BULETINUL INSTITUTULUI POLITEHNIC DIN IAŞI
Publicat de
Universitatea Tehnică „Gheorghe Asachi” din Iaşi,
Tomul LIX (LXIII), Fasc. 2, 2013
Secţia
CONSTRUCŢII DE MAŞINI

STRUCTURAL AND ECONOMIC IN SEISMIC PROTECTION THROUGH ADDED DAMPING

BY

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Received: October 13, 2013
Accepted for publication: October 24, 2013

Abstract. When analyzing structures subjected to seismic hazard, a common way of thinking in the engineering world is that they have to resist, their resistance being linked to larger cross sections. Without a doubt increasing the cross sections of structure elements will lead to improved behaviour. Present study, though, proposes an economically superior method that will improve the structure’s parameters without the need of extra material consumption. Thus is attained threw insertion of added damping, and the efficiency of this technique is compared to the “increase of cross section” method. Several numerical studies are conducted on a set of multi-story steel structures located in a highly seismic area (a_g = 0.24 g) of Romania. The efficiency of added damping approach is expressed (numerically and graphically) in terms of extra amount of steel consumption.

Key words: damping, reinforcing, steel consumption.

1. Introduction

Throughout the centuries scientists have pondered to resolve one of earth most life threatening disaster: earthquakes. Live loss and destruction of entire cities have motivated civil engineers to resolve this impending issue.

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Some of the achievements have been successfully implemented getting through to almost intact structures, after the seismic event.

Engineers worldwide have developed national codes, and continue to improve them with new findings so that the designed structure can withstand seismic action with minimum damage. Interest in this science has led to the development of a small industry concerned with seismic protection equipment that, assembled on the building, reduces the seismic response. There is a multitude of choices in the field of seismic protection, the main three categories being: passive, active and hybrid control of vibrations. Damping in this study is presented in the form of increased global damping percentage in the analysis program.

An important aspect of this issue is the economical part of equipping structures with seismic protection. The total investment of the building includes not only construction material, but also important apparatus. In many cases the cost of apparatus can surpass the cost of the structure, like in the case of a hospital for example, where one MRI (Magnetic resonance imaging) machine can cost up to 2.3 million dollars. So one can conclude from this that buildings accommodating expensive apparatus must behave ideal in the case of an earthquake, to protect it from the slightest interference. In order for the structure to reach such an exemplary seismic response it must be enhanced with state of the art technology for seismic protection (Popescu *et al*., 2012).

It is also important to consider the fact that investing in seismic protection equipment can save future costs, thus leading to an overall economy for the entire project.

2. Structures. Loading

2.1. Structures

This study presents two sets of three structures with similar shape, but different heights. The difference between the two sets is the number of openings, the first has three openings and the second set, five openings. Each set has 3 structures of six, nine and twelve stories, and have been designed to sustain the ULS loading combo. The structures are located in a highly seismic zone of Romania, the city of Bucharest with the peak ground acceleration of 0.24 g (Popescu & Balea, 2013).

Each of the three frames is designed in three ways: the first one is the reference structure, with a cross section distribution throughout the frame exactly like the one resulted after the analysis. The second one has the same cross sections, but the global damping percentage is increased from 5% to 10 or more. The third type of structure has been reinforced, in order to match story drift requirements, through the increase in cross section dimensions, thus of the structure’s weight. The purpose for this study is to align the reinforced structure story-drift graph to the 10% damped structure. In some cases, in order to ease the analysis process, more than 10% damping was used. This is represented in the Figs. 2, 3 and 4, for the 3-bay structures, and Figs. 5, 6 and 7 for the 5-bay structures.

2.2. Loading

Dead and live loading are calculated so that together they add up to approximately 1000 kg per meter square, resulting in: 24 Kn/ 16 Kn of dead loading/live loading at current level and 18 Kn/ 12 Kn for the top floor.

Vrancea accelerograme, recorded on the 4th of March 1977, at Bucharest, represented in the Fig. 1 below, describes the most devastating earthquake Romania has dealt with and also, was recorded. It has become an important tool for the study of seismic behaviour in our country.

Time-history dynamic analysis is used to determine the dynamic behaviour of the structure through direct integration of the dynamic equation of equilibrium. Unlike modal response spectrum analysis, which produces the best estimation of the structural response, through static methods like SRSS or CQC, the ones determined through time-history analysis are exact, starting from a non-linear design of the frame (FEMA 356, 2000).

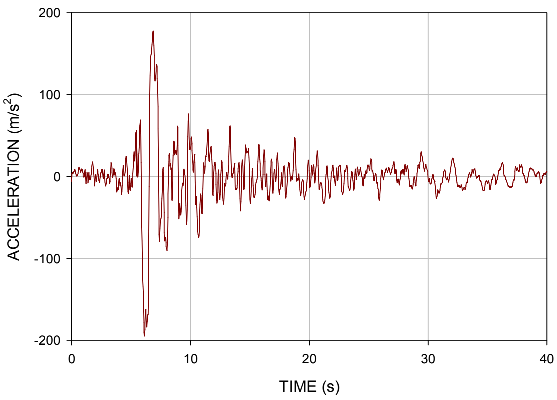

Fig. 1 – Vrancea Accelerograme.

3. Computed Parameters

3.1. Story Drift Comparison

Story-drifts, defined as the relative displacement between two consecutive floors, is an important tool in civil engineering as it a good indicator of structural performance. The Romanian code (P100/1, 2006; Eurocod 3, 2007) provides a limit value of 0.008 * floor height for buildings having non-structural elements fixed so as to not affect the structural deformations or having structural elements with high deformability. Story-drift percentage was calculated thus:

$$d_{rel,i+1} = \frac{d_{i+1} - d_i}{h} \times 100, \quad (1)$$

where: $d_{rel,i+1}$ – story-drift, [%]; d_{i+1}, d_i – lateral displacement of level "i+1" and of level "i", [m]; h – level height, [m].

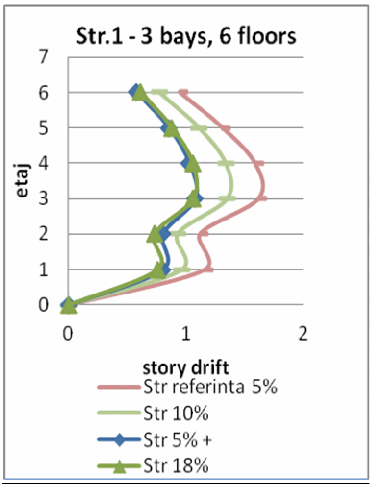

Fig. 2 – Story-drift- structure 1.

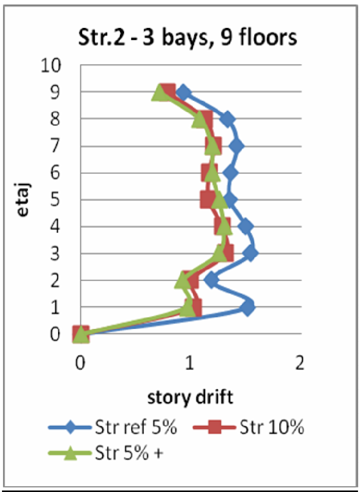

Fig. 3 – Story-drift- structure 3.

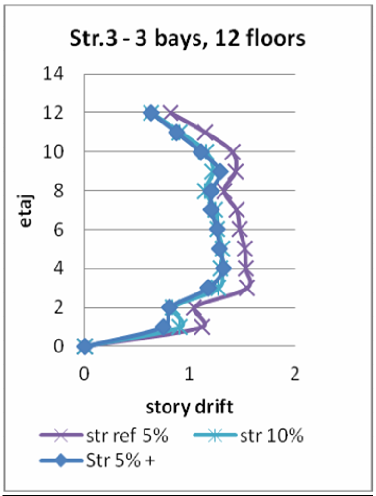

Fig. 4 – Story-drift- structure 4.

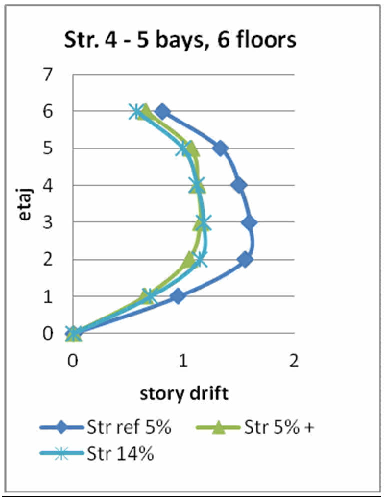

Fig. 5 – Story-drift- structure 5.

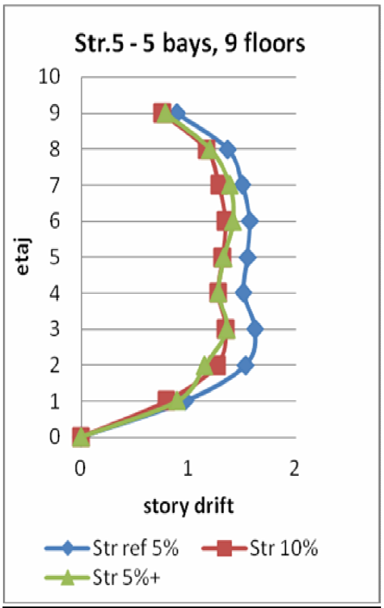

Fig. 6 – Story-drift- structure 5.

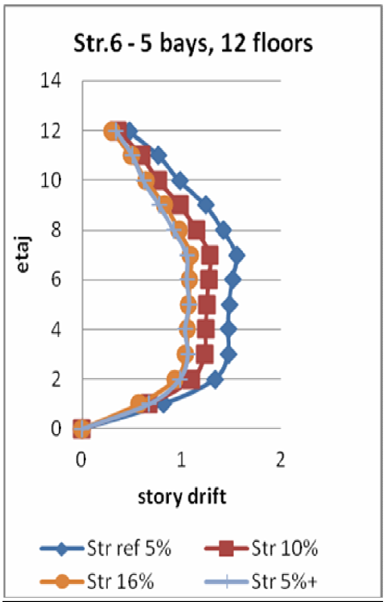

Fig. 7 – Story-drift- structure 6.

Graphs that resulted from time-history analysis with Vrancea accelerograme. Legend:

– "Str. referință 5%" = Reference structure, with 5% global damping.
– "Str. 10%" = Same reference structure with added damping of n%.
– "Str. 5%+" = Reinforced structure with 5% global damping percentage.

Table 1
Saved Material Consumption/ Damping Percentages:

Acc.	Str.	Bay/Fl.	Ref. str. weight	+str. weight	Damping	% economy of ref. str.	% economy/ 1% damping
			[Kn]	[Kn]	[%]	[%]	[%]
Vrancea	Str. 1	3/6	225.5	254	13	12.64	0.97
Vrancea	Str. 2	3/9	381.6	422	5	10.59	2.12
Vrancea	Str. 3	3/12	480	613.8	5	27.88	5.58
Vrancea	Str. 4	5/6	347.2	378.2	9	8.93	0.99
Vrancea	Str. 5	5/9	574.4	627	5	9.16	1.83
Vrancea	Str. 6	5/12	864.1	1065.5	11	23.31	2.12

First column shows the accelerograme that was used in this study, which is Vrancea ’77 accelerograme, presented in the Fig. 1. Second column presents the name of the structure, and the third its geometrical conformation: bays and number of floors. Forth and fifth column are intended for the weight of reference and of the reinforced structure, while the sixth column presents the percentage of extra material that is saved, if added damping is used. The last column indicates the percentage of economy per 1% extra damping.

As we can see, from this table, the percentage of saved material reaches to the value of 28%. This is an outstanding saving, considering the large investments the construction business creates. Observing the values of the table, one can notice that the first half, representing the structures of 5 bays, reaches smaller percentages of extra material. This fact is due to the difference of slenderness between the 2 types of structure. The height is the same, but the number of bays differs; therefore, the second type is more susceptible to seismic or wind loads.

4. Conclusions

The main purpose of this study, and the research that stands behind it, is the estimation of the beneficial effects of added dumping, in the case of steel multi-storey structures, and also, to synthesize the structure’s response in terms of steel consumption. For this study, steel frames of different heights were used to underline the effect of damping, and to compare it to another solution: increasing cross-sections (mainly wider cross section for columns).

Technical terms such as parameters of seismic behaviour, or weight of the structure, are easily put in numbers. The comparison between steel consumption and the cost of the seismic protection equipment needs a “common divisor”. To avoid introducing financial terms in a technical study, present research proposes another parameter which is: units of saved investment (meaning percentage of saved investments costs).

All these experiments demonstrate how added damping can help build feasible and stronger structures, which withstand earthquake hazard. The study wants to reduce the theoretical understanding of the matter, and to put numbers instead, so that future beneficiaries are easily persuaded to optimize their structures.

Ultimately considering the material implication of an earthquake, one can only conclude that seismic protection enhancement of structures can lead to a definite advantage to its owner, and the data presented before demonstrates it. Even though the “added damping” method doesn’t define the technology for the seismic protection, the multitude of solution that exist today on the market, encouraged the study for a general approach that includes all types of damping. Analyzing in detail the problem of choosing a specific method that suits frames of steel, will be a future lead for research.

Acknowledgements. This paper was supported by the project "Improvement of the doctoral studies quality in engineering science for development of the knowledge based society-QDOC" contract no. POSDRU/107/1.5/S/78534, project co-funded by the European Social Fund through the Sectorial Operational Program Human Resources 2007-2013.

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STRUCTURAL ŞI ECONOMIC ÎN PROTECȚIA SEISMICĂ PRIN AMORTIZARE SUPLIMENTARĂ

(Rezumat)

Analizând structuri supuse la hazardul seismic, un mod popular de gândire este că structura trebuie să reziste, această rezistență fiind asociată cu secțiuni de elemente mărite. Fără îndoială, îngroşarea secțiunilor elementelor va duce la îmbunătățirea comportamentului structurii. Acest studiu propune o metodă superioară din punct de vedere economic, care va îmbunătăți parametrii structurii fără nevoia de consum în plus de material. Metoda foloseşte amortizare globală adaugată, iar eficiența acestei tehnici este comparată cu metoda îngroşării secțiunilor. Se efectuează mai multe studii numerice pe un set de structuri multi-etajate amplasate într-o zonă foarte seismică a României (a_g = 0.24 g). Eficiența amortizării sporite este exprimată (numeric şi grafic) în termeni procentuali de consum de material.