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SEISMIC ISOLATION OF AN OLD R.C. HOSPITAL BUILDING IN BUCHAREST, ROMANIA

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ABSTRACT

The “Victor Babes” building hosts the most important infectious disease hospital in Bucharest. As it was erected without any official technical rules, it has been recently the object of an extensive technical assessment. Before starting the works we have tried to discover its history and to find out information on its initial project and on its behavior during past earthquakes. As usual, the disappointment was total (no documents and drawings were found), so we started the technical assessment with zero information. A geotechnical study together with nondestructive technique methods were performed in order to identify the existing foundation medium below the building, its foundation structure, its dynamic eigencharacteristics and the actual quality of the used materials. It was also necessary to perform architectural and structural surveys in order to get the primary information required by a structural analysis. The studies allowed us making reliable statements regarding the load paths, stress states and the stability of the building. As its current technical state does not comply with the legal requirements in force, some solutions of intervention were considered. Finally a base isolation procedure was imposed due to the fact that it is the only hospital for infectious diseases in Bucharest and, therefore, it can not be decommissioned in order to perform a classical strengthening solution. The possibility of the seismic isolation application was favored by the actual configuration of the building (a strong and stiff floor structure at the ±0.00m level and isolated footings under columns at a depth of -0.60m). The principles of seismic isolation for Romania will be also presented, together with the proposed isolation system for mitigating the vulnerability of the hospital building.

Keywords: hospital; seismic isolation; strengthening; technical assessment; Vrancea earthquake

1. INTRODUCTION

The “Victor Babes” building was “*designed*” and built during the 1940s, about 20 years before 1963, the year when the first official building design code P13/1963 was endorsed. The building had several destinations and, since the 1980s, the building has been changed into a hospital.

The city of Bucharest experienced during the period of existence of the building the following major earthquakes: March 4, 1977 (M_W = 7.4), August 30, 1986 (M_W = 7.1), May 30/31, 1990 (M_W = 7.0/6.4), and the probability for a severe and damaging earthquake to occur is very high. The consequences of such a disaster will vary greatly, depending upon the circumstances following the quake, and no one can predict with certainty what condition will be present immediately after the occurrence of a strong motion. The city is particularly vulnerable to seismic hazard, especially due to its economical problems, as policy decision makers did not allocate the necessary funds to secure the building stock, including the buildings with hospital destinations.

The hospital building resisted all these seismic events, due to its regular in plane configuration and, above all, due to its fundamental eigenfrequency of vibration, that was out of the band of dominant frequencies to which the energy of the above mentioned strong ground motions was maximal.

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The technical assessment of the "Victor Babes" hospital building was caused by the existence of a state of uncertainty about its strength and stability, potentiated by a number of damaged columns in the two basements, and by some damaged short columns existing between the rigid first floor and the column foundations. It should be mentioned that the short column effect was also encountered on the perimeter of the building.

2. ARCHITECTURAL DESCRIPTION

The "Victor Babes" hospital building has a regular rectangular shape in plane, with sides of 113.30 m x 12.70 m (Figure 1).

Figure 1. Overall image of the building, together with the detail of a jutty

The most remarkable detail of the building architecture is the main façade. There are three "jutties" – areas that are detached from its main façade – and which provide a certain architectural composition. The width of each jutty is equal to 10.00 m and the detachment from the main façade line is equal to 2.10 m. In front of each jutty there is a ground level building, having dimensions equal to 9.60 m x 5.00 m. The access to the building is via two main entrances, located in two of the main façade jutties, and through six secondary entrances with direct ways in.
The building height regime is GF + 3F, in the area of the central jutty GF + 4F and in the area of the marginal jutties B + GF + 4F. The height at the level of the cornice is equal to +17.30 m. The height of the current level in the GF + 3F area is 4.00 m and in the jutties area it is 3.15 m. In the area of the marginal jutties there are basements which are reached through technical room, with a height of 2.90 m. The built area of each basement is 245 m^2. The access to both basements is provided by RC stairs. The vertical circulation between the floors of the building is assured by three identical two-ramps RC internal staircases and a lift.
The in-plane configuration of the building reveals two spans (one of 4.50 m and one of 7.70 m) and 23 bays with different dimensions. The building has a garret, sheltered with a galvanized plate sheet covering applied on a wooden roof boarding.
The external walls (25 cm thickness) are of brick masonry type and are components of the bearing structure. The interior partitions are of two categories: original partitions of brick masonry type (12.50 cm and 25 cm thickness) and new partitions of light modern materials. Only the 25 cm thick partitions embedded in the existing concrete frames were considered in the structural model of analysis, as they contribute to the overall stiffness and to the energy dissipation at different loading stages.

3. STRUCTURAL DESCRIPTION

The building which is subject of this paper was carried out at a time when there was no technical regulation to take into account the effects of the seismic action on buildings. The building was conceived using exclusively the gravity loads design concept, specific to the interwar period and extended, unfortunately, a long time after the violent Vrancea earthquake that occurred on November 10, 1940. At that time no basic knowledge on earthquake design was available, but no engineer placed himself in the following position: "*I am aware that I do not know the subject, and I should stay away*". On the contrary, everyone involved himself and expressed his opinions as much as possible. Notable in this sense is the conclusion formulated by one of the top engineers of that period: "*The theory shows us and practice confirmed that the works done with technical judgment, respecting the principles of constructive art, did not suffer a lot even during earthquakes far more violent than the one that we have been given.*" (Beles, 1941). This formulation has accredited the idea according to which a RC building, properly designed for gravity loads and complying with the German norm DIN 1045/1932 for dimensioning concrete, also being well-executed, can withstand earthquakes in Romania. It is obvious that the necessity of designing buildings for seismic actions was not sustained. Another representative of the engineering elite of the time affirmed after the world's first total collapse of a reinforced concrete building: "*the causes of the collapse must be sought in an ensemble of a different nature than that of the knowledge of ensuring buildings to seismic loads that existed at the moment of its collapse*".

These examples certify the fact that some of the personalities with great influence among the civil design engineers in Romania did not believe in the necessity of designing buildings to seismic actions. These aspects were presented in order to understand the "*atmosphere*" in which the "Victor Babes" hospital building was designed and built:

- the empirical design concepts of the engineering elites that had major influence on common designers;
- the design concept in the elastic range exclusively for gravity loads;
- disregarding the building design for loads generated by seismic actions;
- an insufficient knowledge of the reinforced concrete theory;
- the technical means available at the time for the execution of the works;
- getting a maximum profit.

The structural system of the building comprises a "*superstructure*", a "*substructure*" consisting of two partial basements and a "*foundation structure*".

The superstructure of the structural system is made of RC frames arranged in two orthogonal directions: 24 frames on the transverse direction and 3 frames on the longitudinal one.

The columns have variable cross-sections on their height: 50 cm x 50 cm (GF + 1st F), 40 cm x 40 cm (2nd F) and 35 cm x 35 cm (3rd F). The beams arranged on the transverse direction of the building have cross-sectional dimensions of 35 cm x 40 cm at all levels (axes D-E) and 35 cm x 70 cm (axes C-D). The spans of beams are 4.00 m (axes D-E) and 7.20 m (axes C-D), see Figure 2. The beams arranged on the longitudinal direction of the building have cross sectional dimensions equal to 25 cm x 40 cm (axes C-E), 35 cm x 35 cm (axis D) and 25 cm x 35 cm (axes C-D-ribs). By means of instrumental investigations it has been established that the strength of concrete in the columns of the structural system of the building is poor, corresponding to a strength class of concrete C6/7.5. For this concrete strength class the characteristic compressive strength on the cylinder is f_{ck} = 6.0 N/mm^2 and on the cube f_{ck} = 7.5 N/mm^2. The floor structure plates are 15 cm thick and were made in monolithic concrete solution.

The substructure of the structural system consists of two partial basements existing at the edges of the building, both on the Eastern and Western sides.

The foundation structure consists of isolated foundations with variable dimensions (widths of 0.60 m, 0.80 m and a height of 0.60 m) under the RC columns. The surveys have revealed the existence of foundation beams, which support the brick masonry walls, between the perimeter isolated columns.

4. VIBRATION EIGENCHARACTERISTICS

Despite the fact that the "Victor Babes" hospital building has faced four strong seismic events during its existence, one can state that this building is in quite a good state of conservation. This statement is inconsistent with the technical legislation in force, according to which the building is in an alarming situation. As the building is well maintained, no visible damage was observed, excepting the basements and the short columns of the visitable central area. Thus, the only objective way to get information on the building was to identify the parameters governing its dynamic behavior by performing dynamic testing. In many respects, the practice of vibration testing to such old buildings should be current practice.

The type of testing, its extent and the required quality of the results, follow the defined objectives: to obtain the modal eigenfrequencies, the modal eigenshapes and information on damping. This information helps the designer to calibrate structural models of analysis that are suitable for the given purpose – the technical assessment. To evaluate the dynamic behavior of the building an experimental study was performed by applying the *ambient vibration testing method*.

The instrumental data acquisition was performed with Kinemetrics equipment of high performance and sensitivity. When determining the location of the vibration sensors the shape of the building and its current technical condition were taken into account. Six configurations with eight sensors were considered in order to obtain the necessary instrumental information (Figure 2).

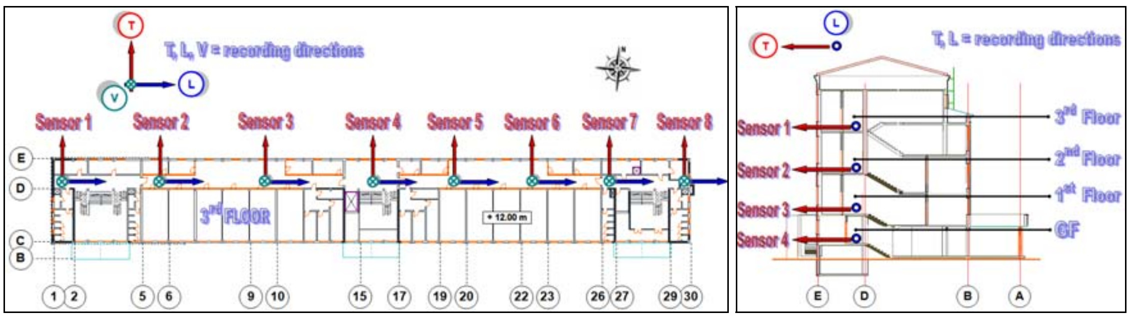

Figure 2. Location of 8 sensors at the 3rd floor and on a vertical arrangement in the main staircase (axes 15-17)

The duration of each of the recordings was approximately 300 seconds/arrangement and the sampling rate was set to 500 samples/second. It is noted that the identified spectral values had no stability over time, aspect which resulted from the processing of successive samples of the recorded signals.

The following types of signal processing were performed: numerical integration in time domain, obtaining in this manner from the basic signal (velocities) the vibration displacements; Fast Fourier Transform (FFT) of the real signal, both for velocities and displacements (Fourier Amplitude Spectra), auto-correlation functions (cross-correlation of an input signal with itself), by means of which it was possible to detect an inherent periodicity in the signal itself and to determine the damping ratio; simple mathematical combinations (sums or differences) between some primary records to indicate, when appropriate, average motions or rotations in different planes of oscillation and the Fourier Amplitude Spectra for the above mentioned combinations. Figure 3 presents samples of time domains and Fourier Amplitude Spectra representations for the longitudinal direction.

By processing the experimental data the following eigenperiods of vibration were obtained: $T_{1,L}$ = 0.31 s; $T_{1,T}$ = 0.33 s; $T_{1,V}$ = 0.03...0.04 s; $T_{1,TORS}$ = 0.22 s.

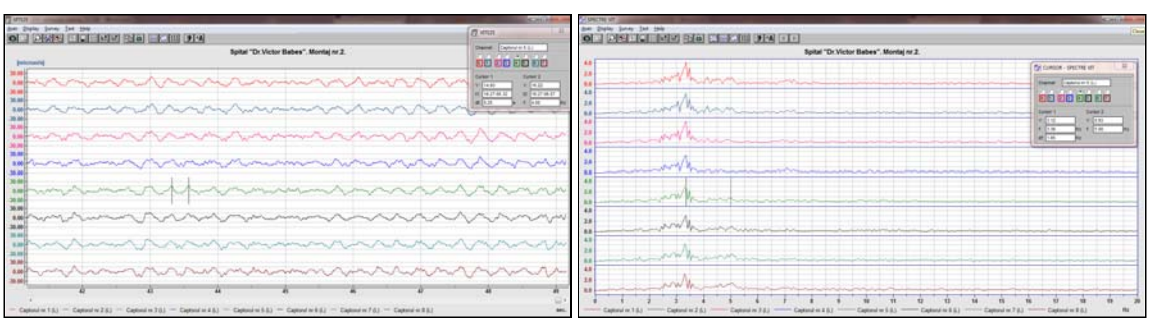

Figure 3. Ambient vibration testing; longitudinal direction; velocities (μm/s). Time domain and corresponding Fourier amplitude spectra representations.

Following an extensive program of acquisition, processing and interpreting the instrumental data, several conclusions were formulated:

- the instrumental investigations exclusively refer to the overall behavior in the linear-elastic range of the "Victor Babes" hospital building, taking into account the limitations imposed by the low level of stress given by the excitation source associated with the ambient vibrations;
- the recorded signals to identify the eigendynamic characteristics of vibration revealed "*a non-synchronous state*" between the motions recorded in various instrumented points; this fact showed that the 3rd floor structure does not provide a maximum degree in what concerns the "*working together*" of the three sections of the building – between which are expansion joints only in the RC slabs (axes 9, 15 and 20, Figure 2);
- the examination of the *fundamental eigenvalues* derived from records showed that these pertain to a *narrow band of frequencies*, which made it possible to conclude that the entire building shows a quite homogeneous performance in case of free vibrations, along both horizontal directions (there are not notable differences between the values of the fundamental vibration eigenfrequencies on the two considered directions);
- from the examination of the results of the instrumental investigations, it was found out that a higher degree of flexibility on the transversal direction of the building (corresponding approximately to the N-S direction) is present;
- the dynamic characteristics of the investigated building are parameters on the basis of which some judgments regarding its behavior to strong future seismic actions can be made; the existence of a large number of eigenfrequencies besides the fundamental eigenfrequencies (on both directions) proved that the building doesn't possess a *well-defined dynamic identity* and, therefore, has a pronounced sensitivity to strong seismic actions with spectral compositions situated in the area of the building eigenfrequencies;
- the processing of the data recorded on the floor structure of the 3rd storey put to evidence a coupling between the lateral vibrations of the building, which revealed the existence of an overall torsion phenomenon ($T_{1,\ Torsion} = 0.22$ s);
- based on the autocorrelation functions of the recorded signals, the values of the critical damping obtained by specific processing via the dedicated software DASYLab pertain to the range 5.67...6.17, values corresponding to buildings with RC moment resisting frames;
- the large height of the building levels, the existence of intermediate floors next to the jutties, as well as the presence of elastic and inertial discontinuities in the staircases zones, were revealed by the records, pointing out that these areas of the building are potentially vulnerable to future seismic actions;
- it can be stated that the "Victor Babes" hospital building shows *a high degree of vulnerability* to seismic actions with spectral content in the vicinity of the building's eigenfrequencies.

5. STRUCTURAL ANALYSIS FOR THE TECHNICAL ASSESSMENT

The building eigencharacteristics obtained through instrumental investigations helped to accurately calibrate the structural models of analysis for the so-called "*building with fixed structural physical base*".

The structural models of analysis were conceived and analyzed using the ETABS structural analysis software, following the provisions of the code P100-1/2013. Three structural models of analysis (SMA) have been developed, as follows (Figure 4):

- a SMA for gravity loads, considering non-cracked sections of the RC structural elements (with unreduced element sections stiffness);
- a SMA for loads generated by the earthquake incidence, considering the sections of the RC beams and columns with reduced stiffness, in order to take into account their possible cracked state ($0.8E_C$ for columns and $0.6E_C$ for beams);
- a SMA for the computation of the building horizontal displacements, considering the sections of the RC beams and columns with reduced stiffness ($0.5E_C$ for both columns and beams).

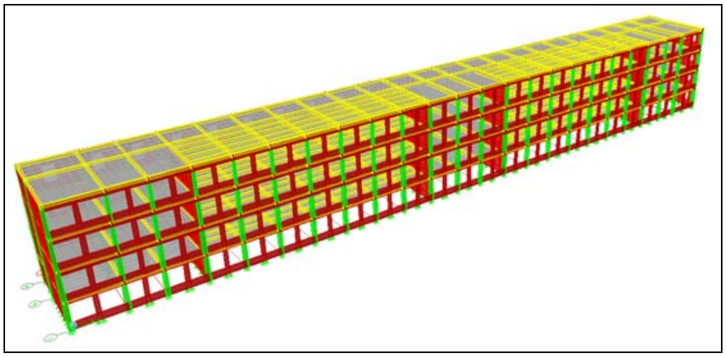

Figure 4. 3D structural model of analysis in the elastic range for the "*fixed base*" case

6. SOME RESULTS OF THE TECHNICAL ASSESSMENT

Investigating the level of protection of buildings having structural system moment resisting frame types to seismic actions, a "*level 2 methodology*" stipulated by the Romanian legislation in force was selected. Based on this methodology, the assessment of the current technical state of the building was achieved following the next steps:

- a detailed qualitative assessment based on site inspection of the building;
- performing non-distructive tests in order to assess the strength characteristics of the materials and the building dynamic eigenproperties;
- structural analysis of the structural system of the building.

According to the Romanian code P100-3/2008, the safety evaluation to seismic actions and placing the building in a *seismic risk class* can be performed by using three *indicators*, "R_1", "R_2" and "R_3", associated to the following categories of conditions:

- the degree of fulfillment of the seismic framing conditions (the degree of completion of structural framing conditions, of structural elements conditions and of constructive rules for structures which sustain the seismic action effects), noted "R_1";
- the degree of structural damage, which indicates the rate of structural damage produced either by seismic actions or other causes, noted "R_2";
- the degree of structural assurance to seismic actions, which represents the ratio between the seismic capacity of a building and the structural demand for seismic actions, expressed in terms of strength, noted "R_3".

The values of these three indicators are associated to a certain *class of seismic risk* and help the technical expert to establish a final conclusion about the "*expected seismic response*", to include the buildings into a specific *class of seismic risk* and to establish the decision of intervention.

"R_1" which quantifies from the qualitative point of view the building framing, was assessed taking into account the following ten framing criteria: *the structural system quality, the masonry quality, the floor structures, the in-plane configuration, the configuration in elevation, the distances between walls, the elements which can produce lateral pressure, the type of foundation and the foundation medium, the possible interaction with adjacent buildings, and the nonstructural elements.* A value of the "R_1" indicator equal to 60 was obtained ($R_{1,max}$ = 100, according to P100-3/2008; seismic risk class R_sII).

The "R_2" indicator defines the degree of seismic damage of the building. Taking into account the present use of the building which requires permanent maintenance, a value equal to 63 for the "R_2" indicator was assigned ($R_{2,max}$ = 100, according to P100-3/2008; seismic risk class R_sII).

The "R_3" indicator for the entire structural system was determined by comparing "*the capable base shear force*" (corresponding to a possible failure mechanism which can develop plastic hinges at the ground floor extremities) with the "*necessary base shear force*" associated to the behaviour in the plastic range. The structural analysis that was performed led to the mean values of the "R_3" indicator, as follows: "$R_3 = 0.53$" on the longitudinal direction and "$R_3 = 0.43$" on the transversal direction.

Corroborating all the qualitative aspects with the values that were obtained for the above mentioned three indicators, it was concluded that the "Victor Babes" hospital building can be assigned to the *seismic risk class R_sII*, that is "*buildings which under the effect of the design earthquake can undergo major unacceptable structural damage (given that the loss of stability is unlikely)*". As the value of the "R_3" indicator resulted smaller than the one provided by the seismic code P100-3/2008, the *strengthening of the building became necessary* (Vlad et al. 2014).

7. STRONG MOTIONS PECULIARITIES AND SEISMIC ISOLATION IN ROMANIA

7.1 The peculiarities of the strong motions occurring in Romania

Every country that wants to apply the base isolation method in the building design must develop a coherent research strategy in the following three main directions:

- to determine the characteristics of the strong seismic motions that have occurred in that country (a requirement to be solved exclusively by seismologists);
- to develop appropriate structural analysis methods (a requirement to be solved by engineers devoted to the design process);
- to write codes exclusively for building design using the base isolation method (requirement to be solved equally by seismologists, engineers and authorities).

As it is known, the use of the base isolation method is widespread in countries like Japan, China, Russia, the United States, New Zealand, Italy, Armenia a.s.o. In these countries, all the earthquakes that have occurred since 1940 were surface seismic motions, with focal depths up to 60 km. For all countries where surface earthquakes have occurred, the application of the "*base isolation*" concept within the design process is quite simple. This statement is based on two aspects:

- by studying the response spectra of the structural systems with elastic behavior expressed in absolute accelerations, it was found out that these are centered in areas characterized by short periods, usually lower than 1.0 s;
- by studying the response spectra of the structural systems with elastic behavior expressed in relative displacements, it was found out that these are characterized by low values of the displacements.

The two above mentioned aspects were the basis for the elaboration of new structural analysis methods and specific design provisions for a range of short periods and for a low displacement range.

The earthquakes with hypocenters at depths of 60÷300 km are called "*intermediate focus*" seismic events. There are three areas in the world where such earthquakes occur: Hindu Kush (Pakistan - Afghanistan), Bucaramanga (Colombia) and Vrancea (Romania). The first two locations correspond to completely uninhabited regions, while the third one corresponds to a densely populated region. From this brief presentation one can conclude that the seismic motions occurring in the Vrancea region, at depths ranging between 70÷200 km, have a totally peculiar nature and until recently, there has been only journalistic interest for them.

A *first feature* that differentiates the earthquakes that occur in the Vrancea region from all other earthquakes that occur worldwide is the "*focal mechanism*" (the focal depth, the frequency content of the seismic motion, the seismic waves directivity, the incidence of the strong seismic motions, the return periods a.s.o).

The *second feature* specific to the Romania territory is represented by the "*depth of the sedimentary layer*". In the paper entitled "*La séismogenèse du territoire de la R.P. Roumanie*" (Ciocardel et al. 1965) and presented at the 7th Congress of the "Carpathian-Balkan Geological Association", held in Sofia - Bulgaria in 1965, elements referring to the propagation of the seismic waves through the granite and basalt layers were presented, together with aspects related to the change of the seismic wave propagation velocities during their crossing through the geological deposit of sedimentary nature. The authors established technical-geological criteria for dividing the surface of the country into seismic zones.

One of the most important ideas that emerged as result of the performed investigations was the one related to a suggestive graphic image of the thickness of the sedimentary deposit over the entire territory of Romania.

As a result of the studies that were carried out, it is known that in the area of the Danube docks the sedimentary deposit has a variable thickness in the range of tens of meters, its thickness increases westwards to several hundred of meters, reaching in the Vrancea region over 15 km.

At the Cheia seismological station (a mountain resort), the granite layer is close to the surface and, consequently, the thickness of the sedimentary deposit is a few tens of meters, as mentioned for the Danube docks. In Bucharest, the sedimentary deposit has a thickness of about 1.5 km.

Later on, starting from an idea of engineer Emilian Titaru, a group of researchers published in 1972 a "*geological map*" (Ciocardel et al. 1972). This map highlights the fact that the only "*hole*" in the world with considerable dimensions, filled with a deposit made up of sedimentary layers, is found in the seismic Vrancea zone in Romania.

In the following, a short definition of "*resonance*" is given, in order to understand what "*resonance*" means in the case of the seismic action. Usually resonance refers to the vibration of a structure when one of the temporal periods of an external dynamic excitation matches one of the structure eigenperiods. It is important to specify that in the above definition of resonance the spatial character of the vibration is not considered.

The "*complete resonance*" can be regarded as a combination of both spatial and conventionally defined resonance, and can be several orders of magnitude stronger than the temporal resonance alone.

The seismic waves that are propagated through the lithosphere can generate, in a considered seismic zone, a phenomenon called "*first resonance*", as a result of the identity or the approaching of one of the periods of these waves with one of the eigenperiods of the sedimentary geological deposit motion. This period can be called "*dominant period*" of the sedimentary geological deposit motion. The big depths of sedimentary deposits in the seismic zones of Romania have as direct effect the fact that the corner periods of the response spectra can be five times greater than the corner values of earthquakes from the United States, Japan, and from almost the rest of the world (Vlad et al. 2008).

Another important characteristic refers to the *number of cycles* of a seismic wave in the lithosphere, having the same period. This number of repetitions of identical cycles is also transmitted to the sedimentary geological deposit. The seismic waves that propagate through sedimentary deposits can produce the effect of a "*second resonance*" in a building placed at the surface, as the result of the identity or of the approach, of one of the seismic waves' periods propagation through the sedimentary deposit to one of the eigenperiods of the building motion. Following this reasoning, a component of the seismic motion with "*enough acceleration*" can produce a significant effect on the sedimentary deposit, which, in its turn, can generate a significant effect on buildings at the surface.

One can state that the maximum acceleration of the seismic motion in "*free field*" at the Earth surface is the one corresponding to the sedimentary geological deposit, and its size depends on the earthquake seismic magnitude, epicentral distance, number of cycles with the same period etc.

Due to the sedimentary deposit features, there are great differences between the spectral characteristics of the different seismic zones existing in Romania (Vlad et al. 2008). One can notice that the accelerations in the case of Vrancea earthquake, computed for Bucharest, have large values in the range of periods up to 2.5 s. Instead, the SA spectrum computed for the El Centro earthquake shows that the acceleration values strongly diminish for periods longer than 1.2 s (Figure 5).

7.2 Seismic isolation in Romania

The goal of base isolation is to *reduce the seismic forces* that are exerted by an earthquake on a building structure. That's why the building which is going to be seismic isolated must be "*placed*" in a zone of the SA spectra of specific locations with convenient periods. At the same time, values of horizontal displacements that the isolators must undergo should be taken into consideration.

So, at the design of a "*seismic isolation*" for *El Centro type earthquakes*, the seismic forces can be reduced by placing the building in the period range of 1.2÷2 s. At the same time, for this period range, the horizontal displacements that the isolators must undergo are small, of about 10...12 cm.

In contrast with the above presented case, the design of a "*seismic isolation*" in Bucharest, for *Vrancea type earthquakes*, the seismic forces can only be reduced by placing the building in the period range over 2.5 s. The straight consequence of being obliged to place the building in the zone of very long periods consists in the fact that the isolators that are to be used must assure horizontal displacements of 33...40 cm.

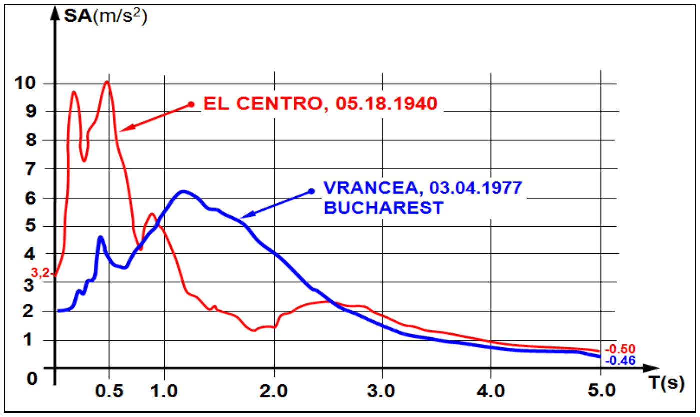

Figure 5. Comparison of the SA spectra for the March 4, 1977, Vrancea and the May 18, 1940, El Centro earthquakes

There are two basic aspects concerning the seismic isolation in Romania.

a. *The first aspect.* In the peculiar conditions of the seismic action in Romania it is required that for the seismic isolation of buildings very long fundamental eigenperiods of vibration should be achieved. In the case of buildings *without seismic isolation*, the protection measures against earthquakes are based on the fundamental principle of the achievement of a high capacity of ductility. This principle was formulated by Kiyoshi Muto as follows: "*enough strength and high ductility*". In the case of buildings *with seismic isolation*, a paraphrase of the Muto principle can be formulated as follows: "*very little strength, but very long fundamental period is necessary*". By applying the existing provisions in design codes, the risk of getting a "*seismic action*" that could lead to big strength demands can occur, even in the case of buildings with very long periods of vibration. That is why it is necessary that the response spectra for the design of buildings with seismic isolation to exist. Their use should clarify what minimum strength demands are necessary in the case of the design of buildings with long fundamental eigenperiod of vibration, required by the seismic isolation method.

b. *The second aspect* refers to the seismic isolation devices. These must allow large displacements of about 33 cm, besides the safety reserves. If by structural analysis it results that the seismic isolation devices must allow horizontal displacements equal to 33 cm, for safety reasons they should allow displacements of more than 40 cm in agreement with the EUROCODE 8 requirements. That is why it is necessary to clarify the use of seismic isolation devices in Romania. Towards this aspect, one must know if these devices can assure the same vertical level during the motion of the base of the building superstructure. If these devices have also displacements in a vertical plane (like in the case of the neoprene devices), then, as a result of the loads transmitted by the superstructure, they can have displacements with different values. For an efficient use, these seismic devices must have such configurations in order not to affect the behavior of the superstructure by supplementary and differentiated vertical displacements.

8. SEISMIC ISOLATION OF THE VICTOR BABES HOSPITAL BUILDING

The strengthening solution of the "Victor Babes" hospital building consists of two separate "*interventions*", which were imposed, on one hand, by the actual configuration of the building and, on the other hand, by the fact that the hospital building cannot be easily decommissioned in order to apply a general strengthening classical solution. Thus, the strengthening of the building will begin with the complete demolition of the three jutties together with their rebuilding, assuring proper connections with the remaining part.

The aim of these operations has the purpose of increasing the capacity to horizontal forces of the main building and of reducing the horizontal deflections of the structure to lateral loads (story drifts). For the connection of the three extensions to the existing structure some local columns and beams will be strengthened. Moreover, the damaged columns of the partial basements will also be retrofitted.

Afterwards a seismic isolation of the entire building (the existing one + newly built jutties) will be put into practice. The possibility of the seismic isolation application depends primarily on the actual configuration of the building. When a building is built on an isolation system it should have a fundamental eigenperiod longer than both its fixed base eigenperiod and the "*known*" dominant period of the ground motion. The first mode of the isolated building then involves deformation only in the isolation system, the structure above having the behavior of a solid rigid.
In the case of the "Victor Babes" Hospital building the introduction of a seismic base isolation system is favored by the existence of a strong and stiff floor structure at the ±0.00 m level and of isolated footings under columns, at a depth of -0.60 m. Between these existing structural elements, by cutting the lower part of the columns, suitable isolation devices will be mounted. During the preliminary design stage, the basic properties, type and number of the isolators were established.
Placing the building onto a system of seismic isolation will cause a considerable decrease of the seismic forces, thus the induced displacements will affect only the seismic isolation system, the building being determined to behave like a rigid unit. Particularly high displacements requirements led, among other things, to the need to secure an area of at least 40 cm.
In Figure 6 a structural model of analysis for the structural system of the building after the new jutties were added is presented. The base isolation system was provided for the entire building.

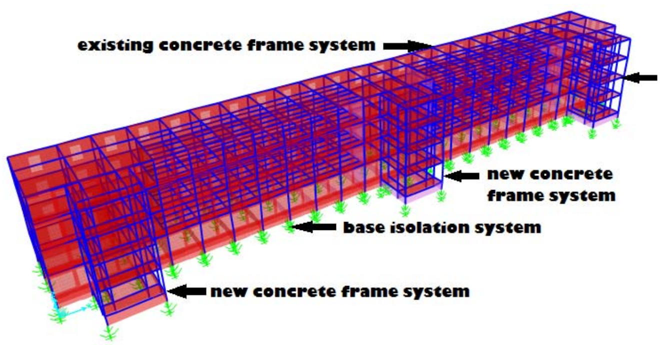

Figure 6. 3D structural model of analysis including the base isolation system

In the preliminary design process numerical simulations were made, using an isolation system consisting of 78 "*curved surface sliders*", or "*friction isolation pendula*", produced by FIP Industriale S.p.A., which use gravity for the restoring force. In its presentation brochure "ANTI-SEISMIC DEVICES" it is stipulated: "*Energy dissipation is provided by friction in the main sliding surface. The parameters of the bi-linear constitutive law depend on the radius of curvature and friction coefficient. For very large displacements curved surface sliders may be substituted by double concave curved surface sliders*".
The curvature radius of the concave surface determines the effective stiffness of the isolators, as well as the equivalent vibration period of the superstructure Naeim and Kelly (1999). The used friction isolation pendula were designed based on the following equation: $R_{nec} = gT/2\pi$. The average nominal coefficient of the dynamic friction of the isolation system for the preliminary design was assumed to be μ_{av} = 4.63%. As the type of the needed isolator is not of catalog-type, tests according to the European standard 15129:2009 are envisaged. Following the results of the tests, fine adjustments of the coefficient of the dynamic friction will be performed. The equivalent stiffness of the seismically isolated system was determined using the formula: $K_{equiv} = Mg\,(1/R + \mu_{av}/D)$. From the analysis of the normalized response spectrum in the elastic range one can observe that the dynamic amplification factor decreased from a value of 2.5 corresponding to 5% damping and 1.78 s period to a value of 0.36 corresponding to 28% damping and 3.5 s period. By reducing the dynamic amplification factor the effects of the seismic action on the building are also reduced. The total weight of the seismic isolated superstructure is 102,150 kN and the maximum transmitted horizontal force is 10,650 kN.
As a result of the introduction of the three new jutties, the strength capacity of the fixed base initial building to horizontal forces ($Q_{cap,initial}$=7,380 kN) resulted substantially increased, therefore these forces can be taken over by the new structural system composed of the remaining initial structure and

the three new jutties ($Q_{cap,final} = Q_{cap,initial} + Q_{cap,jutties}$). Thus the resulting horizontal force is greater than the maximum force transmitted by the isolation system (10,650 kN).
The contribution to the overall stiffness and capacity of the building, provided by the 25 cm thick masonry walls (which were not affected by the previous seismic motions) with, or without voids, was considered in the structural models of analysis using "*panel*" type elements. The proposed strengthening solution aimed to limit the drifts, so that the damage of some partition walls should be greatly reduced, while the behavior of most of them should remain in the elastic range.
In some computational models, besides the 78 curved surface sliders, different numbers of "*fluid viscous dampers*" were additionally used. The typical force-velocity law of fluid viscous dampers is non-linear.
One of the options for the building seismic isolation system is presented in Figure 7 and 8.

Figure 7. Longitudinal section showing the building isolation system

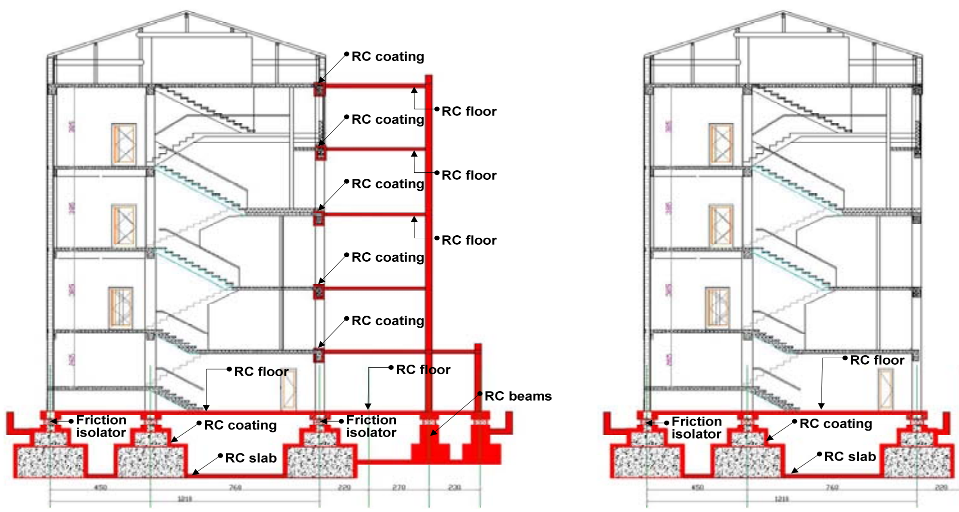

Figure 8. Transversal sections showing the building isolation system

The structural analysis followed the requirements of the new Romanian code P100-1/2013 (a safety factor equal to 1.2), the seismic action being considered through the response spectrum corresponding to the computed damping, on the transversal, longitudinal, at 45°, and N-S directions.

9. FINAL REMARKS

The technical assessment and the attempt of the seismic base isolation of the "Victor Babes" hospital building was presented in the paper. The structural analysis for the technical assessment of the building was performed using different structural models of analysis, based on the ETABS software. The structural analysis of the building with seismic isolation, that was performed with the SAP2000 software, led in this stage of works to an equivalent fundamental eigenperiod of vibration of the isolated building equal to 3.50 s and a displacement equal to 32.90 cm (Figure 9). The obtained solution with satisfactory accuracy also showed a significant reduction of the base shear force for the isolated structure accompanied by an increase of its strength and stiffness capacity. At the same time the values of the relative displacements resulted within acceptable limits. A contribution to these results was also brought by the introduced rigid and resistant outer frames.

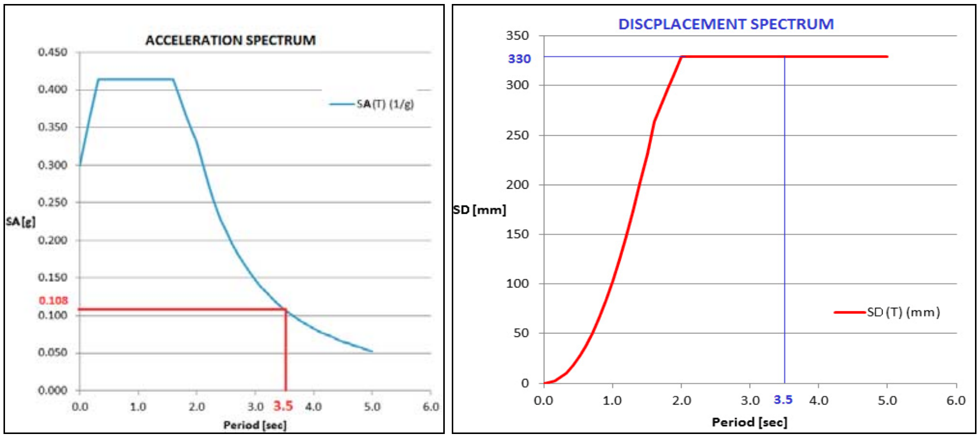

Figure 9. Acceleration and displacement spectra

During the preliminary design stage, the basic properties and types of the isolators were not yet been defined. The structural analysis was conducted by assuming the properties of the *curved surface sliders* manufactured by FIP Industriale. Simple adjustments in the final nonlinear structural model of analysis may be necessary. The hospital buildings need to be immediately in service after the occurrence of major seismic events in order to be able to treat casualties. The worldwide experience showed that the best way of protecting both hospital buildings and medical equipment is the seismic isolation technology. The anticipated response of the equivalent fixed-base structure during a strong earthquake would have been inelastic, with associated structural and non-structural damage. This emphasizes the value of base isolation in ensuring essentially elastic response to a severe seismic motion. These preliminary findings are to be confirmed by detailed studies in the final stage of design.
The works for this paper emphasized once more the basic objective concerning the base isolation in Romania, which is the conception of an isolator prototype, with an adequate behavior to large lateral displacements, which are characteristic for the Vrancea earthquakes.

10. REFERENCES

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