ANALYTICAL STUDY ON THE APPLICATION OF SEISMIC ISOLATION TECHNOLOGY TO THE VULNERABLE BUILDINGS IN ROMANIA

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ABSTRACT :

For the seismically vulnerable buildings in Romania, the possibility of the seismic isolation technology, which is one of the most effective method for the seismic rehabilitation of existing buildings, is discussed. The nonlinear response analysis is carried out for the seismically isolated reinforced concrete buildings that have 0.05-0.20 of weight base shear coefficient for the super structure and 0.02-0.2 of shear coefficient and 2.0-6.0 sec natural period for the seismically isolated story. For the input ground motion, the N-S record obtained at INCERC Bucharest on Mach 4, 1977 is used. As the result of numerical analysis, it is obtained that the seismic isolation technology is feasible for the vulnerable buildings in Romania and the optimum application cases are obtained.

KEYWORDS: Seismic, vulnerable, building, rehabilitation, isolation, nonlinear, Vrancea, earthquake

1.INTRODUCTION

Romania is one of the earthquake prone countries in the world. In 1977 Vrancea subcrustal earthquake, thousands of people's lives were lost and many medium and high rise buildings were severely damaged or even collapsed. Figure 1 shows the epicenters of earthquakes in Romania after Lungu et. al., 2001. It is well known that most of the seismic activity in Romania is due to Vrancea subcrustal source just near the Carpathian Mountains. Bucharest is the capital city of Romania at about 150 km to the south west of Vrancea district; long period components of the ground motion were recorded in Bucharest during strong Vrancea earthquakes. On the other hand, there are many medium and high rise

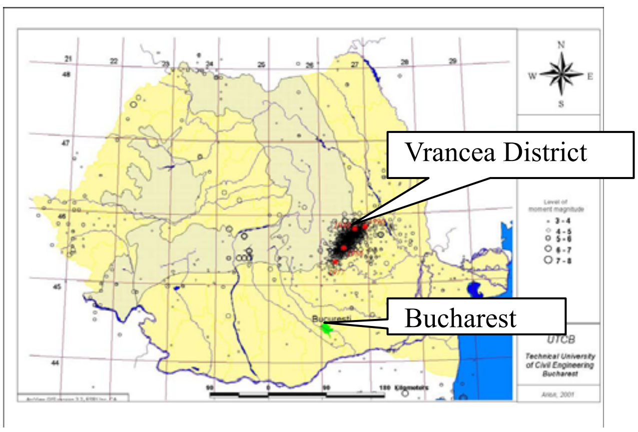


Figure 1 Epicenters of Earthquakes in Romania, 984-2000 [Lungu et. al., 2001]

Photo. 1 Severely Damaged Building in 1977 Vrancea Romania Earthquake [JICA Report]

buildings in Bucharest which have relatively long natural periods. This is why the severe damage of high-rise buildings occurred in Bucharest. Photo1 shows one of the severely damaged residential buildings in 1977 earthquake. After this earthquake, Romanian government revised the seismic code to ensure higher strength and ductility for the newly designed buildings. However the old buildings completed before 1977 have lower strength and ductility and they are prone to severe damage in the future strong earthquakes. Romanian government has been promoting the retrofitting of existing buildings, but because of not only the technical problem but also the social problem, that is, disturbing the daily life of inhabitants by the retrofitting works of building inside, little progress has been made with the retrofitting works still now. In order to solve this social problem, the seismic isolation technology has been used in the world and recognized to be a feasible method for retrofitting; therefore in this paper the analysis on the application of seismic isolation technology to the vulnerable buildings in Romania is carried out through the case study.

2.THE STATE OF THE PRACTICE OF THE ROMANIAN BUILDING STOCK

Vacareanu et. al., 2007 investigated the ultimate strength and ductility of the existing building stock in Romania based on the development of seismic regulations. The major developments in four generations of earthquake resistant design codes in Romania can be described as follows:

a. Pre-code period – a) Prior to 1945 – no code; b) 1941 Draft Instructions / 1945 Instructions for earthquake resistant design of buildings – enforced, but not compulsory
b. Low-code period – P13/1963 revised in 1970 as P13/1970 earthquake resistant design codes – enforced and compulsory
c. Moderate-code period - P100/1978 revised in 1981 as P100/1981 earthquake resistant design codes – enforced and compulsory; incorporated lessons from March 4, 1977 Vrancea subcrustal earthquake
d. Moderate to high-code period – a) P100/1990 revised in 1992 as P100/1992 earthquake resistant design codes – enforced and compulsory; b) P100-1/2006 earthquake resistant design code - enforced and compulsory since January 1st, 2007; in line with Eurocode 8 Part 1 provisions.

For investigation purposes two model buildings are selected; RC1H -high-rise RC moment resisting frame building and RC2H - high-rise RC structural walls building. Figure 2 shows the ductility factor (μ) and Figure 3 shows the ultimate strength for the model building types selected which are based on the information provided by design codes and on engineering judgment. From these results, it should be recognized that especially in the period 1941-1977, the ultimate capacity is very low.

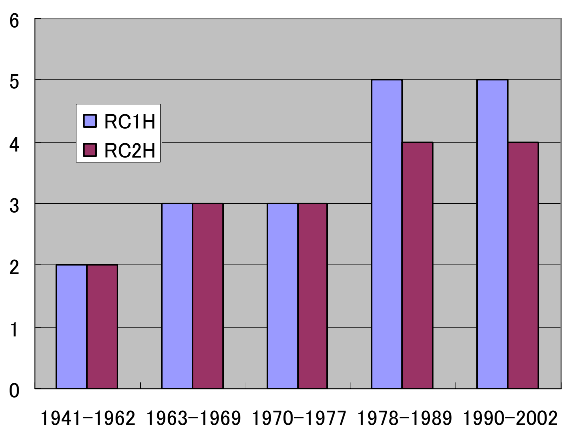


Figure 2 Ductility of the Buildings in Romania [Vacareanu et. al., 2007]

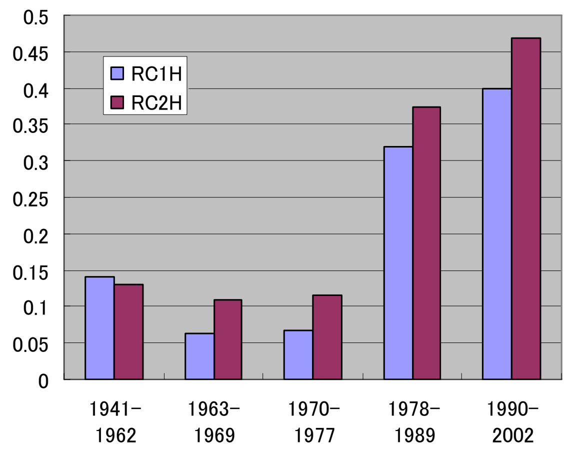


Figure 3 Ultimate Shear Coefficient of the Buildings in Romania [Vacareanu et. al., 2007]

3. ANALYTICAL METHOD

3.1 Analytical building model

The analyzed building is a ten story seismically vulnerable residential building designed in 1960's and located in Bucharest that has a weak and soft groundfloor usually used as the shopping stores etc. The seismic isolator is inserted at the top of the first story columns. Figure 4(a) shows the rough picture of the originally selected building before seismic retrofitting and Figure 4(b) shows the retrofitted building. Figure 4(c) shows the vibration model for numerical analysis in which each story's mass is concentrated to the each story's floor. Table 1 shows the building characteristics before seismic isolation as shown figure 4(b). In this table, each story's mass, each story's initial stiffness and elastic period are provided by the modal analysis.

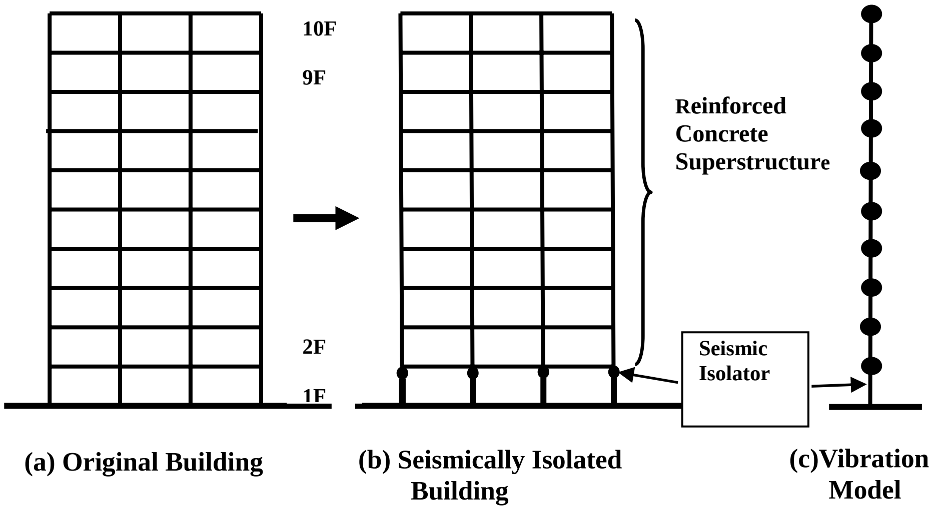


Figure 4 Analytical Model for the Response Analysis

Table 1 Characteristics of the Original Building for Numerical Analysis

Item	unit	1F	2F	3F	4F	5F	6F	7F	8F	9F	10F
W	KN	5000	5000	5000	5000	5000	5000	5000	5000	5000	5000
ΣW	KN	50000	45000	40000	35000	30000	25000	20000	15000	10000	5000
Ke	(KN/mm²)	1500	2180	2100	1980	1807	1613	1373	1093	767	407
T	sec	T_1=0.72 sec, T_2=0.29 sec, T_3=0.18 sec									

W: Story Mass, Ke: Initial Elastic Stiffness, T: Initial Elastic Period

3.2 Parameters for the Numerical Analysis

3.2.1 The superstructure

Table 2 shows the numerical parameters of the superstructure for the seismic response analysis. The ultimate shear coefficient of the first story has four values, that is, 0.05, 0.10, 0.15 and 0.20. The upper story's strength is modified by the dynamic amplification factor. The allowable ductility μ of each story in term of story drift δ divided by yielding displacement δ_y is assumed to be 2.0 based on the values shown in Figure 3. In order to easier carry out the analysis, the same initial stiffness and yielding displacement (δ_y=1.0 cm) are used for the 4 different values of shear coefficients; the crack displacement will have different values in each case. Figure 5 shows the restoring force characteristics of the superstructure. Vertical axis shows the ultimate shear coefficient α_s of the first story and the cracking shear coefficient α_c (=1/3*α_s), respectively. Horizontal axis shows the ductility factor. The allowable ductility factor of 2.0 is also shown. Takeda model is used for the rule of hysteretic loop subjected to cyclic loading.

Table 2 Numerical Parameters of the Superstructure

1st Story's Ultimate Shear Coef.: αs	0.05, 0.10, 0.15, 0.20
Allowable Ductility Factor: $\mu s(=\delta / \delta y)$	2.0
Yielding Story Displacement: δy(cm)	1.0
Total Number of Story (F)	10
Type of Reinforced Concrete Structure	Moment Resistant Frame

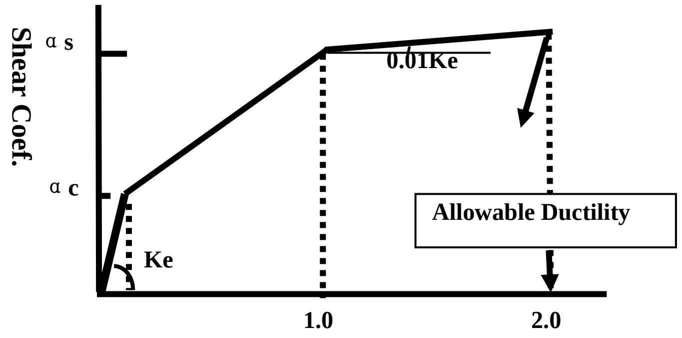


Figure 5 Restoring Force Characteristics of the Superstructure

3.2.2 The seismic isolator

Table 3 shows the numerical parameters of the seismically isolated story for the response analysis. The seismic isolator, which consists of natural rubber bearing and hysteretic damper, is used for the structural design. Seven levels of yielding shear coefficient α_b from 0.02 to 0.20 are used and the five kinds of seismic isolator's natural period T_b from 2.0 to 6.0 sec are used. Table 3 shows also the damping ratio h of 0.01, yielding lateral displacement δ_y of 1.5 cm and the allowable lateral displacement δ_b of 35 cm. This allowable value corresponds approximately to 200 % - 250 % shear strain of the total thickness of the natural rubber. Figure 6 shows these numerical parameters. Degrading Tri-linear model is used for the rule of hysteretic loop subjected to cyclic loading.

Table 3 Numerical Parameters of the Seismically Isolated Story

Yielding Shear Coef.: αb	0.02, 0.04, 0.06, 0.08, 0.1, 0.14, 0.20
Period of Seismic Isolator: Tb (sec)	2.0, 3.0, 4.0, 5.0, 6.0
Viscous Damping Ratio: h	0.01
Yielding Displacement: δy (cm)	1.5
Allowable Lateral Displacement: δb(cm)	35
Type of Seismic Isolator	Natural Rubber +Hysteretic Damper

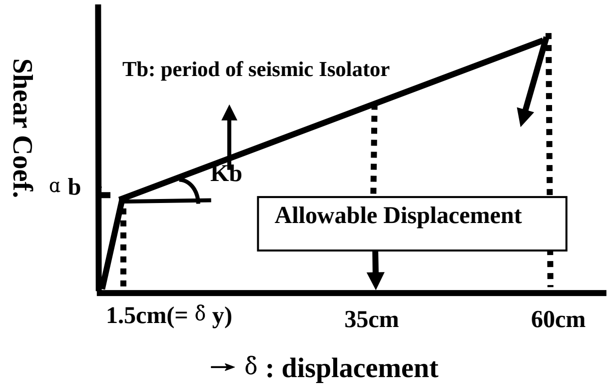


Figure 6 Restoring Force Characteristics of the Seismically Isolated Story

3.3 Input Ground Motion

The input ground motion used for earthquake response analysis is the recorded motion on N-S direction at the National Building Research Institute, INCERC at Bucharest in March 4, 1977 Vrancea subcrustal earthquake. Time history of the NS component's acceleration is shown in Figure 7. Figure 8 shows the elastic response spectrum in terms of displacement and velocity varying with the damping ratio. From Figure 8 one can notice the large response amplification that occurs at around 1.0 and 3.0 second period. This means that the ground motion will amplify the earthquake response of the long period buildings, i.e., the seismic isolated buildings and/or the high rise buildings.

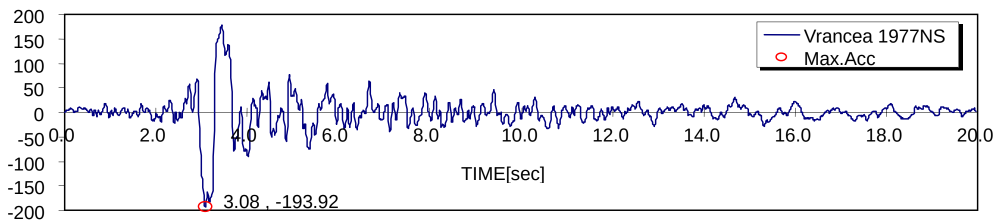


Figure 7 Time history of The Vrancea Earthquake

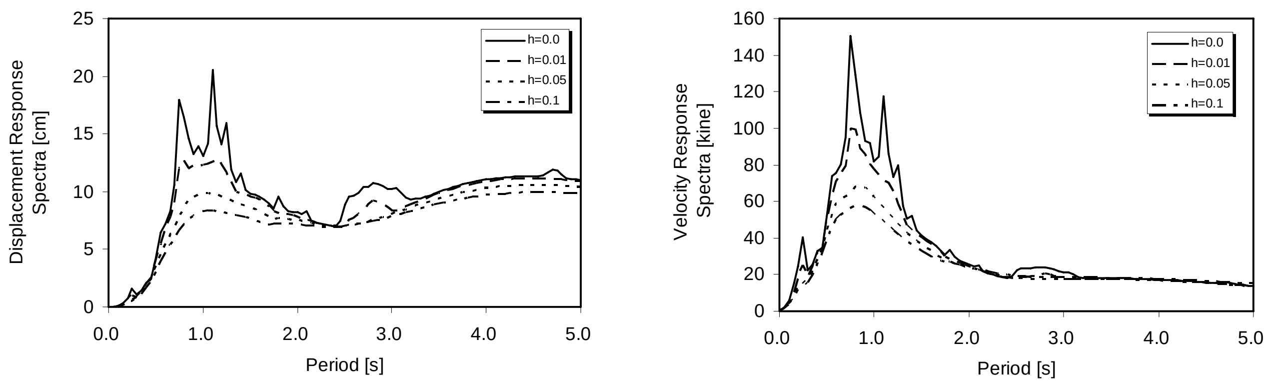


Figure 8 Elastic Response Spectrum of the 1977 Vrancea Earthquake

3.4 Nonlinear Earthquake Response Analysis

The nonlinear time-history earthquake response analysis is performed for the seismic isolated buildings described in chapter 3.3 subjected to the input ground motion shown in chapter 3.4. The numerical algorithm for solving the differential equation of motion the Newmark's β method is employed. Ten seconds duration time of input ground motion is used in analysis. From the nonlinear time-history seismic response analysis, the lateral displacement and shear force of the seismically isolated story and of the superstructure are obtained and the feasibility study on the application of seismic isolation technology can be performed.

4.RESULTS OF NUMERICAL ANALYSIS

The results of the nonlinear time-history earthquake response analysis are shown in Figure 9 – Figure 12. In these figures the relationships between the lateral displacement of the seismically isolated story δ and the ductility factor of the superstructure μ are highlighted with respect to the parameters of the ultimate shear coefficient of the superstructure α_s, the period of the seismically isolated story T_b and the yielding shear coefficient of the seismically isolated story α_b. From these figures, δ decreases according to the increase of α_b. This means that according to the increase of α_s, the input energy from the ground motion will be transferred from the seismically isolated story to the superstructure. On the other hand, μ increases as T_b becomes longer. This means that according to the increase of T_b, the input energy from the ground motion will be concentrated to the seismically isolated story. Moreover two allowable values, allowable ductility factor of the superstructure μ_s(=0.2) and allowable displacement of the seismically isolated story δ_b(=35cm) are shown in the figure. The applicable values of the seismic isolation technology are inside the zone confined by these two lines. It is recognized that the applicable zone will become larger as α_s increases.

Figure 9
Horizontal Displacement of Seismically Isolated Story versus Ductility Factor of Superstructure
(Strength of Superstructure α s=0.2)

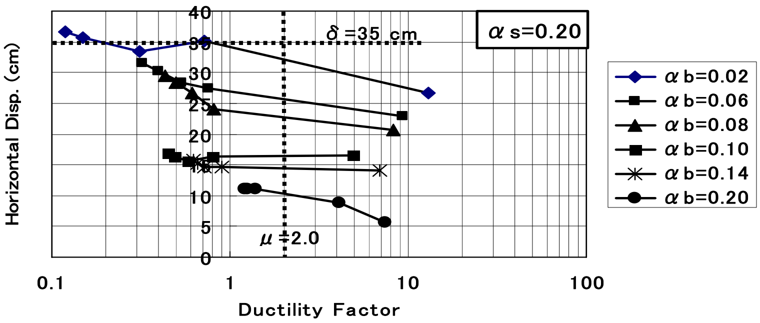
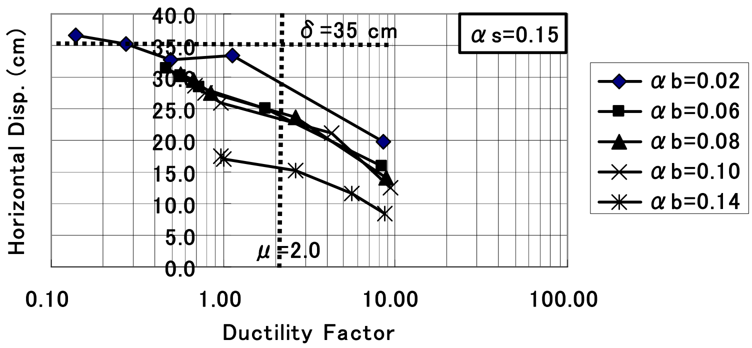


Figure 10
Horizontal Displacement of Seismically Isolated Story versus Ductility Factor of Superstructure
(Strength of Superstructure α s=0.15)



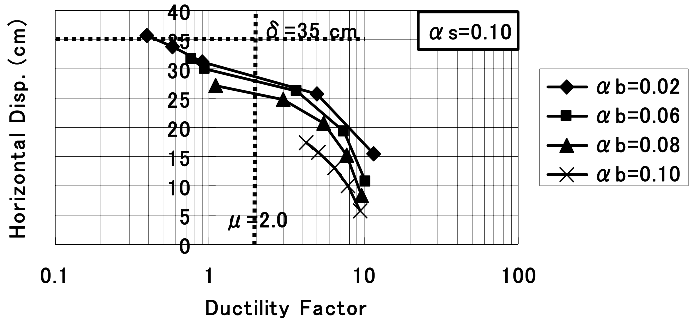


Figure 11
Horizontal Displacement of Seismically Isolated Story versus Ductility Factor of Superstructure
(Strength of Superstructure $\alpha s=0.10$)

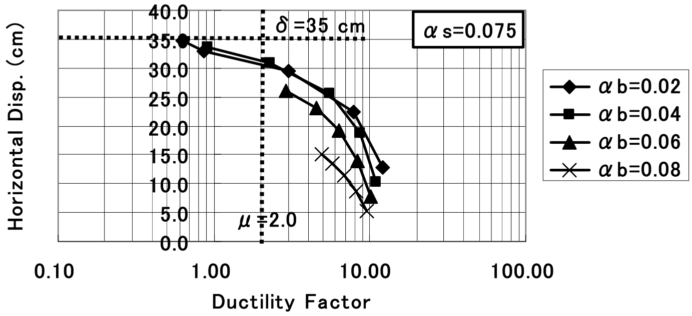


Figure 12
Horizontal Displacement of Seismically Isolated Story versus Ductility Factor of Superstructure
(Strength of Superstructure $\alpha s=0.075$)

Finally the optimum cases in the application of seismic isolation technology based on the practical viewpoint are summarized in Table 4 – Table 7. The vertical axis shows the seismic isolation period Tb and the horizontal axis shows the yielding shear coefficient α_b of seismically isolated story. These tables are classified to the four levels, namely, 0.2, 0.15, 0.1, 0.075, of the ultimate shear coefficient of the superstructure α_s. In each table, the applicable combinations of T_b and α_b considering the allowable ductility factor of 2.0 of the superstructure and the allowable lateral displacement of 35 cm of the seismically isolated story are shown by the round mark and the shaded color. From these tables one can notice obviously that there are optimum combinations; in the case of the lower ultimate shear capacity of the superstructure the number of the optimum combinations decreases.

Table 4
Optimum Combination of T_b and α_b under the Allowable Conditions
(Strength of Superstructure $\alpha_s=0.20$)

T_b \ α_b	0.02	0.06	0.08	0.10	0.14	0.20
2.0						
3.0	○	○	○	○	○	
4.0	○	○	○	○	○	○
5.0		○	○	○	○	○
6.0		○	○	○	○	○

Table 5
Optimum Combination of T_b and α_b under the Allowable Conditions
(Strength of Superstructure $\alpha_s=0.15$)

T_b \ α_b	0.02	0.06	0.08	0.10	0.14	0.20
2.0						
3.0	○	○				
4.0	○	○	○	○	○	
5.0		○	○	○	○	○
6.0		○	○	○	○	○

Table 6
Optimum Combination of T_b and α_b under the Allowable Conditions
(Strength of Superstructure α_s=0.10)

T_b \ α_b	0.02	0.06	0.08	0.10	0.14	0.20
2.0						
3.0						
4.0	○					
5.0	○	○				
6.0		○	○			

Table 7
Optimum Combination of T_b and α_b under the Allowable Conditions
(Strength of Superstructure α_s=0.075)

T_b \ α_b	0.02	0.06	0.08	0.10	0.14	0.20
2.0						
3.0						
4.0						
5.0	○					
6.0	○	○				

5.CONCLUSION

For the seismically vulnerable soft and weak groundfloor buildings in Romania the feasibility of the seismic isolation technology, which is one of the most effective methods for the seismic rehabilitation, is discussed. The nonlinear time-history seismic response analysis is carried out for the seismically isolated reinforced concrete buildings. From the numerical analysis it is obtained that the seismic isolation technology is feasible for the analyzed buildings and the optimum application cases are obtained. These results are useful for the structural design of the seismically isolated buildings in Romania.

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