Effective framework for seismic analysis of cable-stayed-bridges Part 2: Analysis' results.

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ABSTRACT: Referring to the article named "Effective framework for seismic analysis of cable-stayed bridges, part.1" in which the studied structure and its modeling are discussed, in this second part one present the study of the values of the monitored parameters in a statistic way. This in an important aspect in order to evaluate if the number of the considered seismic events may be enough to obtain reliable results. The spatial variability of the ground motion is modelled taking into account a time delay of the displacements imposed at the interaction points structure-terrain. The displacements have been obtained from the integration of artificial generated accelerograms, spectra-compatible with the ones suggested by the Eurocode 8. The time delay between the arrival of the seismic waves at the interaction points structure-terrain depends on the propagation velocity of the shear waves. It is been considered the structural response, with the imposition of the same seismic event, under 10 different velocities of the shear waves, from 200 m/s to 1000 m/s, with the purpose of studying eventual critical aspects of the structural response. The structural response of the bridge is evaluated studying the time histories of 10 monitored parameters, kinematical and tensional.

1 INTRODUCTION

This study deals with the seismic analyses of the bridge over the Cuiabà River; it is a prestressed composite cable-stayed bridge, built up from 2000 to 2001 in Mato Grosso, Brazil, with three spans of 71.75 m, 157 m, 71.75 m, for a total length of about 300m.

Referring to the article named "Effective framework for seismic analysis of cable-stayed bridges, part1: modeling of the structure and of the seismic action" (Bontempi, Sgambi, Santoboni, 2006), in which the studied structure and its modeling are discussed, once having established a list of the monitored parameters of the bridge, it has been done the evaluation of their values in a statistic way, in order to evaluate if the number of the considered seismic events may be enough to obtain reliable results.

2 PROBABILISTIC APPROACH TO THE EVALUATION OF THE RESPONSE OF THE STRUCTURE

It has been done the evaluation of the results in a statistic way, in order to evaluate if the number of the considered seismic events may be enough to obtain reliable results.
Once defined the 10 maximum values of the time histories, reached by every couple of horizontal and vertical generated spostograms, considered in its 3 combinations, the results of both the synchronous and asynchronous motion have been studied. It has been evaluated the seismic combinations maximizing each monitored parameter.

One has considered the estimation of the average, variance and standard deviation. Histograms have been evaluated, showing, for established intervals, the number of the registered events; the gaussian distribution has been drawn, considering the obtained values as continuous variables.
The statistic reliability of the obtained results has been evaluated by the comparison of the shape of the gaussian distribution with the histograms, by the use of the parametrical χ^2 Pearson's test, and doing some physical evaluations.
The χ^2 Pearson's test, utilized for the chosen discretization intervals, corresponding to the assigned probability $\alpha = 0.05$ is negative in for of the examined cases, not verifying the conformity of the results to the theoretic model of continuous variable.
The distribution of the histograms is often not so regular, and in many cases, in the 10 considered cases, an event is positioned outside the boundary corresponding to 95% of probability. In Figure 1 the gaussian distributions and histograms' trends of the values reached by the axial stress of the 7th cable, in the case of asynchronous motion are shown.

Therefore, the obtained results give sufficiently good results, which could be improved by the use of a higher number of considered events.

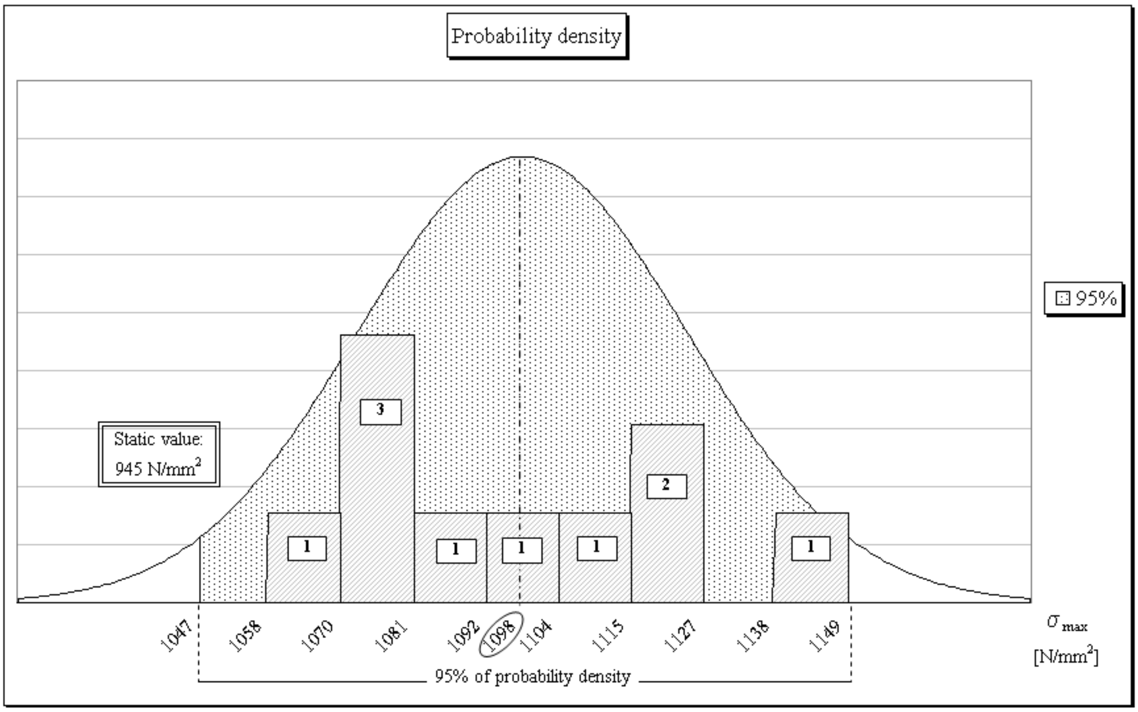


Figure 1. Gaussian distribution and histograms' trends of the values reached by the axial stress of the 7th cable, in the case of asynchronous motion.

3 DETAILED RESULTS

An evaluation has been made of the differences in percentage of the averages of the maximum values reached by each monitored parameter, during the time histories, in both the cases of synchronous and asynchronous motion. Figure 2 shows these differences: there, a percentage major than zero means that in the asynchronous motion the values of the parameters are higher than the synchronous ones. Their values are shown in Table 1.

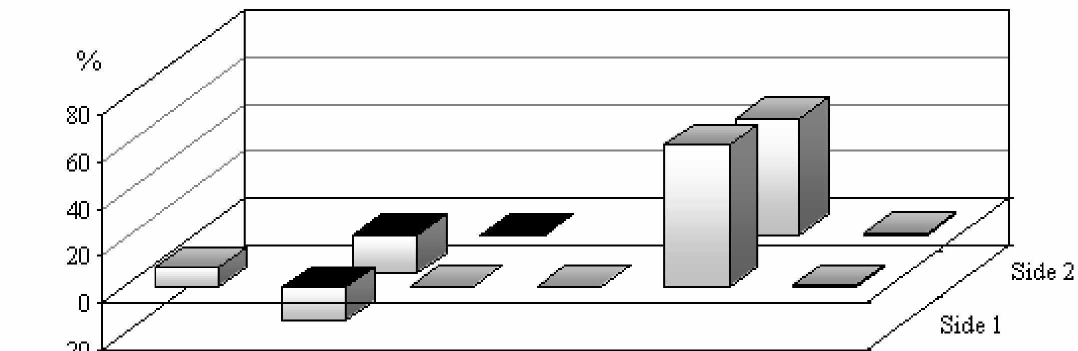
1. Taking into account the asynchronism of the motion leads to substantially different values of the axial force in the middle of the span, whose increment, with respect to synchronous motion, is of about 60%.

2. Differences of about 15% are registered in the transversal displacements of the piers, less than the case of asynchronous motion, however not greater than 3 cm.

3. The differences of the vertical displacements are of 8%; 4 cm in absolute value.

4. There are no remarkable differences on the other parameters, always less than 1%.

Therefore the higher differences are registered in the axial force in the middle of the span in the longitudinal beams; in the case of asynchronous ground motion, in fact, the different displacement imposed at the base of the contact points structure-terrain, because of the time delay, lead to a considerable increment of the force.



	Uz middle	Uy pier	Cable 7	N upp.t.	N middle	My
Side 1	8,19	-14,46	0,20	0,23	60,54	0,75
Side 2		-16,66	-0,03		49,60	0,60

Figure 2. Differences in percentage between the averages of the maximum values of the parameters in both the cases of synchronous and asynchronous motion.

Since the time delay depends on the shear wave velocity, the response of the structure under different values of the velocity has been studied, with the purpose of establishing the dependence between wave velocity and structural response and evaluating the possible existence of a critical value, which may show a particular behavior of the structural response.

With those purposes, the response of the structure has been evaluated under a range of velocity which goes from 200 m/s to 1000 m/s (Tab. 2), even if the lower values are not compatible with a "Eurocode type A" soil, used for the evaluation of the response spectra, under the same seismic event, with the load combination maximizing the earthquake in the longitudinal direction:

seismx + 0.3 seismy + 0.3 seismz

For every parameter, the maximum value of the time history is been registered.

The differences in percentage of the maximum values from the ones obtained in the synchronous case and their trend, function of the wave velocity, are graphically shown in Figures 3 - 8.

Table 1. Values of the parameters in both the cases of synchronous and asynchronous ground motion.

	Side	Synchr	Asynchr
Vertical displ. U_z middle span [m]		-0.27	-0.50
Transversal displ. U_y piers [m]	1	0.08	0.23
	2	0.05	0.20
Axial stress 7th cable [N/mm2]	1	94300	109600
	2	94600	110200
Axial force upper transv. [kN]		434500	498900
Axial force middle span [kN]	1	599700	1779200
	2	581100	2000100
Moment M_y anchoring 7th cable [kN*m]	1	175500	676500
	2	179400	686400

Table 2. Time delay. between the arrival of the seismic waves at the contact point structure-soil.

DISTANCES				
	Abutment 1	Pier 1	Pier 2	Abutment 2
x [m]	-149.75	-78.50	78.50	149.75
Distance [m]	0.00	71.25	228.25	299.50
TIME DELAY [s]				
v [m/s]	Abutment 1	Pier 1	Pier 2	Abutment 2
200	0.00	0.36	1.14	1.50
300	0.00	0.24	0.76	1.00
400	0.00	0.18	0.57	0.75
500	0.00	0.14	0.46	0.60
600	0.00	0.12	0.38	0.50
700	0.00	0.10	0.33	0.43
800	0.00	0.09	0.29	0.37
900	0.00	0.08	0.25	0.33
1000	0.00	0.07	0.23	0.30

1. The more the velocity diminishes, the more the time delay increases, and the effects of the asynchronism are greater.

2. On the average, with velocities from 600-800 m/s up to 1000 m/s, the effects of the asynchronism are evident only for the axial force in the middle of the longitudinal beam, which already for a velocity of 1000 m/s has a difference of 60% from the one computed in the case of synchronous motion.

3. The differences between the values progressively increase as the shear wave velocity decreases; in particular, with the minimum considered velocity of 200 m/s, there are differences of the 600% in the axial force in the middle of the longitudinal beam, of the 500% in the bending moment over the longitudinal beam, at the connection of the 7th cable, and of 200% in the vertical displacement in the middle of the longitudinal beam.

4. The monitored parameters' response develops a nonlinear tread.

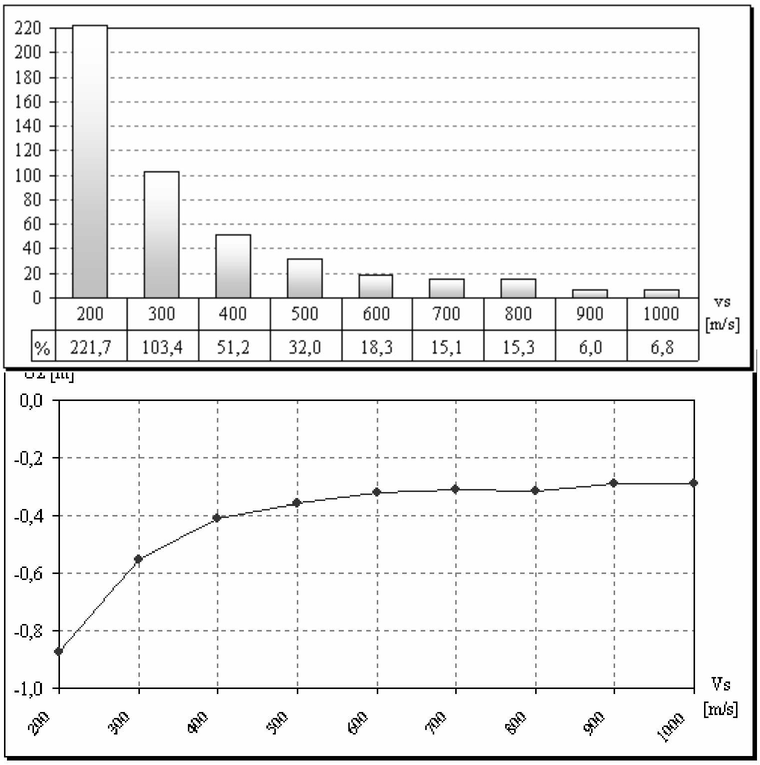


Figure 3. Vertical max. displacement in the middle of the span: differences in % from the max. value obtained in the case of synchronous motion and parameter trend in function of the shear waves velocity.

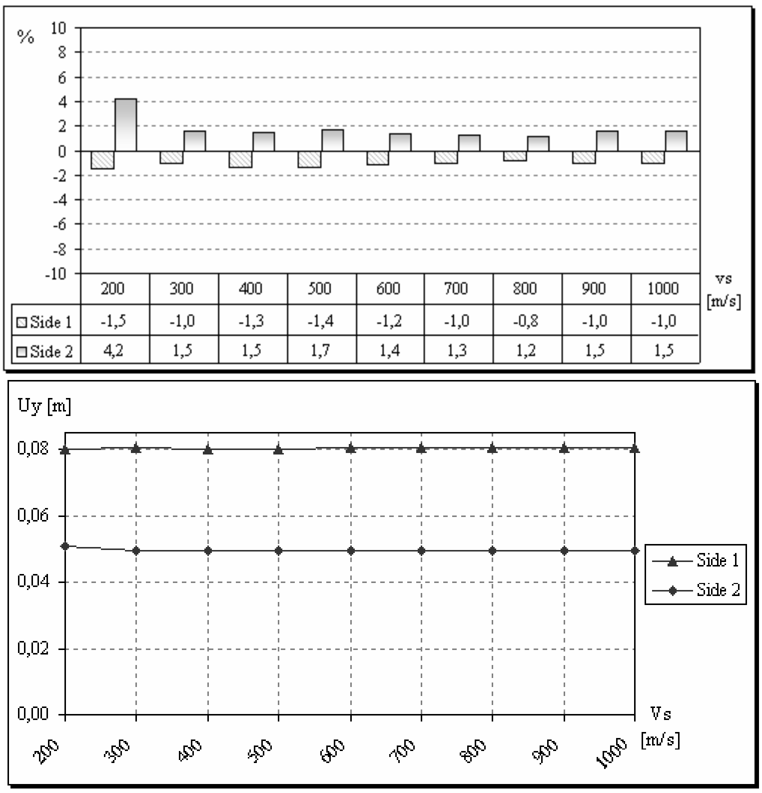


Figure 4. Transversal max. displacement of the pier: differences in % from the max. value obtained in the case of synchronous motion and parameter trend in function of the shear waves velocity

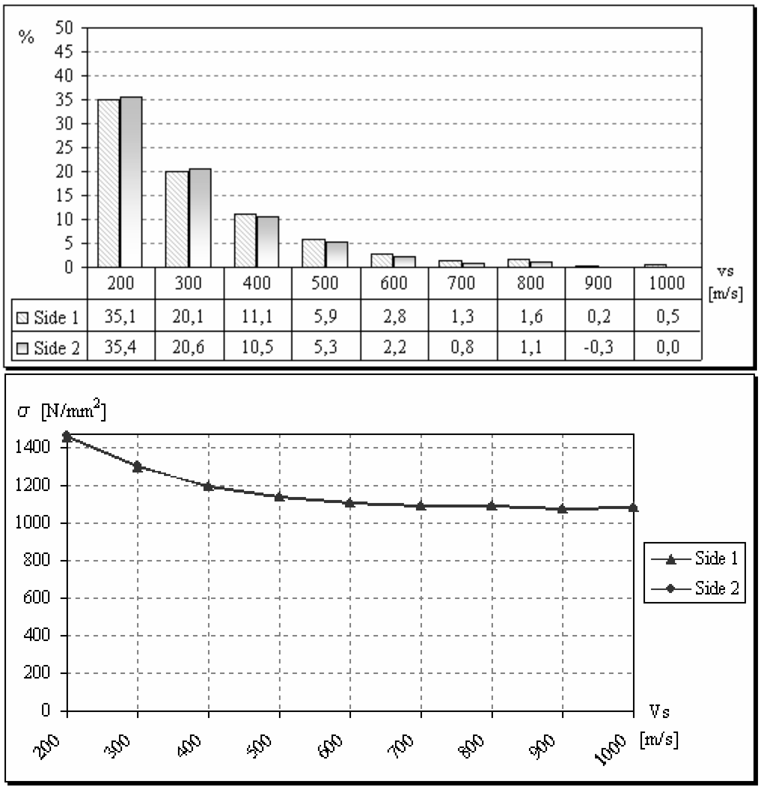


Figure 5. Max. axial stress of the 7th cable: differences in % from the max. value obtained in the case of synchronous motion and parameter trend in function of the shear waves velocity.

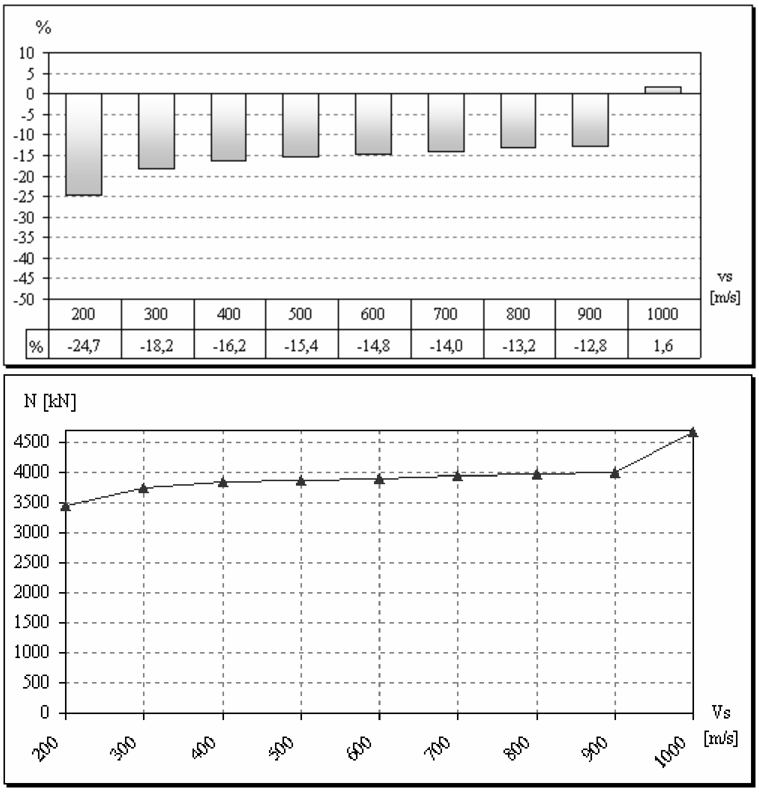


Figure 6. Max. Axial force in the upper transverse: differences in % from the max. value obtained in the case of synchronous motion and parameter trend in function of the shear waves velocity.

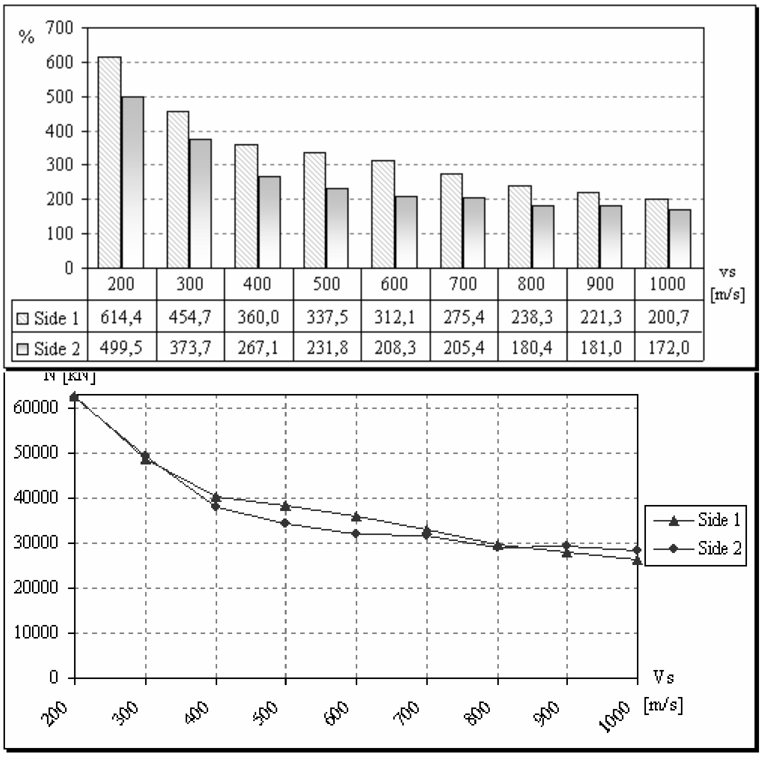


Figure 7. Max. axial force in the middle of the longitudinal beam: differences in % from the max. value obtained in the case of synchronous motion and parameter trend in function of the shear waves velocity.

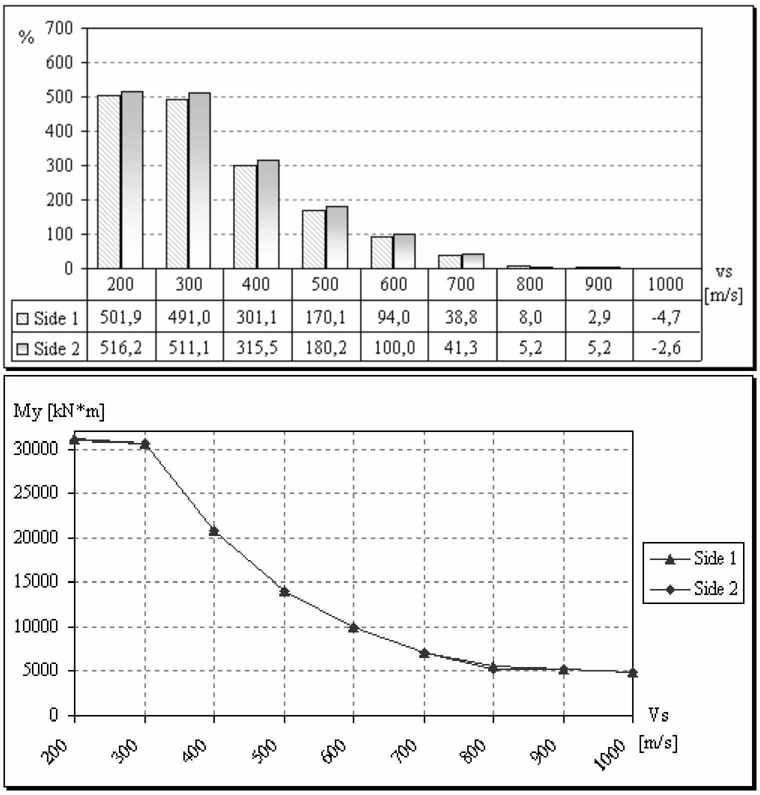


Figure 8. Max. moment at the connection of the 7th cable: differences in % from the max. value obtained in the case of synchronous motion and parameter trend in function of the shear waves velocity.

4 CONCLUSIONS

In this study it is considered the dynamic response of a medium-span cable-stayed-bridge. The bridge is considered by different modelling. The seismic action is assigned by the application of different spostograms, obtained by the double integration of generated spectra compatible accelerograms. It has been evaluated the dynamic response of the structure considering the time histories of static and kinematical parameters under different seismic events, in both the cases of synchronous and asynchronous ground motion. The main results of these studies are:

1. Neglecting the effects of asynchronous ground motion can lead to serious mistakes also into the evaluation of the structural response of medium-span bridges. Considerable differences in the observed parameters are registered only in the axial force in the middle of the longitudinal beam, with an underestimation of 60%;
2. Considering the structural response under different values of the shear wave velocity, from 200 m/s up to 1000 m/s, shows that the differences at the lower velocities are really high; the trend of the values reached by the monitored parameters shows a nonlinear behaviour of the structural response;
3. The statistical evaluation of the results shows that the reliability of the results can be improved by the use of a higher number of considered events.

ACKNOWLEDGMENTS

Thanks to Professor D.M. Frangopol for his useful discussions on this study. The financial supports of University of Rome "La Sapienza" and COFIN2004 are acknowledged. Nevertheless, the opinions and the results presented here are responsibility of the Authors and cannot be assumed to reflect the ones of University of Rome "La Sapienza".

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