RESPONSE OF LEAD-RUBBER BEARING ISOLATED STRUCTURE

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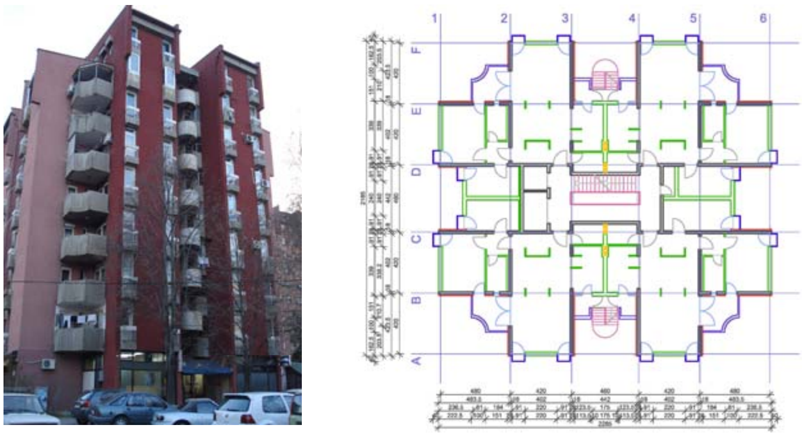
ABSTRACT :

A GF+7 storey, orthogonally almost symmetric, shear wall residential tower building has been studied in all details in order to clarify the influence of lead-rubber bearings (LRB) seismic isolation upon its seismic performance.
The ambient vibration measurements of the building have been performed by 6 GPS synchronized MICROMED's TROMINO seismometers, out of which 2 TROMINOs were fixed at the top of the building for providing GPS associated 3D ambient vibration recordings during the entire course of the measurement (4 hours). Mobile set of 4 TROMINOs has been used to acquire GPS synchronized recordings at all 4 corners and each storey of the building.
Mode shapes, natural frequencies and damping ratios of the existing fixed-base building are obtained by ARTeMIS (Ambient Response Testing and Modal Identification Software) processing of the acquired signals and used for verifying the formulated analytical model.
The LRB seismic isolation system consisting of 32 LR bearings has been designed for maximum expected earthquake in accordance with USB-97 code provisions. Four different real-earthquake time history acceleration records were used to quantitatively define and compare nonlinear responses of fixed-base and LRB isolated structures.
The paper details the results and findings of this study that result in substantial elongation of the fundamental period as well as reduction of interstory drifts, floor accelerations and base shear of isolated relative to fixed-base building.

KEYWORDS: Seismic isolation, lead-rubber bearings, ambient vibrations, TROMINO, dynamic analysis.

1. INTRODUCTION

Analytical and experimental results presented are derived under the NATO Science for Pease 978029 Project "Development of Low-Cost Rubber Bearings for Seismic Protection of Structures in Macedonia and Balkans", launched in a support to affirmation of seismic isolation concept in the Republic of Macedonia and Balkans as efficient strategy of building protection against destructive earthquake effects.
The dynamic response of the real seven-story residential building in Skopje (Figure 1-a) has been studied in all details for elucidating potential influence of seismic isolation under the maximum expected earthquake actions at a site of construction.
The building structural system consists of reinforced concrete shear walls in two orthogonal directions (Figure 1-b). The building has ground floor /GF/, seven stories and loft /L/ (GF+7+L). The disposition of RC shear walls is almost symmetrical in both orthogonal directions.



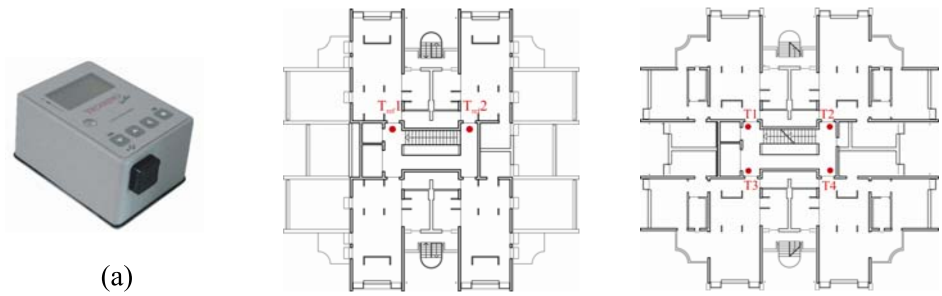
(a) (b)

Figure 1 Building (K1), Taftalidze 1settlement, Skopje

To assure adequate vertical load resistance due to high vertical stiffness, sufficient horizontal flexibility and energy dissipation mechanism the Lead-Rubber Bearing (LRB) isolation system was chosen.

1. DYNAMIC CHARACTERISTICS OF THE REAL STRUCTURE

To identify the parameters of FB mathematical model, the ambient vibration measurements were performed on the real structure.



(a) (b) (c)

Figure 2 TROMINO instruments arrangement

Ambient vibration measurements were performed by six GPS synchronized TROMINO (Micromed, Italy) seismometers. Two, placed at the top of the building were set as referent ones (Figure 2-b). Other four, the

mobile set (Figure 2-c), had been moved from story to story, from top to the bottom of the building, providing ten minutes 3D measurements at all four corners and each storey.
The mode shapes, natural frequencies (Table 2.1) and damping ratios of the real structure have been defined based on Fourier analyses of amplitude spectra's (Figure 3) of recorded signals, as well as by ARTeMIS (Ambient Response Testing and Modal Identification Software) processing of 34 GPS synchronized 3D signals.

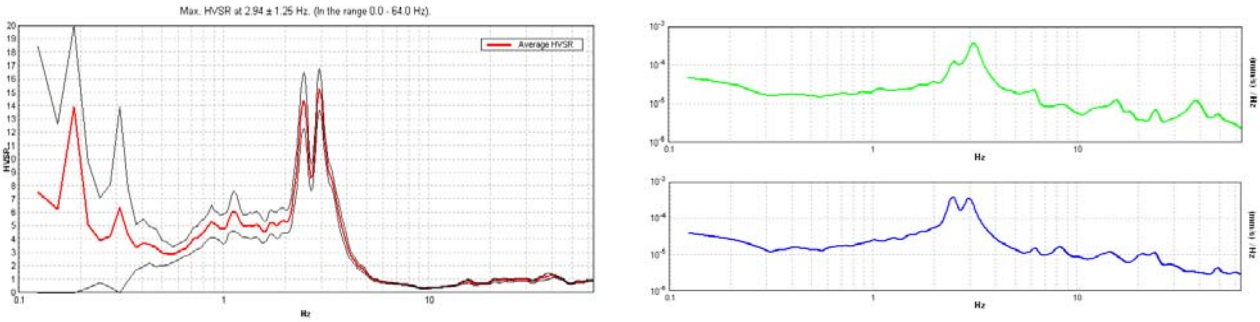


Figure 3 Amplitude spectra's

2. MATHEMATICAL MODELING AND ANALYSIS

Modeling
Two mathematical models were defined for evaluating and comparison of the response of the real structure: (1) The Fixed Base (**FB**) model representing dynamic behavior of the real structure; and (2) Seismic Isolated (**SI**) model representing the dynamic behavior of the structure isolated by LRB seismic isolation system (Figure 4).

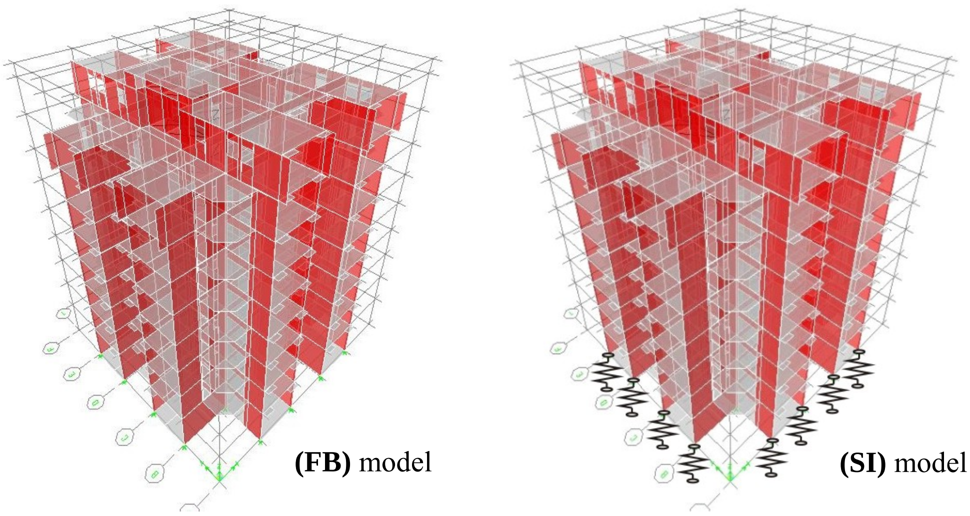


Figure 4 Mathematical models

Dynamic analyses of both models have been performed by ETABS (Nonlinear version 9.0.4). Used shell elements combine membrane behavior and bending of the plates. The finite element model was chosen to satisfy the needs of the analysis.
The total mass for dynamic analyses (structural system plus additional loading of 2.5kN/m^2, distributed uniformly on all floor elements) has been defined based on the study of actual building loadings tuned to fit the elastic frequencies of the FB model that were determined by ambient vibration measurements.
Parameters of adopted FB mathematical model, viz dynamic characteristic of the real structure obtained by ambient vibration testing's, are presented comparatively in Table 2.1 indicating fear identification of the geometry and material parameters of the principal structural system.

Table 2.1 Natural frequencies/comparative results

	Ambient vibration testing		Modal analysis		f_M/f_A (%)
Frequency	f_A(Hz)	Direction	f_M (Hz)	Direction	
f1	2.40	Torsion	2.16	Torsion	10.0
f2	3.10	Translation -x	3.10	Translation -x	0.0
f3	3.20	Translation -y	3.15	Translation -y	1.6

Seismic isolation system

Seismic isolation system applied consists of 32 LRB, uniformly arranged in the base, placed at intersections of structural modulus. Three different LRB bearing groups were designed based on the calculated axial forces. Each of these groups was designed according to UBC-97 designing procedure which also includes deformation and stability checks.

Figure 5 LRB layout

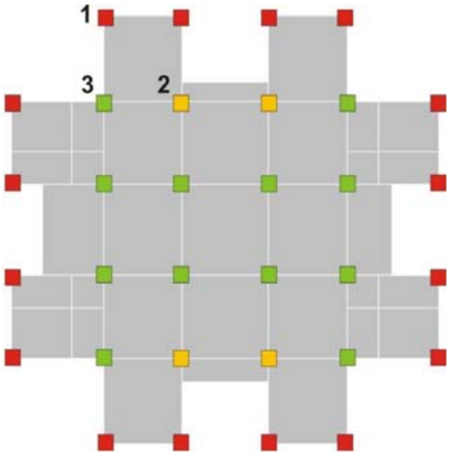


Table 2.2 LRB Design parameters

Group	Parameter	Value	Unit
GROUP_1	Edge of the bearing (a) =	50	cm
	Total height of the bearing (h) =	40	cm
	Number of rubber layers (N) =	32	
	Thickness of the individual layers (t) =	1	cm
	Diameter of the lead core (dp) =	7	cm
	Number of steel plates (Ns) =	31	
	Thickness of steel plates (ts) =	2	mm
	Thickness of top and bottom cover plates =	2.5	cm
GROUP_2	Edge of the bearing (a) =	60	cm
	Total height of the bearing (h) =	43	cm
	Number of rubber layers (N) =	32	
	Thickness of the individual layers (t) =	1	cm
	Diameter of the lead core (dp) =	7	cm
	Number of steel plates (Ns) =	31	
	Thickness of steel plates (ts) =	2	mm
	Thickness of top and bottom cover plates =	2.5	cm
GROUP_2	Edge of the bearing (a) =	70	cm
	Total height of the bearing (h) =	40	cm
	Number of rubber layers (N) =	32	
	Thickness of the individual layers (t) =	1	cm
	Diameter of the lead core (dp) =	7	cm
	Number of steel plates (Ns) =	31	
	Thickness of steel plates (ts) =	2	mm
	Thickness of top and bottom cover plates =	2.5	cm

Table 2.3 LRB Link parameters

Characteristics	Group_1	Group_2	Group_3
Effective stiffness (kN/m)	418.05	771.86	1222.15
Elastic stiffness (kN/m)	4745.78	7157.09	9940.51
Yield force (kN)	10.20	18.84	29.83
Stiffness ratio	0.07	0.09	0.10

Selected earthquake time histories

Dynamic responses of FB and SI models have been calculated for four types of real earthquake time histories of different frequency characteristics, scaled to 0.3g, which value is determined based on the detailed site response analyses. The paper presents and discusses results related only to El-Cento ($a(x)_{max}$=2.942m/sec^2, $a(y)_{max}$=1.809m/sec^2).

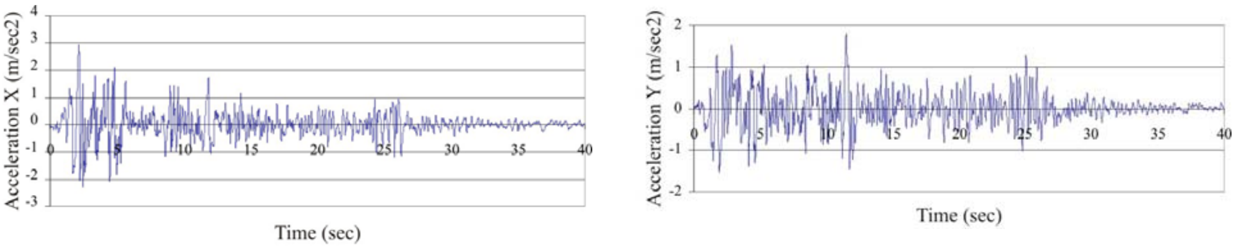


Figure 6 Scaled El-Centro time histories (0.3g)

Representative points for dynamic analysis

Four representative nodes (Figure 7) have been selected to elucidate the seismic isolation effects of studied building:

- node P_682 in the base of the structure;
- node P_682 on level 100 (second floor);
- node P_682 on level 400 (fifth floor); and
- node P_682 on level 700 (loft).

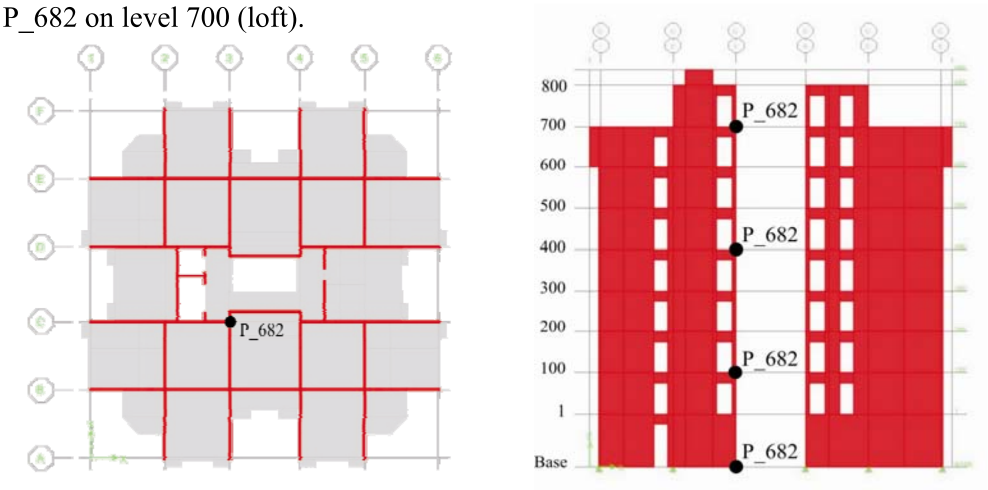


Figure 7 Representative points

The results derived are presented in terms of dynamic characteristics of studied FB and SI models (Table 2.4), base shear force (Table 2.5), storey displacements (Table 2.6), interstorey drifts (Table 2.7), and storey accelerations (Table 2.8).

Table 2.4 Periods of vibration

Mode	FB Model		SI Model	
	T (sec)	Direction	T (sec)	Direction
1	0.4637	Torsion	2.38	Translation -y
2	0.3225	Translation -y	2.38	Translation -x
3	0.3178	Translation -x	2.32	Torsion
4	0.1336	Torsion	0.26	Torsion
5	0.0961	Translation -y	0.18	Translation -y
6	0.0943	Translation -x	0.18	Translation -x
7	0.0517	Translation -x	0.99	Torsion
8	0.0467	Translation -y	0.083	Torsion
9	0.0376	Translation -y	0.07	Translation -x
10	0.0267	Translation -x	0.07	Translation -y

Table 2.5 Base shear force

	Shear force (kN) (direction X)			Shear force (kN) (direction Y)		
	FB model	SI Model	Reduction (%)	FB model	SI Model	Reduction (%)
max.	12232.30	2890.29	76.4	8533.40	3362.09	60.6
min.	15006.70	3266.24	78.2	9674.37	2768.30	71.4

Table 2.6 Story displacements

	Displacement (m) (direction X)			Displacement (m) (direction Y)		
	FB model	SI Model	Amplification (%)	FB model	SI Model	Amplification (%)
Level 100	0.0046	0.1439	96.8	0.0032	0.1516	97.9
Level 400	0.0128	0.1449	91.2	0.0083	0.1528	94.6
Level 700	0.0197	0.1458	86.5	0.0127	0.1538	91.7

Table 2.7 Interstory drifts

	Drift (m) (direction X)			Drift (m) (direction Y)		
	FB model	SI Model	Reduction (%)	FB model	SI Model	Reduction (%)
Level BASE	0.0000	0.0000	/	0.0000	0.0000	/
Level ISO	/	0.1431	/	/	0.1507	/
Level 001	0.0021	0.0004	81.0	0.0016	0.0005	68.8
Level 100	0.0025	0.0003	84.0	0.0016	0.0004	75.0
Level 200	0.0027	0.0004	88.9	0.0017	0.0004	76.5
Level 300	0.0027	0.0003	85.2	0.0017	0.0004	76.5
Level 400	0.0028	0.0003	89.3	0.0017	0.0004	76.5
Level 500	0.0025	0.0003	88.0	0.0016	0.0004	75.0
Level 600	0.0024	0.0003	87.5	0.0015	0.0003	80.0
Level 700	0.0020	0.0003	85.0	0.0013	0.0003	76.9
Level 800	0.0016	0.0002	87.5	0.0012	0.0003	75.0

Table 2.8 Story accelerations

	Acceleration (m/sec^2) (direction X)			Acceleration (m/sec^2) (direction Y)		
	FB model	SI Model	Reduction (%)	FB model	SI Model	Reduction (%)
Level 100	3.106	3.025	2.60	2.026	1.931	4.70
Level 400	6.779	3.034	55.2	3.629	1.932	46.8
Level 700	9.045	2.944	67.5	4.362	1.918	56.0

3. CONCLUSIONS

General conclusions resulting from analytical and experimental study of the selected structure, entirely verify positive aspects of the seismic isolation on the structural earthquake response.

1. Increase of natural period (Table 2.4). As result of the increased flexibility of the system, natural period of the structure increased from T=0.46sec to T=2.38sec, distancing natural period of the system from the predominant periods of the expected earthquake actions.
2. Reduction of base-shear (Table 2.5). Reduction of the base-shear force is evident in the model with implemented seismic isolation. The base-shear force under the El-Centro earthquake excitation has been reduced 4.6 in X direction in 3.5 times in Y direction.
3. Increase of displacements (Table 2.6). Increased flexibility of the system led to increase of the total displacements due to the elasticity of the existing isolation. Displacements of the system are concentrated at the isolation plane level. Total displacement at the level 700 under the El-Centro earthquake excitation has risen from 0.0197m to 0.1458m in X direction and from 0.0127m to 0.1538m in Y direction.
4. Reduction of interstory drifts (Table 2.7). Implementation of the isolation system resulted into the reduction of the interstory drifts to negligible level, so it can be said that they practically do not exist. This reduction enables the structure to behave as almost ideally stiff. In this way the damage risk of the structural and non-structural elements is minimized.
5. Reduction of story accelerations (Table 2.8). Analysis of SI Model has shown significant reduction of the story accelerations. Acceleration at platform 700 under the El-Centro earthquake excitation have been reduced from 9.045m/sec^2 to 2.944m/sec^2 (3.07 times) in X direction, and from 4.362m/sec^2 to 1.918m/sec^2 (2.27 times) in Y direction.
6. Energy dissipation mechanism. Contrasting the classical structure where the energy dissipation mechanism is based on the plastic deformations at certain points of the structure, in the seismically isolated structure energy dissipation mechanism is concentrated at the isolation level enabling simple design, control and eventual repair.

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