Seismic assessment of RC building designed by local practice

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Abstract. Current research works and observations have shown that the parts of the Kingdom of Saudi Arabia are considered as low to moderate seismic zone. However, most of the residential buildings were designed for gravity loading only and lack of detailed to resist the seismic load. This research focused on the seismic evaluation of an existing typical residential building that was assumed to be located in different regions (Makkah, Jeddah, Gizan and Haql). This was accomplished by conducting a pushover analysis to simulate the nonlinear behaviour of the building. The analysis results in the failure mechanism of the building so that the weak elements can be monitored. These results help engineers to take any action for rehabilitation and strengthening work.

Keywords: seismic assessment, concrete building, pushover, local practice

1. Introduction

According to The U.S. Global Survey (USGS) data, seismic activities have been detected recently in Tabuk (2009) and Giza (2013). These indicated that part of the Kingdom of Saudi Arabia could be considered as low to moderate seismic zone. The seismic may destroy the building structures, and the risk can be very high regarding occupant safety and property damage.

It is well known that a seismic load should be considered as an important aspect of the building design, especially in the seismic prone region. Generally, the buildings can resist the low level of seismic without significant damages. The buildings can have major damage under the high level of seismic, however, no collapse occurs. The majority of building codes[1] are based on these criteria. Saudi Building Code (SBC 301)[2], has been developed and release for immediate implementation.

However, it is believed that the majority of building in Saudi Arabia was designed by local practice, although they were built in the seismically active regions. In the local practice design, the building is designed mainly for gravity load and lack of lateral load resistance. The previous guideline did not put any restraint on the design standards so that different designer may select different design methods.

This study presents a numerical model to simulate the behaviour of the building under earthquake. The aim of this study is to assess the performance of a generic building designed by local practice in the four different levels of seismic zones (Makkah, Jeddah, Gizan and Haql). This investigation is to evaluate the safety of the building against possible earthquake.
2. Pushover analysis

The structural engineering professions have adopted the nonlinear static procedure called pushover analysis to predict seismic demands for a building [3–6]. Recently, it becomes a common technique, which provides acceptable results. This analysis explicitly applies a static analysis to represent a dynamic phenomenon during an earthquake.

In pushover analysis, a specific lateral load is subjected to the building. The load magnitude increases incrementally until the building collapse or reaches target displacement. The target displacement represents the top displacement of the structure under an earthquake. This analysis produces capacity curve or pushover curve, which is the relationship between base shear and roof displacement. Figure 1 illustrates the pushover analysis and pushover curve.

![Figure 1: Pushover analysis illustration and pushover curve](image)

Pushover analysis is based on the assumption that the behaviour of the structure can be related to the behaviour of an equivalent single-degree-of-freedom (SDOF) system. The structure behaviour is controlled by single-mode, and the shape of this mode remains constant throughout the time history response. These approaches are theoretically incorrect, but previous studies [5,9,10] showed that they lead to good predictions of the maximum seismic response of multi-degree-of-freedom (MDOF) structure.

The target displacement can be determined using the capacity spectrum method according to ATC-40 (ATC 40) [8]. In the capacity spectrum method, pushover curve and demand spectrum are initially converted into ADRS (Acceleration Displacement Response Spectrum) format. The target displacement can be defined as the intersection between pushover curve and demand spectrum in the ADRS format, as shown in Figure 2. This method is already built-in SAP2000 software package [11]. Thus, the target displacement can be obtained directly after the pushover analysis is performed.

![Figure 2: Capacity spectrum method](image)
Once target displacement is determined, the seismic performance of the building can be evaluated according to the limits in ATC-40[8]. There are two categories, global performance and local performance. The global performance is tied to the inter-storey ratio (IDR). The performance levels are Immediate Occupancy (IO), Life Safety (LS) and Collapse Prevention (CP). Table 1 shows the limits for each performance level. These limits represent minor to major damage, as shown in Table 2. On the other hand, the local performance can be determined based on plastic hinge rotation capacities in the structural elements, such as beams and columns. Table 9-6 and Table 9-7 in ATC-40 [8] provide the deformation limits in terms of plastic hinge rotations of beams and columns.

### Table 1: Deformation limits for each performance levels (ATC-40)

| Level                          | Intermediate Occupancy (IO) | Life Safety (LS) | Collapse Prevention (CP) |
|-------------------------------|-----------------------------|------------------|--------------------------|
|                               | 0.7%                        | 0.7% - 2.5%      | 2.5% - 5%                |

### Table 2: Performance level of the building

| Level                          | Description                                                                 |
|-------------------------------|-----------------------------------------------------------------------------|
| Operational (O)               | Very little damage, temporary drift, the structure retains original strength and stiffness, all systems are normal. |
| Immediate Occupancy (IO)      | Little damage, temporary drift, the structure retains original strength and stiffness, the elevator can be restarted, Fire protection still works. |
| Life Safety (LS)              | Fair damage, some permanent drift, some residual strength and stiffness left, damage to partition, the building may be beyond economical repair. |
| Collapse Prevention (CP)      | Severe damage, large displacement, little residual stiffness and strength but loading bearing column and wall function, the building is close to collapse. |

### 3. Generic building

A six-storey reinforced concrete (RC) building is analysed in this study. Figure 3 shows the structural plan. The RC design section details are provided in Table 3 and Table 4. The slabs consist of solid slab and joist slab. As the building is design for gravity load only, the rebar extension in the end span is less than the requirement. Thus, it is assumed that the beam cannot resist positive moment at both ends of the beam.

![Figure 3: The selected building layout](image)
**Figure 4: Typical rebar layout in continuous beams**

**Table 3 Beam Schedule**

| TYPE | W (mm) | H (Mm) | BOTTOM BAR | TOP BAR | STIRRUP |
|------|--------|--------|------------|---------|---------|
|      |        |        | Straight   | Bent    | Straight |
| B1   | 1000   | 270    | 8 ϕ16      | 6 ϕ16   | 6 ϕ16   |
| B2   | 800    | 270    | 6 ϕ16      | 4 ϕ16   | 6 ϕ14   |
| B2'  | 1200   | 270    | 14 ϕ16     | 4 ϕ16   | 14 ϕ16  |
| B3   | 800    | 270    | 6 ϕ16      | 2 ϕ16   | 6 ϕ16   |
| B4   | 600    | 270    | 6 ϕ16      |         | 4 ϕ16   |
| B5   | 400    | 270    | 3 ϕ14      |         | 3 ϕ14   |
| B6   | 300    | 270    | 3 ϕ14      |         | 3 ϕ14   |

**Table 4 Column Schedule**

| Dimension (mm) | Rebar | Dimension (mm) | Rebar | Dimension (mm) | Reinforcement |
|----------------|-------|----------------|-------|----------------|---------------|
| c1 c2 n dia   |       | c1 c2 n dia   |       | c1 c2 n dia   |               |
| **Ground Floor** |       | **First Floor** |       | **Second Floor** |               |
| C1 300 1000 16 16 | 200 1000 16 16 | 200 800 12 16 |
| C2 300 800 14 16 | 200 800 12 16 | 200 700 12 16 |
| C3 300 700 12 16 | 200 700 12 16 | 200 600 10 16 |
| C4 300 600 10 16 | 200 600 10 16 | 200 600 8 16 |
| C5 400 12 16     |          |               |       |               |               |
| C6 200 800 12 16 | 200 600 10 16 | 200 600 8 16 |
| C7 450 750 6 16  |          |               |       |               |               |
| C8 200 750 14 16 | 200 750 14 16 | 200 750 12 16 |

| **Third Floor** | **Fourth Floor** | **Fifth Floor** |
|-----------------|------------------|-----------------|
| C1 200 600 10 16 | 200 600 8 16    | 200 500 6 16   |
| C2 200 600 10 16 | 200 600 8 16    | 200 500 6 16   |
| C3 200 600 8 16  | 200 600 8 16    | 200 500 8 16   |
| C4 200 600 8 16  | 200 600 8 16    | 200 500 8 16   |
| C5               |                  |                 |
| C6 200 600 8 16  | 200 600 8 16    | 200 500 8 16   |
| C7               |                  |                 |
| C8 200 700 12 16 | 200 600 10 16   | 200 600 8 16   |
4. Numerical model

The structural model has been developed in the SAP 2000 program[11]. Frame elements are adopted to model the beams and columns. The concrete slabs are modelled using shell element with mesh area. The rigid diaphragm is assigned to simulate the actual behaviour of the building frames. Figure 5 shows the 3D structural model.

![Isometric view of the model in SAP2000](image)

**Figure 5: Isometric view of the model in SAP2000**

To perform pushover analysis, nonlinear frame hinge is assigned to both ends of the beams and columns. The FEMA 356[12] provision has been adopted to define the hinge rotation. This allows monitoring progressive yielding of the structural components. The pushover analysis is carried out using a displacement control strategy. At this stage, the building is subjected to the lateral load pattern until the roof displacement reaches a target value. The minimum and maximum number of states are set as 10 and 100, respectively. Pushover analysis is performed for the building located at four different regions in KSA (Makkah, Jeddah, Gizan, and Haql). To define the demand spectrum, SBC 301 was adopted, as shown in Figure 6.

![Response spectrum for each region](image)

**Figure 6: Response spectrum for each region**
5. Results and discussion

Figure 7 shows the capacity curves in X and Y direction obtained from pushover analysis. These curves indicate the global performance of the building against the lateral load. It can be seen that initially, the pushover curves increase linearly as the building is still within the elastic zone. Then, the slope of the pushover curves gradually decreases when the lateral load increases. This is expected because the structural elements start yielding, and the structure loses its stiffness.

![Figure 7: capacity curves obtained from pushover analysis](image)

As discussed in Section 2, the target displacement can be defined by superimposing demand spectrum on a capacity curve into spectral coordinate or ADRS format for the capacity spectrum method. Figure 8 shows the capacity spectrum method for all regions obtained from SAP2000 program.

![Figure 8: Performance point by capacity spectrum method](image)
Figure 9 shows plastic hinge formation for the building at the performance level. For the building designed for seismic, the majority of the structural elements are still within elastic limits (no plastic development). Several plastic hinges develop both in the beams and column. On the other hand, for the building designed for gravity load, many plastic hinges occurred mainly in the column with Collapse Prevention (CP) level.

![Makkah](image1)
![Jeddah](image2)
![Gizan](image3)
![Haql](image4)

**Figure 9: Plastic hinge formation at performance level in Frame 2**

6. Conclusions

Based on this study, the following conclusions can be made for the structural configuration investigated:

1. Pushover analysis is a relatively simple method to evaluate the nonlinear behaviour of the building in an earthquake. Pushover analysis considers both material and geometrical nonlinearity.
2. Pushover analysis is an approximate approach based on static loading and does not need time history records. It may not accurately represent a dynamic response, particularly for a complex structure.
3. The performance level of the structure depends on the target displacement, which is the intersection of demand and capacity curves and the hinges developed in the beams and the columns.
4. Pushover analysis may help engineers to take action for rehabilitation work because pushover analysis can expose the weak elements.
5. Based on this study, the building is relatively safe for all regions. However, some hinges have developed and exceeded the limitation criteria in Haql region. It shows that the structure suffers some damages, and potential local failure can occur.

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