SEISMIC SAFETY EVALUATION OF THE PIPELINES NETWORK

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ABSTRACT:

This paper aims at presenting a computational methodology for the seismic evaluation of steel pipelines networks, existing in the urban areas of Romania, characterized by an important seismic hazard. First, a short presentation of the state of the art of critical infrastructure composed of different classes of pipelines system, existing in urban areas, is given. In order to evaluate the seismic safety of existing urban piping network systems as well as different degrees of importance from a seismic design point of view, the paper presents a computational methodology based on Finite Element simulations. For the validation of the proposed methodology, a numerical case study has been performed, which aims to evaluate the seismic behavior of steel pipelines, as part of the network system existing in the North- Eastern region of Romania, characterized by a high seismic hazard. The numerical experiments based on Finite Element Analysis (FEA) methodology allows the evaluating of seismic safety of pipelines network, and can be further useful for monitoring critical infrastructure's components exposed to strong earthquakes during their life-cycle.

1. INTRODUCTION

The general objective of any societal strategy is to enable to overcome natural, industrial and environmental disasters in a way that enables the reduction of environmental, human, economic and social losses. Based on this assertion, the following objectives have been identified recently (Tusler, 2005) increasing the awareness of the public to promote an understanding of risks, vulnerability, and prevention of disasters at international level; the promotion of multi-disciplinary partnerships, including the extension of prevention networks; the improvement of scientific knowledge in the area of disaster prevention. In the promotion of all these goals for a sustainable society, the scientific and academic sectors are directly involved. In developed urban areas with a high potential of strong earthquakes, an important issue is the functioning of all vital lifelines, during and after a strong event (Ancas, 2011). Recently, the European Commission has defined critical infrastructure component of pipelines network, which has to be operational in case of any type of disaster (Council Directive, 2008).

2. PIPELINE NETWORK SYSTEMS

One of the critical infrastructure systems is the water pipeline network. Since the urban areas nowadays are strongly dependent on this type of infrastructure, the classification of pipeline system existing in seismic areas is compulsory (P100-1, 2006) as follows:

- 1st class systems, whose performance is vital for its continuous functioning; The fulfillment of the needed performance is essential for the safety of the functioning for certain critical subsystems in case of an earthquake, in order to prevent major human losses, to minimize a possible destructive impact on the environment;
- 2nd class systems, that must remain operational after the occurrence of an earthquake, but their functioning is not necessary during this extreme event. The installations or equipment from this class are important, but an interruption of their operation is possible for minor repairs;
- 3rd class systems which contains the equipment systems whose malfunction may be acceptable, even for a longer period of time, until the repairs have been done without implying major damage.

In order to propose a computational methodology for the seismic performance evaluation of a water pipeline network,

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existing in urban areas, exposed to repetitive strong earthquakes, a case study based on numerical experiments is presented in what follows (Ancas and Atanasiu, 2008).

3. CASE STUDY

3.1 System geometry

The pipelines network section, considered as a specific component of the critical infrastructure, existing in Romanian urban areas, exposed to repetitive earthquakes of important magnitudes on Richter Scale, is made of steel S235 grade, with a tube section of Ø508 and 0.01 m thickness, being supported by reinforced concrete columns of class C16/20 with rectangular section of 0.40 x 0.40 m^2, as shown in Tab. 1. In the present study, a part of this critical infrastructure, of 12 m length with a span of 3 meters between columns, is considered, having a height of 2.2 m. A bi-dimensional FE modelling has been done using different software, considering for each of these two FE models the same restrains conditions, material and geometry, respectively.

Table 1. Material properties

Material	Elasticity Modulus [N/m2]	Poisson Ratio ν	Density ρ [kg/m3]
Concrete C16/20	$275 \cdot 10^8$	0,2	2500
Steel S 235	$210 \cdot 10^9$	0,3	7850

3.2 FE Modelling

A simplified FE model has been built consisting of 24 finite elements, as follows: 5 elements of bar type, 14 elements of rib type and 5 elements of restrain type, within FE simulations based on AxisVM10 and SAP2000, respectively. The computational methodology for numerical experiments involved three different procedures. Thus, the Modal Analysis (MA), Linear Elastic Spectrum Analysis (LESA) and Time History Analysis (THA) considering significant earthquakes accelerations, have been performed within both FE software environment. In case of THA procedure, the registered accelerograms of Vrancea earthquake on 4th of March 1977, having a magnitude of 7.1 have been applied on Richter scale, one of the strong earthquakes in Romania, affecting many urban areas. Figure 2 is presenting the FE model built within the SAP2000 and AxisVM10 software environment, respectively.

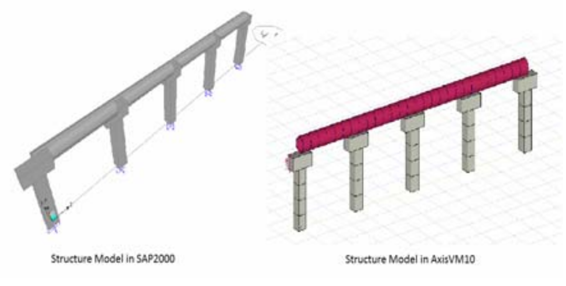

Figure 2. The structure's FE model using Sap2000, respectively AxisVM10

4. FE SIMULATION & ANALYSIS

4.1 Computational Procedures

After building the FE model, from the point of view of materials, sections, geometry, restrains, releases and the input of external actions one could advance the assignation of load cases and their combinations. With respect to Romanian Standard (CR0, 2005), the load cases needed in application of MA procedure based of software (AxisVM10, 2010); SAP2000, 2010) has been performed, considering the first 15 Eigen-modes corresponding to a total value of Mass Participation Factor of 99%, upon one direction of the bi-dimensional FE model.

The MA procedure is leading to obtain the solution of the generalized Eigen-value problem, (Chopra, 2006) given in Eq. 1:

$$\left\lfloor K - \Omega^2 \cdot M \right\rfloor \cdot \Phi = 0 \tag{1}$$

where K = stiffness matrix
M = diagonal mass matrix
Ω = diagonal matrix of the eigenvalues, known as spectral matrix
Φ = matrix of corresponding modal shapes.

The second computational procedure, used in simulations, was based on LESA procedure, considering that critical existing component is located in the Iasi region of Romania, with the corner period of $T_C = 0.7$ sec, and the dynamic magnification factor of horizontal ground acceleration of $\beta_0 =$ 2.75, as given in (P100, 2006).

The LESA procedure is performed with the normalized forms of Elastic Spectrum Response for horizontal components of acceleration, as presented in Eq.2 to Eq.5, following the recommendations given in (P100, 2006):

$$0 \le T \le T_B \quad \beta(T) = 1 + \frac{(\beta_0 - 1)}{T_B} \cdot T \tag{2}$$

$$T_B \le T \le T_C \quad \beta(T) = \beta_0 \tag{3}$$

$$T_C \le T \le T_D \quad \beta(T) = \beta_0 \cdot \frac{(T_C)}{T} \tag{4}$$

$$T \le T_D \quad \beta(T) = \beta_0 \frac{T_C \cdot T_D}{T^2} \tag{5}$$

where: $\beta(T) =$ normalized spectrum of elastic response
$\beta_0 =$ maximum value of the dynamic amplified factor of ground horizontal acceleration
$T =$ period of vibration considering a model with a single degree of freedom for the structure
$T_B, T_C =$ domain's limits for the periods of vibrations.

4.2 Results interpretation

Table 3 presents the dynamic characteristics for the first 5 modes of vibrations.

Table 3. Dynamic Analysis Results

FE Model	Dynamic Charact.	Mode of vibration				
		1	2	3	4	5
FE Model in SAP 2000	T (sec)	0,043	0,039	0,035	0,03	0,027
	Particip. mass factor on X (%)	0	0	0	0	0
	Particip. Mass factor on Y (%)	71	0	5,7	0	0,7
FE Model in AxisVM10	T (sec)	0,044	0,036	0,026	0,019	0,013
	Particip. mass factor on X (%)	0	0	0	0	0
	Particip. mass factor on Y (%)	70,3	0	1,4	0	0,2

Figure 4 and Figure 5 are reproducing the first five mode shapes of vibrations, which are almost identical for the FE models computed within both software used.

Following the recommendations of the Romanian Seismic Code (P100, 2006), the following coefficients have been applied: the importance factor $\gamma = 1.4$, for the 1st class system; ground acceleration for the horizontal component of the ground motion, $a_g = 0.20$ m/sec^2; the behavioural factor $q = 5$, for frame structures with one level, high ductility class, the influence factor of structures redundancy $\alpha_u / \alpha_l = 1.15$ and the critical damping ratio of $\xi = 0.05$.

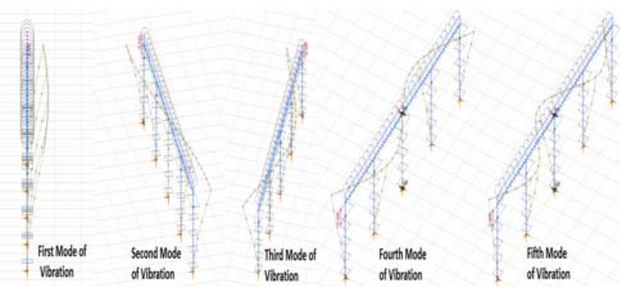

Figure 4. First five mode shapes of FE Analysis in MA, using AxisVM10

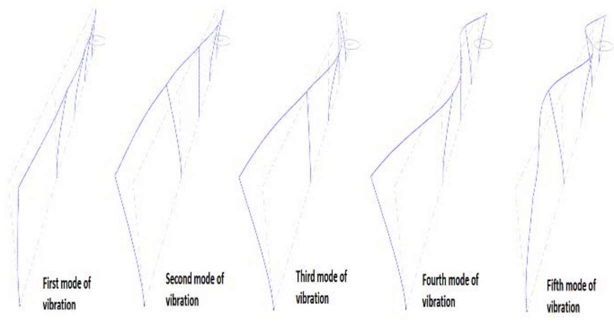

Figure 5. First five mode shapes for FE model build in SAP2000

The results of the sensitivity coefficient for the relative level displacement $\theta_{\max}$, and the maximum displacement d_{max}, at level of the pipelines of 2.2 m, computed using LESA procedure, in SAP2000 and AxisVM10, are given in Table 6.

Table 6. Computational results for seismic sensitivity, LESA procedure

FE Model	Direct. of Seismic Action	$\theta_{\max}$	d_{re} m	d_r^{SLS} m
FE Model in SAP2000	X	0	$0.03\ 10^{-3}$	$0.0618\ 10^{-3}$
	Y	0.1	$0.286\ 10^{-3}$	$0.589\ 10^{-3}$
FE Model in AxisVM10	X	0	0	0
	Y	0.01	$0.292\ 10^{-3}$	$0.601\ 10^{-3}$

The third numerical experiment has been based on THA procedure, performed within the SAP2000 software environment, using the same coefficients as in LESA procedure. The computational results are listed in table 7.

Table 7. Computational results of displacements, THA procedure

Computational Model	Direction of Seismic Action	d_{re} (m)	d_r^{SLS} (m)
FE Model in SAP2000	X	$0.005\ 10^{-3}$	$0.01\ 10^{-3}$
	Y	$0.086\ 10^{-3}$	$0.177\ 10^{-3}$

For the checking of the seismic safety in Safety Limit State (SLS) of the investigated structure, the computational results given in Table 6 and Table 7, respectively, and the formula recommended in P100(2006) have been considered:

$$d_r^{SLS} = \upsilon \cdot q \cdot d_{re} \le d_{r,a}^{SLS} \quad (6)$$

where: υ = seismic reduction factor
q = behaviour factor
d_{re} = maximum displacement result of FEA.

The maximum values of displacements in SLS case are given in Table 6 and Table 7.

According to P100 (2006), the admissible displacements allowed in SLS case, for this class of structures, is determined applying the relationship: $d_{r,a}^{SLS} = 0.008 \cdot h$, with h the level height. This admissible value is 17.6x10^{-3} m for this case study. As it can be identified from Table 6 and Table 7, the values of d_r^{SLS}, based on both LESA and THA procedure, respectively, are less than the admissible limit recommended by the P100(2006) code. Thus, the seismic safety level is satisfied.

5. CONCLUSIONS

The present paper investigated, using a methodology based on FE simulations and dynamic analysis, the seismic safety of the pipeline network system existing in the urban areas of high seismic risk. The FE dynamic analysis has been performed within two different FE computational environments, allowing the checking of the computational accuracy. The case study validated the computational methodology for the evaluation of seismic safety of existing pipeline networks, being suitable for further applications, in case of critical infrastructure's component, operating in seismic urban areas.

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