

Cost-effective Comparison of Alternatives to Retrofit Seismic Damage in Schools

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AUTHOR CONTRIBUTIONS

All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by De-León-Escobedo David. The first draft of the manuscript was written by De-León-Escobedo David and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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Abstract: The safety level of currently used strategies for schools retrofit, given a seismic damage, does not consider life-cycle costs. In this paper, the cost/benefit of two repair techniques, mentioned in technical guides for seismic rehabilitation of schools in Mexico, are compared to assess their cost-effectiveness to reach an optimal performance in the longterm. The school structural reliability and the expected life-cycle costs are calculated for the seismic hazard of each region. The probabilistic approach allows for the modelling of uncertainties due to the seismic hazard and to the structural capacity are included for each case and failure limit states are considered by incorporating the cost of damage/failure consequences on structural and non-structural members. Monte Carlo simulation techniques were used to assess the school failure probability and the expected total costs. These expected total costs include repair costs and future costs due to possible deaths, loss of contents, and loss related to the translation to other facilities while the school is being retrofitted. The results show that an appropriate retrofit scheme should be selected according to the type and extension of the damage. For the case study considered here, from the 3 proposed retrofit types, the one with the least life-cycle cost was selected.

Keywords: Schools retrofit, seismic damages, structural safety, seismic hazard

1. INTRODUCTION

Schools are structures that frequently result damaged after an earthquake. The seismic hazard level is a main factor to determine the damage type and extension and, therefore, the selection of adequate retrofit schemes that should be applied to prevent the schools to suffer severe damages or failure in the rest of the school lifetime. The present paper proposes a risk-based formulation to assess the cost/benefit of alternative retrofit schemes by calculating the failure probability and the expected life-cycle cost of each alternative.

There are several descriptions of the seismic activity in Mexico (Sandoval & Ordaz, 2026; Rosenblueth, 1986; Singh & Ordaz, 1994). In other research, a methodology to perform a cost-benefit (C/B) analysis to assess possible options such as retrofitting or reconstruction of structures focused on mitigation of direct physical losses due to seismic actions (Jaimes & Niño, 2017). A number of works have considered the life-cycle perspective on the assessment of structural performance under seismic hazard as by Esteva et al, (2002) and Morales (2019). Cost/benefit studies have been proposed for the rehabilitation of structures like by Del Vecchio et al. (2020), Sousa et al. (2020), García-Manjarrez & De León, (2021) and Vatterli et al. (2022). However, the proposals on the retrofit of schools are scarce and they have not considered neither the failure probability nor the life-cycle costs in an explicit way.

General guidelines were proposed by INIFED (2016) without consideration of cost/benefit ratios. The safety assessment of masonry schools was obtained through reliability tools and

some recommendations were provided for schools under seismic hazard (De León & Guadarrama, 2020; De León & Ismael, 2022). Some retrofitting techniques have been proposed without an economic analysis (Sousa et al., 2020). Tabernero et al., (2024) proposed a vulnerability assessment where the failure analyses were performed using a set of 10 seismic records scaled at increasing values of peak ground acceleration (*PGA*). Four seismic retrofit alternatives were proposed to evaluate two major design approaches, stiffening and flexibilization. For each considered case, seismic fragility curves were derived, and seismic risk was assessed as limit state probability in 50 years considering *PGA* as a random variable. A very simple and low-cost alternative, such as flexibilization by decoupling the facades from the lower floors, was found to produce excellent results. Koohfallah et al., (2024) calculated the seismic resilience of a steel school building including retrofitting options based on FEMA P-58 under mainshock-aftershock effects. The authors used a high school with conventional structural system, with two alternative retrofitting schemes, to calculate their resilience levels. They assessed these indices for two hazard levels: 2 and 10 % exceedance probabilities in 50 years. The strategy applied by these authors reveals that the resilience has the desired impact of measuring the improvement of the school's performance. Besides, it was shown that the resilience is instrumental to select the most adequate retrofitting option.

Ghiasi et al. (2026), suggested the assessment of the seismic resilience of critical structures was considered to have a pivotal role in comprehensive disaster prevention and mitigation strategies. Steel bracings and shear concrete walls were the alternative retrofitting techniques and the FEMA P-58 methodology was employed across various seismic risk levels (2 %, 10 %, 20 %, and 50 % in 50 years) and the PACT software was used to estimate costs. For the case study considered in this paper, retrofitting with reinforced concrete shear walls showed superiority compared to special concentric braced frames.

In the present paper, a formulation based on the calculation of the failure probability and the expected life-cycle cost, for each type of retrofit alternative, is proposed and applied to 2 actual schools that suffered seismic damage. The life-cycle cost contains the cost of consequences of damages due to the occurrence of a intense earthquake. A retrofit alternative should pass the reliability criterion which requires that the school failure probability is less

than the target failure probability (ISO 9893, 2021). If the requirement is not satisfied, the dimensions and resistance provided should increase.

2. METHODOLOGY

The proposed procedure resorts on the calculation of the failure probability of the critical frame of the school under the seismic forces that corresponds to the school location. The calculation of the failure probability involves the identification of the critical structural components and the assessment of the maximum forces on them due to the seismic hazard. If the safety margin is LS , the failure probability is the event when these margin is exceeded as presented by Esteva et al. (2002).

$$F_p = P(LS < 0) \quad (1)$$

LS represents the event where the structure losses its load capacity and becomes unstable. The limit state maybe expressed by either bending moment, shear or axial force or the combination of axial load and moment. Once a response analysis is performed, the maximum responses are compared to the member capacities and the failure probabilities are obtained through Monte Carlo simulation. The simulation process follows conventional rules and the use of the total probability theorem as described by Ang & Tang (2007):

$$F_p = \sum_{i=1}^n P(LS < 0 | PGA_i) P(PGA_i) \quad (2)$$

Where PGA_i is the peak ground acceleration for the discretized scenario “ i ”.

The procedure resorts on the calculation of metrics for the objective and quantitative of assessment and comparison of safety effectiveness and cost of retrofit alternatives. These metrics put a particular emphasis on the uncertainties involved on the seismic loads and response and the structural capacities of the members.

An appropriate retrofit scheme tackles the damages produced by an earthquake but also mitigates the potential damages in the rest of the school lifetime. In order to do that, the school safety level should be measured through a couple of tools that includes the uncertainties inherent in the process: loads prediction and resistances modeling. In this paper, the first tool is the failure probability and Monte Carlo simulation techniques are

implemented for the calculations. The simulation process implies the following considerations: the mean value of demand is obtained from the nonlinear response analyses of the school model and the probability distribution of demands and capacities are lognormal. Previous research works like De León-Escobedo (2024) found that this distribution is the best fit.

Current regulations for reinforced concrete structures, as established by GCDMX (2023), prescribe formulations to calculate the mean value of the resistances. Also, the limit state that correspond to the critical cross sections is identified through preliminary response analyses. With these mean values and the coefficients of variation recommended, for example, by García-Manjarrez & De León (2021), the trials for the simulation process are performed. In the application to the case studies, some samples of these process are shown.

The second tool employed in this work is the expected life-cycle cost which, as being done in other works, provides an insight on the effectiveness of alternative retrofit schemes for the horizon of the remaining school lifetime. This tool requires the consideration not just of the retrofit cost but the costs related to damage/failure consequences and this is an essential feature for a complete comparison of alternative retrofit techniques, Ang & De León (1997). When the school failure probability exceeds the target (acceptable) value, the considered retrofit type should be modified to rise dimensions (either by increasing some thicknesses or by the addition of rebars or the change of the structural shape for a heavier section, etc.). The response analyses are repeated until the school failure probability is below the target value, De León & Delgado (2008). The expected life-cycle cost is assessed by considering the cost of the retrofit and the cost of the failure consequences, which include the potential deaths, the cost of lost contents, the cost of structural and non-structural damage and the cost of business interruption.

A simplified blocks diagram shows the proposed formulation; see Figure 1.

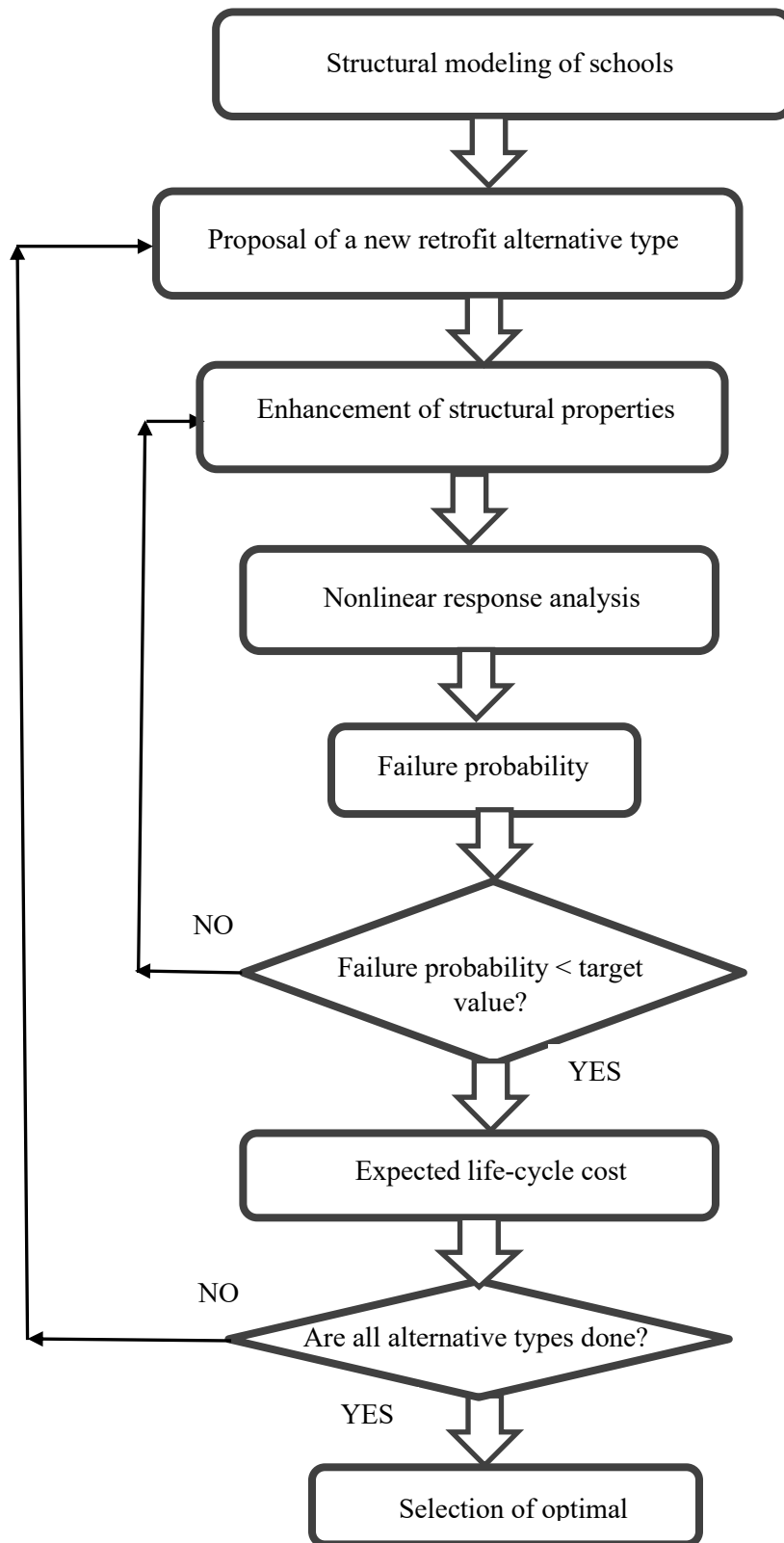


Figure 1. Proposed procedure

The failure limit state for bending is:

$$LS_i = M_{\max i} - M_{ri} \quad (3)$$

where $M_{\max i}$ and M_{ri} are the maximum acting moment and the corresponding resisting value for the structural element i . If the failure is governed by shear, the safety margin is:

$$LS_i = V_{\max i} - V_{ri} \quad (4)$$

where $V_{\max i}$ and V_{ri} are the maximum acting shear force and the resisting value for member i respectively.

When the loads that govern the failure are the axial force and flexure, as a response of the structural element i :

$$LS_i = 1 - P_{acti}/P_{ri} + M_{acti}/M_{ri} \quad (5)$$

Where P_{acti} is the acting axial force and P_{ri} is the axial capacity, both for the member i , in a column of the school.

Uncertainties are considered in both acting and resisting forces as presented by Bojórquez et al. (2017). All variables are taken as random lognormal variables as considered by De León (2010) and García-Manjarrez & De León (2021).

As the seismic effects have a coefficient of variation of 0.33, the variability of the acting forces will be considered as these value (De-León-Escobedo, 2024). In addition, the coefficient of variation of the resisting forces is taken as 0.15 as recommended in previous works (De León-Escobedo et al., 2024). The expected values of P_{act} and M_{act} , which are the effects of the seismic demands, corresponds to the spectral pseudoaccelerations for the seismic forces for each considered site. The largest LS indicates the limit state that governs.

The conditional probabilities:

$$P(LS < 0 | PGA_i) \quad (6)$$

are calculated from the structural responses obtained for the scenario PGA values and by using Monte Carlo simulation techniques as described by Ang & Tang (2007). The capacities

and responses follow the recommendations of current codes like GCDMX (2023) and practical retrofit guidelines like INIFED (2016).

The calculation of the expected life-cycle cost of the schools, is performed by applying previously proposed formulations by De León-Escobedo (2024) and Ang & De León (1997). The mean value of the total cost $E(LC)$ consists on the initial cost C_i and the updated value of the average future cost, which includes the costs due to the potential retrofits of the school due to the earthquakes that may occur during the rest of the school lifetime. For the calculation of the future cost, a model of the number and size of earthquakes that may occur in the school lifetime, should be established. This model is ahead discussed and depends on the level of seismic hazard at the school site. The future costs, which represent the mean value of the costs due to the failure consequences $E(PCF)$, is usually expressed (De León-Escobedo, 2024) as:

$$E(PCF) = C_F F_P PVF \quad (7)$$

where:

$$C_F = C_{co} + C_{int} + C_{inj} + C_d \quad (8)$$

where C_{co} is the cost of the school contents, C_{int} is the cost of interruption of the school functionality, C_{inj} is the cost of injuries and C_d is the cost of potential deaths. And PVF is the present value of the future costs.

$$PVF = (1 - \exp(-\vartheta LT))/(\vartheta LT) \quad (9)$$

ϑ is the net annual interest rate and LT the school lifetime.

For the calculation of C_{co} , the cost considers school articles and lab instruments and materials. The other cost components are ahead described.

3. APPLICATIONS

3.1 School 1 Tetela del Volcán, Morelos

The school 1 is located at Tetela del volcán, Morelos and the plan view and elevation of the structure are shown in Figure 2. The structure has one level and two classrooms of 7.0 x 7.0 m and it is built

with reinforced concrete frames and masonry divisory walls. The columns are 0.45 x 0.30 m, the beams 0.35 x 0.25 m and the wall width is 0.12 m.

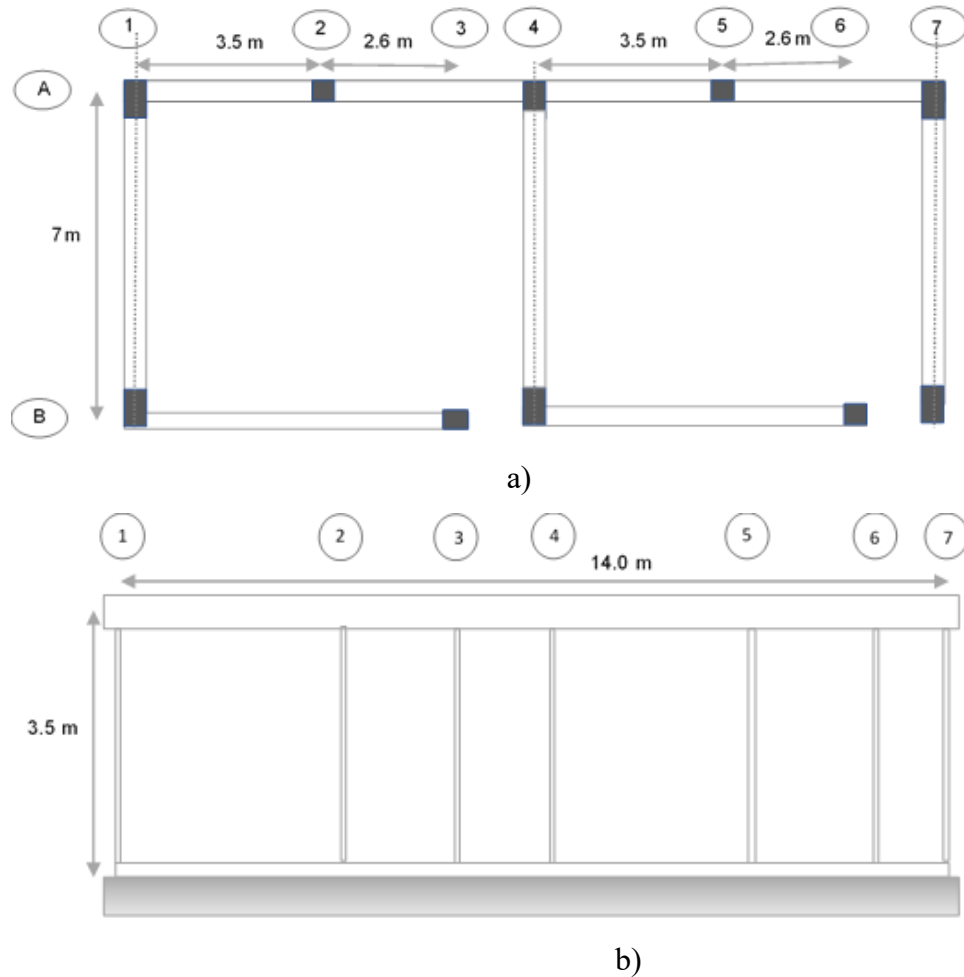


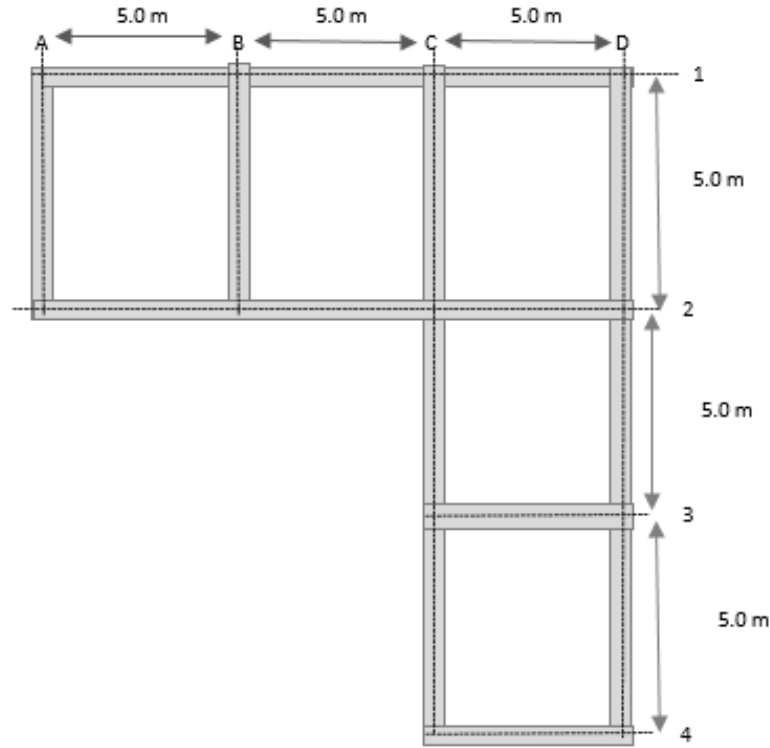
Figure 2. a) Plan view b) Elevation of school at Tetela del Volcán

The materials properties are: compression resistance of reinforced concrete 250 kg/cm^2 , steel capacity $4,200 \text{ kg/cm}^2$ and capacity of the brick walls 15 kg/cm^2 . The load due to the weight of students and benches is 100 kg/m^2 .

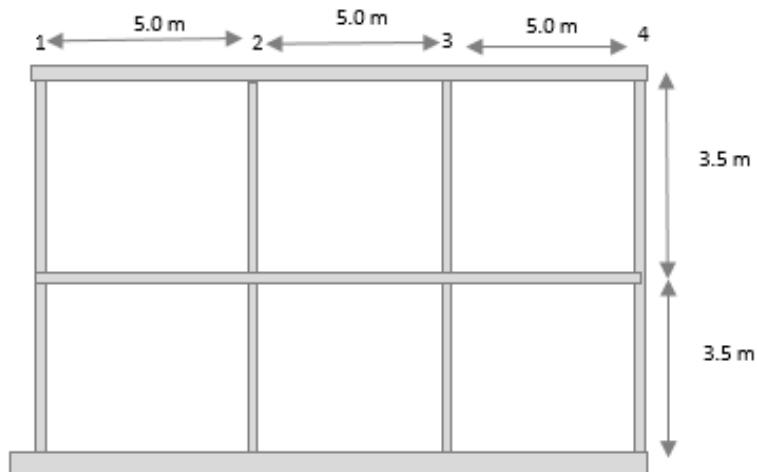
3.2 School 2 Tehuacán, Puebla

The school 2 is located at Tehuacán, Puebla and has 2 levels with 5.0 m spans. Its structural system is built by reinforced concrete frames with masonry divisor walls. The columns are 0.65 x 0.45 m, the beams are 0.55 x 0.30 m and the wall width is 0.12 m. The plan has an irregular “L” shape, the plan and elevation views may be seen in Figure 3.

The capacities of materials are: reinforced concrete capacity 250 kg/cm^2 , steel capacity $4,200 \text{ kg/cm}^2$ and capacity of brick walls 15 kg/cm^2 . The school load due to students and school benches and desks is 100 kg/m^2 according to current design regulations as established in GCDMX (2023).



a)



b)

Figure 3. a) Plan view and b) elevation of school at Tehuacán

4 OBSERVED DAMAGES

4.1 Tetela del Volcán

The main damages were at columns 2A y 3B, as shown in Figure 4. Other minor damages were observed at walls in axis 1, 4 y 7. Also, the slab presented small cracks with 7 mm width close to the affected walls. Some pluvial pipes were separated from the walls and some broken glass fell from the windows.

4.2 Tehuacán

Some damages were observed at the top of the walls at axis 1 and 7 between axis A and D. There were cracks in the walls with maximum width of 5 mm with an angle of 45° and, in the beams, at the axis 1, 3 and 5 the cracks had 1 cm width at the right end (see Figure 5). The columns did not have any damage. The slab had cracks with less than 1 mm width at



Figure 4. Damages at a column in School Tetela del Volcán

locations close to the damaged walls. The pluvial pipes were separated from the walls and some lamps fell from the roof. Some broken glasses were found.



Figure 5. Damages at the School Tehuacán

5 MODEL FOR THE SEISMIC LOAD

Seismic loads were calculated according to the guide in the Manual for electrical infrastructure by CFE (2015) which suggests first to calculate the seismic accelerations at the rock level through the spectrum derived for constant hazard. Later on, the final accelerations are obtained according to the local soil conditions. These tasks are performed through the PRODISIS software which provides the specific features of the ground motions that correspond to the site and the expected seismic demand for the structure in Mexico.

5.1 Preliminar structural models

A set of preliminar models were employed to reproduce the observed damages with the existing records of the earthquake of September 19th., 2017, from recording stations close to the school locations. With these results, the critical members were identified and the current mechanical properties of the damaged members were calibrated (De León-Escobedo, 2024). Also, the INIFED (2016) technical guidelines were followed.

5.2 Failure probabilities for the schools under damaged conditions

The school failure probabilities, for the damage conditions, were calculated by following the above described procedure and by reducing the structural capacities of the damaged members. For example, the totally collapsed column shown in Figure 4, for the school Tetela del Volcán, was not included in the response analysis of the structural model. As a consequence, the school failure probability results as high as 0.39. In a similar way, for the school at Tehuacán, the failure probability is 0.23. These results are consistent with the high level of damage observed and suggest that an immediate retrofit is required for both schools. The failure probabilities have to be lowered to the order of 10^{-3} by applying a sufficiently strong retrofit that reinforces the school safety along the remaining school life. These order of probabilities, known as target failure probability, has been found to be the adequate level for schools according as previously reported by García-Manjarrez & De León (2017) and by ISO 8930 (2021). The reduction on failure probability will have two positive effects: the first one is the improvement on the school safety level and the second one the reduction on the life-cycle cost as formulated by De León-Escobedo (2024).

6 RETROFIT ALTERNATIVES

Each retrofit scheme is essayed by sequentially increasing the size of the added pieces. For example, for the retrofit scheme 1, steel structural angles are added on the corners of the damaged members and, as a first trial, the thickness of the angles are proposed as small as possible, for example 1/8". Then, after a response analysis is performed, the demands are compared to the resistances and if it is found that the failure probability of the critical member is higher than 10^{-3} , it means that the proposed retrofit is not sufficient and the angles thicknesses have to be increased until the retrofit is sufficient. The section properties included the added Steel angles and transformed section methods were used to get the combined materials properties. For school 1, the columns 9 and 10 were retrofitted by adding 4 angles of steel A-36 6"x6"x3/8" and, for the beams 1 and 10, 4 angles of steel A-36 2"x2"x3/8" / 8 5 " were added in the corners. Figure 6 shows a general view of the retrofit. As above mentioned, the adequate reinforcement level is found in an iterative way: once a proposal is made, the failure probability is calculated and it should have a lower value than the target failure probability 10^{-3} . If these failure probability exceeds the threshold, the dimensions and size of reinforcements are increased until the requirement is reached.

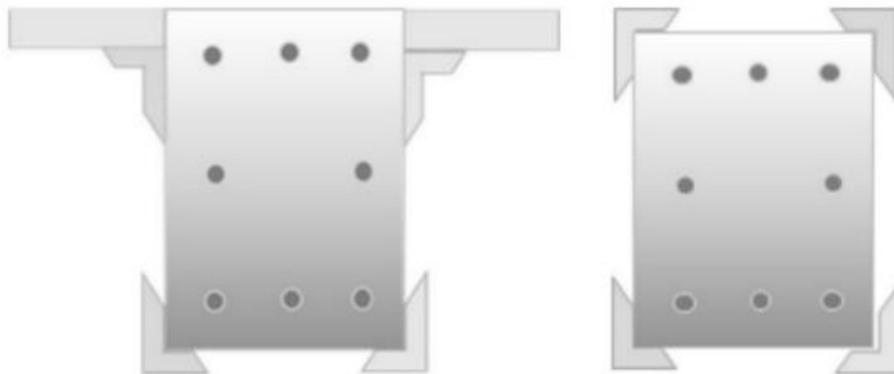


Figure 6. Retrofit scheme number 1 for school 1

Retrofit type 2 consists on the jacketing of damaged columns and beams. By following the same iterative procedure, as for retrofit 1, the original dimensions of the damaged columns and beams are increased. In the case of the columns, the required dimensions were 60X45

cm while for the beam the resulting size was 45X35 cm. In the column, 8 rebars No. 6 were added. Figure 7 shows the retrofitted cross sections.

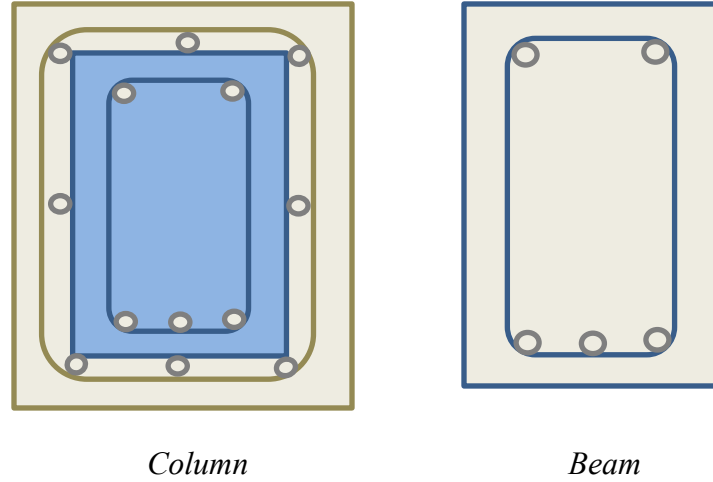


Figure 7. Retrofit scheme number 2 for school 1

7 COSTS AND FAILURE PROBABILITIES OF RETROFITTED SCHOOLS

7.1 Retrofit costs

The cost of the retrofit works were calculated by using traditional calculations that consider the costs of materials, labour and other consequent items. For retrofit type 1, these costs were \$16,000 and \$31,000 USD for the schools at Tehuacán and Tetela del Volcán. For retrofit type 2, these costs were \$13,000 and \$24,000 USD for the schools at Tehuacán and Tetela del Volcán, respectively.

7.2 Failure probabilities after retrofit

The new structural properties, for the retrofitted members, are taken as the mean values of the capacity for each retrofit type and for each school whereas the mean value of the demands are the forces obtained from the response analysis as described by De León-Escobedo, Ang, & Guadarrama (2023). As above mentioned, the demand and capacity variables are taken as lognormal and the failure probabilities are calculated by applying Monte Carlo simulation techniques. Some expressions are typical for the calculation of the lognormal parameters λ and ζ , as described by Ang & Tang (2007); these parameters are the central and dispersion parameters of the lognormal distribution.

$$\lambda = \ln(\mu) - \zeta^2/2 \quad (10)$$

$$\zeta = (\ln(1 + CV^2))^{1/2} \quad (11)$$

Where:

μ is the mean value and CV the coefficient of variation. For the cases considered here, the exceedance of the resisting moment was the critical failure mode. And this is because the ratio between demand and capacity, for bending moment, was higher than for shear or axial forces. Table 1 shows a sample of these calculations and the indicator for failure (demand > capacity) or survival (demand < capacity) for both retrofit types and both schools.

Table 1. Sample of simulations for the failure probabilities of schools for retrofits 1 and 2.

Demand and capacity are moments in tn-m

Telela del Volcán		
R1		
Demand	Capacity	Indicator: 1=failure, 0= survive
10.6	14.2	0
9.4	15.5	0
7.4	12.8	0
12.1	16.8	0
10.6	15.1	0
13.8	12.3	1
11.2	16.1	0
9.7	16.4	0
12.9	17.7	0
11.9	18	0
R2		
11.6	14.9	0
10.3	13.6	0
9.2	15.3	0
12.8	16.9	0
15.1	14.7	1
11.4	14.1	0

13.7	17	0
12.2	15.4	0
7.8	11.3	0
9.9	14.8	0
Tehuacán		
R1		
9.8	13.6	0
12	14.7	0
10.8	12.9	0
13.5	16.8	0
11.3	14.6	0
9.5	13.1	0
10.2	13.9	0
12.6	15.4	0
13.7	13.2	1
10.6	13.8	0
R2		
10.5	12.6	0
9.8	13.4	0
11.8	11.6	1
10.9	13.6	0
12.2	15.7	0
13.1	10.9	0
9.6	13	0
11.3	14.7	0
10.7	13.8	0
12.6	15.1	0

The resulting failure probabilities are, for Tetela del Volcán: 0.0026 for R1 and 0.0086 for R2 whereas, for Tehuacán, 0.0045 for R1 and 0.006 for R2.

8 EXPECTED LIFE-CYCLE COST OF RETROFIT STRATEGIES FOR BOTH SCHOOLS

According to Eq. (7), all the cost components are calculated from local prices and conditions. For example, typical costs for office and school implements are obtained from commercial reports (<https://todooficina.com/equipamiento/>). The cost of fatalities is obtained by using a published rate $0.0168 / m^2$ proposed for collapsed buildings due to seismic events as explained by De-León-Escobedo & Ismael-Hernández (2022) and De León-E. et al. (2023). These rate was calculated as the average value of the number of deaths divided by the total plan area of the building for a sample of collapsed buildings during the earthquakes of 1985 in Mexico City. Also, the cost per died person is obtained from the human capital approach, as proposed by Rosenblueth (1986). These approach calculates the loss of income of the deceased individual, if it would have survived, during the rest of his productive lifetime. These loss is estimated from an assumed average age of children (8 years) at the school and the expected annual income of individuals (6000 USD) at the school site.

Besides, for the cost of injuries, it is considered a similar reported rate as explained by De León-Escobedo, Ang, & Guadarrama (2023). See Table 2 for the resulting costs per ítem and per school.

Table 2. Estimated cost components in USD for each school

	Tehuacán	Tetela del Volcán
<i>Cc=</i>	\$ 2,500	\$ 7,000
<i>Ce=</i>	\$ 1,800	\$ 7,400
<i>Cin=</i>	\$ 11,000	\$ 46,000
<i>CF=</i>	\$ 9,000,000	\$ 14,000,000
<i>CD=</i>	\$ 9,015,300	\$ 14,060,400

As observed, the major cost component is the one of fatalities for both schools. This fact justifies the code recommendatios to set schools in the most important group of constructions for safety considerations. In order to calculate the expected life-cycle cost, for

both schools and both retrofit alternatives, the retrofit costs are added to the product of the failure probabilities presented in Table 1, the cost components shown in Table 2 and the present value factor used to transport future costs to present value costs. For the calculation of the present value factor, an interest rate ϑ of 8 % and a lifetime LT of 50 years are used. Table 3 shows the expected life-cycle costs per retrofit strategy and per school.

Table 3. Calculated expected life-cycle costs (USD) per retrofit strategy and per school

	Tehuacán	Tetela del Volcán
R1	\$ 56,400	\$ 70,700
R2	\$ 69,200	\$ 146,300

9 DISCUSSION OF RESULTS

It is worth to note that the damage type and extension, besides the level of seismic hazard, are the critical factors that determine the type of retrofit that is more convenient to improve the school safety level. Uncertainties on the seismic load were higher than those of the members capacities. The improvement on the structural safety try to enhance the school performance for the earthquakes that may occur in the rest of the school lifetime. However, in order to assess the economical effectiveness of these improvements it is required a cost/benefit balance which, in this work, is achieved through the calculation of the school failure probability and the expected life-cycle cost. For example, for the cases considered here, the addition of steel angles at the corners of the damaged members was more effective than the jacketing of the cross section. The failure probability of the schools was significantly reduced by using R1 as compared to R2 (see Table 1) for both schools. These results may be explained because the confinement provided by the steel angles to the damaged section contributed more to the school safety, than the jacketing itself, even with an increment on the section size. This is true, particularly when the future cost is high (which is the case here because of the high value of the fatality cost) and when it is combined with a high value of the failure probability (when the retrofit is not very effective).

The expected life-cycle cost is a helpful metric to support the decision-making because the higher cost of R2 for both schools reinforces the selection of R1 as the most convenient strategy. Also, the high number of students, due to the high number of stories and the large plan area of the building, explains the higher retrofit costs of the school 2.

Therefore, extensive damages require a global-type retrofit like the introduction of steel braces or walls at some bays. Extensive and strong damages may require a change on the structural type and retrofit on non damaged members. However, for small damages like the ones observed in the cases studied here, a localized-type retrofit are appropriate. Also, a slight damage level, like non structural damage or damage on finishings may require only superficial improvements.

For the examples considered here, the highest cost component was the one that corresponds to expected fatalities, and its high amount is because of the number and age of students at the schools. For the considered cases, the failure probability was lowered from 0.39 (before retrofit) to 0.0026 (after retrofit) for the school at Tetela del Volcan and from 0.23 (before retrofit) to 0.0045 (after retrofit) for the school at Tehuacán with retrofit R1. The reductions were from 0.39 to 0.0086 for the school at Tetela del Volcán and from 0.23 to 0.006 for the school at Tehuacán with retrofit R2.

The study may be used to generate recommendations for extension of the school lifetime and to derive cost/benefit justifications for inspection/instrumentation of large and important schools.

The soil conditions, foundation type and isolators or damper devices were not considered in these work, future research may include these aspects.

10 CONCLUSIONS AND RECOMMENDATIONS

A risk-based formulation to compare retrofit costs in schools was proposed with specific consideration to the seismic hazard and the expected life-cycle costs.

- The proposed procedure balances costs, consisting on the retrofit cost and the probable future costs, against the benefit of an adequate safety level for the rest of the school lifetime,
- It was found that the type of retrofit depends on the damage type, level and extension, the seismic hazard level of the school región and the level of failure consequences. For widely extended damage, a general retrofit like the introduction of steel braces or walls, is required.

However, for localized or moderate damages, like in the cases here considered, a localized-type retrofit is required.

- It was shown that the expected life-cycle cost is an effective way to measure the longterm adequacy of the retrofit strategy because it includes the failure probability and the expected future costs on the school lifetime.
- It is recommended to keep a permanent monitoring program on schools to make oportune decisions on inspection and maintenance to prevent the schools for having strong damages or failures.
- It is recommendable to extend the proposed formulation to cover other school structural types, other retrofit alternatives and other failure modes in order to propose general guidlines for all the schools that were built at zones having specific levels of seismic hazard.

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COMPETING INTERESTS

The authors have no relevant financial or non-financial interests to disclose.

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