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Seismic Risk Management Of An Elementary School Building Based On Minimum Expected Life-Cycle Cost

Dr. Neritan Shkodrani[1], Msc. Elfrida Alliu[1], Dr. Shkëlqim Daja[2]

[1]*Department of Civil Engineering, Polytechnic University of Tirana, Albania*
[2]*Department of Applied Geology and Environment, Polytechnic University of Tirana, Albania*

ABSTRACT

In earthquake disaster prevention, one serious problem confronting the world's earthquake- prone countries is seismic performance of buildings. A building is expected to remain safe and provide its intended function throughout its life span, with only small performance interruptions or damage due to earthquakes.

It is necessary to identify buildings that are in risk and carry out their reconstruction or seismic retrofit in order to provide more strength and ductility. However the seismic retrofits come to a premium. Therefore, seismic retrofit of buildings entails an important risk-management decision problem as an optimal balance between the cost for the reinforcement and the future risks that must be achieved.

This paper presents a decision methodology in seismic risk management considering only one fundamental risk, the cost imposed on the decision maker. The risk is expressed as the expected life-cycle cost, which is the expected amount of payments during the life of the building. These include the initial costs of the design and its construction, the additional cost for the reinforcement and the expected cost of damages generated due to earthquakes during the life span of the building.

As an example, the proposed methodology is applied to an actual school building newly designed in Lushnja. The seismic evaluation of building is realized through the Japanese seismic screening method for seismic safety evaluation of existing reinforced concrete buildings. The actual cost of existing building and the additional cost for strengthening by using shear walls are estimated. In this case study, it is examined the cost effectiveness of shear walls used for strengthening of the school building in reducing the life-cycle cost

INTRODUCTION

In Albania a Seismic Zoning Map on a scale of 1: 500000 and Earthquake Resistant Regulation, KTP-N.2-89, have been in force since 1979 and 1989, respectively. Seismic Zoning Map is associated to 100-years return period and divides the country into three MSK-64 intensity zones (VI, VII and VIII). Intensity IX is allocated only to some epicenter zones of large historically earthquakes.

Many buildings are designed according to this regulation and among them many educational system buildings, such as elementary schools, middle schools and high schools and universities. The majority of school buildings are low rise, ground floor (GF), ground floor plus one story (GF+1)-72% and GF+2 to GF+4 stories (27%). The GF and GF+1 stories dominates in rural areas, while GF+2 and higher school buildings dominate in urban area [1].

Seismic risk studies according to the existing school buildings, like other types of buildings, in Albania are practically nonexistent. According to a study of the Natural Disaster Risk Assessment in Albania, October 2003, the school buildings constructed in the period 1960-1990 are of a structural standard that does not comply with the seismic environment in which they have been built [1]. In fact, it is rational to assume that especially due to underestimated site seismicity from seismic regulations before adoption of KTP-N.2-89 Seismic Resistant Code, in 1989. Also, according to this study for post-1990 school buildings massive damages and collapses are expected from low-probability, high-impact events [1].

As we know, Eurocode 8 is expected to be implemented in the near future in the design process and it will lead in a new probabilistic seismic hazard map of Albania associated to 475-years return period [2]. The considered Design Earthquake (DE) it is expected to change as well. In another study related to engineering characteristics of the shaking for the expected earthquake at the Semani site, located in Fier County, authors have shown that Design Earthquake according to KTP-N.2-89 Seismic Resistant Code can be only a Serviceability Earthquake (SE) according to Eurocode 8 [3].

In this situation society should prepare to identify existing buildings that are in risk and carry out their reconstruction or seismic retrofitting in order to reduce the risk due to earthquakes. The common way to reduce the risk due to earthquake is providing more strength and ductility to the considered building. However, these measurements come at a premium; the society should do this based upon a budget which would be invested in future events. This causes a barrier to the efficient spreading of safer buildings in society, because seismic retrofitting of buildings seems to be a risk-management decision problem as an optimal balance between initial costs and cumulative damage cost due to earthquakes that occur during the life span of the building.

Takahashi et al. [4] have proposed a seismic risk-management methodology aiming to persuade the society to invest in seismic system of existing buildings through a retrofitting process. Seismic risk-management problem in fact is a decision problem among multiple alternatives. Alternatives for seismic upgrade may be strong and ductile frames, shear walls, steel braces, column jacketing, energy dissipation systems, base isolation system etc... The alternative which minimizes the total expenses (the life-cycle cost) during the life span of the building, including the initial cost and the cumulative damage due to earthquakes, is chosen as the optimum selection.

This paper applies the proposed methodology of seismic risk-assessment and management to an existing RC elementary school building, newly designed according to Earthquake Resistant Regulation, KTP-N.2-89, mentioned above. The life-cycle costs of two alternatives are compared: the first one is existing RC moment frame school building and the second one is the same frame building retrofitting by using shear walls. Through the considered case study it is demonstrated that strengthening by using shear walls is effective in reducing the life-cycle cost. The selected school building is assumed to be located in Lushnja city, Fier prefecture in Albania.

METHODOLOGY

The Seismic risk-management problem in fact is a decision problem among multiple retrofitting alternatives that we have mentioned above. The alternative that minimizes the life-cycle cost (LCC) can be chosen as the optimum selection, but considering the standard of construction in Albania, not all the abovementioned alternatives can be actually available as retrofitting techniques. Traditional techniques, like the strengthening by shear walls, may be considered as the most plausible alternative for seismic upgrading of existing buildings. The LCC is the sum of initial construction cost and the expected damage cost by future earthquakes and the alternative which minimizes the expected LCC is considered as optimum.

In this paper the optimum alternative is not defined according to minimum expected loss criterion, but by considering the alternative that really can be applied in a retrofitting process.

Assuming a renewal process for earthquake occurrences in the seismic sources surrounding the building under consideration Takahashi et al. (2004) formulated the expected life-cycle cost of each alternative, E[C_L], as:

$$E\left[C_L\right] = C_I + t_{life} + \sum_{all\ sources} \sum_{j=1}^{K} \nu\left(m_j\right) E\left[C_D\left(m_j\right)\right] \tag{1}$$

Where, C_I is the initial cost, $E[.]$ is the expectation operator, $C_D\left(m_j\right)$ is the damage cost due to earthquakes of magnitude , t_{life} is the lifetime of the building, $\nu\left(m_j\right)$ is the mean occurrence rate of an earthquake of magnitude m_j. In Eq. (1) it is assumed that earthquake occurrence follows a Poisson process.

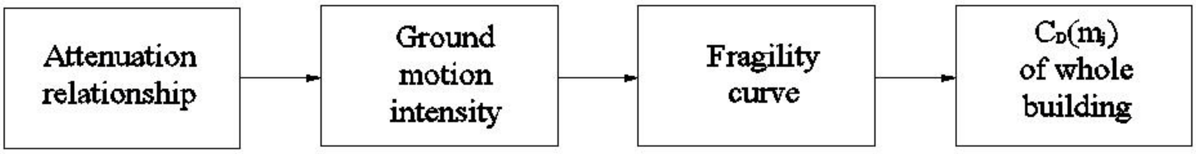


Figure 1 Simulation model for the computation of E[C_D(m_j)]

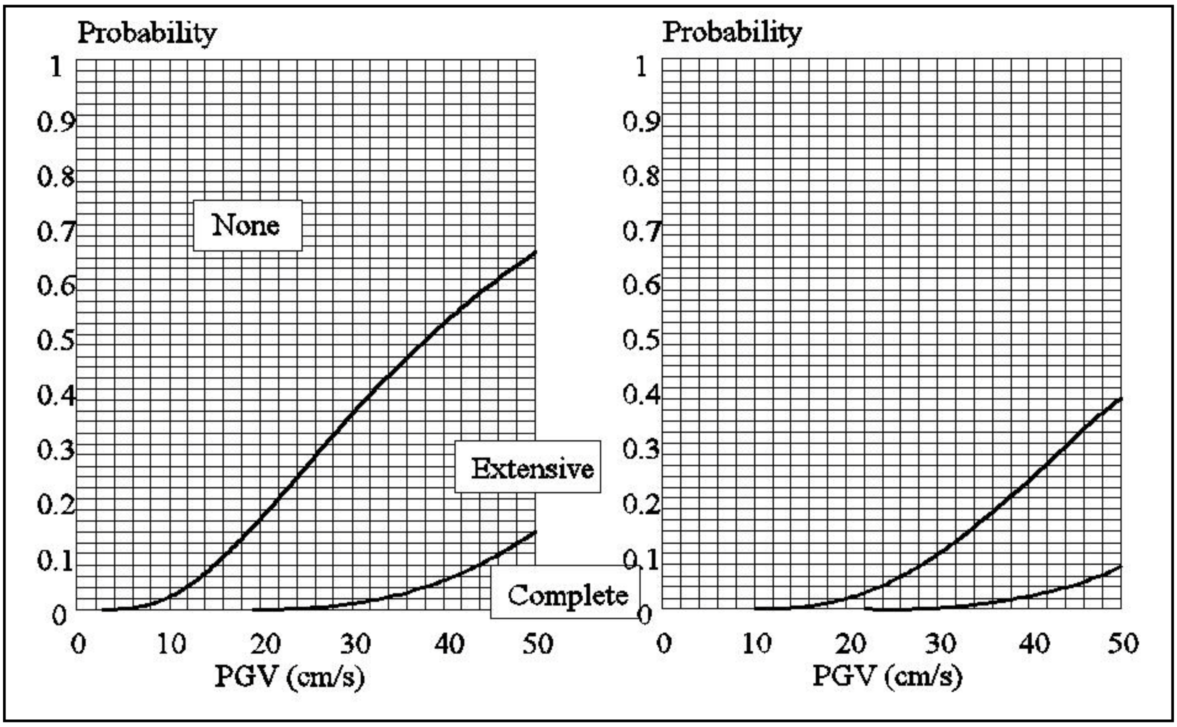


Figure 2 Fragilty curves of a) existing building; b) strengthening building

In Eq. (1), the expected damage cost $E[C_D\left(m_j\right)]$ caused by earthquakes of a specific magnitude m_j in a given source should be estimated by using different simulation model. The simulation models can be of different "courses" but the most economical one, which is used in the case study, is shown in Figure 1 [5]. Through this simple simulation model, it is possible to show the results instantly and in the most cost efficient way to the clients.

Based on this simulation model, the expected damage cost ($E[C_D(m_j)]$ can be easily estimated as Eq. (2).

$$E\left[C_D(m_j)\right] = \left(P_N \times 0.0 + P_E \times 0.5 + P_C \times 1.0\right) \times C_I \qquad (2)$$

In this equation P_N, P_E and P_C are the probabilities that the house falls into the damage states of None, Extensive and Complete, respectively. The probabilities values P_N, P_E and P_C can be estimated using Figure 2 (Murao & Yamazaki; 2000) as a function of Peak Ground Velocity (PGV) at the site for certain magnitude. In computing PGV at the bedrock, the attenuation relationship by Shi & Midorikawa (1999) [6] is used:

$$\log PGV_b = 0.58m_j + 0.0038D + d - 1.29 - \log(X + 0.0028 \times 10^{0.50m_j}) - 0.002X \qquad (3)$$

Where,

PGV_b: PGV at the bedrock (cm/s); D: depth of the hypocenter (km); d: earthquake type; X: the shortest distance between the site and the fault plane.

PGV at the site is calculated by multiplying the PGV at the bedrock with soil amplification value selected according to the soil type.

APPLICATION TO UPGRADE OF EXISTING CITY HALL BUILDING

Building under considerations

A four story RC school building expected to be constructed in Lushnja city is considered here. This building consists of RC moment frames that have 4-stories and 2-spans in transverse direction. The columns are short columns with standing walls (110 cm height), long columns and extremely short columns with standing and hanging walls 950 cm height). Building has a total area of about 1800 m^2. In Figure 3a it is shown a three dimensional model of this structure. The structure is newly designed according to Earthquake Resistant Regulation, KTP-N.2-89. According to the recent seismic diagnosis, the safety of the structure was determined to be insufficient (Is = 0.501 (4F); Is = 0.286 (3F); Is = 0.222 (2F); Is = 0.155 (1F)). Note that seismic requirement, which expresses the minimum seismic demand of the structure, is known as target performance index, Iso, and its minimum value is Iso = 0.6.

For the sake of seismic upgrade, in order to achieve the required strength which satisfies the target performance index Iso, shear walls are installed in the longitudinal direction and standing walls and hanging walls are separated from the columns and removed, so that the strength and ductility are increased. These modifications are shown in the Figure 3b. After strengthening of the existing building, the safety of the structure was determined to be sufficient (Is = 2.517 (4F); Is = 1.438 (3F); Is = 1.118 (2F); Is = 1.006 (1F)). In all the cases, seismic index Is is more than target seismic index Iso = 0.6.

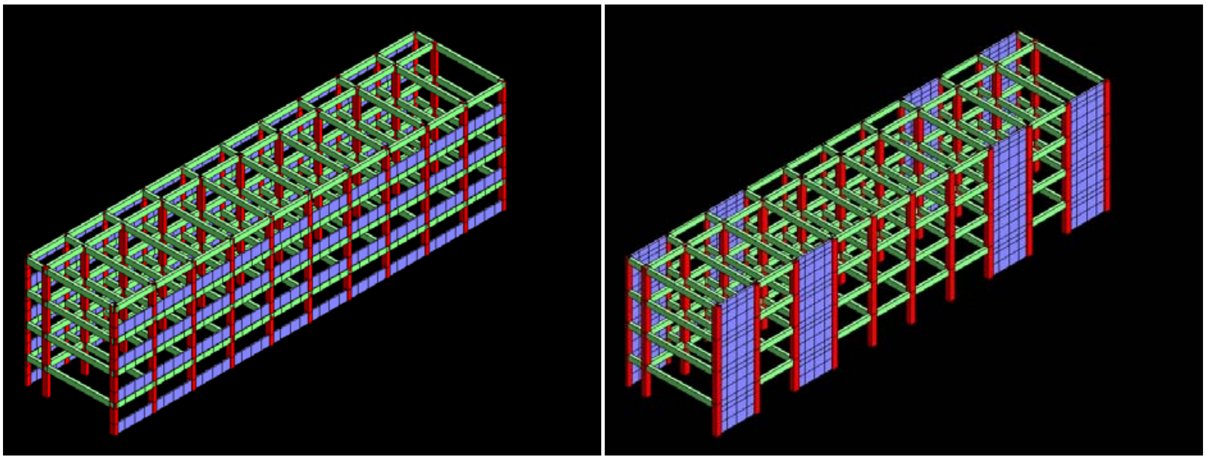


Figure 3 a) Existing structure; b) Modified structure

In this case study, the life-cycle costs of two design alternatives are compared: the first (a_1) is the existing building before the seismic upgrade and the second (a_2) is the upgrade one. The design lifetime of the school building is 50 years, that is t_{life} years in Eq. (1). The construction cost of the existing building is estimated to be 450 thousands EU, and the upgrade cost 38.4 thousand EU (around 8.5% of the existing building cost). So, the initial costs of a_1 and a_2 are therefore 0 thousand EU and 38.4 thousand EU, respectively.

Seismic activity of Lushnja area

Lushnja area is included on the Periadriatic Depression, strongly affected by post-Pliocene compressional movements, and represents the westernmost frontal part of compressional domain, in direct convergence with Adria microplate. The Lushnja Depression represents a plate relief with rare hills. The Western Lowland of Albania is a molasses basin, originated in Serravallian and filled with Miocene-Pliocene molasses.

The Lushnja zone marks the boundary between the Albanides and the Apulian platform. Along the outer boundary of Albanides, there are generated strong earthquakes. The segment of Vlora-Lushnja has generated earthquakes of $M_{max}<7.0$. Historically it is known the complete destruction of Apollonia (an ancient city) in 217 year. Other strong earthquakes hit the study area: April 16, 1601; January 19, 1833; January 2, 1866 intensity of Io=IX (MSK-64) in Vlora; June 14, 1893 intensity of Io=IX (MSK-64) in Kudhesi-Vlora; December 17, 1926 magnitude of M_W=6.2 in Durres; November 21, 1930 magnitude of M_W =5.8 in Llogara-Vlora; February 23, 1940 magnitude of M_W=5.6 in Cakran-Fier; November 21, 1930 intensity of Io=IX (MSK-64) in Llogora-Vlora; September 1, 1959 magnitude of M_W=6.0 in Lushnja; March 18, 1962 magnitude of M_W=6.2 in Fieri; November 16, 1982 magnitude of M_W=5.8 in Rroskovec-Fieri. According to the seismic regionalization of Albania, the maximum expected intesity at Semani is Io_{max}=VIII degree (MSK-64) for 100 years period of time.

A seismotectonic model proposed before for Albania [2] divides it into 10 seismic sources of assumed seismicity. According to Aliaj, Lushnja area is included in Preadriatic Lowland (PL) zone which is a coastal zone containing post-Pliocene oblique- compression thrust faults, N to NNW - striking, which is cut by rare ENE - trending strike-slip faults. A square area with dimensions 50 x 50 km), which surrounds the Lushnja site is considered as a seismic source zone and 14 earthquakes with $M_W \geq 5.0$ are taken into account. Figure 4 shows location of considered past earthquakes in the surrounding zone of Lushnja site for the period from 1939 to 1997. The strongest earthquake which hit this zone has the magnitude $M_W = 6.2$.

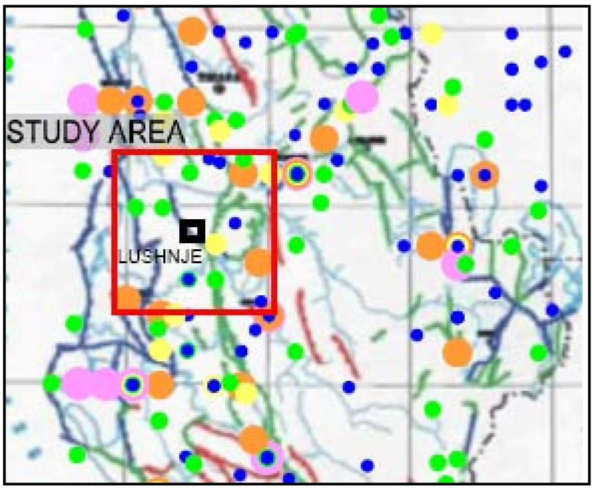


Figure 4 Seismic source (square), epicenters of past earthquakes (circle)

Based on the historical data, we modeled the activities of the seismic source zone using Poisson model, which means that earthquake occurrence in time follows a Stationary Process. Generally earthquakes follow Gutenberg and Richter distribution and for the mention zone of interest earthquake distribution is obtained after a regression process. Regression line which represents Gutenberg-Richter recurrence law is shown in Figure 5a. In order to evaluate the mean occurrence rate of earthquakes per year (mean annual occurrence rate), it is assumed that only earthquakes with magnitudes 5.0, 5.5 and 6.0 may occur. Figure 5b shows the mean annual occurrence rates for the three categories of earthquakes, which are estimated using the data obtained from Figure 5a, through the regression line.

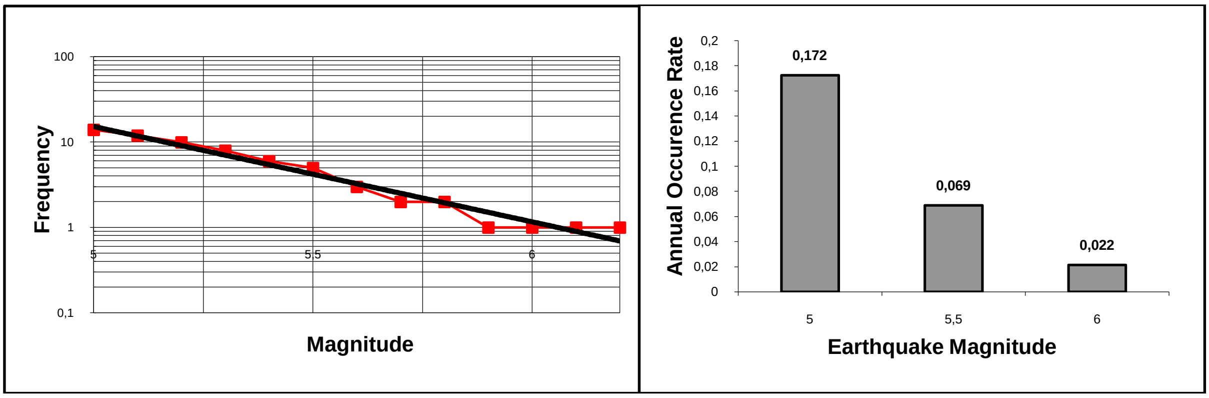


Figure 5 a) Total number of past earthquakes; b) Magnitude vs. annual occurrence rate of earthquakes occurred within the seismic source (Poisson model)

Simulation for damage cost $E[C_D(m_j)]$

As it is mentioned above, the expected damage cost $E[C_D(m_j)]$ caused by earthquakes of a specific magnitude m_j can be easily estimated by using Eq. (2). In this equation, the probability values P_N, P_E and P_C can be estimated by using Figure 2 as a function of PGV at the site. PGVs at the bedrock are evaluated through Eq. 3 for the considered earthquake magnitudes $M_W = 5.0$, 5.5 and 6.0 and using D = 20.0 km as reasonable depth for Albanian earthquakes considered as shallow earthquakes; d = -0.02 for inter-plate earthquake; X = 7.0 km, as the shortest distance of the considered site from the fault plane which has generated past earthquakes. PGV at the site is calculated by using an amplification factor of 1.7, because of the presence of soft soils at the considered site. After the calculations, PGV (cm/s) at the surface soil have resulted: PGV (5.0) = 9.7; PGV (5.5) = 17.3; PGV (6.0) = 29.6, respectively to the magnitudes 5.0, 5.5 and 6.0.

The expected damage cost ($E[C_D(m_j)]$) for each considered magnitude are estimated through Eq. (2) and are shown below in Table 1 and Figure 6.

Table 1 Expected damage cost (EU thousand)

Alternative	$M_W = 5.0$	$M_W = 5.5$	$M_W = 6.0$
Existing Building	4.5	27	60.75
Strengthened Building	0	2.44	24.4

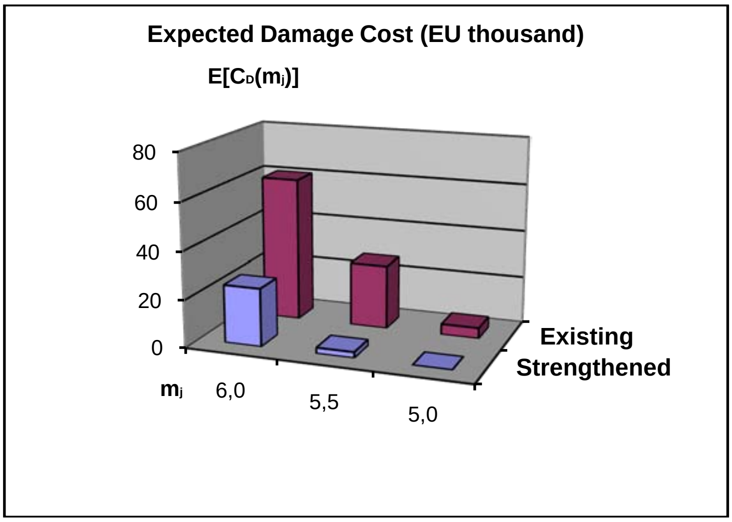


Figure 6 Expected damage cost for each magnitude

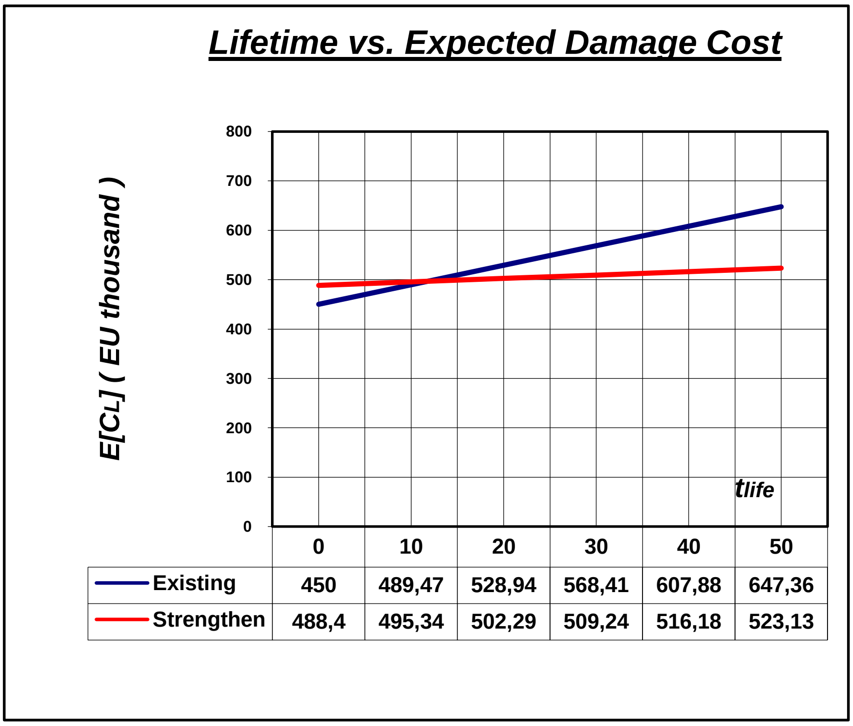
The above table and figure demonstrate that the reduction of the expected damage cost by applying strengthening of the building with shear walls is greater as the magnitude of the earthquakes becomes larger.

Expected life-cycle cost

Finally, the evaluation of the relationship between the lifetime (t_{life}) and the expected damage cost $E[C_L]$ of the two alternatives, for existing and strengthened school building, are shown in Figure 7. This relationship is estimated by substituting $\nu(m_j)$ and $E[C_D(m_j)]$ values into Eq. (1). They intersect at 11.8 years after the starting time. This indicates that strengthening by shear walls is effective from the aspect of life-cycle cost if the life-time is longer than 11.8 years. The difference at the end of the remaining lifetime ($t_{life} = 50$ years) is 124.2 thousand EU. This is an expected profit to the decision maker gained by using retrofitting of the building in this risk management.

Table 2 Evaluation of expected damage cost (EU thousand)

Crossing lifetime	11.8 years
Difference at 50 years	124.2 thousand EU



	0	10	20	30	40	50
Existing	450	489,47	528,94	568,41	607,88	647,36
Strengthen	488,4	495,34	502,29	509,24	516,18	523,13

Figure 7 Lifetime vs. expected damage cost

CONCLUSIONS

During the design it is very important to show the effectiveness of appropriate design alternatives and to encourage the society to invest in them during the design of new buildings or the updating of existing ones. Especially this is important for school building.

In this paper, the life-cycle cost effectiveness of strengthening by using shear walls was discussed. The building under consideration is a school building located in Lushnja. The building is newly designed according to Earthquake Resistant Regulation, KTP-N.2-89, but according to the recent seismic diagnosis, the safety was determined to be insufficient. In order to achieve the required strength, shear walls were installed in the longitudinal direction and standing walls and hanging walls were separated from the columns and removed, so that the strength and ductility of the structure were increased and the structure was determined to be sufficient . The life-cycle cost of the upgrade building is compared with that of the existing building without the upgrade. This case study demonstrates that the life-cycle cost can be reduced by the upgrade using different techniques.

This study is just one example, which tries to show the life-cycle cost effectiveness of appropriate investments, especially for important buildings, like the schools, hospitals and commercial buildings. This will motivate community to invest for a safer environment.

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