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Simplified methodological approach for repair time based on workforce population distribution of building portfolios from a resilience perspective

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Abstract: Recovery from catastrophic seismic events is subjected to multiple aspects involving the resilience capacity. Disaster Risk Reduction management includes policies focus on preparedness to overcome the challenges associated to response on a post-disaster event. Most of those covers up the distribution of available resources to recovery from the damage state for the whole elements-at-risk. This paper presents a simplified methodology to estimate the maximum repair time using the distribution of resources through workforce population for intervention of building portfolio. This approach uses the risk metric: average annual repair time and the workforce population capacity. The risk metric could be obtained from conventional probabilistic seismic risk assessment. Therefore, several scenarios are defined to estimate the total repair time to recovery based on the percentage of the workforce population capacity. This gives a simplified tool for policymakers to stablish the thresholds limits for allowable repair time and percentage of population used for recovery. Finally, an example of its application is presented for a school building portfolio.

Keywords: repair time, resources distribution, seismic risk assessment, business interruption losses.

1. Introduction

Probabilistic seismic risk assessment of buildings portfolios is a powerful tool using within the Disaster Risk Reduction, *DRR*. This is mainly focus on calculation of risk metrics expressed in terms of economic losses such as average annual loss, probable maximum loss ASTM E2026 (2016), Zanini *et al.* (2019). The average annual repair time, *AART* is a new risk metric figure that represents the estimated repair time in days as indicated by Aroquipa and Hurtado (2022). Nonetheless, the Disaster Risk Reduction *DRR* management involves a wider scope other than economic losses covering social aspects as evidenced in Pearson and Pelling (2015). Then, the need for estimation of maximum repair time to recovery, identification and distribution of required workforce resources is essential to improve the preparedness policies in DRR management Akkar *et al.* (2021). As a result of those needs specific methodologies have been proposed for the distribution of resources Freddi et al. (2021), Eslamian *et al.* (2021). Those approaches are mainly based on expert judgement.

This paper proposed a simplified methodological approach to estimate the maximum repair time considering the distribution of workforce population for a building portfolio. Likewise, FEMA (1999, 2012), Terzic and Yoo (2016), and Yamin *et al.* (2017) proposed a more detailed methodological approaches to assess the repair time for an individual building. Which required the definition the multiple parameters to evaluate the repair time, where for some cases they included schedules and resources distribution disaggregated by building floor and designation of repairing typology (i.e., replacing of finishings, crack control for reinforce concrete columns or beams) refer to FEMA (2012), Terzic and Yoo (2016). Those methodologies will be impractical when thousands of buildings should be assessed. However, FEMA (1999) uses the repair time within a building portfolio mainly for estimating the indirect cost associated with business interruption. Then, the proposed approach uses the conventional probabilistic seismic risk assessment *RA* for buildings portfolios, where main parameters including hazard definition, exposure identification, damage estimation (vulnerability) and loss estimation are required as indicated in Cardona et. al. (2012). Then, the next step involves the estimation of maximum repair time using the *AART* risk figure and workforce population available at the study zone. Also, the indirect cost associated with business interruption losses could be obtained. As a result, the methodology allows to evaluate the maximum repair time and indirect cost due to business interruption losses as function of distribution of resources. Furthermore, their effectiveness is presented using the simplified resilience index, *SRI* proposed by Aroquipa and Hurtado (2022). Finally, a case study is presented here with the application of the proposed methodology for a building portfolio of about 7,500 school buildings. It contains a unique building typology regarding the 780-PRE building school system. It is a 2-story height building with reinforce concrete moment frames structural and infill masonry walls system Aroquipa (2016). The buildings are located at the region of Cusco in Peru.

2. Total repair time methodology

A simplified methodological approach is presented here to estimate the maximum repair time considering distribution of workforce population available. This approach uses the conventional probabilistic seismic risk assessment for buildings portfolios and workforce population. This approach requires a total of three steps. The first step requires to perform the *RA* which requires the definition of the input parameters including hazard definition, exposure identification, damage estimation (vulnerability Yamin *et al.* (2017)), and loss estimation Cardona *et al.* (2012). The next step requires the definition of workforce population capacity, workforce population required by building typology to perform the intervention process, and intervention cost per day Aroquipa and Hurtado (2022). Then, the final step, involves the calculation of maximum repair time as function of percentage of workforce population capacity and indirect cost for business interruption losses. Figure 1 presents a summary of the overall methodological approach.

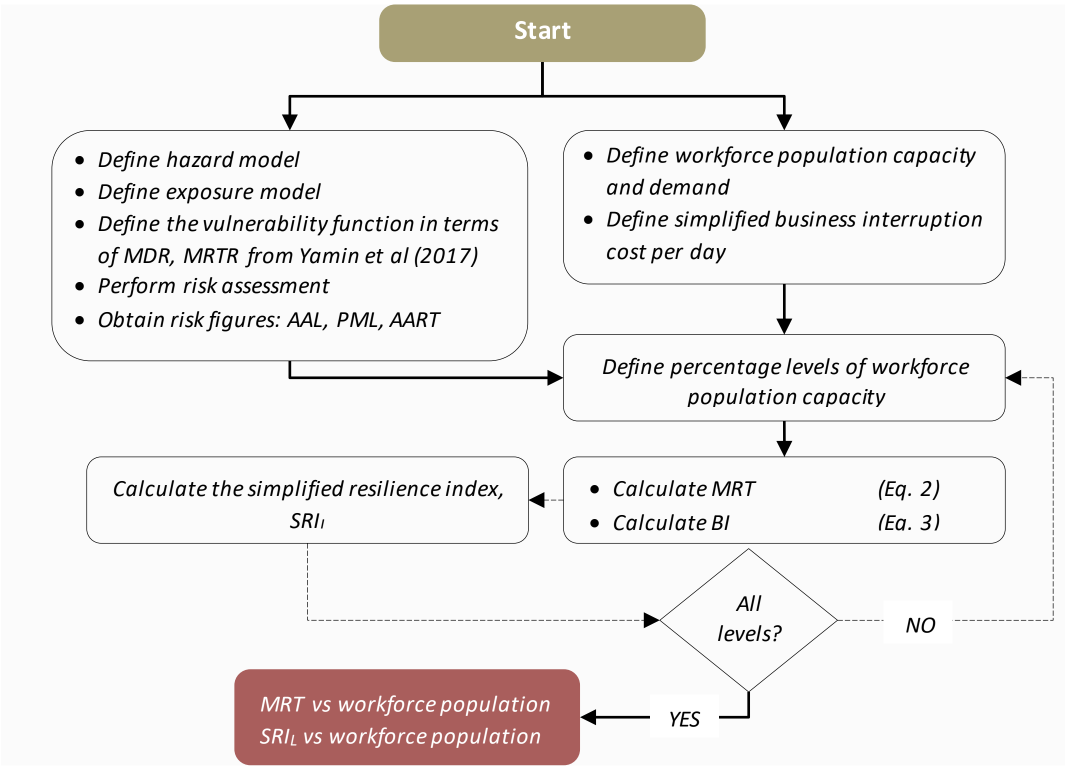


Figure 1 – Methodological approach

The maximum repair time calculation as function of percentage of workforce population capacity is obtained using the $AART$. The $AART$ results and workforce population required should be disagregated by building typology. Those could be obtained using Equation 1 and 2. Afterwards, the business interruption losses is calculated as the maximum repair time multiplied by the indirect cost per day using Equation 3.

$$nBIP_i = \frac{f_p * W_C * f_{R|BT_i}}{W_{R|BT_i}} \tag{1}$$

$$MRT = \sum_{i=1}^{n} nBIP_i * \overline{AART_i} \tag{2}$$

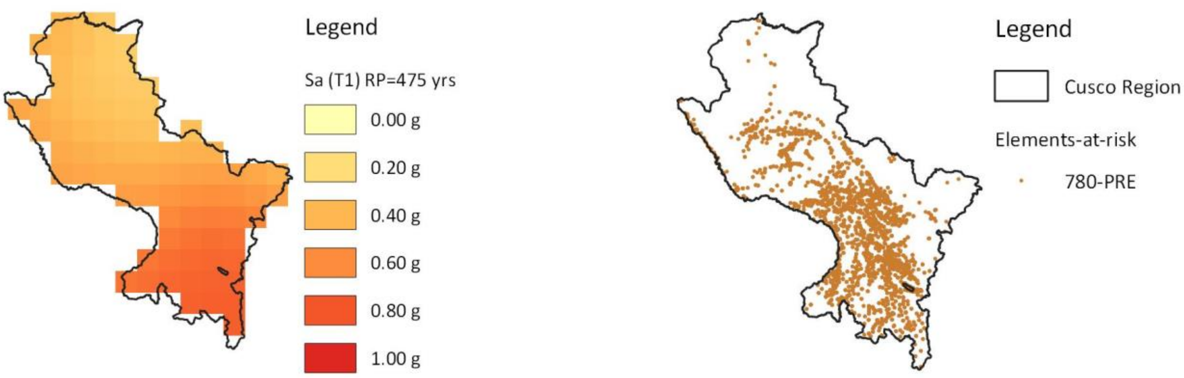
$$BI = \sum_{i=1}^{n} nBIP_i * \overline{AART_i} * IC_i \tag{3}$$

where, $nBIP_i$ refers to total number of buildings that could be repaired in parallel for the *i-th* building typology; f_p is the percentage of the workforce population capacity; W_C is the workforce popultaion capacity; $f_{R|BTi}$ is the pertange representative of the whole portfolio for the *i-th* building typology; and $W_{R|BTi}$ is the workforce population required for the *i-th* building typology; MRT is the maximum repair time in days; $AART_i$ refers to average annual repair time for the *i-th* building typology; BI is the total business interruption losses; IC_i is the indirect cost per day for the *i-th* building typology.

3. Results

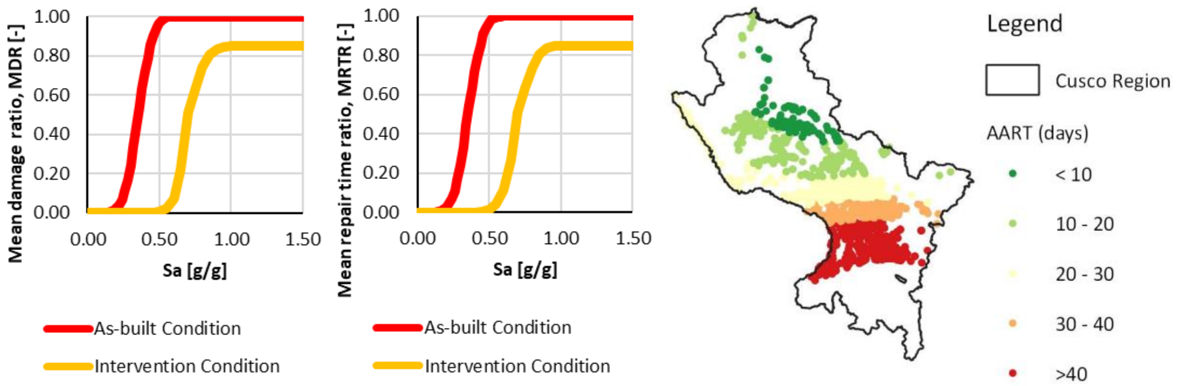
3.1 Seismic risk assessment

The study case is a building portfolio conformed by a unique typology of 780-PRE school buildings. For the seismic *RA* a total of three cases were considered. Case 1 relates to the buildings for the as-built condition. Case 2 refers to the 5% of the whole buildings in a condition of intervention involving a seismic retrofit process, the other 95% represents the buildings for the as-built condition. Finally, Case 3 refers to the 10% of the whole buildings in a condition of intervention involving a seismic retrofit process, the other 90% represents the buildings for the as-built condition. The seismic *RA* was performed using the CAPRA-GIS software E.R.N.-A.L. (2011). Figure 2 presents the summary of the risk assessment inputs and outputs. The risk metrics obtained from those analysis includes the average annual loss *AAL*, average annual repair time AART, and probable maximum loss *PML* with a return period of 2,500 years based on the ASTM E2026 (2016).



a) Seismic Hazard model (Return period 475 yrs)

b) Exposure model



c) Vulnerability model

d) Risk figure: AART (Case 1)

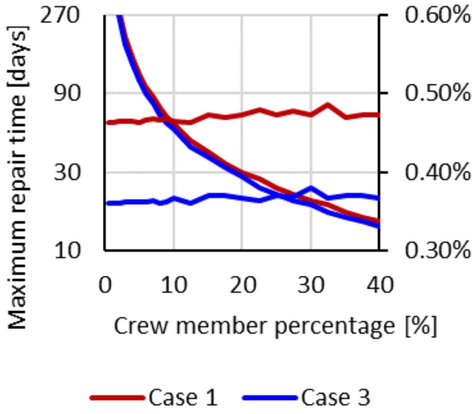
Figure 2 – Risk assessment study case summary

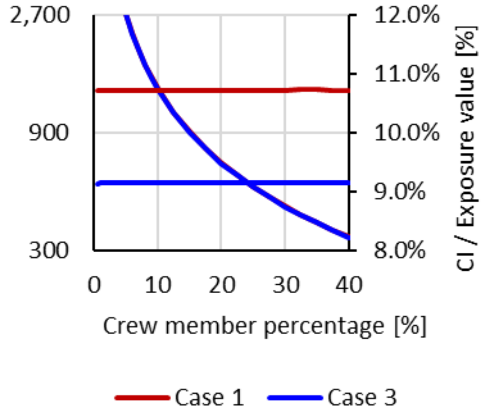
3.2 Maximum repair time

The workforce population capacity for the study cases is about 93,000 persons. The repair cost per day is defined as a fixed cost and it has a value of $882 and $736 per day for the case of the buildings without and with intervention respectively. Then, the maximum repair time and business interruption losses are obtained solving the equations 1-3, with the defined previous parameters and results from previous sub-section. The business interruption losses are presented as percentage of the total exposure value of the portfolio. The results data is summarized in Table 1 for the three cases, while Figure 3 shows the results for the case 1 and case 3.

Table 1 – Repair time results for AART

Workforce population		Total repair time (days)		
(%)	(pax)	Case 1 Int. = 0%	Case 2 Int. = 5%	Case 3 Int. = 10%
0.5	467	1,241	1137	1,141
1	935	603	610	541
2	1,870	298	295	269
5	4,675	118	118	108
10	9,351	59	60	55
20	18,703	30	30	28
30	28,055	20	20	19
40	37,407	15	15	14





a) *AART*

b) *PML* (RP = 2,500 yrs)

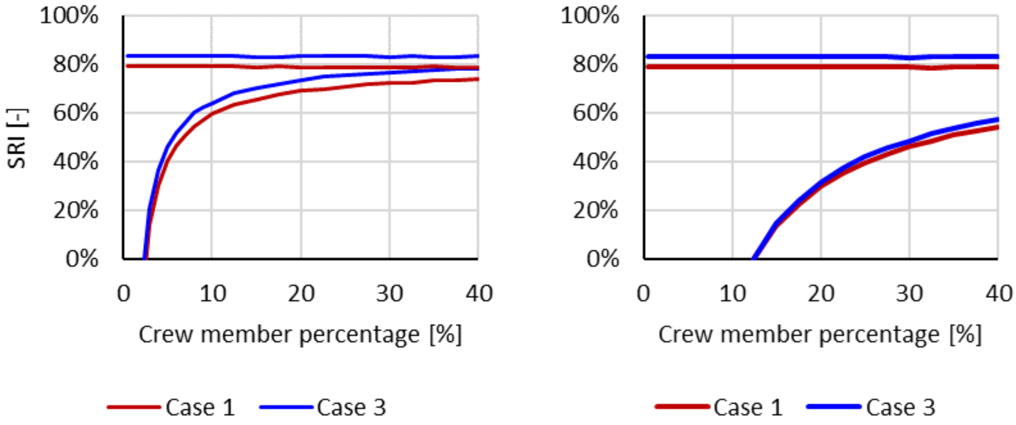
Figure 3 – Repair time vs percentage of workforce population

3.3 Effectiveness

A sensibility analysis is performed to validate the effectiveness of the proposed methodological approach. The validation process uses the simplified resilience index at loss estimation stage level as stated by Aroquipa and Hurtado (2022). The SRI_L is computed using equation 13 from Aroquipa and Hurtado (2022). The workforce index weighting factor is set to zero, for the average annual loss and probable maximum loss is set to a value of 0.50 for each one. The limit repair time is set to a value of 210 and 730 days for average annual losses and probable maximum losses respectively. Those values where obtained based on recommendations given by Fu *et al.* (2021). The results are summarized in Table 2 for the three cases, while Figure 4 shows the results for Case 1 and Case 3.

Table 2 – Summary of results for simplified resilience index

Workforce population		Simplified resilience index (%)		
(%)	(pax)	Case 1 Int. = 0%	Case 2 Int. = 5%	Case 3 Int. = 10%
0.5	467	-189.7	-170.8	-177.0
1	935	-51.5	-54.2	-40.1
2	1,870	14.5	15.5	21.9
5	4,675	53.5	54.6	58.6
10	9,351	66.2	67.3	70.6
20	18,703	72.3	74.1	76.7
30	28,055	74.5	76.1	78.5
40	37,407	75.6	77.4	79.9



a) *AART* b) *PML* (RP = 2,500 yrs)

Figure 4 – Sensitivity results for simplified resilience index

4. Conclusions

Using a consistent and simplified methodological approach through the distribution of available resources, it was possible to assess the sensibility in the maximum repair time related to the percentage of workforce population capacity. This approach defines the maximum repair time of a building portfolio as a function of the workforce population capacity. Furthermore, this could be extended to estimate the losses associated with the business interruption time. Then, the indirect costs could be computed in a simplified way and added to the total direct cost from results of the seismic risk assessment.

Finally, their effectiveness showed a highly sensitivity upon the workforce population within the simplified resilience index. Also, the results showed their applicability for policymakers, where figures such as repair time vs workforce population and simplified resilience index vs workforce population allows to identify in an easy way threshold limits. One clear example is the allowable time for recovery from a disaster event that is incorporated and combined within the simplified resilience index. Then, the thresholds limits could be included within the preparedness policies at earlier stages of the Disaster Risk Reduction programs. Further studies should be carried out to compare the results of the repair time using the detailed methodological approach as indicated by FEMA (2012) and Terzic and Yoo (2016) to improve the fragility or vulnerability functions.

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