SENSITIVITY ANALYSIS ON THE BUILDINGS AND LANDSLIDES 
SEISMIC RESPONSE TO THE APPLICATION OF ARTIFICIAL AND 
RECORDED ACCELEROGRAMS 

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ABSTRACT:

In the paper the results of the dynamic analyses performed on landslides and buildings are presented. The aim of the project is the comparison of the influence due to the application of artificial and recorded accelerograms. So two different sets of artificial and recorded accelerograms have been applied on landslides and buildings. To have the accelerograms a probabilistic approach was adopted, on the basis of the data available from the Italian hazard map, for the studied site, two expected pseudo-acceleration elastic response spectra considering two return period (50 and 475 years) have been selected and used as target spectra. Starting from these targets two sets of seven artificial accelerograms have been calculated and two sets of seven recorded accelerograms have been selected from the available accelerogram database. To perform the dynamic analyses, in the first case (landslides) the method of Newmark has been used and the results, in term of expected displacements, are discussed. In the second case (buildings) the dynamic analyses have been performed using the “MIDAS Gen” software and the results, in term of storey base shear, acceleration and interstory drift are presented. The results, obtained by the application of the different sets of accelerograms, are similar, suggesting, in this kind of analysis, the possible use of both artificial and recorded accelerograms.

KEYWORDS: recorded accelerogram, artificial accelerogram, landslide, r.c. frame building, dynamic nonlinear time history analysis.

1. INTRODUCTION

To accurately evaluate the seismic behaviour of buildings and landslides it is necessary to use dynamic analyses. Obviously the choice of the seismic input is a fundamental step to perform a correct analysis. The seismic input can be expressed in term of artificial or recorded accelerograms. In both cases the accelerograms have to be well-matched with the expected pseudo-acceleration elastic response spectra of the studied site. In the case of recorded accelerograms, the choice is related to the knowledge of seismic characteristics of the site as the expected magnitude-distance combination, data not easily available. On the other hand, the characteristics of the artificial accelerograms (e.g. frequency content, duration, etc.) are strictly dependent on the generation methodologies and can be very different from the recorded ones. In some seismic codes the use of recorded accelerograms is suggested. In this paper, the results obtained by the application of both input types are discussed.

For the definition of the seismic input a probabilistic approach was adopted, because the studied site is located in a region where the seismic structures are still not very well known. Therefore, as it was impossible to separate the seismic hazard contribution coming from the possible sources, the cumulative contribution, on a probabilistic basis, was derived from all relevant neighbouring seismogenetic areas, which better represents an envelope of the expected seismic actions. On the basis of the data available from the Italian hazard map (Gruppo di Lavoro, 2004), for the studied site, two 5% damped pseudo-acceleration elastic response spectra, with return periods of 50 and 475 years, were selected and considered as target spectra. For each return period one sets of seven artificial and one sets of seven recorded accelerograms selected from available database were considered. These sets of inputs were used to perform dynamic analyses of different existing buildings and landslides.
1.1. Artificial accelerograms

Starting from each pseudo-acceleration elastic response spectrum of target (50 and 475 years) seven non-stationary accelerograms were generated through the procedure proposed by (Sabetta and Pugliese, 1996); the procedure is based on the Arias value (Arias, 1970) and the duration of the significant phase of the accelerogram: to obtain these parameters seven values of magnitude-distance couples, compatible with the expected maximum acceleration value, were chosen. In Figure 1 the uniform pseudo-acceleration elastic response spectrum of target and the response spectra of the computed artificial accelerograms, for the two return periods, are plotted. In the same Figure two accelerograms used in the analyses, for the two return periods, are presented.

1.2. Recorded accelerograms

The recorded accelerograms were selected from strong motion record databases (ESD, PEER, COMOS), fixing the constraint of the spectrum compatibility with the target spectrum defined from the probabilistic seismic hazard assessment. The selection of the seven real spectrum-compatible accelerograms was conducted by using an algorithm (Dall’Ara et al., 2006) that automatically combines the records downloaded from the strong motion databases and identifies the best set that more reproduce the probabilistic response spectrum. The first criterion for the selection of real accelerograms is the geological characteristics of the site where the accelerometric station is installed. The site must be classified as a stiff soil site. Finally, the selected accelerograms were scaled to the target peak ground acceleration in order to have a good fitting of the mean response spectrum with respect to the probabilistic spectrum. A threshold of the scaling factor could be considered as further criterion of selection. In Figure 2 the uniform pseudo-acceleration elastic response spectrum of target, the response spectra of the recorded accelerograms and the average response spectrum of the recorded accelerograms, for the two return periods, are plotted. In the same Figure two accelerograms used in the analyses, for the two return periods, are presented.

In Table 1.1 the main characteristic parameters of the artificial and recorded accelerograms are reported: pga—peak ground acceleration, pgv—peak ground velocity, $s_{25}$—spectral intensity (period 0.1-2.5 s, Housner, 1952), $s_{05}$—spectral intensity (period 0.1-0.5 s), a.i.—Arias intensity (arias, 1970), $d_{90}$—Trifunac duration (Trifunac and Brady, 1975), $T_{90}$—dominant period at $d_{90}$, $P_{90}$—destructive potential (Saragoni et al., 1989) at $d_{90}$, $d_t$—total duration, $T_m$—dominant period at $d_t$, $P_d$—destructive potential at $d_t$.

As shown in the Table the average of the characteristic parameters of the artificial and recorded accelerograms are similar, particularly considering the $s_{25}$ and $s_{05}$ parameters.
2. LANDSLIDES

2.1. Geologic, geomorphologic and geotechnical characteristics of the landslide

The analyzed landslide is characterized by alluvial deposits (debris and clay) on marls and limestones. It is a complex rotational slide (Figure 3), in particular the sector c is identified as an active landslide, instead the sectors a and b are classified as inactive landslides. The area of the entire landslide is 400,000 m², the volume is 8 million m³, the length is 1,080 m, the width is 590 m and the maximum depth is 50 m.
On the basis of the geotechnical (11 bore-holes, 9 SPT tests, inclinometric and piezometric measures), geophysical (10 seismic refraction profiles) investigations and using the results of the laboratory tests (13 samples), the characteristics of the landslide materials, used in the analyses, have been obtained (Table 2.1 where $V$: volume, $M$: mass, $\rho$: density, $\phi$: friction angle, $\alpha$: failure surface angle).

### 2.2. Dynamic analysis method

The method used to determine the displacement of a landslide during an earthquake is the one proposed by Newmark (1965). This method calculates the response of a body, that stands on an inclined surface to a seismic acceleration acting at the base. It assumes the landslide is a rigid block with its own frictional properties at the surface-block boundary. The aim of the calculation is to determine the relative displacement induced by an earthquake of known characteristics and to estimate the stability of a mass during a seismic event. The base-block interface has a rigid-plastic behaviour and the resistance is expressed by the Mohr-Coulomb criterion. In the analysis it is assumed that if the limit resistance is exceeded a relative displacement between the base and the block may occur, representing the landslide. When the relative velocity becomes zero the block is again in contact with the base until the limit resistance is exceeded another time. This method can be applied on the whole landslide, after calculating the resultant of the resistant and acting forces. Displacement steps are summed up over the duration of the acceleration time history.

### 2.3. Results

The dynamic analyses, considering the accelerograms characterized by a return period of 475 years, were performed to the different sectors of the landslide, in particular the entire landslide, the a-b landslide and the c landslide. For each landslide a parametric analyses, considering three different level of the water table, was performed (saturation of 40%, 50% and 60%).

Table 2.2 shows the results, in term of final displacements, are shown applying the artificial accelerograms and recorded accelerograms. In the Table the average final displacements, applying the different accelerograms, are reported.

### Table 2.1 Geometric and geotechnical characteristics of the landslides

<table>
<thead>
<tr>
<th></th>
<th>$V$ (m$^3$)</th>
<th>$M$ (t)</th>
<th>$\rho$ (t/m$^3$)</th>
<th>$\phi$ (°)</th>
<th>$\alpha$ (°)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Entire landslide</td>
<td>24.347</td>
<td>48.450</td>
<td>1.99</td>
<td>17</td>
<td>10.0</td>
</tr>
<tr>
<td>a-b landslide</td>
<td>10.447</td>
<td>20.790</td>
<td>1.99</td>
<td>17</td>
<td>10.5</td>
</tr>
<tr>
<td>c landslide</td>
<td>2.980</td>
<td>5.930</td>
<td>1.99</td>
<td>17</td>
<td>11.0</td>
</tr>
</tbody>
</table>

### Table 2.2 Displacements (m) applying the artificial (left) and recorded (right) accelerograms

<table>
<thead>
<tr>
<th>Entire landslide</th>
<th>acc 1</th>
<th>acc 2</th>
<th>acc 3</th>
<th>acc 4</th>
<th>acc 5</th>
<th>acc 6</th>
<th>acc 7</th>
<th>average</th>
</tr>
</thead>
<tbody>
<tr>
<td>40%</td>
<td>0.027</td>
<td>0.032</td>
<td>0.029</td>
<td>0.024</td>
<td>0.027</td>
<td>0.025</td>
<td>0.034</td>
<td>0.028</td>
</tr>
<tr>
<td>50%</td>
<td>0.059</td>
<td>0.059</td>
<td>0.058</td>
<td>0.050</td>
<td>0.058</td>
<td>0.058</td>
<td>0.057</td>
<td>0.057</td>
</tr>
<tr>
<td>60%</td>
<td>0.127</td>
<td>0.120</td>
<td>0.113</td>
<td>0.121</td>
<td>0.105</td>
<td>0.134</td>
<td>0.121</td>
<td>0.121</td>
</tr>
<tr>
<td>a-b landslide</td>
<td>acc 1</td>
<td>acc 2</td>
<td>acc 3</td>
<td>acc 4</td>
<td>acc 5</td>
<td>acc 6</td>
<td>acc 7</td>
<td>average</td>
</tr>
<tr>
<td>40%</td>
<td>0.043</td>
<td>0.045</td>
<td>0.044</td>
<td>0.037</td>
<td>0.043</td>
<td>0.036</td>
<td>0.051</td>
<td>0.043</td>
</tr>
<tr>
<td>50%</td>
<td>0.091</td>
<td>0.098</td>
<td>0.091</td>
<td>0.081</td>
<td>0.090</td>
<td>0.073</td>
<td>0.099</td>
<td>0.089</td>
</tr>
<tr>
<td>60%</td>
<td>0.210</td>
<td>0.186</td>
<td>0.191</td>
<td>0.194</td>
<td>0.196</td>
<td>0.186</td>
<td>0.217</td>
<td>0.197</td>
</tr>
<tr>
<td>c landslide</td>
<td>acc 1</td>
<td>acc 2</td>
<td>acc 3</td>
<td>acc 4</td>
<td>acc 5</td>
<td>acc 6</td>
<td>acc 7</td>
<td>average</td>
</tr>
<tr>
<td>40%</td>
<td>0.067</td>
<td>0.066</td>
<td>0.066</td>
<td>0.057</td>
<td>0.066</td>
<td>0.052</td>
<td>0.074</td>
<td>0.064</td>
</tr>
<tr>
<td>50%</td>
<td>0.146</td>
<td>0.135</td>
<td>0.140</td>
<td>0.130</td>
<td>0.139</td>
<td>0.122</td>
<td>0.153</td>
<td>0.138</td>
</tr>
<tr>
<td>60%</td>
<td>0.372</td>
<td>0.324</td>
<td>0.348</td>
<td>0.336</td>
<td>0.343</td>
<td>0.379</td>
<td>0.346</td>
<td>0.350</td>
</tr>
</tbody>
</table>
In Figures 4 and 5 the displacements vs. the time, for the artificial and recorded accelerograms respectively, are shown, considering the three analyzed landslides and the different water levels.

As shown in the Figures, the c landslide presents the most dangerous situation, confirming the geomorphologic analysis (active landslide), instead the analysis performed considering the entire landslide gives the lowest displacements. The influence of the water level is fundamental, in fact the water levels at 50% and 60% produce displacements that can influence the stability of the buildings. Considering the results in term of average final displacements, it is noticed that the differences got applying the two sets of accelerograms (artificial and recorded) are not very high. In general the displacements obtained by the application of the recorded accelerograms are lower than the other one, probably due to the lower values, for some periods, of the average response spectrum of the recorded accelerograms with respect to the target spectrum.

The dynamic analyses, considering the accelerograms characterized by a return period of 50 years, were performed only on the c landslide, considering a saturation of 60%, because in the other cases the displacements are negligible. In Table 2.3 the results, in term of final displacements, are shown applying the artificial accelerograms and recorded accelerograms. In the Table the average final displacement, applying the different accelerograms, is reported. In Figure 6 the displacements vs. the time for the artificial and recorded accelerograms are shown. Also in this case the results in term of average final displacements applying the two sets of accelerograms (artificial and recorded) are similar.

Table 2.3 Displacements (m) applying the artificial recorded accelerograms

<table>
<thead>
<tr>
<th>c landslide artificial accelerograms 50 years</th>
<th>c landslide recorded accelerograms 50 years</th>
</tr>
</thead>
<tbody>
<tr>
<td>acc 1</td>
<td>acc 2</td>
</tr>
<tr>
<td>60%</td>
<td>0.024</td>
</tr>
</tbody>
</table>

Figure 4 Displacement (m) behaviour applying the artificial accelerograms

Figure 5 Displacement (m) behaviour applying the recorded accelerograms

Figure 6 Displacement (m) behaviour applying the artificial and recorded accelerograms
3. BUILDINGS

3.1. Characteristics of the analysed buildings

The first building, designed according to the old Italian seismic code, is a three-storey r.c. frame building with masonry infill. The shape of the building (Figure 7) is roughly rectangular (33m x 10m). The frames are mono-directional and oriented parallel to the short sides. Concrete mean strength is \( f_{cm}=37\text{MPa} \) and steel mean yielding stress is \( f_{ym}=514\text{MPa} \) (Feb44k) for both longitudinal and transversal steel. The second building, designed without any seismic prescription, is a four-storey r.c. frame building with masonry infill. The shape of the building (Figure 8) is roughly rectangular (36m x 12.7m) with two r.c. cores. The frames are mainly mono-directional and oriented parallel to the long sides. Concrete strength is \( f_{cm}=37\text{MPa} \) and steel yielding stress is \( f_{ym}=514\text{MPa} \) (Feb44k) for both longitudinal and transversal steel.

![Figure 7 Building 1](image1)
![Figure 8 Building 2](image2)

3.2. FEM models and dynamic analysis method

The nonlinear time-history dynamic analyses were developed through the software MIDAS Gen Ver. 721. The inelasticity in beams and columns was modeled with distributed plasticity fiber elements. The fiber constitutive models used for concrete and steel were the Kent and Park model (1971) extended by Scott e al. (1982) and the Menegotto and Pinto model (1973), respectively. The core walls of the second buildings were described using Shear-Wall elements included on the Finite Element Library of MIDAS program coupled with Drucker-Prager plasticity model (1952). Each floor was considered as a rigid diaphragm in its plane, and its mass was lumped at the centre of mass; hence for each floor only three degree of freedom were considered. The soil-structure interaction was neglected. The analyses were performed considering accelerograms acting in X and Y direction separately.

The implicit method of Newmark was adopted to integrate the equation of motion of the discrete system, performing full Newton-Raphson iterations until convergence was attained. In particular it was adopted a constant acceleration method, with the Newmark parameters \( \gamma=1/2 \) and \( \beta=1/4 \). A viscous damping was adopted by defining the damping matrix as proportional both to the mass matrix and to the stiffness matrix and fixing at 5% the damping ratio for both the first and the second period of the structure.

3.3. Results

For the comparison between the results obtained with the recorded and the artificial accelerograms the relative floor accelerations, the interstory drift ratio and the shear ratio were selected and reported for building 1 in Figures 9, 10 and 11, respectively. In all figures, the continuous lines refer to 475 years return period and dashed lines refer to 50 years return period. On the left are shown the results for accelerograms acting in the X and on the right the ones for accelerograms acting in the Y direction. For all the three considered quantities the differences between recorded and artificial accelerograms are very limited.
Similar results were obtained for building 2. As an examples in Figure 12, the shear ratio for the return periods of 50 and 475 years is shown: the left graph refers to the X direction and the right one refers to the Y direction.

4 CONCLUSIONS

As a general conclusion, on the bases of the results obtained, it is possible to notice that the use of recorded and artificial accelerograms leads to similar results, on the average, both in the case of buildings and landslides. This is obviously a preliminary result: further analyses have to be performed considering different types of buildings and landslides. Moreover other criteria of generation and selection of accelerograms have to be investigated.
ACKNOWLEDGMENTS
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REFERENCES


ESD. European Strong Motion Database. http://www.isesd.cv.ic.ac.uk/.


