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EARTHQUAKE PROTECTION OF A HISTORICAL BUILDING THROUGH BASE ISOLATION

BY

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Abstract. Earthquakes present a potential great danger to historical buildings in seismic zones. The intervention strategy must be a process that requires teamwork of engineers, architects and authorities. The rehabilitation should be in accordance with the principles of the IABSE Symposium, Venice 1983 "Strengthening of Building Structures – Diagnosis and Therapy".

The paper presents the seismic isolation of a historical building using double-concave friction pendulum bearings. The building is listed in the historical monuments list, published in "Monitorul Oficial", no. 670 bis from October 01, 2010, having the indicative PH-II-m-B-16310. The name is listed as „Salonul de dans Dumitru Nicolae". The intervention solution leads to a reduction of the internal forces in the structural elements of about 3.2 times on both directions of the building.

Key words: accelerogram; double-concave friction pendulum bearing; nonlinear time-history analysis; seismic isolation.

1. Introduction

The interventions on historical buildings show a high complexity, because the structural rehabilitation must not change the cultural value of the

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building. The complexity of it, is due to the fact that, the methodologies used in the rehabilitation of historic buildings, differ from those used in the design of new buildings, to which is added the lack of norms that govern the interventions on historical buildings and cultural heritage.

For „Salonul de dans Dumitru Nicolae” building, the seismic base isolation was chosen, using double-concave friction pendulum bearings. The intervention solution was adopted in accordance with the design theme drawn by the client - National Village Museum "Dimitrie Gusti" - for relocation, consolidation and restoration of the building, taking into account the possible effects of a future earthquake. Currently the building is located in the Aluniş village, Prahova County.

2. Description of the Building

The building was erected in 1928 on the initiative of Dumitru Berbec. Until 1945 was the family property, thereafter became the property of the Village Hall (Fig. 1).

The building is rectangular (about 14 × 10 m), with the long side disposed on the street alignment. In the west part, the building is withdrawn from the property limit with 1 m. To the street side is developed a hallway on the entire length of the façade, decorated with fretted and turned wooden elements.

Fig. 1 – General view of the “Salon de dans Dumitru Nicolae” building (photo P. Mortu, 2012).

At the entrance, opposite to it, in an area of 3.6 m^2 (2.95 × 1.96 m) is developed a zone for the orchestra. The volume is cantilevered and covered by an extension of the main roof covering.

The entrance, centrally located, is supported, from the compositional point of view, on an important volume that breaks the monotony of the envelope.

The foundation system is composed of isolated footings (100 × 100 cm), made of river stones bounded with mortar. The current loads, has imposed with time, the intermediary support of the wooden soles with different wooden pieces having variable cross-sections. The building is raised from the ground level to about 50 cm.

The vertical structure is made of oak columns with the cross-section of aproximatively 12 × 12 cm. The lateral stiffness is provided by the wooden diagonals. The wooden framework, of different wooden species, is composed of props, which rest on base soles of 15 ×15 cm, purlins, wedges and rafters. The lateral stiffness, of the wooden framework, is provided by diagonal elements and pliers. The roof is covered with flat steel sheets, with rabbets, batten on the lathing. The special forms of the central volume, above the entrance, and the two skylights, are covered with scales steel sheets. The cornice height is 3.8 m and the total height of the building (to the ridge) is 8 m.

3. Seismic Evaluation of the Existing Building

The seismic evaluation of the building requires qualitative and quantitative assessment of the capacity of the structure to resist to the imposed loads. The evaluation must take into account the global configuration, the dimensions of the bearing and non-bearing elements, the quality and the strength of materials, the wear state and possible damages due to the accidental or extraordinary actions.

According to P100-3/2008, the „Salonul de dans Dumitru Nicolae” building, corresponds to KL1 knowledge state, because:

(i) in terms of geometry, the global configuration of the elements and the dimensions of the structural elements are known from the surveying plan.

(ii) regarding the details configuration, there is no structural design project of the building, so that, there were chosen structural details based on common practice from the construction period.

(iii) regarding the materials, there are no direct informations about the materials characteristics. There were chosen values according to the period of construction, associated with the values from the limited tests made on site.

In the superstructure, the qualitative analysis of the damages that have been developed over time and the effects evaluation, were made by the following procedures:

a) direct visual observation of the structural elements;

b) observations on the effective geometrical dimensions of the compartimentation and enclosure elements;

c) check of the bearing capacity of the main types of structural elements.

The framework is rudimentary made, from gross elements, even carved, with insufficient cross-sections, rare arrangement, with some splitting. A pronounced degradation may be visible on the steel covering sheet, but without penetrations. In time, the building has deteriorated, locally can be seen differential settlements and degradations of the structural elements (wood foundation soles, rafters). After the earthquakes from November 10, 1940 (Gutenberg-Richter magnitude 7.4), March 4, 1977 (Gutenberg-Richter magnitude 7.2), August 30, 1986 (Gutenberg-Richter magnitude 7.0) and May 31, 1990 (Gutenberg-Richter magnitude 6.7), the building revealed global conformation deficiencies. There were observed damages in foundation soles, rafters and purlins.

The technical assessment established that the structural system presents deficiencies due to the small cross-section of the elements, poor materials quality, building degradation - emphasized the lack of maintenance in recent years – and rudimentary foundation system and place the building in seismic risk class R_SII.

4. Seismic Analysis of the Isolated Building

The isolation system, used as an intervention solution for the „Salonul de dans Dumitru Nicolae" building, is composed of six double-concave friction pendulum bearings, an upper bearing frame and a lower bearing frame.

The preliminary design of the isolation systems was performed considering the analysed structure a system with one dynamic degree of freedom. The structure was isolated at a vibration period, T_{is} = 3.5 s, taking into account a damping ratio of the isolation systems, ξ_{ef} = 20%.

The displacement demand of the isolation systems, d_{dc}, to the design earthquake was determined by (P100-1/2006; P100-3/2008; EN 1998-1:2004):

$$d_{dc} = \left(\frac{T_{is}}{2\pi}\right)^2 a_g^d \beta(T_{is})\eta = \left(\frac{3.5\text{ s}}{2\pi}\right)^2 0.24\times 9.81\text{ m/s}^2 \times 0.718\times 0.632 = 0.332\text{ m} ,(1)$$

where: a_g^d is the ground acceleration corresponding to the design earthquake; $\beta(T_{is})$ – normalised spectral ordinate, corresponding to the vibration period, T_{is} and η – damping correction factor.

The effective horizontal stiffness, k_{ef}^{fpb}, of one double-concave friction pendulum bearing was determined by (Constantinou, 2004:

$$k_3 = \frac{G_{SC}}{n_{is}\left(R_1 - h_1 + R_2 - h_2\right)} = \frac{1{,}850 \text{ kN}}{6\left(2.35 \text{ m} - 0.1 \text{ m} + 2.35 \text{ m} - 0.1 \text{ m}\right)} = 68.5 \text{ kN/m};$$

$$Q = \frac{G_{SC}\left[\mu_{1f}\left(R_1 - h_1\right) + \mu_{2f}\left(R_2 - h_2\right)\right]}{n_{iz}\left(R_1 - h_1 + R_2 - h_2\right)} =$$

$$= \frac{1{,}850 \text{ kN}\left[0.03\left(2.35 \text{ m} - 0.1 \text{ m}\right) + 0.04\left(2.35 \text{ m} - 0.1 \text{ m}\right)\right]}{6\left(2.35 \text{ m} - 0.1 \text{ m} + 2.35 \text{ m} - 0.1 \text{ m}\right)} = 10.8 \text{ kN/m};$$

$$k_{ef}^{fpb} = \frac{Q + k_3 d_{dc}}{d_{dc}} = \frac{10.8 \text{ kN} + 68.5 \text{ kN/m} \times 0.332 \text{ m}}{0.332 \text{ m}} = 101 \text{ kN/m}, \quad (2)$$

where: G_{SC} is the total weight of the building in the special combination of loads; n_{is} – number of double-concave friction pendulum bearings, R_1 – radius of curvature of the sliding surface 1; R_2 – radius of curvature of the sliding surface 2; h_1 – distance from the pivot point of the articulated slider to the sliding surface 1; h_2 – distance from the pivot point of the articulated slider to the sliding surface 2; k_3 – horizontal stiffness of the friction pendulum bearings after sliding onset on both surfaces; Q – characteristic strength of the friction pendulum bearings; μ_{1f} – friction coefficient of the sliding surface 1; and μ_{2f} – friction coefficient of the sliding surface 2.

The damping ratio, ξ_{eff}, is checked by (Fenz & Constantinou, 2006):

$$k_2 = \frac{G_{GS}}{n_{iz}\left(R_2 - h_2\right)} = \frac{1{,}850 \text{ kN}}{6\left(2.35 \text{ m} - 0.1 \text{ m}\right)} = 137 \text{ kN/m};$$

$$D^* = \left(\mu_{f2} - \mu_{f1}\right)\left(R_2 - h_2\right) = \left(0.04 - 0.03\right)\left(2.35 \text{ m} - 0.1 \text{ m}\right) = 0.0225 \text{ m};$$

$$\xi_{\text{eff}} = \frac{100}{4\pi}\left\{\frac{4\left[Qd_{dc} - D^{*2}\left(k_2 - k_3\right)\right]n_{is}}{\frac{1}{2}n_{is}k_{ef}^{fpb}d_{dc}^2}\right\} = \quad (3)$$

$$= \frac{100}{4\pi}\left\{\frac{4\left[10.8 \text{ kN} \times 0.332 \text{ m} - \left(0.0225 \text{ m}\right)^2\left(137 \text{ kN/m} - 68.5 \text{ kN/m}\right)\right]6}{\frac{1}{2}6 \times 101 \text{ kN/m} \times \left(0.332 \text{ m}\right)^2}\right\} = 20.3\%,$$

where: k_2 is the horizontal stiffness of the friction pendulum bearings after sliding onset on sliding surface 1 and D^* – displacement after sliding onset on both surfaces.

The nonlinear dynamic analysis of the „Salonul de dans Dumitru Nicolae” building was performed using the ETABS v8.4.5 computer program (licence 7915/2005). At the isolation level was modeled a bi-directional system of reinforced concrete beams, which takes into account the behaviour of the upper bearing frame.

In the performed time-history analysis, the buildig was considered with linear behaviour, and the double-concave friction pendulum bearings, were considered with nonlinear behaviour. In the modelling of the double-concave friction pendulum bearings were used two *Isolator 1* link type elements and a *Gap* element, which were put in parallel.

The seismic action is described by three sets of accelerograms recorded at the INCERC-Bucharest site, corresponding to the earthquakes from March 4, 1977, August 30, 1986 and May 30, 1990. The accelerograms have been scaled, to the maximum ground acceleration of 0.24 g.

In Fig. 2 is presented the time history of the displacements, at the level of the isolation plane, for March 04, 1977 seismic action.

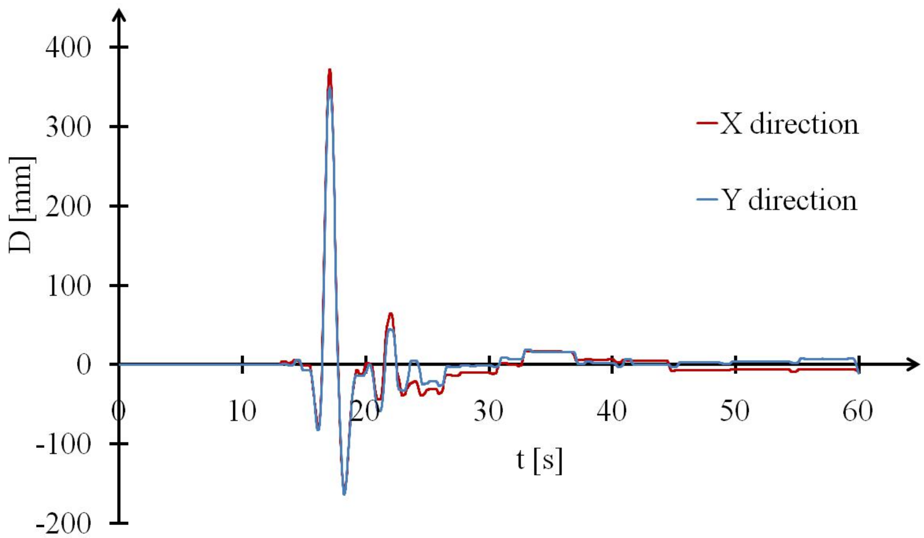

Fig. 2 – The time-history displacements of the isolation system to March 04, 1977 seismic action.

Because there were used only three accelerograms, the design displacement is the maximum displacement given by the March 04, 1977 seismic action. Thus, the maximum displacement was on the *x* direction of the building with the value of 37.1 cm, being greater than the value determined from preliminary design.

In Fig. 3 is presented the time history of the accelerations, at the level of the isolation plane, for March 04, 1977 seismic action.

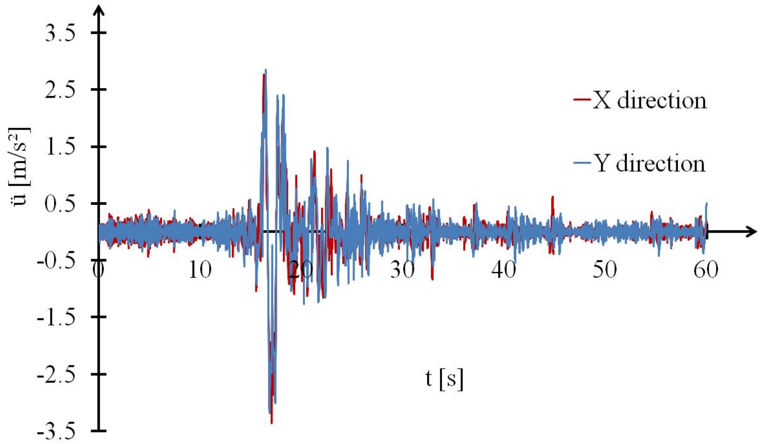

Fig. 3 – The time-history accelerations of the isolation system to March 04, 1977 seismic action.

In Fig. 4 is presented the formwork plan of the upper bearing frame and in Fig. 5 is presented a cross-section through the isolation plane.

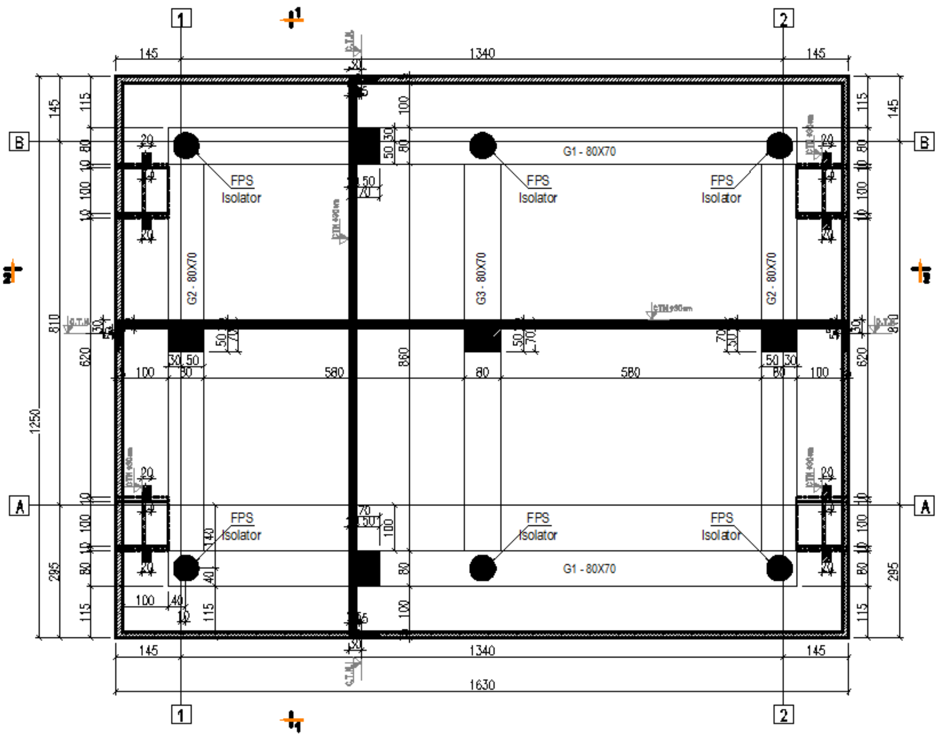

Fig. 4 – The formwork plan of the upper bearing frame.

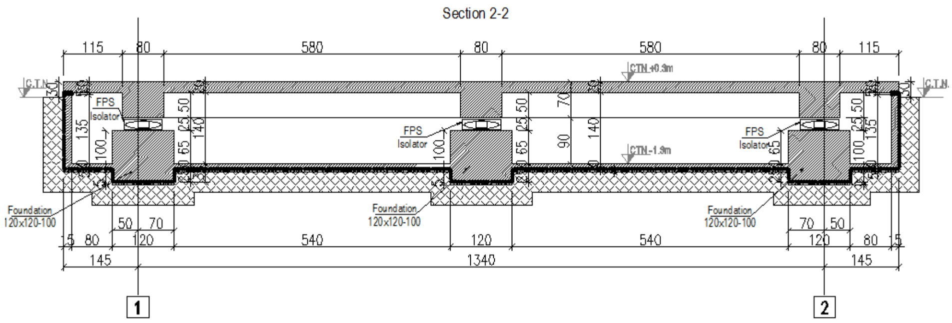

Fig. 5 – Cross-section through the isolation system.

5. Conclusions

The paper presents an intervention solution on a historical building through seismic base isolation. The building is listed in the historical monuments list, published in “Monitorul Oficial”, no. 670 bis from October 01, 2010, having the indicative PH-II-m-B-16310. The name is listed as „Salonul de dans Dumitru Nicolae”. The isolation system, used for the „Salonul de dans Dumitru Nicolae” building, is composed of six double-concave friction pendulum bearings, an upper bearing frame and a lower bearing frame.

The internal forces reduction in the structural elements was of about 3.2 times on both directions of the building, considering the increase of the safety index around the value of 0.85 on both directions of the building.

REFERENCES

Constantinou M.C. (2004, October), *Friction Pendulum Double Concave Bearing*. Technical Report, Retrived January 05, 2012, from http://nees.buffalo.edu/docs/dec304/FP-DC%20Report-DEMO.pdf.

Fenz D.M., Constantinou M.C., *Behaviour of the Double Concave Friction Pendulum Bearing*. Wiley InterScience, Buffalo, 2006.

* * * Etabs v8.5.4 [computer software]. (2005). Berkeley: Computers and Structures Inc.

* * * *Cod de proiectare seismică P100, Partea I - Prevederi de proiectare pentru clădiri*. P100-1/2006.

* * * *Cod de evaluare si proiectare a lucrărilor de consolidare la clădiri existente, vulnerabile seismic*. P100-3/2008.

* * * *Design of Structures for Earthquake Resistance – Part 1: General Rules, Seismic Actions and Rules for Buildings, European Standard*. EN 1998-1:2004.

PROTECȚIA SEISMICĂ A UNEI CLĂDIRI MONUMENT ISTORIC PRIN IZOLAREA BAZEI

(Rezumat)

Cutremurele prezintă un pericol potențial mare pentru clădirile istorice aflate în zone seismice. Strategia de intervenție trebuie să fie un proces care necesită munca în echipă a inginerilor, arhitectilor si autorităților de stat. Reabilitarea trebuie să fie în acord cu principiile Simpozionului IABSE, Veneția 1983 "Strengthening of Building Structures – Diagnosis and Therapy".

Articolul prezintă izolarea seismică a unei clădiri monument istoric, folosind izolatori tip pendul cu două suprafețe de lunecare. Construcția este înscrisă în Lista Monumentelor Istorice, publicată în Monitorul Oficial la României nr. 670 bis din 1 octombrie 2010, având indicativul PH-II-m-B-16310. Denumirea înscrisă în listă este „Salonul de dans Dumitru Nicolae". Soluția de intervenție a dus la reducerea eforturilor în elementele structurale de aproximativ 3.2 ori pentru ambele direcții ale clădirii.