Seismic Performance of Gravity Load-Designed RC Frame Buildings in Jordan: a Prelude into the Effect of Masonry Infills

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Abstract. Fifty four infilled reinforced concrete (RC) frame buildings were selected and designed to represent typical Jordanian low and medium rise buildings designed to resist gravity loads only. Using SAP2000 software, nonlinear static analysis was performed on three dimensional models of the representative buildings. The study parameters included building height; horizontal and vertical irregularities; as well as type and layout of walls. The inverted triangular and Square Root of Sum of Squares (SRSS) lateral load patterns were used for irregular buildings. Analysis results indicated that commonly encountered horizontal and vertical irregularities associated with presence of re-entrant corners and soft stories negatively affects the elastic stiffness, energy dissipation and lateral resisting capacities of the investigated buildings. Analysis results confirmed that using RC walls, rather than masonry walls, in the staircase unit greatly enhances the seismic performance of buildings provided the RC walls followed a symmetrical plan arrangement about one of the principal axes. The majority of the investigated buildings exhibited a maximum inter-story drift ratio below 1.5% at the yielding strength and 3.8-4.8% at ultimate strength indicating that severe structural damage may take place under strong earthquake excitations. Plastic hinge formation signified the use of faulty design concepts violating the traditional strong column-weak beam concept of earthquake-resistant design. Compared with the inverted triangular lateral load pattern, using the SRSS pattern for pushover analysis of irregular buildings had a negligible impact on lateral load resistance but significantly affected stiffness and energy dissipation values.

1. Introduction

Although the rate of seismic activity associated with the Dead Sea Transform faulting system is identified as being moderate, the current population distribution in Jordan by which urbanization is mostly concentrated in seismic prone areas and the rapid development of the country tend to greatly amplify the induced level of seismic risk. Unfortunately, the vast majority of existing reinforced concrete (RC) building frames in Jordan has been mainly designed for gravity loads with no consideration for earthquake resistance thereby giving rise to higher levels of seismic risk.

Even in today’s design practices, local engineers chose to ignore the interaction between the RC frame system and the masonry infill walls that are typically used as interior partitions and exterior walls. Masonry walls are regarded as nonstructural elements; their contribution to the seismic weight might be considered but not to the lateral strength and stiffness of the structural system. In fact, the
structural contribution of infill walls and the reduction in the fundamental period of vibration of composite frame-infill systems resulting in a change of the seismic demand cannot be neglected especially in regions of high or even moderate seismicity [1-4]. The structural performance of RC frame buildings in recent earthquakes has demonstrated that frame-infill interaction greatly affects the dynamic characteristics and response of these buildings. Over the past few decades, a large number of experimental and analytical investigations into the effect of different types of infill walls on the seismic performance of RC and steel frames confirmed that infill walls modify the global structural response of frame buildings subjected to seismic loads. Actually, Murty and Jain [5] demonstrated that the presence of masonry infills in RC frames increases the level of axial forces in the frame members while reducing the bending moments thereby changing the lateral load transfer mechanism from predominant frame action to predominant truss action. The presence of openings and the absence of infill walls from specific stories or even the unsymmetrical plan arrangements of these infills add to the complexity of the frame-infill interaction problem giving rise to short columns, soft stories and torsional effects.

Researchers have proposed several analytical models that define the seismic response of masonry infills and their interaction with the bounding frame. These models are grouped into two main categories: The simple macro modeling approach where the infill panel is replaced with an equivalent diagonal strut aiming at representing the global behavior of the infill panel and its effect on the performance of the frame-infill system [6-10]. Alternatively, researchers [11-13] have used more complicated and time-consuming finite element methods to model the different behavioral aspects of the frame-infill system. Despite the overwhelming evidence of the effects of masonry infills on the seismic performance of RC or even steel frames, seismic codes tend to overlook this problematic design issue. In their review of 16 national code approaches to the seismic design of masonry infilled reinforced concrete frames, Kaushik et al. [14] concluded that only 3 of the reviewed codes recommend modeling the masonry infills using equivalent diagonal struts. Yet, the required sectional properties for the struts are not specified in these documents. The fact that presence of openings reduces both strength and stiffness of masonry infills was neglected in all of the reviewed codes. Few codes discussed methods of reducing the damage in masonry infills due to openings and specified limits on their slenderness ratios to prevent out-of-plane failure. Because of the complex interaction between the infill and the bounding frame and of the large number of relevant parameters, the first edition of the Jordanian Code for Earthquake-Resistant Buildings [15] which was released in 2005 completely ignored this interaction.

Using nonlinear static analysis, this study aims mainly at investigating the effect of local concrete masonry infills on the seismic response of gravity load-designed non-ductile RC frames that constitute about 60% of the residential building fabric in Jordan. The investigated parameters include the building height; horizontal and vertical irregularities; in addition to the layout of masonry walls and the presence or absence of RC walls.

2. Selection of buildings

To achieve the study objectives; 54 buildings representing non-ductile RC frames with concrete masonry infills are examined. The buildings under consideration are assumed to have been designed for gravity loads only thereby representing RC frames that have been constructed prior to the enforcement of the local seismic code [15] in 2005.

The selected buildings are grouped according to their plan areas into 3 groups (G1, G2 and G3-with plan areas of about 250, 350 and 450 m², respectively) and then according to their heights or number of stories (2, 4 or 6 stories). Each of the area-height categories (Gi-Nj) included 3 model buildings with no RC walls: one with a symmetric plan arrangement of the masonry walls about the y-axis including those used in the staircase unit (designated as Gi-Nj-R-M1), another with the same
arrangement of walls but with re-entrant corners giving rise to plan irregularity (designated as Gi-Nj-IR-M1) whereas the staircase unit was positioned to provide a non-symmetrical arrangement of walls about the y-axis in the third model which had no re-entrant corners (designated as Gi-Nj-R-M2). The 4- and 6-story height categories included an additional building with no RC walls, regular in plan but with a soft ground floor designated as Gi-N4-SS-M1 and Gi-N6-SS-M1, respectively. In addition each area-height category included 2 buildings with RC walls. The RC walls, used in the staircase unit, were positioned to provide symmetry about the y-axis in buildings as indicated by the term RC1 (building designated as Gi-Nj-R-RC1) and were shifted off the y-axis in buildings as indicated by the term RC2 (building designated as Gi-Nj-R-RC2). A building with an elevator shaft (ES) designated as Gi-N6-R-ES was included in each of the 6-story subcategories. Figure 1 displays typical floor layouts for a number of the G1 buildings with a plan area of about 250 m².

3. Structural modeling and analysis

3.1. General

Following stipulations of the local design codes [16, 17], the selected buildings were designed as non-ductile frames to resist gravity loads only. To avoid unnecessary vertical irregularities, columns and RC walls were considered continuous over the building height with a typical story height of 3.25 m (center-to-center between floor slabs). Typical roof and floor slabs were designed as 250 mm one-way joist construction. Masonry walls, both interior and exterior, were considered as nonstructural walls and their contribution to and interaction with the structural system was neglected at the design stage. Median values for the mechanical properties of typical construction materials used in residential RC frame buildings in Jordan within the time period of interest (1985-2005) were adopted. Possible variation in material properties were not taken into account at the modeling stage. Accordingly, normal weight concrete with an average 28-day compressive strength, \( f_{c'} \) of 25 MPa characterized by
the Mander et al. [18] stress-strain model for confined and unconfined concrete was adopted. The complete stress-strain curve with strain hardening was used for both main ($f_y = 420$ MPa) and secondary reinforcement ($f_{ys} = 280$ MPa).

3.2. Structural modeling

3.2.1. Modeling of slabs, beams and columns. Using SAP2000 [19] three dimensional structural models were built for each of the representative buildings. Elastic beam elements with a T-section were used to model the joist construction in the different floor slabs. Beam and column elements were modeled as elastic frame elements with lumped plasticity at member ends. Plastic hinges were assigned at a distance equal to half the plastic hinge length from the face of the joint. Length of the plastic hinge was taken as half the depth of the member cross-section (in the direction of analysis). Moment-curvature relations for beam and column elements were defined automatically by the software using the plastic hinge properties described in FEMA-356 [20] or ATC-40 [21]. Beam and column stiffnesses were based on the approximate values presented in ACT-40 [21] for the effective initial stiffness: Effective moments of inertia for beams and columns were taken as $0.5I_g$ and $0.7I_g$, respectively where $I_g$ is the gross moment of inertia. In view of their large in-plane rigidity, roof and floor slabs were assumed to act as rigid diaphragms. Fixity was assumed at column bases.

3.2.2. Modeling of infill walls. To ensure the contribution of masonry infill walls to the lateral stiffness and strength of the bounding RC frames and make use of this additional mass, gaps between the infill wall and the bounding frame elements should be eliminated. Local infill walls are usually constructed using 100 or 200 mm thick hollow concrete masonry units (blocks) that are typically produced with a unit compressive strength of about 3 MPa. The masonry courses are 200 mm high and are constructed using Portland cement mortar. According to BS 5628 [22], the local mortar with mix proportions of 1: 0.5: 4 (cement: lime: aggregates) by volume is classified as type (ii) mortar. The characteristic compressive strength of the masonry walls, $f_k$, is computed as 3 MPa whereas the modulus of elasticity is computed using $E = 1000 f_k$ as recommended by Eurocode 6 [23] resulting in a value of $E = 3000$ MPa. Cracking strength of the infill panel, $f_{tp}$, is approximately taken as 0.25 MPa. Assuming perfect contact between the masonry infill panel and the bounding beams and columns and neglecting out-of-plane failure, the initial in-plane stiffness of the wall prior to cracking is based on the equivalent strut model suggested in FEMA-356 [20]. While the thickness ($t_{inf}$) and modulus of elasticity ($E_{me}$) of the diagonal strut are those of the infill wall itself, the effective width ($w_{ef}$) is given by

$$w_{ef} = 0.175 \left( \lambda_1 h_{col} \right)^{-0.4} r_{inf}$$

$$\lambda_1 = \frac{E_{me} t_{inf} \sin(2\Phi_d)}{4 E_{fc} I_{col} h_{inf}}$$

$$\Phi_d = \tan^{-1}\left( \frac{h_{inf}}{I_{col}} \right)$$

where $\lambda_1$ is a coefficient that determines the level of frame-infill interaction, $h_{col}$ is the column height measured center-to-center between beams; $h_{inf}$ is the height of infill panel; $E_{me}$ is the modulus of elasticity of the infill material; $I_{col}$ is the moment of inertia of column and $\Phi_d$ is the angle describing the inclination of the diagonal strut with the horizontal.

Considering concrete crushing and bed joint sliding while neglecting the infill wall damage caused by deformation of the bounding frame, the tri-linear force-displacement relation proposed by Fajfar et al. [24] was used to characterize the response of concrete masonry infills. The effect of openings on the infill wall stiffness was considered by multiplying the effective width of the equivalent diagonal compression strut by the infill wall stiffness reduction factor ($\lambda$) proposed by Asteris [25] given by
where $\alpha_w$ is the ratio of opening area to the infill wall area.

3.2.3. **Modeling of RC walls.** RC walls, 150 mm thick with a single layer of reinforcement are used for the 2- and 4-story buildings whereas 200 mm thick walls with two layers of reinforcement are used for the 6-story buildings in compliance with local practices. RC walls are modeled using shell elements. Behavior of the 6-story slender walls is considered to be dominated by flexure whereas behavior of the 2- and 4-story intermediate walls is considered to be dominated by shear-flexural failure. The effective moment of inertia of the wall cross-section, $I_{eff}$, is taken as 0.5$I_g$ in accordance with the ATC-40 [21] recommendations to account for the effect of concrete cracking.

3.3. **Pushover analysis**

The simultaneous effects of gravity and lateral loads are typically included in the nonlinear static (pushover) analysis. Taking into account that dead loads constitute the most significant proportion of gravity loads in residential buildings and that the variance in live loads is insignificant; pushover analysis was carried out using 25% of the live loads set by the design code in addition to dead loads.

Nonlinear static analysis was performed, using SAP2000 [19], for the two principal directions (x and y shown in figure 1) of the representative buildings to arrive at their capacity curves. Gravity loads were applied first using force control. A predefined pattern of horizontal forces was then applied to the structural model using displacement control wherein lateral forces are increased monotonically while preserving the ratio between lateral forces applied at the different story levels. Two lateral load patterns were applied in this study: The inverted triangular pattern which was used for regular building structures and the multi-modal or the Square Root of Sum of Squares (SRSS) lateral load pattern which was applied for irregular building structures. Lateral forces were applied to regular buildings in the form of an inverted triangle that matches the fundamental mode shape of the building in compliance with the provisions of the equivalent static force method of the local seismic code [15]. Using the SRSS pattern for irregular buildings, the lateral force at story level was calculated as square root of sum of squares combination of the load distributions obtained from modal analyses.

4. **Analysis results and discussion**

4.1. **Capacity curves**

4.1.1. **General.** Pushover curves displaying the base shear -roof displacement relationship ($V-\Delta$) were obtained in both principal directions, x and y, for each of the buildings under consideration. Notable differences in pushover curves obtained for the x and y building directions were observed. This is associated with the fact that columns and walls in gravity load-designed RC frames are located and oriented with no intention to provide for equal stiffness in the two orthogonal directions.

![Figure 2. Capacity curves for G1-N2-R-M1 a) pushover curves, b) idealization of capacity curve](image-url)
Conservatively, orthogonality effects were neglected and the building lateral resistance was characterized by the curve showing lower capacity to resist lateral loads. The selected pushover curve was idealized by a bilinear (elastic-plastic) curve in accordance with ATC-40 [21] considerations for the displacement coefficient method. Figure 2a displays the two pushover curves obtained in the x and y directions for building G1-N2-R-M1 whereas figure 2b shows the pushover curve characterizing the response of the building to lateral loads and the accompanying idealized pushover curve.

The maximum lateral resistance based on the actual capacity curve; the pre-yield or effective elastic stiffness (ke) defined as the ratio of the yield base shear capacity (V_y) to the yield displacement (Δ_y) as identified on the idealized curve; and the energy dissipation capacity computed as the area under the idealized V-Δ curve are reported in tables 1-3 for the investigated buildings.

### Table 1. Lateral load resistance based on actual pushover curve (x10^3 kN)

| Building Description     | 2-story          | 4-story          | 6-story          |
|--------------------------|------------------|------------------|------------------|
|                          | Masonry Walls    | RC Walls         | Masonry Walls    | RC Walls         | Masonry Walls    | RC Walls         |
| Semi symmetrical         | 4.8              | 6.1              | 27.1^a           | 4.7              | 5.9              | 25.5^b           | 4.6              | 5.6              | 21.7^b           |
| Unsymmetrical            | 4.8              | 0.0^a            | 5.7              | 18.8             | 4.6              | -2.1^a           | 5.6              | 21.7             | 4.2              | -8.7^a           | 4.8              | 14.3             |
| Re-entrant corners       | 4.3              | -10.4            | 42               | -10.6            | 4.1              | -10.9            |                 |                 |
| Soft story               | 4.4              | -6.4             | 3.9              | -15.2            |                 |                 |                 |                 |
| G2 Buildings             |                 |                  |                  |                  |                  |                  |                  |                  |
| Semi symmetrical         | 5.6              | 6.2              | 10.7             | 5.5              | 6.1              | 10.9             | 4.9              | 5.8              | 18.4             |
| Unsymmetrical            | 5.6              | 0.0^a            | 6.2              | 10.7             | 5.4              | -1.8             | 6.0              | 11.1             | 4.8              | -2.0             | 5.8              | 20.8             |
| Re-entrant corners       | 5.3              | -5.4             | 5.0              | -9.1             | 4.7              | -4.1             |                 |                 |
| Soft story               | 4.5              | -18.2            | 4.3              | -12.2            |                 |                 |                 |                 |
| G3 Buildings             |                 |                  |                  |                  |                  |                  |                  |                  |
| Semi symmetrical         | 8.9              | 9.4              | 5.6              | 8.4              | 9.2              | 9.5              | 8.3              | 9.1              | 9.6              |
| Unsymmetrical            | 7.9              | -11.2^a          | 9.0              | 13.9             | 7.8              | -7.1             | 8.9              | 14.1             | 7.8              | -6.0             | 8.6              | 10.3             |
| Re-entrant corners       | 7.9              | -11.2            | 7.8              | -7.1             | 7.5              | -9.6             |                 |                 |
| Soft story               | 6.8              | -19.1            | 6.5              | -21.7            |                 |                 |                 |                 |

^a Numbers in this column represent % increase (+) or decrease (-) in lateral resistance with respect to counterpart building with a symmetrical arrangement of masonry walls about the y-axis; ^b Numbers in this column represent % increase (+) or decrease (-) in lateral resistance with respect to counterpart building with masonry walls.

4.1.2. Effect of building height. In this study, no attempt was made to maintain a constant stiffness-to-mass ratio in similar buildings with different plan areas. Thus, the effect of building’s plan area on its seismic response, if any, could not be examined. However, the effect of building height can be clearly seen in table 1 which reveals a reduction in lateral resistance with the increase in number of stories: Compared to 2-story buildings with a symmetrical arrangement of walls about the y-axis, a maximum reduction of 12.5% in lateral resistance capacity is observed when RC walls are absent. A lower reduction of 6.5% is observed when RC walls are used in the staircase unit. Similar reductions in effective stiffness are noted with the increase in height. Energy dissipation capacity, on the other hand, was found to increase with the increase in building height.

4.1.3. Effect of using unsymmetrical plan layouts. The discussion in subsections 4.1.3 to 4.1.6 is based on analysis results presented in tables 1-3. When masonry walls are used, shifting the location of the staircase unit off the y-axis (figure 1d) reduced the lateral load resistance and stiffness by a maximum
of 11 and 19%, respectively. Slightly higher reductions were noted upon shifting the location of the staircase unit comprising RC walls: maximum reductions of about 14, 27 and 12% were noted in lateral resistance, elastic stiffness and energy dissipation capacity, respectively.

Table 2. Effective elastic stiffness based on idealized pushover curve (kN/mm)

| Building Description | G1 Buildings | | G2 Buildings | | G3 Buildings |
|----------------------|-------------|-----------------|-----------------|-----------------|
| | Masonry Walls | RC Walls | Masonry Walls | RC Walls | Masonry Walls | RC Walls |
| Semi symmetrical | 119 | 146 | 22.7 | 62 | 80 | 29.0 | 42 | 59 | 40.5 |
| Unsymmetrical | 107 | -10.1 | 120 | 12.2 | 54 | -12.9 | 62 | 14.8 | 40 | -4.8 | 43 | 7.5 |
| Re-entrant corners | 113 | -5.0 | 56 | -9.7 | 38 | -9.5 |
| Soft story | | | 61 | -1.6 | 41 | -2.4 |
| Semi symmetrical | 142 | 144 | 1.4 | 80 | 77 | -3.8 | 50 | 52 | 4.0 |
| Unsymmetrical | 133 | -6.3 | 141 | 6.0 | 65 | -18.8 | 71 | 9.2 | 43 | -14.0 | 47 | 9.3 |
| Re-entrant corners | 131 | -7.8 | 71 | -11.3 | 56 | 12.0 |
| Soft story | | | 60 | -25.0 | 43 | -14.0 |
| Semi symmetrical | 248 | 278 | 12.1 | 131 | 125 | -4.6 | 87 | 102 | 17.2 |
| Unsymmetrical | 210 | -15.3 | 255 | 21.4 | 112 | -14.5 | 122 | 8.9 | 79 | -9.2 | 85 | 7.6 |
| Re-entrant corners | 245 | -1.2 | 122 | -6.9 | 84 | -3.5 |
| Soft story | | | 115 | -12.2 | 75 | -13.8 |

Refer to table 1 for the footnotes.

Table 3. Energy dissipation capacity based on idealized pushover curve (kN.m)

| Building Description | G1 Buildings | | G2 Buildings | | G3 Buildings |
|----------------------|-------------|-----------------|-----------------|-----------------|
| | Masonry Walls | RC Walls | Masonry Walls | RC Walls | Masonry Walls | RC Walls |
| Semi symmetrical | 970 | 1324 | 36.5 | 1801 | 2639 | 46.5 | 2309 | 3689 | 59.8 |
| Unsymmetrical | 1021 | 5.3 | 1255 | 22.9 | 1677 | -6.9 | 2588 | 54.3 | 1686 | -27.0 | 3273 | 94.1 |
| Re-entrant corners | 692 | -28.6 | 1401 | -22.2 | 1846 | -20.1 |
| Soft story | | | 2019 | 12.1 | 2638 | 14.3 |
| Semi symmetrical | 978 | 1688 | 72.6 | 1992 | 2676 | 34.3 | 2548 | 3866 | 51.7 |
| Unsymmetrical | 1189 | 21.6 | 1683 | 41.5 | 1747 | -12.3 | 2702 | 54.7 | 2507 | -1.6 | 3901 | 55.6 |
| Re-entrant corners | 976 | -0.2 | 1856 | -6.8 | 2543 | -0.2 |
| Soft story | | | 1946 | -2.3 | 2880 | 13.0 |
| Semi symmetrical | 1553 | 1688 | 8.7 | 2844 | 3781 | 33.0 | 3033 | 5660 | 86.6 |
| Unsymmetrical | 1415 | -8.9 | 1683 | 18.9 | 2112 | -25.7 | 3320 | 57.2 | 3408 | 12.4 | 5561 | 63.2 |
| Re-entrant corners | 1285 | -17.3 | 1984 | -30.2 | 2616 | -13.8 |
| Soft story | | | 1992 | -30.0 | 2778 | -8.4 |

Refer to table 1 for the footnotes.

4.1.4. Effect of re-entrant corners. The presence of re-entrant corners had a pronounced negative effect on the seismic response of the investigated buildings. Re-entrant corners reduced lateral resistance
capacity by 4-11% and energy dissipation by a maximum of 30%. In general, this type of plan irregularity had a negative impact on elastic stiffness with a maximum reduction of 11%.

4.1.5. Effect of soft story. While reducing the stiffness by 2-25%, presence of the soft story at ground floor level reduced the lateral load resistance by 6-22%. The ground floor soft story had an inconclusive, yet significant, effect on energy dissipation varying between -30 to +14%.

4.1.6. Effect of RC walls. Using RC rather than masonry walls in the staircase unit improved lateral resistance by 6-27% where the building plan is semi-symmetrical and by 11-22% in case of unsymmetrical plan layouts. In general, the use of RC walls increased the effective elastic stiffness: A maximum increase of 41 and 21% was observed in case of semi-symmetrical and unsymmetrical plan layouts, respectively. Moreover, using RC walls significantly enhanced the energy dissipation capacity compared to the case where masonry walls are used: a maximum increase of 94% was noted.

4.1.7. Effect of using an elevator shaft. Compared to the 6-story building with RC walls in the staircase unit, adding an elevator shaft enhanced lateral resistance by 9-43% and energy dissipation by 7-48%. Inconsistent variations in stiffness ranging from -12 to +33% were noted.

4.1.8. Effect of lateral load pattern. Compared to the case where pushover analysis was performed using the inverted triangular lateral load pattern, using the SRSS pattern was found to have a minor influence on lateral load resistance: observed variations in base shear capacity did not exceed 5%. The SRSS pattern had a more pronounced, yet inconsistent, effect on the stiffness (-21 to +32%) and energy dissipation capacity (-17 and +36%) of the buildings under consideration.

4.2. Lateral displacements and hinging patterns
At displacement levels corresponding to global yielding, as identified on the idealized V-Δ curves, the investigated buildings experienced maximum inter-story drift ratios below 1.5%. Maximum inter-story drift ratios of about 4-5% were noted at ultimate displacement levels where the ultimate point corresponds to the displacement at which a 20% decrease in lateral load resistance capacity occurs. Data on plastic hinge formation, including hinge locations and damage state of hinges, at global yielding and ultimate displacement levels indicated that unfavorable design concepts (strong beams and weak columns) have been implemented in the 2- and 4-story buildings. However, hinge formation in 6-story buildings started at beam ends in lower floors and propagated to upper floors which preceded yielding of the base columns that have larger section capacities compared to the 2- and 4-story buildings thereby satisfying, though unintentionally, the strong column-weak beam concept. Using RC walls rather than masonry walls in the staircase unit was found to increase the number of hinges with yielding damage state in the beams and decrease the number of similar hinges in columns regardless of the location of the staircase unit. This confirms that using RC walls has reduced the seismic demand on columns and thereby reduced the expected damage levels in these columns.

5. Conclusions
The following points highlight the main observations based on the results of pushover analyses:

- In each of the three area groups, similar buildings exhibited lower lateral resistance and stiffness as the height of the building increased. However, energy dissipation and absolute drift values of the investigated buildings increased as the building height increased. Observed reductions in lateral resistance due to the increase in number of stories from 4 to 6 were more pronounced in buildings comprising a soft story as compared to regular buildings.
- Existence of horizontal irregularities in the investigated buildings, associated with the presence of re-entrant corners, reduced the stiffness (k_e) by a maximum of 11%, energy dissipation by a maximum of 30% and lateral resisting capacity by 4-11% compared with the
counterpart regular buildings. A similar negative effect of re-entrant corners on the base shear capacity of local RC frames infilled with stone-concrete walls was reported by Al-Nimry et al. [26]: Reductions of 5% and 10% were observed in low and medium rise buildings, respectively. Comparable results regarding the general influence of horizontal irregularities, including setbacks and re-entrant corners, on the seismic response of buildings were reported by a number of researchers [27-30]. Existence of vertical irregularities, associated with the presence of a soft story at ground floor level, reduced the effective elastic stiffness by 2-25% and lateral resistance capacity by 6-22% compared with the counterpart regular buildings. Again, similar results were reported by Al-Nimry et al. [26] wherein the presence of a ground floor soft story in local RC frames infilled with stone-concrete walls reduced the base shear capacity by 25 and 15% for low and medium rise buildings, respectively. Based on engineering judgment, Gulkan and Yakut [27] estimated the influence of a soft story by 13.5%. Sucuoglu and Yazgan [28] arrived at similar values based on field observations of actual earthquake damage. Al-Ali and Krawinkler [29] showed that the seismic demand (base shear) for a building comprising a soft story is 7% higher than the corresponding base shear value for the regular building. Magliulo et al. [31] concluded that the presence of a ground floor soft story could magnify the building response up to 20% compared with similar regular buildings.

- Analysis results confirmed that using 2 RC walls, rather than masonry walls, in the staircase unit have a significant positive effect on the lateral resistance capacity (6-27%), energy dissipation capacity and elastic stiffness. Except for energy dissipation, enhancements in lateral response were more pronounced as the building height increased. The use of RC walls reduced the demand and hence expected damage levels in the columns. The majority of the investigated buildings exhibited inter-story drift ratio of about 4-5% at ultimate strength indicating that severe structural damage may take place in these buildings when subjected to strong ground motions.

- Compared with the inverted triangular lateral load pattern, using the SRSS lateral load pattern for irregular buildings resulted in significant variations in stiffness and energy dissipation amounting to 32 and 36%, respectively whilst having a marginal impact (1-5%) on base shear capacity.

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