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INTERACTIVE WEB-BASED SOFTWARE FOR SEISMIC SAFETY ASSESSMENT OF SPECIAL IMPORTANCE BUILDINGS

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ABSTRACT

Recently, some advanced approaches for seismic risk assessment, such as the Hazus software (FEMA, 1999) and the Risk-UE (Mouroux and Lebrun, 2006) project have been developed. These approaches are based on the capacity spectrum method which considers a uniform acceleration response spectrum to represent the hazard ground motion and a capacity spectrum to represent the vulnerability of a structure.

In order to update the SISMICAT (2003) emergency management plan in Catalonia, Spain, and to contribute to study the seismic risk at a municipality scale, a simplified methodology based on the capacity spectrum method is proposed for evaluating the seismic safety of buildings of special importance as hospitals and schools. The definition of the seismic actions is based on the results of a probabilistic seismic hazard assessment for the region. The acceleration response spectra have been scaled and adjusted according to the Eurocode 8 (CEN, 2003) spectral shapes and the soil effects are also included based on the results of a seismic mesozonation. The buildings are classified into structural typologies and described by a bilinear capacity spectrum. The expected damage has been estimated for return periods of 475 and 975 years.

Finally, the safety of the buildings of the special importance is assessed based on the expected damage and the seismic performance levels suggested by the Vision 2000 (SEAOC, 1995) committee. The seismic performance is evaluated for return periods of 475 and 975 years based on the Operative and Life Safety performance levels, respectively. Also functionality and losses indexes are evaluated as well as an estimation of the recovery time based on the methodology proposed by Valcárcel (2013).

An interactive web-based software, ASSEE, is being developed to implement the method proposed. For the validation and the verification of this interactive web-based software, an application to a set of schools of Catalonia is presented.

INTRODUCTION

The seismic emergency management plan for the Catalonia region, SISMICAT (2003), analysed the seismic risk at the municipality scale. The municipalities with the higher seismic risk were identified and required to draft their own and more detailed seismic emergency action plans. In order to

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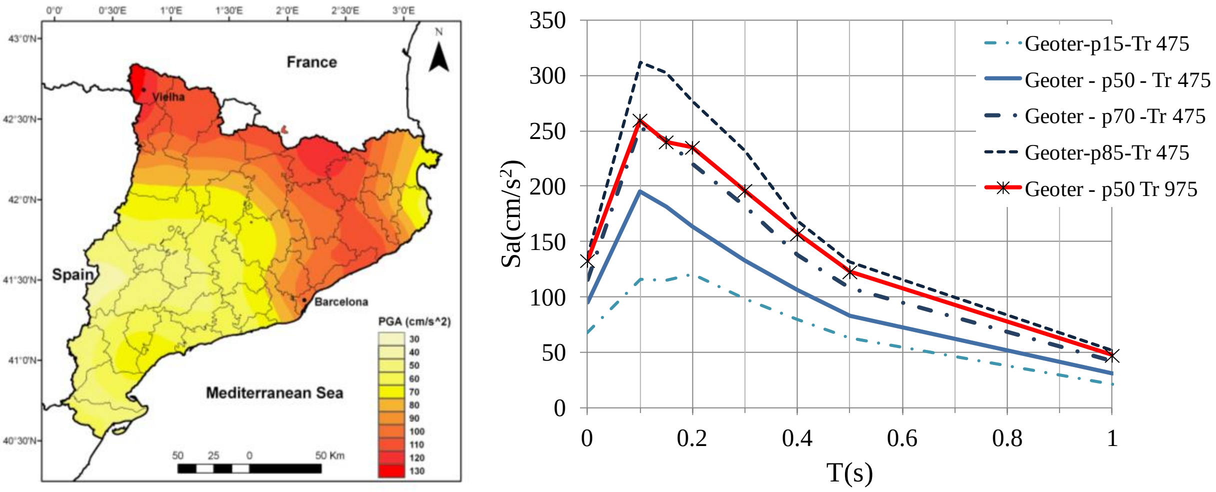
contribute to the development of these detailed seismic action plans, the interactive software ASSEE will allow its users to evaluate the seismic risk and safety for buildings of especial importance within these municipalities. ASSEE stands for evaluation of the seismic safety of special importance buildings or Avaluació de la Seguretat Sísmica d'Edificis d'Especial importància, in Catalan.

The ASSEE software is designed based on the methodology for the seismic safety evaluation developed by Valcárcel (2013) which consists of a simplified application of the capacity spectrum method for evaluating the seismic safety of buildings of special importance as hospitals and schools. The methodology proposed by Valcárcel (2013) includes guidelines for estimating the seismic action expected to affect the building and for evaluating its expected seismic performance, probable seismic damage and its associated level of safety.

The ASSEE software will be available to be used through the Internet by municipality officials for performing individual seismic safety evaluation to the buildings identified as of special importance for the municipality. The user will specify the basic information for the special importance building to be analysed and the ASSEE software will perform the whole seismic safety evaluation. The results will be available in a summary report as proposed by Bosch (2013).

Estimating the seismic action

The local seismic action used for this evaluation comes in the form an acceleration spectra obtained from the Probabilistic Seismic Hazard Analysis (PSHA) developed for Catalonia by IGC and GEOTER (2008). This study produced mean values (p50), and percentiles 15 (p15) and 85 (p85) of the spectral acceleration for return periods of 475, 975 and 1975 years. Fig.1a shows the Peak Ground Acceleration (PGA) for a return period of 475 years, while Fig.1b shows the acceleration spectra, for different percentiles and return periods for the city of Barcelona.



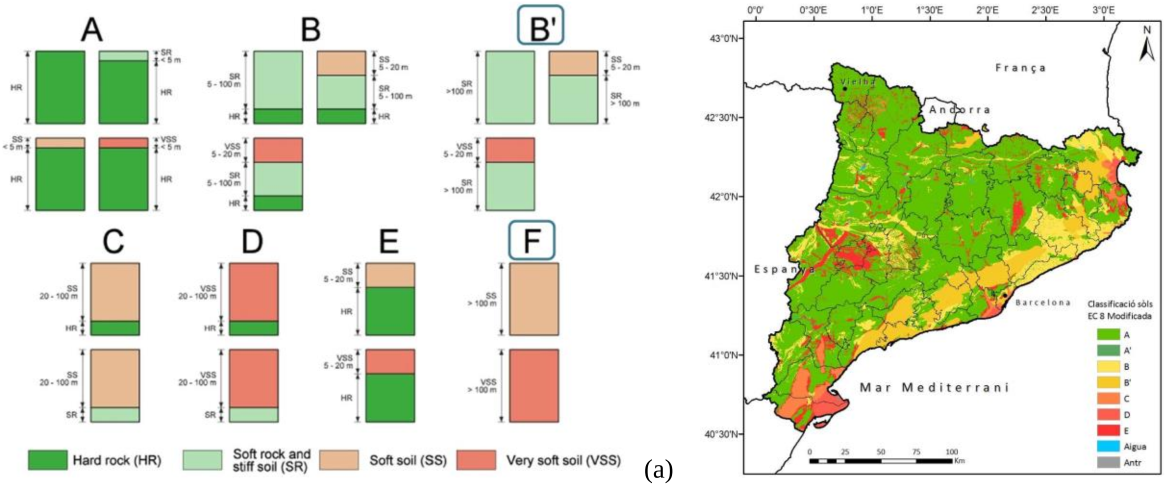
(a) (b)

Figure 1. PSHA results (IGC, 2008): a) PGA for a return period (Tr) of 475 years; b) Acceleration spectra for different percentiles and return periods for the city of Barcelona

For the safety assessment these acceleration spectra are modified to be adjusted to the form of the Type II spectral shape of the Eurocode 8 (EC8) (CEN, 2003) following the recommendations of Bosch (2013). In order to consider site effects, the soil type at the location of the special importance buildings has been identified using the seismic mesozonation map developed for Catalonia (IGC, 2011).

Seismic mesozonation map of Catalonia

The seismic mesozonation map of Catalonia (IGC and GEOCAT, 2013) at a scale of 1:100,000 is a simplification of the geological map based on the soil classification proposed by the EC8 that was adapted to the Catalonia region. This soil classification considers soil geomechanical characteristics, its thickness and the velocity contrast of the adjacent layers. The soil classification of the Catalonia mesozonation includes a total of 7 soil classes (Fig.2a). Two of these soil classes are modifications from those available on the EC8 as they incorporate the effect of the deeper geologic features: B', which includes soft rocks thicker than 100 m, and F class, representing soft or very soft soils of a single layer with a thickness of more than 100 m. Fig. 2a shows the representation of the soil columns corresponding to the 7 soil classes while the mesozonation map of Catalonia is shown in Fig.2b.



(a) (b)

Figure 2. Modified EC-8, soils classification in Catalonia (IGC, 2011)

The seismic site effect of each of the soil classes was analysed within the scope of the SISPYR project and a normalized acceleration response spectrum including soil effects was obtained for each one of the soil classes allowing in this way to finally obtain a local acceleration response spectrum adequate to the soil conditions for each of the special importance buildings being analysed (Colas et al., 2012). These normalized acceleration response spectra with soil effects are shown in Fig.3.

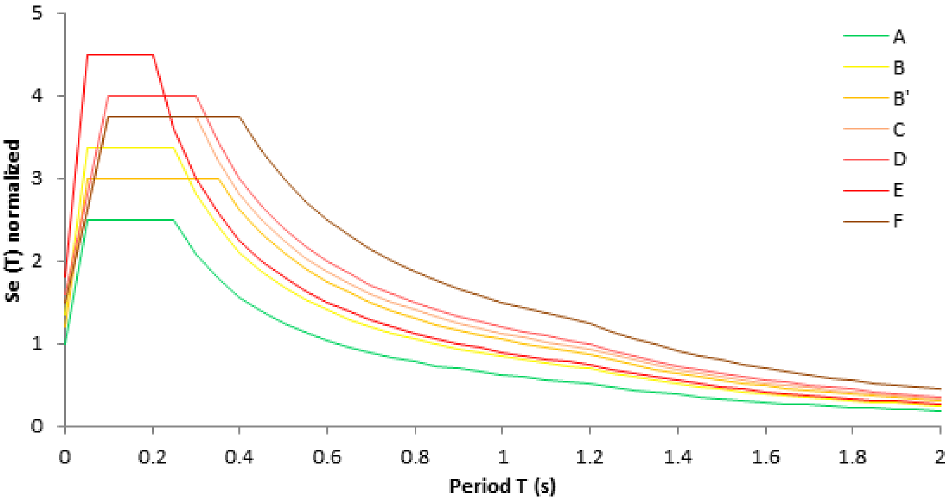


Figure 3. Normalized acceleration response spectra proposed for each mesozonation soil class, defined on Fig.2 (Colas et al., 2012)

Vulnerability of the special importance buildings

To evaluate the vulnerability of the special importance buildings, Valcárcel (2013) proposed to perform a visual inspection of the buildings in order to establish the main structural properties of the buildings and to collect and analyse construction memories and architectonic and structural plans. This data has been collected using the seismic vulnerability forms developed by the Geological Institut of Catalonia (IGC) and the Universitat Politècnica de Catalunya (IGC and UPC 2010). Using this form, buildings are classified into structural typologies according to the building typology matrix of the RISK UE project (Milutinovich and Trendafiloski, 2003). Each one of these structural typologies is characterized by a bilinear capacity spectrum. This spectrum is described by the yielding (sd_y, sa_y) and ultimate capacity points (sd_u, sa_u) (Fig.4a).

Seismic performance of school buildings

Once a capacity spectrum has been assigned to each of the special importance buildings studied, the seismic performance is estimated for seismic actions associated to return periods of 475 and 975 years by using the capacity spectrum method. The performance point, the intersection between the capacity spectrum and the correspondent demand spectrum, is estimated following the equal displacement approximation (Fig.4a) as suggested in the RISK UE project. It represents the maximum spectral displacement due to the specific seismic demand considered.

The displacement of the performance point will allow obtaining the damage probability distribution using fragility curves available for each structural typology as indicated by Valcárcel (2013). The fragility curves (Fig.4b) define the probability that the expected damage exceeds a specific damage grade (1-light, 2-moderate, 3-extensive, 4-complete). Once the damage probability distribution is obtained, the mean damage grade can be calculated as the weighted mean of the damage states with respect to its corresponding probability. The mean damage grade value will allow evaluating the seismic safety level of the studied essential building.

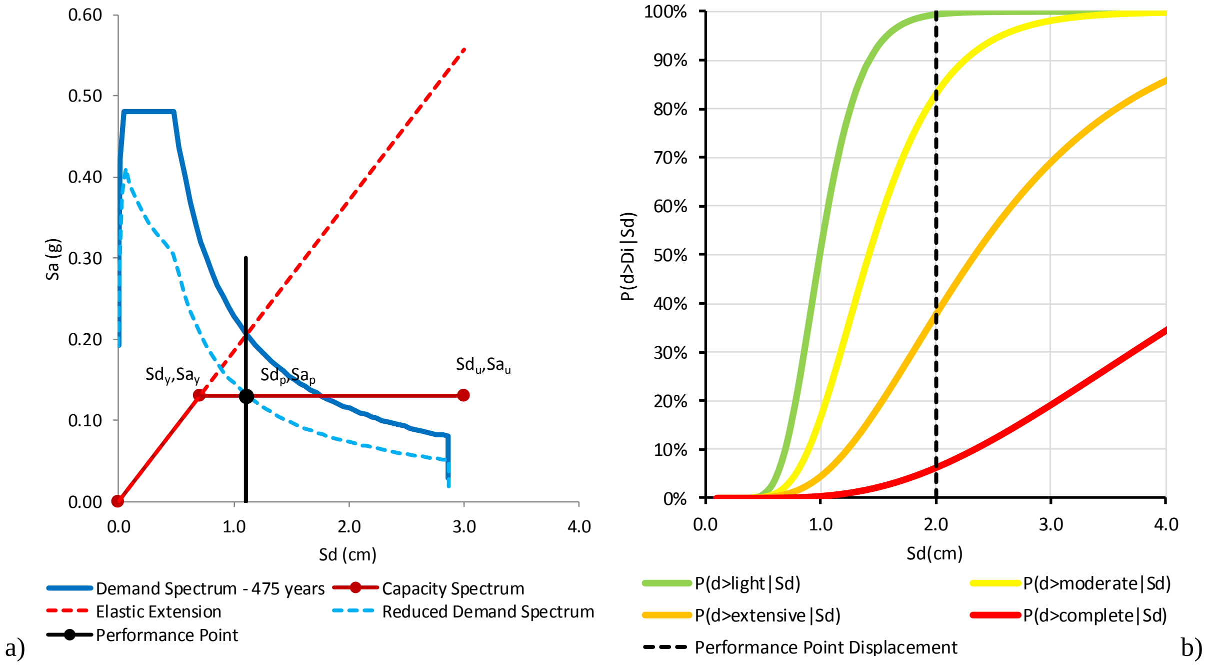


Figure 4. a) Obtaining the performance point using the capacity spectrum method and b) fragility curves for obtaining the damage probability distribution

Seismic safety evaluation

To evaluate the seismic safety of the special importance buildings, Valcárcel (2013) recommended using the mean damage grade and the seismic performance levels suggested by the Vision 2000 Committee. Table.1 shows a summary description of these performance levels suggested. According to the Committee buildings considered as important or essential should comply with the *Operational* performance level (light to moderate damage) for a return period of 475 years and *Life Safety* (moderate to extensive damage) for a return periods of 975 years. Valcárcel (2013), considering the damage scale suggested by Rosseto and Elnashai (2003), stated that a maximum mean damage grade of 2.0 for a return period of 475 years is allowed to comply with the *Operational* performance level and a maximum mean damage grade of 2.8 is allowed for the *Life Safety* performance level. Considering the normalized mean damage grade, these maximum values correspond to 0.5 and 0.7, respectively.

Table 1. Performance levels suggested by the Vision 2000 Committee (SEAOC, 1995).

Performance Level	Description	Damage State	Return Period (Years)
Fully Operational	Continuous service, facility operates and functions after the earthquake. Negligible structural and non-structural damage.	No Damage	72
Operational	Structure is safe for occupancy immediately after the earthquake. Most operations and functions can resume immediately. Repair is required to restore some non-essential services. Damage is light.	Reparable	475
Life Safety	The structure is damaged but remains stable and life safety is generally protected. Damage is moderate. The building can probably be repaired, but it may not be economically feasible.	Probably Reparable	975

Economic Loss Index, Functionality Index and Recovery Time

Valcárcel (2013) also proposed three additional parameters to evaluate the impact of the expected seismic damage. These parameters are the economic loss index, the functionality index and the estimation of the recovery time. The economic loss index depends on the damage probability distribution while the functionality index and the recovery time depend on the normalized mean damage grade as shown in Fig.5. As can be seen for the operational performance level the functionality index is expected to be higher than 0.25 and the recovery time is expected to be lower than 160 days.

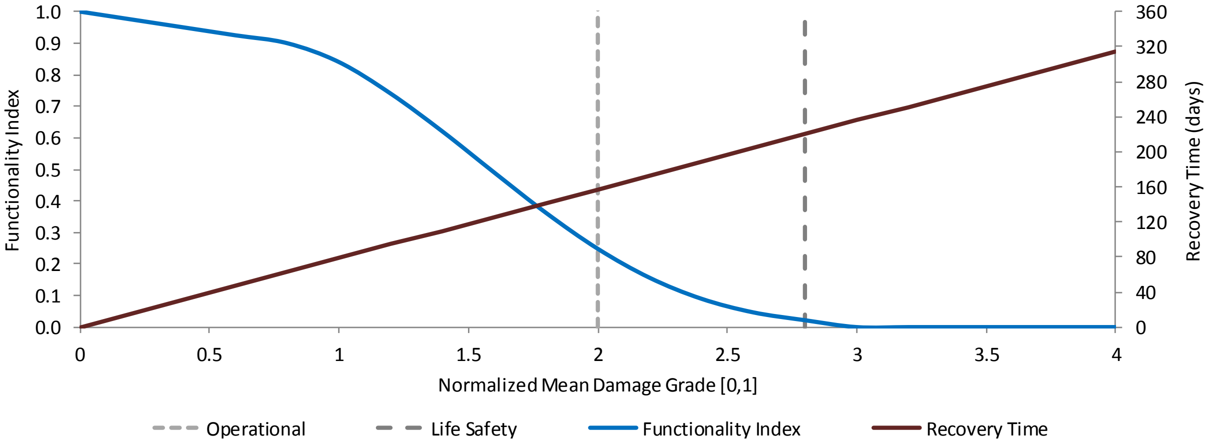


Figure 5. Functionality index and recovery time depending on the normalized mean damage grade

ASSEE Software

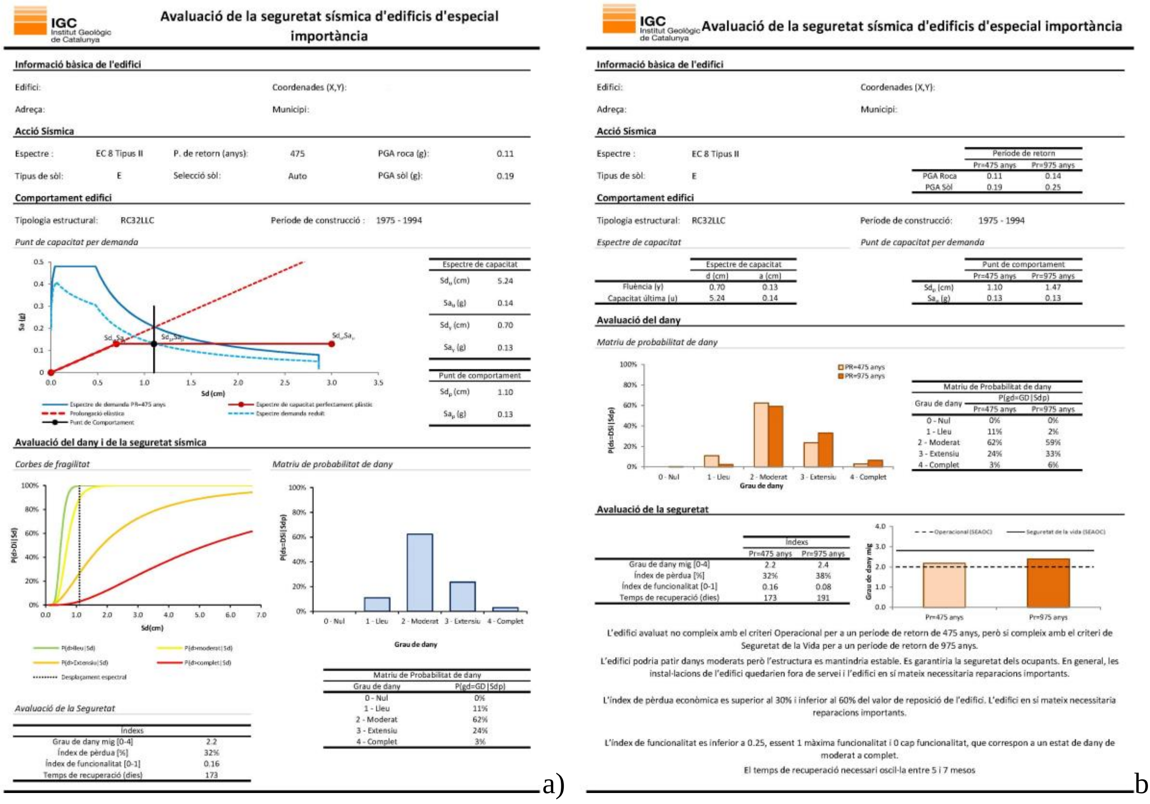
When the ASSEE software is finally implemented in its web platform, the user only will have to enter some basic info of the analysed building to obtain a detailed evaluation of the expected seismic damage and safety for return periods of 475 and 975 years following the presented methodology from Valcárcel (2013). This detailed seismic safety evaluation will be summarized following the result report designed by Bosch (2013) during its application of the methodology to a sample of educative centres from the city of Barcelona.

The ASSEE user will have to provide some basic info about the structure to be analysed. This information includes: name, address, location coordinates, economic value and the structural typology previously determined using the seismic vulnerability form from IGC (2010). The program can determine automatically the soil class at the site of the structure or the user can enter it manually.

Then the program will calculate the performance point, the damage probability matrix, the mean damage grade, the functionality index, the economic loss index, the recovery time and an automatic analysis of the results for both return periods of 475 and 975 years. These results will be then saved temporally to be presented to the user. The user will be given the choice to print or save the results in PDF format.

The results report consists of 3 pages. The first presents the results of the whole process of the seismic safety evaluation for a return period of 475 years, while the second does the same but for a return period of 975 years. This type of page (Fig.6a) shows the basic data of the building, the seismic action that affects it, a graphical representation of the performance point determination, the fragility curves considered, the obtained damage probability distribution, the mean damage grade, the economic loss index, the functionality index and the expected recovery time.

The third page (Fig.6b) of the results report provides a comparative summary of the results for both return periods and the analysis of the seismic safety of the structure. The summary compares the seismic action, performance point, damage probability distribution, the mean damage grade and the other safety evaluation parameters for the return periods of 475 and 975 years. The final part of this summary page shows the safety evaluation of the building stating if it fulfils the requirements for the Operational and Life Safety performance levels proposed by the Vision 2000 Committee.



IGC Institut Geològic de Catalunya

Avaluació de la seguretat sísmica d'edificis d'especial importància

Informació bàsica de l'edifici

Edifici:
Coordenades (X,Y):
Adreça:
Municipi:

Acció Sísmica

Espectre : EC 8 Tipus II
P. de retorn (anys): 475
PGA roca (g): 0.11
Tipus de sòl: E
Selecció sòl: Auto
PGA sòl (g): 0.19

Comportament edifici

Tipologia estructural: RC32LLC
Període de construcció : 1975 - 1994

Punt de capacitat per demanda

Espectre de capacitat	
Sd_u (cm)	5.24
Sa_u (g)	0.14
Sd_y (cm)	0.70
Sa_y (g)	0.13

Punt de comportament	
Sd_p (cm)	1.10
Sa_p (g)	0.13

Avaluació del dany i de la seguretat sísmica

Corbes de fragilitat

Matriu de probabilitat de dany

Matriu de Probabilitat de dany	
Grau de dany	P(gd=GD|Sdp)
0 - Nul	0%
1 - Lleu	11%
2 - Moderat	62%
3 - Extensiu	24%
4 - Complet	3%

Avaluació de la Seguretat

Índexs	
Grau de dany mig [0-4]	2.2
Índex de pèrdua [%]	32%
Índex de funcionalitat [0-1]	0.16
Temps de recuperació (dies)	173

a)

IGC Institut Geològic de Catalunya

Avaluació de la seguretat sísmica d'edificis d'especial importància

Informació bàsica de l'edifici

Edifici:
Coordenades (X,Y):
Adreça:
Municipi:

Acció Sísmica

Espectre : EC 8 Tipus II
Tipus de sòl: E

	Període de retorn	
	Pr=475 anys	Pr=975 anys
PGA Roca	0.11	0.14
PGA Sòl	0.19	0.25

Comportament edifici

Tipologia estructural: RC32LLC
Període de construcció: 1975 - 1994

Espectre de capacitat

	Espectre de capacitat	
	d (cm)	a (cm)
Fluència (y)	0.70	0.13
Capacitat última (u)	5.24	0.14

Punt de capacitat per demanda

	Punt de comportament	
	Pr=475 anys	Pr=975 anys
Sd_p (cm)	1.10	1.47
Sa_p (g)	0.13	0.13

Avaluació del dany

Matriu de probabilitat de dany

Matriu de Probabilitat de dany		
Grau de dany	P(gd=GD|Sdp)	
	Pr=475 anys	Pr=975 anys
0 - Nul	0%	0%
1 - Lleu	11%	2%
2 - Moderat	62%	59%
3 - Extensiu	24%	33%
4 - Complet	3%	6%

Avaluació de la seguretat

	Índexs	
	Pr=475 anys	Pr=975 anys
Grau de dany mig [0-4]	2.2	2.4
Índex de pèrdua [%]	32%	38%
Índex de funcionalitat [0-1]	0.16	0.08
Temps de recuperació (dies)	173	191

L'edifici avaluat no compleix amb el criteri Operacional per a un període de retorn de 475 anys, però si compleix amb el criteri de Seguretat de la Vida per a un període de retorn de 975 anys.

L'edifici podria patir danys moderats però l'estructura es mantindria estable. Es garantiria la seguretat dels ocupants. En general, les instal·lacions de l'edifici quedarien fora de servei i l'edifici en sí mateix necessitaria reparacions importants.

L'índex de pèrdua econòmica es superior al 30% i inferior al 60% del valor de reposició de l'edifici. L'edifici en sí mateix necessitaria reparacions importants.

L'índex de funcionalitat es inferior a 0.25, essent 1 màxima funcionalitat i 0 cap funcionalitat, que correspon a un estat de dany de moderat a complet.

El temps de recuperació necessari oscil·la entre 5 i 7 mesos

b)

Figure 6. Results report's page for (a) a certain return period and (b) for the comparative summary (Bosch, 2013)

Application of the methodology to a sample of educative centers of Barcelona

Bosch (2013) applied the methodology proposed by Valcárcel (2013) to a sample of 23 educative centers located in the city of Barcelona, the capital of Catalonia. Bosch (2013) implemented the seismic vulnerability inspection form proposed to determine the structural typology of each one of the structures by performing a visual inspection and analysing the available design information. Fig.7a shows that the majority of the structures analysed correspond to medium heights between 3 to 5 levels. Fig.7b shows the distribution of the structures according to the year of construction and the structural typology assigned. Table.2 shows the description of the identified structural typologies corresponding to a 48% of unreinforced masonry (M), a 35% of reinforced concrete (RC) and a 17% of steel structures.

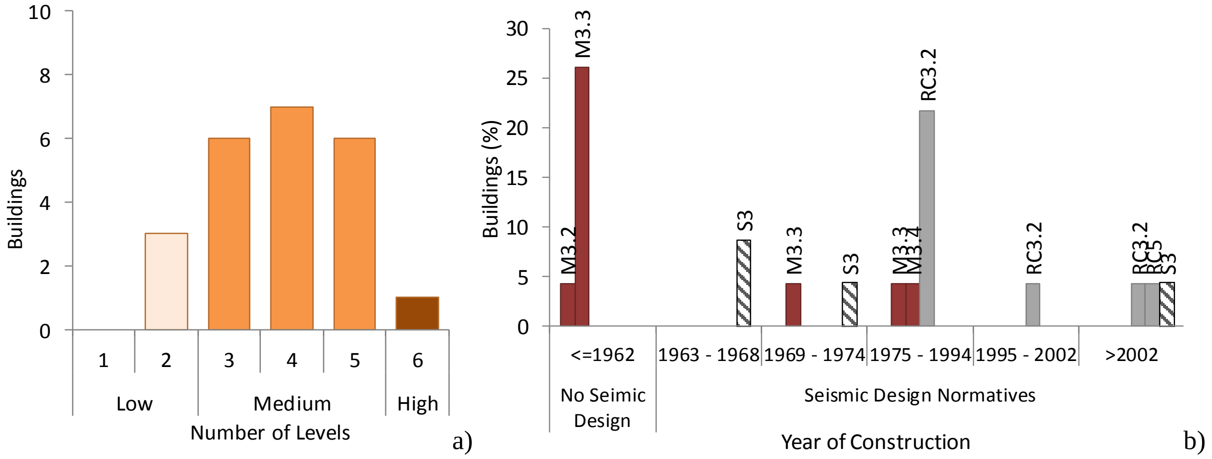


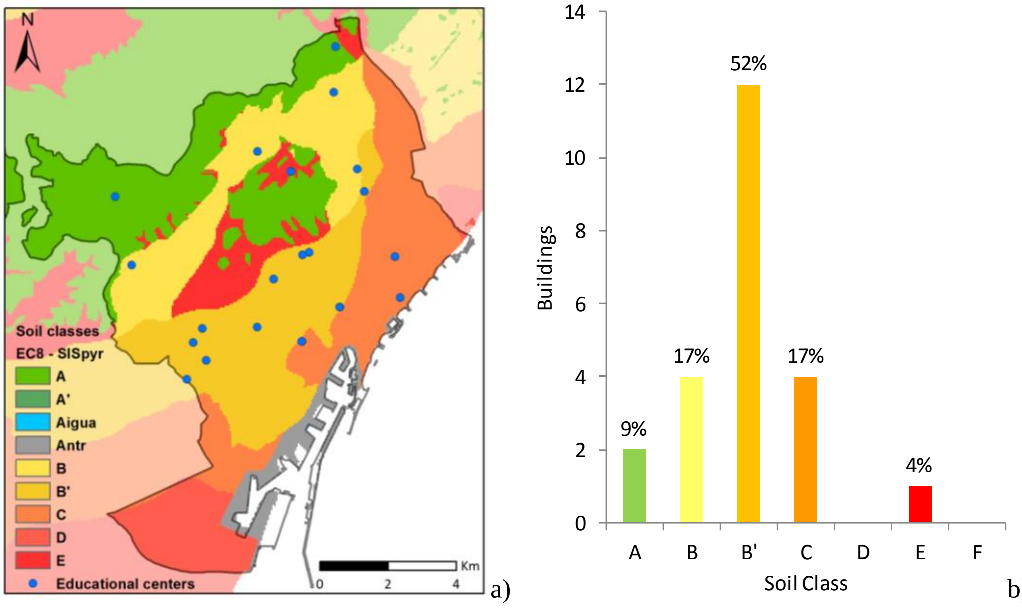
Figure 7. Distribution of the educative centres studied according to their a) number of levels and b) structural typology and year of construction

Table 2. Description of the structural typologies identified in the sample of schools of Barcelona

Structural Typology	Description
M31	Unreinforced masonry bearing walls with wooden slabs
M33	Unreinforced masonry walls with composite steel and masonry slabs
M34	Unreinforced masonry walls with RC slabs
RC32	Irregular RC structures with infilled masonry walls
RC5	Precast concrete tilt-up walls
S3	Steel moment frames with infilled masonry walls

According to the probabilistic seismic hazard analysis of IGC and Geoter (2008), for a return period of 475 years the city of Barcelona would be affected by peak ground accelerations varying from 0.08g to 0.10g. Fig.8a shows the location of the 23 educative centres of Barcelona studied by Bosch (2013) along with the mesozonation of Catalonia to determine the soil class of the site and obtain the local hazard that would affect them. As shown in Fig.8b, a 4% of the buildings are located on soil class E with the highest amplification for low periods and 9% are located on class A (rock) with no amplification. The majority of the educative centres are located on soil class B' with a moderate level of site amplification.

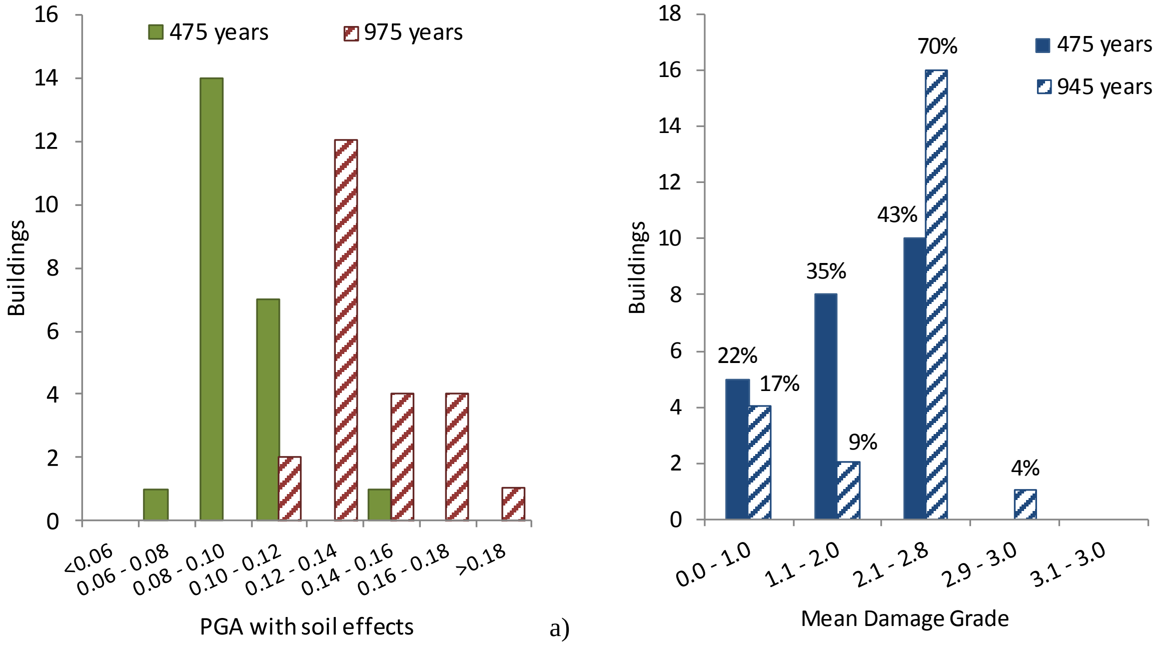
Fig.9a shows the distribution of the educative centres studied according to the peak ground acceleration with soil effects that is expected to affect them for both return period of 475 and 975 years. For a return period of 475 years the majority of the centres have a PGA ranging from 0.08g to 0.10g and for a return period of 975 years the majority are affected by a PGA ranging from 0.12g to 0.14g. The distribution of the mean damage grade obtained for each educative centre is shown in Fig.9b for both return periods considered. As can be seen a 43% of the centres for a return period of 475 years and a 74% of the centres for a return period of 975 years have a mean damage grade higher than 2.0, so moderate to extensive damages can be expected for them.



a)

b)

Figure 8. a) Location of the studied educative centres within the mesozonation of Catalonia and b) distribution of the educative centre according to the soil class at their site



a)

b)

Figure 9. Distribution of educative centres according to a) the local peak ground acceleration and b) the expected mean damage grade

Applying the seismic safety evaluation guidelines suggested by Valcárcel (2013), it can be seen that 10 of the 23 (44%) educative centres considered do not fulfil the *Operational* performance requirement because of having an expected damage grade higher than 2.0 (Fig.10a). This 44% of the centres won't be safe for immediate occupancy and won't be able to resume its functions immediately after the earthquake. Considering the Life Safety performance level, only 1 of the 23 (4%) educative centres studied does not comply with the requirement as the mean damage grade is higher than 2.8 for a return period of 975 years (Fig.10b). This educative centre won't be stable and could not guaranty the safety of its occupants.

Bosch (2013) also analysed the functionality index and the recovery time of the educative centres sample as shown in Fig.11. The results from the functionality index (Fig.11a) show that more than half of educative centres will have a functionality index lower than 0.50 for a return period of 475 years and lower than 20% for a return period of 975 years. As can be seen in Fig.11b the recovery time obtained for the sample is higher than 120 days for the majority of the centres for both of the return periods considered. This high values for the services recovery time is not strange considering the low functionality indexes obtained. Only a few centres are expected to fully restore their functions within a month or less. The economic loss index was not evaluated for this case.

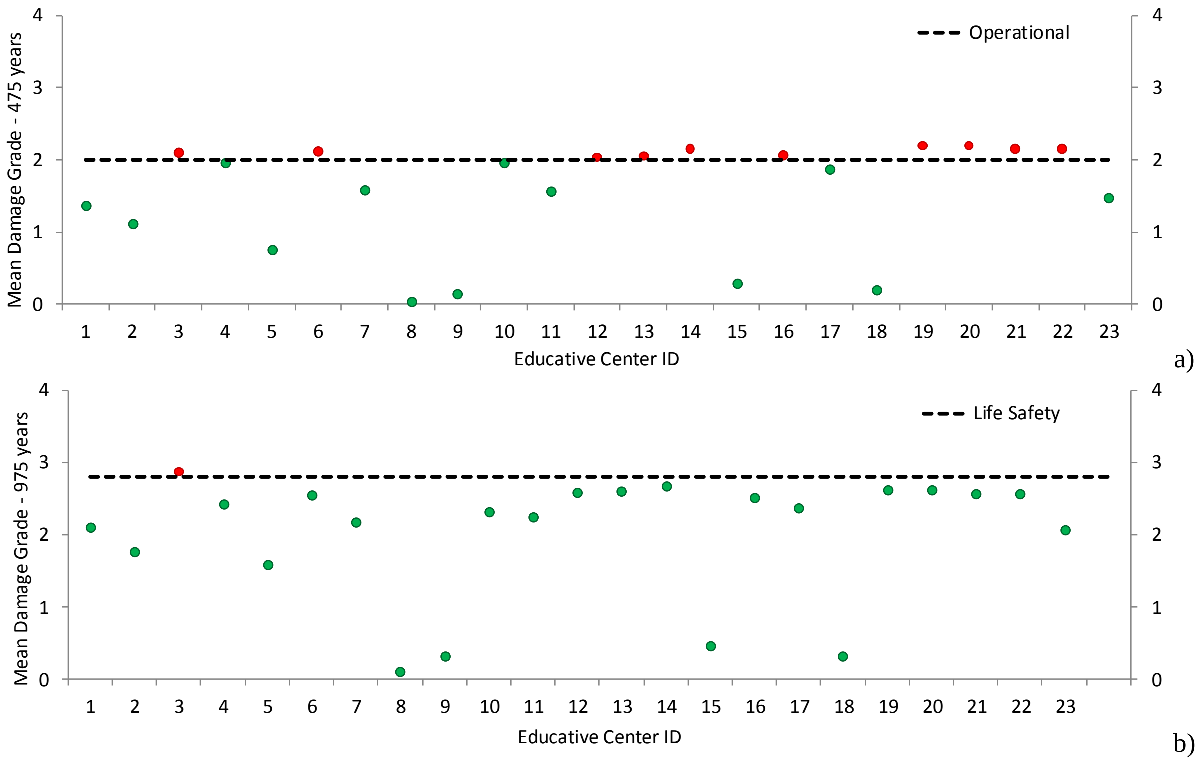


Figure 10. Application of the *Operational* (a) and *Life Safety* (b) performance requirements

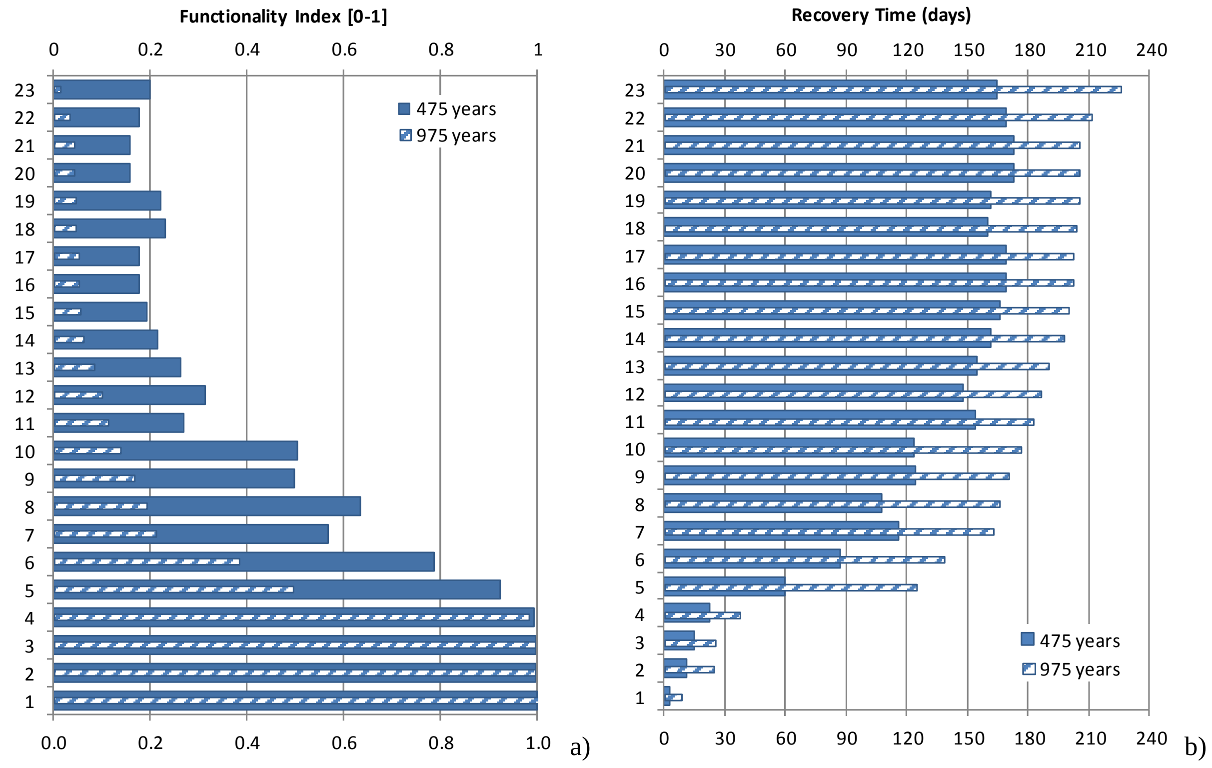


Figure 11. Recovery time (a) and functionality index (b) for the sample of educative centres of Barcelona.

CONCLUSIONS

This work presents the proposed interactive web-based software, ASSEE, for the seismic safety assessment of special importance buildings. The methodology proposed by Valcárcel (2013) for the seismic safety assessment implemented by this software provides a useful and simplified version of the capacity spectrum method in order to facilitate its application to individual structure without having to develop the fully detailed models and structural analysis required by its original version. The use of the mean damage grade to verify the fulfilment of the Vision 2000 Committee performance requirements, as proposed by Valcárcel (2013), provide an easy tool to implement criteria for achieving this objective.

Using the proposed methodology, Bosch (2013) performed a preliminary seismic safety assessment was performed for a set of schools in the city of Barcelona, Catalonia (Spain) for return periods of 475 and 975 years. For a return period of 975 years, all but one school accomplished the requirement of *Life Safety*. On the other hand, for a return period of 475 years, the expected damage in the 57% of the buildings is lower than moderate. For the remaining buildings, the expected damage ranges between moderate and extensive, so a 43% do not satisfy the *Operational* performan requirement.

The seismic safety assessment provided by the software ASSEE, as well as the estimation of the expected losses, etc., should be considered as a preliminary evaluation, useful for screening purposes. Those structures that do not comply with the proposed performance levels should then require more detailed structural analysis in order to enhance the performance and safety analysis.

The ASSEE software will constitute a useful tool for the municipality officials in charge of the seismic risk assessment of especial importance buildings needed for drafting the municipal seismic action plans.

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