to the higher ones. Moreover, significant increase in the obtained storey moments at lower storeys under RS compared to the corresponding low levels under ESF analysis. In addition, RS analysis produces Moments in both directions regardless the direction of loading and the ESF is not. The results obtained from the structure presented herein have shown that the

torsional irregularity in a structure subjected to seismic loading may be influenced by the direction of seismic loading as well the loading approach and strongly lead to analyzing irregular buildings for torsion. Even though the dynamic RS analysis method of seismic design is the prefered method due to the computional advantage in predicting response of structural systems where it involves the calculation of only the maximum values of the induced response in each mode. However, The ESF analysis method is used as a benchmark to scale the design base shear obtained by the dynamic RS analysis before the distribution of the lateral seismic forces over the height of the structure under the dynamic RS base shear. **Sayed et al. (2014)**

10. Conclusion

Based on the results of the survey, it can be inferred that installing shear walls in suitable locations reduces lateral load displacement significantly. Damages from earthquakes and high winds can be minimized by creating shear walls. Flexural and shear failures are the most dangerous forms of failure. Because the RC wall's flexural capacity is smaller than its shear capacity, flexural failure can be avoided by strengthening the lowest component of the wall. Shear failure occurs when the web's reinforcement steel is insufficient, and it may be avoided by providing sufficient horizontal and diagonal reinforcement. Putting steel bars in the direction of applied stresses improves the shear wall's seismic performance. Shear walls on the inside are more effective than shear walls on the exterior. Shear walls are effective at reducing the soft story effect. Shear walls work better in high-rise structures than they do in low-rise buildings.

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