

BASE ISOLATION RETROFIT CHALLENGES IN A HISTORICAL MONUMENTAL BUILDING IN ROMANIA

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SUMMARY

The Iasi City Hall in Romania, constructed in the 1810's is considered a cultural heritage building. The building framing is comprised of unreinforced masonry (URM) bearing wall system with stone masonry foundations. It was damaged during the 1977 Bucharest earthquake, although the building did not experience large accelerations. If a larger earthquake—with intensity compatible with the current design spectrum specified by the Romanian seismic code—occurs at this site, the result will be extensive damage for the building. Seismic isolation provides the optimum retrofit solution because: a) the reduced seismic demand would protect vulnerable structural and nonstructural components, and b) the selected retrofit would eliminate the need for alterations above grade and preserve the historical features of the building. Analysis showed that the retrofit was effective and the existing members would be able to resist the reduced seismic forces without the need for upgrade.

Keywords: seismic retrofit, historic building, base isolation, performance engineering, condition assessment

1 INTRODUCTION

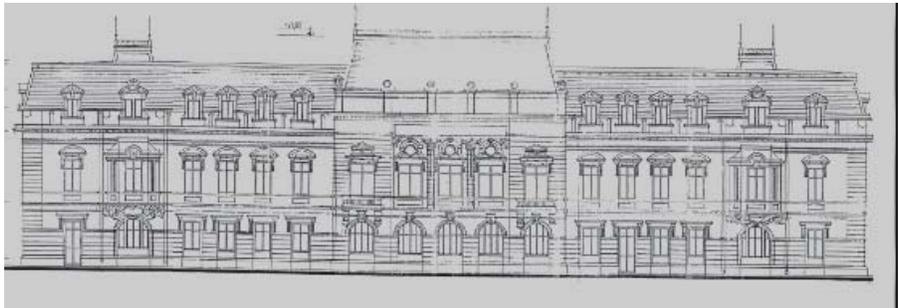
1.1 Building description

Iasi City Hall, formerly known as Roznovanu Palace, is located in the second-most populous city in Romania (see Figure 1). It was originally constructed in the 1810's in neo-classical Viennese style, and its facade was decorated with marble statues of mythological characters such as Diana and Apollo. It was modified in the 1860's and turned into the city hall in 1891. In 1893-94, a second story was added to the structure. It is considered a cultural heritage building and was the Romanian Royal Family residence for a short period during the 1800's. During WWI, the building hosted the headquarters of ministries. A fire in 1958 destroyed most of the second floor, which was restored afterwards, in part, by replacing the original wood floors with new reinforced concrete floors. In 1969, the city administration moved back into the building again.

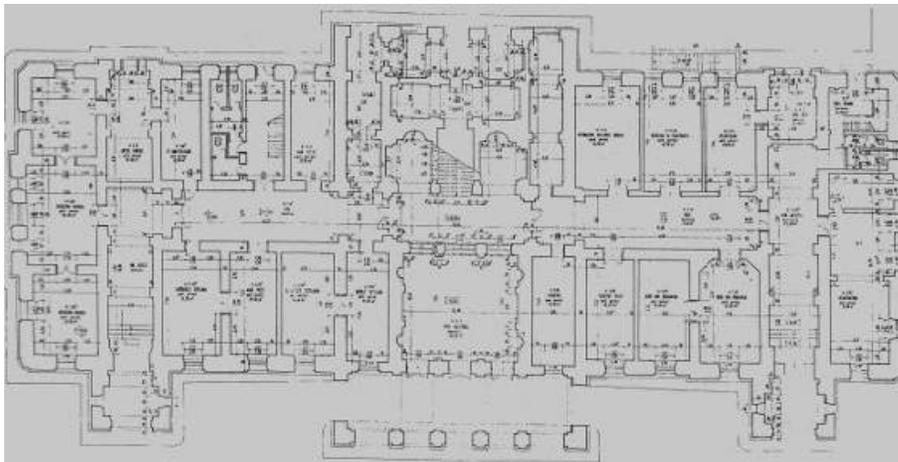
The building framing is comprised of unreinforced masonry (URM) bearing walls with stone masonry foundations. It has a partial basement, ground floor, second floor, and attic level. The building is nearly rectangular, and has a total floor area of approximately 4400 m². The building is approximately 15 m tall. The interior URM wall thickness is 400 to 600 mm, whereas the exterior URM walls are 100 to 170 mm thick. The floor diaphragms, originally wood-framed, currently consist of reinforced concrete slabs spanning between URM walls. The structure has a number of unreinforced masonry chimneys. Figure 2 presents an elevation and plan view of the building.



Figure 1. Iasi City Hall (2010)



Front elevation



Plan view

Figure 2. Architectural drawings of the building

1.2 Earthquake performance

The building was damaged during the 1977 Bucharest earthquake. There were large diagonal cracks in the URM walls, damage to portions of wood diaphragms and cracking of the chimneys. The URM walls were repaired by grout injection, reinforced concrete slabs replaced the wood floors, and the chimneys were anchored with steel ties.

Since this building is a low-rise structure that uses stiff URM walls, it is expected that its fundamental period is much smaller than the transition period and, as such, it would experience the largest spectral acceleration during seismic events. Condition assessment and seismic evaluation (Miyamoto and Gilani, 2007) indicated that this building would experience damage during major seismic events. Hence, in order to preserve this historic building, it must be seismically retrofitted.

2 SEISMIC RETROFIT METHODOLOGY FOR THE IASI CITY HALL BUILDING

2.1 Overview

For historical or essential facilities, base isolation provides an attractive retrofit option. Using this option, alterations of the superstructure is significantly reduced or eliminated. Instead, the structure is de-coupled at the foundation level, since isolators are installed beneath the existing columns or walls. In the past two decades, many buildings in the United States, New Zealand, Japan, and Europe have used this technique. The seismic retrofit of the Bucharest City Hall currently underway also uses this technique.

There are two basic isolation systems: one uses elastomeric rubber (either high-damping rubber or lead-core), and the other uses metallic sliding surfaces (flat or pendulum sliders) to resist and dissipate seismic forces. Base isolation relies on the concepts of structural dynamics to modify the response of the building and reduce the seismic demands on the structure. For isolated structures, the structural period is shifted away from the high-energy portion of the seismic spectrum and predominant frequencies of typical ground motions. In addition, since the isolators are considerably softer than the structure they support, the deformation of the first dynamic mode (and the large participating inertial mass) is concentrated at the isolated level; thus the response above isolators is essentially that of rigid body motion. The isolation system also introduces additional damping to the structures.

2.2 Design objectives and performance goals

The design objective for seismic strengthening of Iasi City Hall is to provide a level of performance during the design seismic event consistent with Romanian building code P100 (2003) requirements and other international standards for essential facilities. To achieve this objective, the following limits were selected: a) story drift ratios of isolated structure to approximately 0.5%, floor accelerations to approximately 0.15g, base shear of isolation to approximately 0.18g, and d) lateral displacement to approximately 450 mm.

It is noted that P100 served as the principal document used for retrofit evaluation. However, provisions of ASCE/SEI 41 (2006) were also checked for compliance. To achieve the design objectives and parameters, it is proposed to seismically isolate the building. This retrofit option was selected because it provides reliable seismic performance, while preserving the historical features of this cultural heritage building. An isolation system consisting of lead-rubber bearings (LRB) and slider bearings were selected to increase the fundamental period of the building to approximately 2.5 to 2.7 sec, and to provide additional damping in the range of 15 to 20%. Given this approach, it is expected that the need for additional strengthening of the structure above the isolation plane would be minimized.

P100), b) control period, $T_C < 0.7$ sec (Figure 3.2 of P100), c) T_B and T_D are 0.07 and 3.0 sec, respectively (Table 3.1 of P100). The 5% damped response spectrum is then developed based on the Formulas listed in P100. Next, All spectral ordinates are amplified by a factor of 1.4 to account for the building “Importance Class” (as required by Table 4.3 of P100). The solid line in Figure 4 represents the target response spectrum per P100.

The design spectrum for the extreme event (or maximum considered earthquake, MCE) is defined by the International Building Code (IBC 2006) as the lesser of the deterministic event and the probabilistic event with a return period of 2500 years (or 2% probability of exceedance in 50-years). Using the Geotechnical Survey and boring logs by S.C. Project-Lopis S.R.L. (2007) and site-specific seismicity parameters, both probabilistic and deterministic spectra were developed. The spectra are shown in Figure 4 as well. The dashed line represents the governing site-specific spectrum.

The P100 spectrum (amplified by 1.4 for Important Class) governs for all periods of interest for an isolated building (longer periods). Therefore, the design of all isolation devices, new and existing structural members, was based on the P100 spectrum.

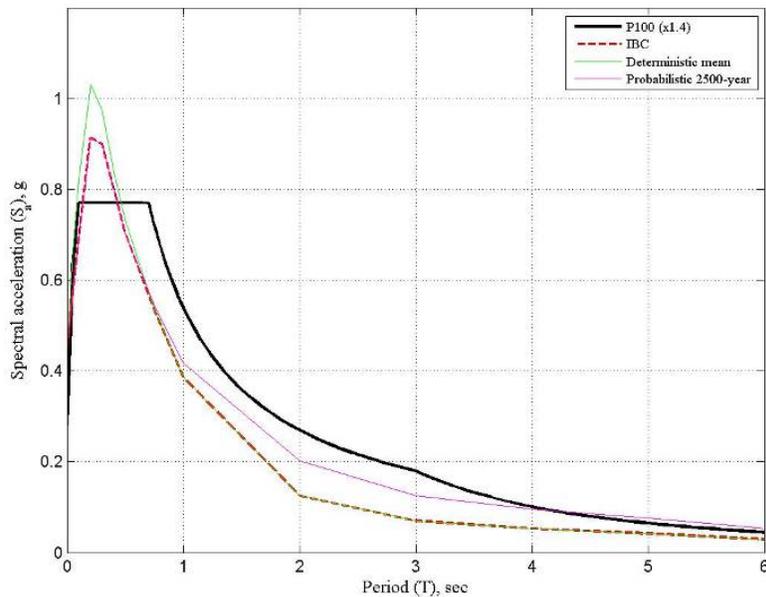


Figure 4. Comparison of the Romanian and IBC design spectra

4 ANALYTICAL MODEL

4.1 General model properties

A three-dimensional analytical model of the building has been prepared using the program ETABS (CSI 2010); see Figure 5. The total seismic mass of the structure is estimated at 16,800 Mg. Live loads are based on Romanian design code, *Basis of structural design in construction*, CR 0-2005. The directional combinations for seismic loading and the load combinations as specified in the Romania code were used in analysis.

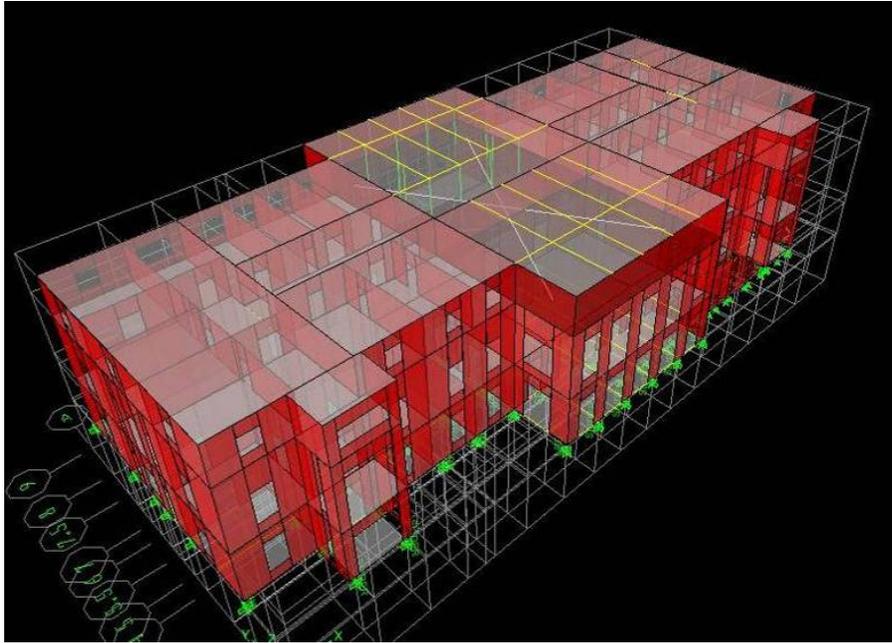
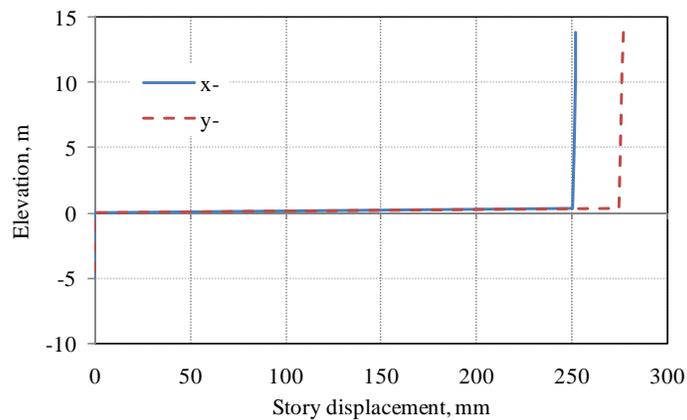


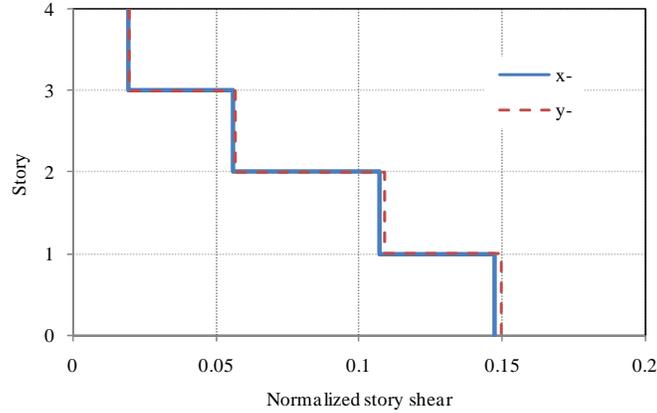
Figure 5. Analytical model of the building

5 ANALYSIS RESULTS

Figure 6a presents the computed displacement profile of the building from the response spectrum analysis. It is noted that the displacement is almost entirely concentrated at the isolation level, and drift ratios above and below the isolation plane are in the order of 0.02% or less. As such, the response is essentially rigid motion, with predominant elastic behaviour above the isolation plane. Figure 6b presents the computed story shear profile of the building from response spectrum analysis (normalized with respect to the building weight). It is noted that the maximum “base” shear coefficient just above the isolation plane is approximately 0.15g, thus satisfying the design objective.



a. Story displacement distribution



b. Story shear distribution

Figure 6. Story responses computed from response spectrum analysis

5.1 Retrofit design assessment

Table 1 presents a comparison of pertinent response quantities computed from response spectrum analysis and target values. It is noted that the design meets the target requirements and, hence, is satisfactory.

Table 1. Design criteria evaluation

Response	Target value	Analysis value	Pass/Fail
Isolator displacement, mm	450	300	Pass
Story drift ratio	0.5%	0.02%	Pass
Base shear coefficient, g	0.18	0.15	Pass
Story shear, g	0.15	0.15	Pass

5.2 Existing member and component evaluation

The existing unreinforced masonry (URM) walls were evaluated for rocking, shear, and toe-crushing strength at unreduced design spectrum demands using ASCE 41 criteria; see Table 2. The existing URM walls were found to be adequate for the unreduced design spectrum loading. Considering an m -factor of unity was used, all walls are expected to remain in the elastic range.

Table 2. Design criteria checks

Response	Target value
Knowledge (k) factor,	0.75
Condition of masonry	Good
Lower bound compressive strength	6200 kPa
Lower bound shear strength	180 kPa
Expected strength multiplier	1.3
Component demand modification (m) factor	1.0

5.3 New member design

New concrete beams are required to support the existing walls, transfer load to the isolators, and redistribute to the existing foundations in a uniform pattern. Beams above the plane of isolation are used to capture the walls with both bearing and clamping force using post-tensioned high strength

rods. During the initial stages of the isolator installation, the beams support the loads above by bridging across holes cut into the walls at each isolator location. After installation of the isolator, the remaining walls between the isolators are cut in order to complete the isolation, at which time the upper beams spans between the isolators in order to transfer the loads from above to the isolators. Beams below the plane of isolation are used to distribute the loads from the isolators uniformly to the continuous foundations below. These new beams also widen the bearing area of the existing foundations, providing enhanced bearing capacity. Additional beams were provided at isolators, perpendicular to the bearing walls above and below the plane of isolation, where necessary to provide resistance to P-Delta moments generated during the design seismic event. New concrete slabs at the ground floor level were designed to span between bearing walls for both gravity loads as well as seismic diaphragm shear loads. New concrete slabs-on-grade are provided below the plane of isolation in order to provide in-plane continuity between walls for seismic loads as well as out-of-plane restraint for retained earth at the building perimeter and basement walls. The retaining walls at the perimeter of the building and basement stairs are designed as cantilevered walls, restrained from sliding by the new concrete structure at the base of the isolation plane

6 VERIFICATION RESPONSE HISTORY STUDIES

Nonlinear response history analysis was conducted to verify the results obtained from the response spectrum analysis. The analysis used three strong motion records from previous Romania earthquakes, and analysis was based on the data obtained from the record producing the maximum response. Three pairs of ground motion, one each from 1977 (Station Incerc), 1986 (Station Iasi), and 1990 (Station Iasi) Vrancea earthquakes were used as seeds for analysis. These motions were selected to be representative of motions expected at the site. The motions were then spectrum matched to the P100 spectrum of Figure 4 and used in analysis. Two component motions for each record were developed. Figure 7 presents one of the pairs of matched records used in analysis.

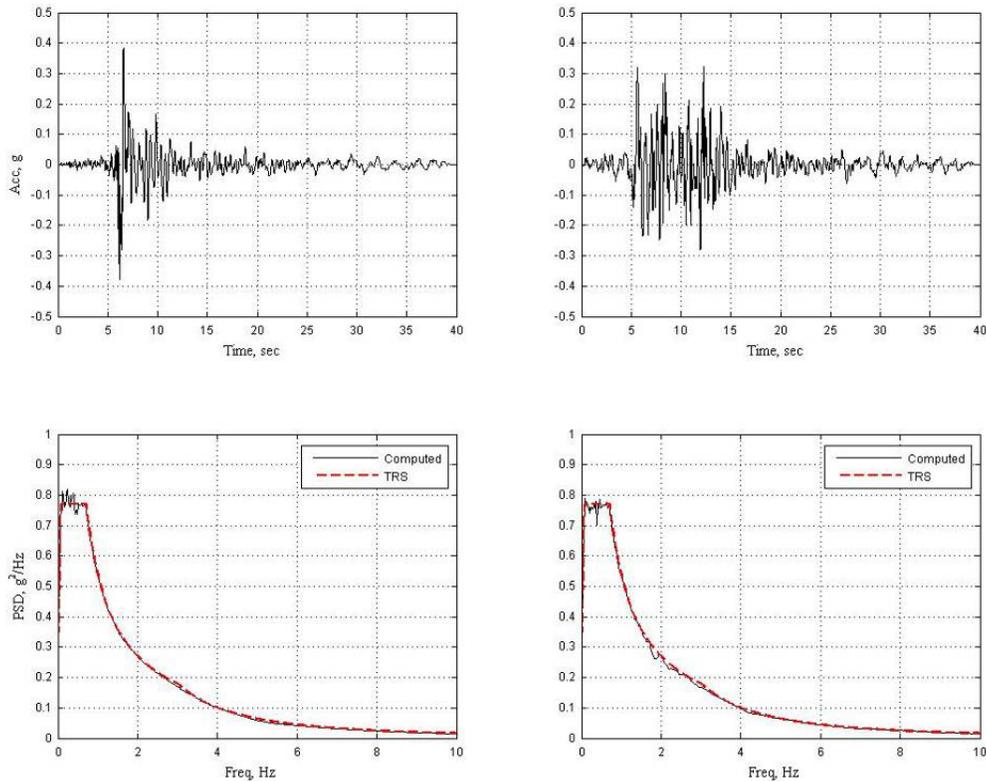
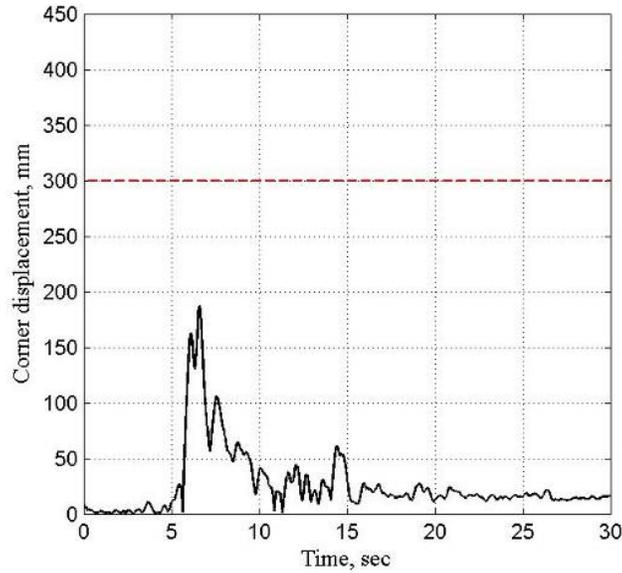


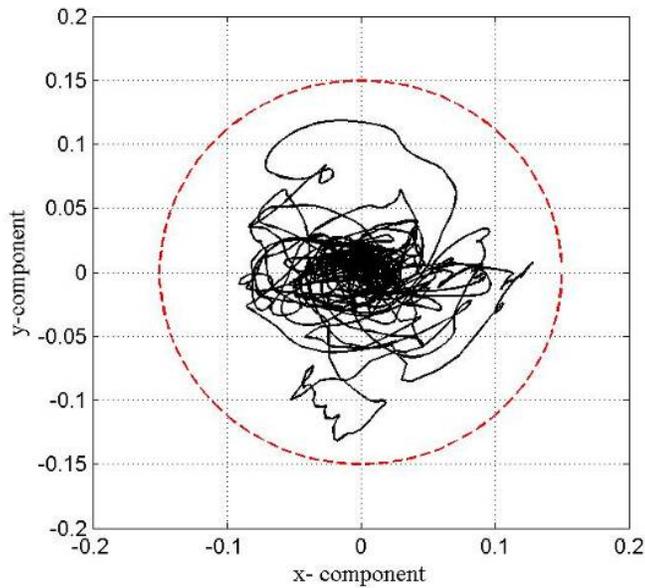
Figure 7. A pair of spectrum-matched records used in analysis

6.1 Analysis results

The nearest adjacent building to Iasi City Hall occurs at the S-W corner near Gridlines P and 3, with a separation of approximately 1000 mm. To allow for the motion of the isolated structure, a moat with a width of 300 mm (12 in) is provided around the building perimeter. Figure 8a presents the computed SRSS displacement at the subject corner. The maximum computed displacement is well below 300 mm. Figure 8b presents the x- and y-component response of the normalized base shear for one response history analysis (the solid line). The dashed line corresponds to a base shear coefficient of 0.15. It is noted that the computed base shear for the isolated structure is less than 0.15g. The maximum computed horizontal acceleration at the roof level is approximately 0.15g.



a. Displacement response



b. Normalized base shear

Figure 8. Response history analysis results

CONCLUSIONS

The historic Iasi City Hall is constructed of nonductile components. It has suffered damage in past earthquakes and does not meet the current Romanian seismic code requirements. The structure will be retrofitted with an isolation system comprised of LRB and sliders and was analyzed using response spectrum analyses.

- Analysis showed that the retrofit including the addition of the isolation system will significantly reduce the building base shear. The computed base shears, accelerations, and displacements were all within the target values.
- After retrofit, the seismic demand on the existing wall members would be significantly reduced and the unreduced demand on the walls was reduced below member capacities
- Response history analysis using three spectrum-compatible pairs of records selected from the Romanian (and Iasi) strong motion record database showed that the response of the isolated structure was satisfactory, and that the response spectrum analysis results used for design and evaluation of components envelope those obtained from time history analyses and are, therefore, appropriate for use in design.

ACKNOWLEDGEMENTS

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