

# SEISMIC SAFETY EVALUATION OF REINFORCED CONCRETE TUNNEL FORM RESIDENTIAL BUILDINGS IN TURKMENISTAN

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## ABSTRACT

Turkmenistan is vulnerable to earthquakes. Over the last thirty years, the country has witnessed a rise in construction, particularly with multi-story RC tunnel-form buildings. To evaluate the potential risk of seismic damage from a significant earthquake, which is likely to happen in the future, we have decided to assess the safety of a typical RC tunnel-form building.

The study evaluated the seismic performance of reinforced concrete (RC) tunnel-form buildings with marble panels in Turkmenistan. These buildings are generally designed using the equivalent elastic method with linear analysis. Although this performance verification method is standard worldwide, it only indirectly evaluates safety in major earthquakes by reducing the design seismic force by the response modification factor (R factor), making it difficult to ascertain the ultimate performance. Therefore, we survey the ultimate seismic performance of the target building in this study using the first screening method of JBDPA and the capacity spectrum method using the Pushover analysis. The results of the first screening were less than the standard value of 0.8, and the seismic resistance was judged insufficient. The same result was also obtained by the capacity spectrum method. The risk of falling of the marble exterior was judged to be not so great because of the use of a joint method with excellent deformation-following properties.

The findings suggested that the case did not have sufficient seismic resistance to a major earthquake. The study recommended increasing the R factor and wall shear strength, as well as leveraging advanced non-linear analysis tools for better prediction of seismic behavior. While the analysis was based on a single case, it underscores the need for broader research on Turkmenistan's RC buildings, highlighting significant potential for enhancing seismic performance through strategic design adjustments.

**Keywords:** seismic performance, RC tunnel-form building, JBDPA.

## 1. INTRODUCTION

Turkmenistan is vulnerable to earthquakes. Economic growth and territorial dynamics mean that seismic events can have nationwide, even global, repercussions. Earthquakes pose a serious risk, capable of overturning years of progress. Over the past three decades, Turkmenistan has seen a construction boom, particularly with multi-story reinforced concrete (RC) tunnel-form buildings covered with white marble panels. A devastating earthquake poses a significant threat to the country's progress, potentially undoing decades of development. To grasp the risk of seismic damage from a major



Figure 1. RC tunnel-form buildings in Ashgabat

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earthquake, which is almost certain to occur in the future, we decided to take a representative example of such an RC tunnel-form structure and discuss its safety.

This study was executed with the following key objectives in mind:

- Investigating and analyzing the performance and behavior of both structural and non-structural elements.
- Predicting the seismic responses of the structural elements of the target building.
- Assessing the seismic safety of the non-structural marble panel elements of the target building

The research Motivation for this study was:

- The target buildings are generally designed using the equivalent elastic method with linear analysis.
- Although this performance verification method is standard worldwide, it only indirectly evaluates safety in major earthquakes by reducing the design seismic force by the R-factor, making it difficult to ascertain the ultimate performance.
- Therefore, we survey the ultimate seismic performance of the target buildings using the first screening method of JBDPA and the capacity spectrum method.

## 2. TARGET BUILDING AND METHODOLOGY

### 2.1. Target building

This study investigates the seismic performance of a 12-story reinforced concrete tunnel-form residential building in Ashgabat, Turkmenistan. The main characteristics of the target building are:

- The structure comprises thinner shear walls, deep beams, and slabs. There is no column.
- The flat walls are expected to bear seismic forces while supporting vertical forces.
- All walls and beams have the same thickness, 30 cm.
- This structure differs from an RC frame with strong columns and weak beams.
- The building is covered with marble panels.
- In addition, masonry non-structural walls are used for exterior and room partitions
- Length and cross-sectional area  $A_w$  of the walls:
  - x-direction 29.95m, 8.985 m<sup>2</sup>
  - y-direction 51.75m, 15.525m<sup>2</sup>
- Each floor area 578m<sup>2</sup> and weight 6936kN.
- Total weight: 83232kN.

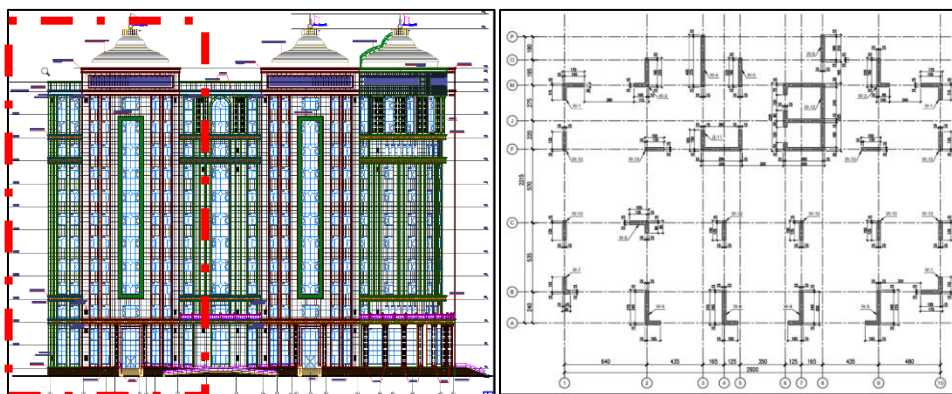


Figure 2. (a) Elevation of building and (b) wall arrangement for all floors

The design spectrum is referred to as illustrated in Figure 3. In our case, the target building is situated in an area with a soil type of III and a PGA of 0.4g. By multiplying the response factor 2.5 to the PGA value of 0.4g, we obtain the design spectral acceleration of 9.8m/s<sup>2</sup>. Using the R factor - 0.3, we reduce the demand spectrum and get the design spectral acceleration value of 2.94 m/s<sup>2</sup>.

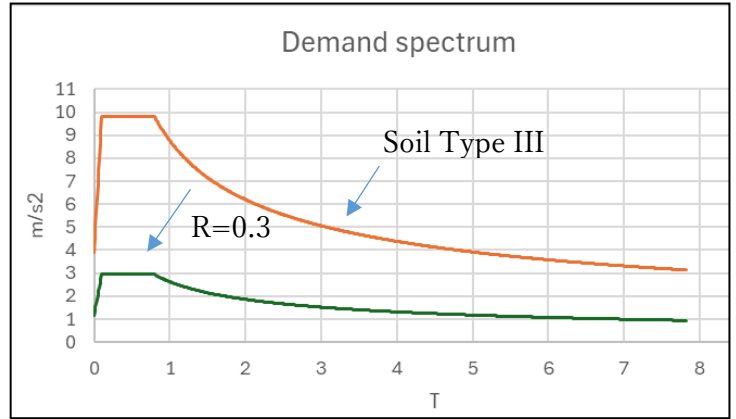


Figure 3. Design spectrum according to Soil type III

## 2.2. Methodology

We employed methodologies as shown in the following:

- First screening method: Based on the JBDPA standard [2001] to provide an initial assessment of seismic capacity.
- Capacity spectrum method: To evaluate the building's seismic performance through pushover analysis.
- Flange wall analysis: To investigate the influence of flange walls on the building's behavior.
- Non-structural element evaluation: To assess the risk of falling of marble cladding.

### 2.2.1. Eccentricity ratio

The eccentric ratio of the story concerned in the directions x and y can be defined using the following formulas according to the seismic code in Japan:

$$R_{ex} = \frac{e_y}{r_{ex}}, \quad R_{ey} = \frac{e_x}{r_{ey}}, \quad (1a,b)$$

Where,

$e_y$  and  $e_x$  : distances between the center of gravity and the center of rigidity in x and y directions.

$r_{ex}$  and  $r_{ey}$  radius of elasticity in x and y directions.

### 2.2.2. First screening method by JBDPA

According to JBDPA, the seismic demand index,  $I_{SO}$ , is a standard level for the seismic index, establishing the minimum safety level a building must meet to withstand potential earthquake risks at its location. If the seismic capacity of a structure, which is measured by the seismic index,  $I_S$ , exceeds the seismic demand, the structure is considered safe. The index,  $I_S$ , is calculated by multiplying the building's strength, ductility, irregularity, and time indices as follows:

$$I_S = E_0 * S_D * T \quad (2)$$

The value of  $I_{SO}$  expressed by the following equation:

$$I_{SO} = E_S * Z * G * U \quad (3)$$

Where  $E_S$  equal to 0.8 for the first-screening method.

$E_0$  in equation (2) can be defined using the following formula:

$$E_0 = \frac{n + 1}{n + i} C_w * F_w \quad (4)$$

Where,  $n$ : the number of stories,  $i$ : story number concerned,  $C_w$ : strength index of walls ( $\tau_w A_w / \sum W \cdot \beta_c, \beta_c = \sqrt{F_c / 20}$  for the first screening),  $F_w$ : ductility factor (1.0 for the first screening.) The first screening provides a rapid assessment of the seismic resilience of RC structures, focusing on the cross-sectional areas of vertical members while disregarding their reinforcement details. For the target structure in this study, we can calculate  $E_0$  only using the cross-sectional area,  $A_w$ , and standard shear strength,  $\tau_w$  (1.0 N/mm<sup>2</sup>) of walls, compressive strength of concrete,  $F_c$  (32.7 MPa), and buildings weight,  $W$ .

### 2.2.3. Capacity Spectrum Method

The analysis begins with calculating the demand spectrum based on spectral displacement (Sd) from the spectral acceleration (Sa) for chosen conditions. The capacity spectrum is then derived from pushover analysis, outlining yield displacement and damage levels. The performance point where demand and capacity spectrums intersect indicates the structure's seismic response capability.

This methodology incorporates deriving the demand spectrum from the Design spectrum defined in the Turkmenistan Design code, utilizing an R-factor, and assumes a 5% damping constant to define the corresponding demand spectrum.

In this study, walls are classified into two categories based on the direction of the applied force. The walls placed parallel to the direction of force

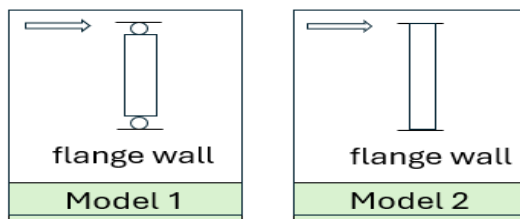


Figure 5. (a) and (b) representing Model 1 and Model 2 of Flange walls

are defined as web walls, and the walls placed orthogonally to the direction of force

are defined as flange walls as shown in Figure 5. In the general design of buildings with walls, the horizontal resisting force of flange walls is often ignored. The first screening also omits the effects of flange walls. Model 1, shown in the Figure 5, ignores the horizontal resistance

of flange walls. This model has pins at the top and bottom edges. In this study, Model 1 is first used for the analysis. Next, a supplemental analysis using Model 2 is performed to see the effect of the flange wall.

Each wall element has shear and bending springs. Figure 6 shows the force-displacement relation of them.

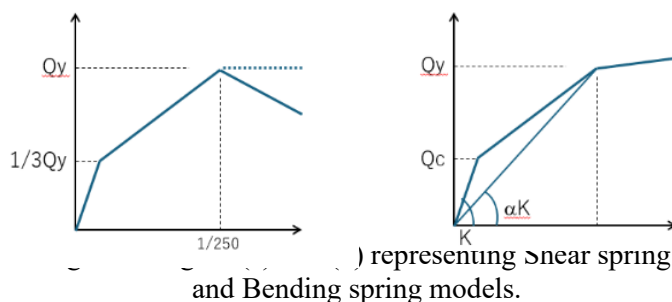


Figure 6. (a) and (b) representing Shear spring and Bending spring models.

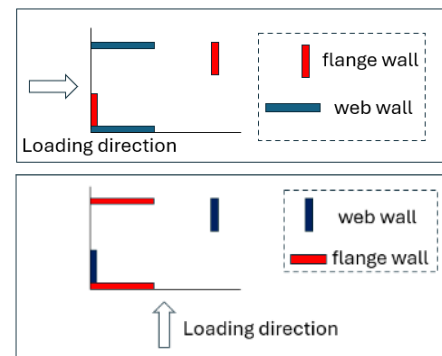


Figure 4. Figure (a) and (b) representing Loading directions,

For web walls, bending properties are evaluated as a wall element. Those are  $w\mu_u$ ,  $w\mu_c$  and  $w(\alpha)$ . For flange walls, bending properties are evaluated as a column element. Those are  $c\mu_u$ ,  $c\mu_c$  and  $c(\alpha)$ . The Japanese technical guideline is used to calculate these values. [Commentary on Standards Related to Building Structure, 2020.].

### 3. RESULTS AND DISCUSSION

#### 3.1. Eccentricity of the building.

According to the results of the eigenvalue analysis, the natural modes of the structure were accompanied by a torsional component due to the unevenly distributed core walls. However, the calculation of eccentricity ratio resulted in less than 0.15. Therefore, the influence of torsion was considered small, and it was decided to ignore the influence of eccentricity in this study.

#### 3.2. First Screening Method Results

Figure 7 shows the results from the first screening method. The findings indicate that the building's seismic capacity is inadequate from the first to the twelfth stories in the x direction and from the first to the eleventh stories in the y direction. This underscores the critical importance of rigorously evaluating the structural strength and safety of buildings in earthquake-prone regions. Given the unexpectedly low seismic capacity revealed by the first screening method, it was deemed necessary to conduct a more detailed evaluation using the capacity spectrum method and pushover analysis.

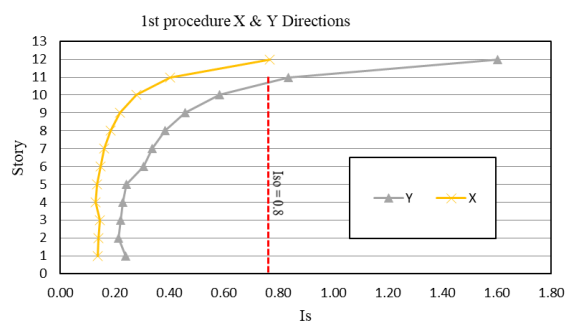


Figure 7. First Screening Evaluation according to JBDPA (x, y dir.)

#### 3.3. Capacity spectrum method results

##### 3.3.1. Seismic response prediction

Outputs of pushover analysis in x direction shows that base shear coefficient  $Q_{su}$  is about 0.11 which confirms the results of the first screen method. Also, this figure shows the predicted value for each floor. From the second figure we can obviously see that inter-story drift ratios until 7th floor does not satisfy the requirements of limit drift angle for shear failure mode which is equal to 1/250.

Outputs of pushover analysis in the y direction show that the base shear coefficient  $Q_{su}$  is about 0.21, which also confirms the results of the first screen method. This figure also shows the prediction value for each floor. From the second figure, we can see that the drift ratio for all floors is satisfies the requirements of the limit drift angle for shear failure mode, which is equal to 1/250.

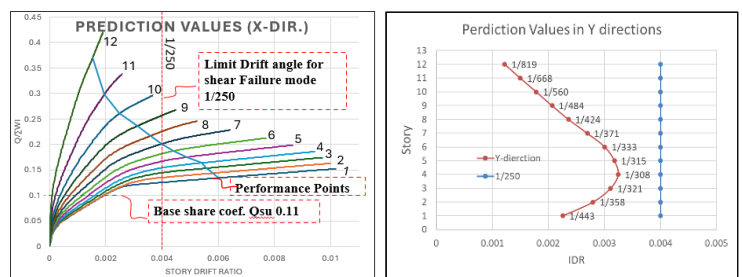


Figure 8. Prediction values in y-direction

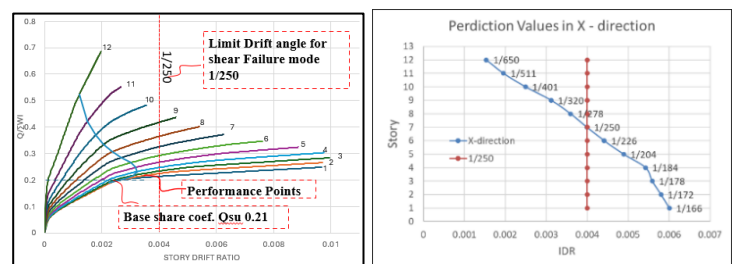


Figure 9. Prediction values in x-direction

### 3.3.2. Flange effect in x direction.

The flange effect was examined in the x direction considering the cracking and yielding of flange walls.

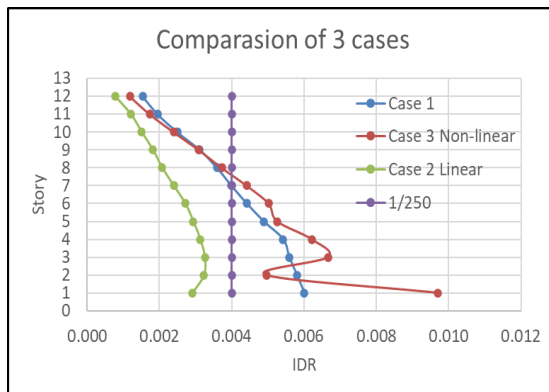


Figure 10. Comparison of 3 cases

Analysis cases:

Case 1: Analysis using Model 1 (neglecting bending stiffness and strength of flange walls).

Case 2: Analysis using Model 2 (assuming flange walls retain elasticity).

Case 3: Analysis using Model 2 (considering bending crack and yield of flange walls).

If the flange wall retains its elasticity, it has a constraining effect on deformation, as shown by the results of Case 2. However, Case 3, which considers cracking and yielding of the flange wall, shows that the flange wall is not so effective in restraining deformation. Therefore, the results of the first screening, which ignores the flange walls, are considered reasonable as Case 1 shows.

### 3.4. Risk of falling of exterior panels

We surveyed the joint method for attaching the exterior panel to the structural frame, comparing the recommended one in Japan. The results showed the panels can follow an inter-story drift ratio of approximately 1/17. This deformation-following performance indicates that the risk of the exterior panel falling may be extremely small.

## 4. CONCLUSIONS

The conclusion of this study were summarized as follows:

- The results of the first screen on the example case discussed in this study indicated that this case does not have sufficient seismic resistance to a major earthquake.
- The capacity spectrum method results also corresponded to the above results.
- Suggestions for improving safety include the following:
  - Increase the  $R$ -factor of wall-based structures such as this case. [cf. In Japanese Seismic code RC ductile frame system:  $R=0.3$ ; for RC wall system  $R=0.55$ ].
  - Increase the wall volume and the shear strength of the walls.
  - Widespread use of practical analysis tools that can perform non-linear analysis.
- The study also scrutinized the behavior of marble exterior panels during seismic events, noting that displacement through bolts and joints could lead to rocking of exterior panels. And we can avoid the falling of exterior panels allowing their rocking behavior.
- The results of this study are based on the analysis of a single case, and further research is needed to grasp the current state of seismic performance of buildings as a whole in Turkmenistan.

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