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LOSS OPTIMIZATION SEISMIC DESIGN (LOSD): BEYOND SEISMIC LOSS ASSESSMENT

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Abstract

During past few decades, seismic design practices have significantly advanced to achieve better preparedness against probable earthquake events. It is reported that most of the modern buildings, in the regions where modern seismic design practices are already in use, succeeded to achieve the life safety limit state during last few earthquakes (Canterbury earthquake 2010, 2011, South Napa earthquake 2014, Chile Earthquake 2015). However, the financial losses associated with every earthquake damaged buildings are enormous. Seismic loss assessment procedure following the PEER performance based design framework has been adopted and developed considerably during the last decade. The loss assessment tool PACT is already in use to estimate the probable seismic loss for buildings. Several other efforts have been made towards effective estimation of expected seismic losses during design life of a building. Nevertheless, use of the currently available tools requires substantial computational effort and prior knowledge of the loss assessment framework. For a designer without any background of seismic loss estimation, it is difficult to follow the current loss assessment framework or to use the available computer tools. Therefore, there is a serious need to develop a framework to rapidly estimate the expected seismic loss associated with a building within its design life.

Herein, the preliminary development of a loss estimation framework is presented that enables the designer to estimate the expected seismic loss with little additional effort. Essentially, the framework is based on the concept of floor level loss estimation methodology reported in the existing literature. In Loss Optimization Seismic Design (LOSD), the designer can quickly estimate the seismic loss and revise the design to restrict the loss within a limit as prescribed by the stakeholders. The normalized losses per unit floor area of typical office building, at different level of inter story drift ratio and floor acceleration, are presented as examples of expected floor level loss functions. During the development of the generalized loss functions typical components, which primarily contribute to the seismic loss in an office building, are duly considered. The distributions of the components in office building are developed from the construction data collected through a rigorous field survey throughout Christchurch city, supplemented with available information in various literature. A designer, without any prior knowledge of the seismic loss estimation framework, can use the developed generalized floor level loss functions to estimate the expected seismic loss for a given hazard level within the current time frame of design process. The applicability of the generalized loss functions is verified with detailed loss calculation for a typical office building. It is observed that the developed generalized loss functions can estimate the expected seismic loss with reasonable accuracy. However, further investigations are required to increase the accuracy of the loss estimation using the generalized loss functions.

Keywords: Earthquake; Generalized Loss Function; LOSD; PACT; Seismic Loss Assessment

1. Introduction

Present performance based seismic design philosophy primarily aims to limit the structural response within some prescribed limits such that the structure satisfies the desired performance. The implementation of performance based seismic design can be traced back to the 1976 Uniform Building Code [1]. However, until recently the performance criteria were prescriptive and qualitative in nature [2 – 4]. Considering the observed performance of the modern earthquake resistant buildings, it can be concluded that the life-safety objective is satisfactorily achieved in most of the recent earthquakes (Canterbury earthquake 2010, 2011, South Napa earthquake 2014, Chile Earthquake 2015). Nevertheless, the financial consequences due the loss of structural and non-structural components, and the cost and downtime required to restore them are massive. Merely achieving the code based performance objectives does not satisfy the stakeholders' expectation when it comes to financial losses. Therefore, during the last decade or so enormous research efforts have been made towards seismic performance assessment of buildings in terms of financial losses [5 – 8]. Recently, FEMA P-58 [9] methodology is prepared based on the framework developed by the Pacific Earthquake Engineering Research (PEER) center [10 – 12]. This new document and associated tools (PACT) can be used to assess the performance of different building types in terms of expected financial loss. Nevertheless, the information and meticulous detail required for loss assessment using PACT require some expertise on the subject, and may be difficult to adopt for day to day design practice.

Considering the huge attention being paid towards the financial loss implication of seismic damages, the next generation seismic design is expected to be based on the criteria that minimize financial losses. Earlier, Krawinkler et al. [13] presented the contrast between the performance based design and performance assessment of buildings. They presented how acceptable monitory loss can be viewed as the 'design target' at the design level within the framework of performance based design. They further pointed out that the relationships between monitory loss and engineering demand parameters are to be developed extensively for efficient application of the loss-targeted design. Later, Dhakal [14] proposed the concept of the Loss Optimization Seismic Design (LOSD). He conceptually presented how the widely used performance criteria, such as immediate occupancy or the collapse prevention, can be satisfied in LOSD even without explicitly defining those performance criteria during the design. The need for easily understandable (for the nontechnical stakeholders such as owner, insurer or common user) performance objectives is growing rapidly after each earthquake occurrence. Therefore, the concept of LOSD needs more attention to cater acceptable solution for the growing interests of the stakeholders. Herein, the preliminary development of a framework for LOSD approach is presented focusing on the direct economic loss as the design target. It is planned that, in due course of time, the framework will be extended to include the downtime and injury as the design targets.

2. Framework for LOSD

LOSD, like any other design approach, also works on the motto *capacity greater than demand*. Nevertheless, the demand is specified and capacity is calculated in terms of likely losses (dollars, downtime and injury). Once LOSD is fully developed, the demands pertinent to LOSD can be specified in the form of tolerable impact levels in national standards/guidelines. Nevertheless, if the specified tolerances are not acceptable to risk-averse stakeholders, they would always have the freedom to specify stricter limits of expected losses they are prepared to accept in different levels of earthquake during the design life of their buildings. All building configurations should satisfy the life safety requirement for which the estimated losses are less than their tolerable limits. A generic and simple loss assessment methodology is key to the successful implementation of LOSD. The design process is schematically presented in Fig. 1.

As introduced by Dhakal [14], the performance is to be measured in *RDI* format where, *R* denotes the expected repair cost, *D* denotes the expected downtime, and *I* denotes the injury vector that include minor/moderate/major injuries and causalities. Evidently, these terms, i.e. repair cost, downtime and injuries/causalities, are more familiar to the nontechnical stakeholders instead of the currently used performance criteria in engineering terms such as damage and deformation measures. Table 1 presents an example of performance requirements in *RDI* format for buildings in different levels of seismicity. The design objectives are to be defined in terms of the acceptable losses during the design life of a structure for different levels of seismicity. Different performance objectives can be selected based on the use of the buildings, such as residential, commercial, emergency etc. Estimation of the expected losses in *RDI* format is a crucial and challenging step in LOSD. Therefore, the methodology to estimate the expected losses needs to be simplified.

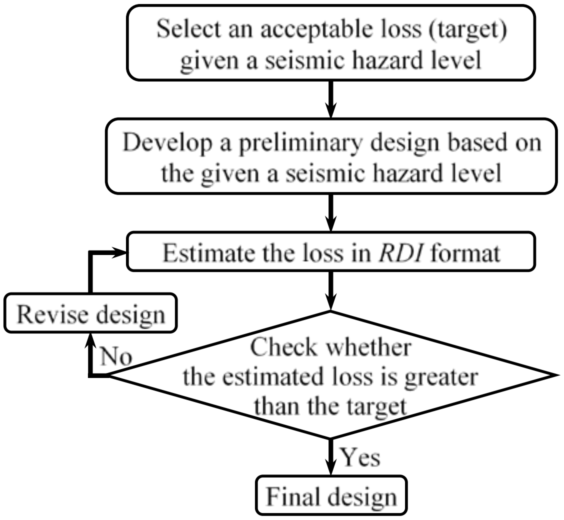


Fig. 1 – Schematic flow diagram of loss optimization seismic design (LOSD) process

Table 1 − Example of performance requirements in *RDI* format for buildings in different seismicity levels [14]

Ground Motion Intensity Corresponding to:	**Performance Measures**	**Allowable Loss (Capacity)**		
		Residential Buildings	**Commercial and Office Buildings**	**Emergency Facilities**
Frequently occurring earthquake (FOE), 50% in 50 yrs.	Repair: μ_R (%)	10^{-1}	10^{-2}	10^{-3}
	Downtime: μ_D	10^{-1} day	10^{-2} day	10^{-3} day
	Injury: μ_I (%)	10^{-1}, 10^{-2}, 10^{-3}	10^{-2}, 10^{-3}, 10^{-3}	10^{-3}, 10^{-3}, 10^{-3}
Design basis earthquakes (DBE), 10% in 50 yrs.	Repair: μ_R (%)	10	1	10^{-2}
	Downtime: μ_D	10 days	1 day	10^{-2} day
	Injury: μ_I (%)	10, 1, 10^{-2}	1, 10^{-1}, 10^{-3}	10^{-1}, 10^{-2}, 10^{-3}
Maximum considered earthquake (MCE), 2% in 50 yrs.	Repair: μ_R (%)	No limit	10	10^{-1}
	Downtime: μ_D	No limit	10 days	10^{-1} day
	Injury: μ_I (%)	50, 10, 10^{-1}	10, 1, 10^{-2}	1, 10^{-1}, 10^{-3}

3. Methodology

During the last decade, significant amount of research has been carried out on seismic loss assessment framework [5, 7 – 9]. The framework developed by the PEER centre to interrelate seismic hazard, structural response, damage and losses is presented in Fig. 2. As per this framework, the engineering demand parameters (*EDP*s) are computed from seismic response analysis for a given seismic hazard. For loss estimation, this has to be followed by probabilistic computation considering the interrelationships between the *EDP*s, damage measure (*DM*) and the decision variable (*DV*). The probabilistic calculations can be very cumbersome, and should be performed using computer based performance assessment calculation tools (such as PACT [9], SLAT [15]). However, the selection of appropriate interrelationships and details of the component inventory require a reasonable understanding and expertise on the probabilistic framework, which may not be suitable for routine design practice.

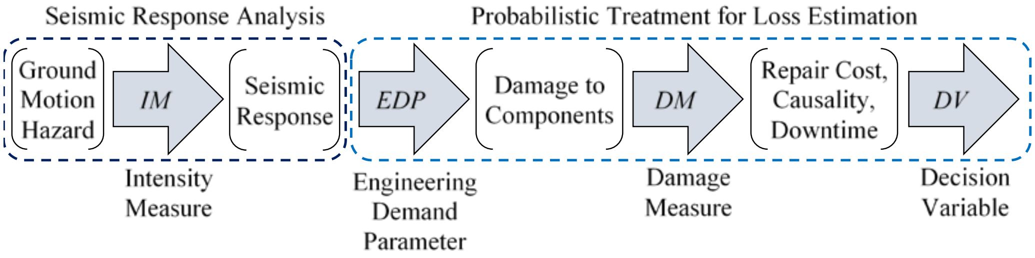


Figure 2 – Schematic illustrations of the key steps in the PEER loss estimation methodology

An important simplification can be achieved in the loss estimation process by condensing the damage measure; in other words, by expressing the expected seismic loss directly with respect to the *EDP*s, such loss-*EDP* relationships are commonly termed as loss functions. Ramirez and Miranda [8] presented building specific story level loss functions assuming typical values of the component density (or quantity) at a particular story and cost of the component. However, these loss functions do not account for the variation of the component density in different buildings. As a result, the predicted seismic loss may be significantly over/under-estimated when the component distributions differ from the assumed values. A refined approach would be to consider the component distributions matching with data collected for different building categories, and then probabilistically introduce the repair/replacement cost for different levels of damages to estimate the expected loss for that component at the given *EDP*.

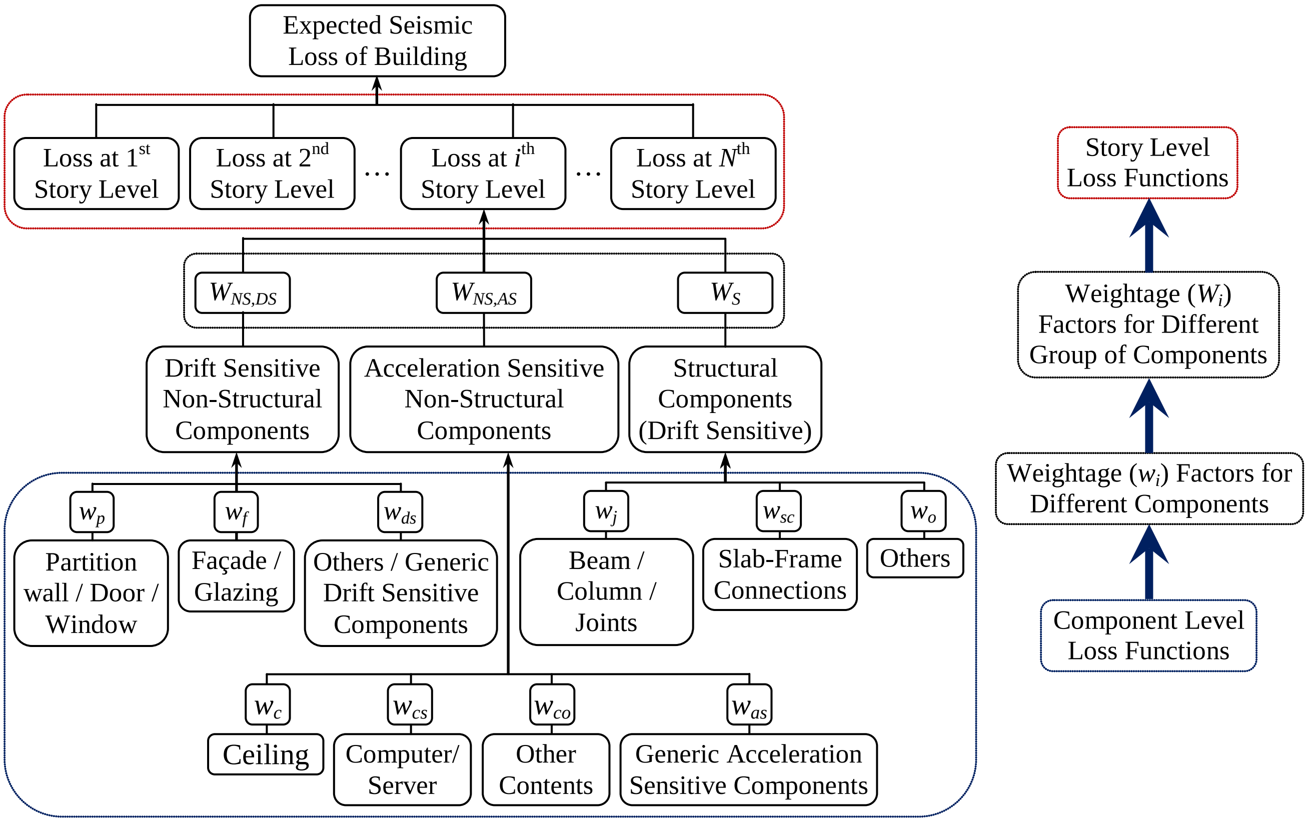


Figure 3 – Schematic representation of computation of seismic loss from component level to building level

In LOSD approach, the sources of expected seismic loss and their contribution to the total loss for a reinforced concrete (RC) framed building are schematically presented in Fig. 3. Here, the key is to establish the loss functions and the weightage factors (w_i) for different components contributing to the total seismic loss of a building. The weighting factors are needed at two levels; first at an individual component (i.e. ceiling etc.) level and second at the component group (i.e. acceleration sensitive non-structural components etc.) level. The w_i at the individual component level is calculated as the ratio of the cost of each component to the total cost of the component group. For example the weighting factor for partitions is the cost of partitions to the total cost of the drift sensitive non-structural elements in a story. It is believed that the component weighting factors calculated this way do not depend on the building usage. The second weighting factors W_is are calculated as the contribution of the component group to the total story value/cost; and this weighting factor will depend on the building usage (for example, the acceleration sensitive components will dominate in the total building value in hospitals and laboratories). It is possible, and advisable, to group the components in categories such as structural components, drift sensitive non-structural components, and acceleration sensitive non-structural components, so that their contributions to the total building cost for buildings with different usages as reported in literature [8] can be readily used. It can be noted that when all the contributing component groups are considered, then $\sum W_i = 1$. An alternate approach of weighting can be to decide the weighting factor of each component as a ratio of its cost to the cost of the whole floor. In that case, the compilation of loss at the group level and the second weighting factor will not be needed at all; the weighted component losses can directly be added to obtain the story level loss. Nevertheless, in this approach the component weighting factors cannot be generic and different sets of factors will be required for different usage of buildings; and hence can be cumbersome. The process of estimating expected seismic loss, from component level to building level, using generalized loss functions is elaborated in the following sections.

3.1 Generalized loss function for component

The first step towards estimating the seismic loss for a building is to have the idea of contributions from different components of the building. Expected loss due to damage of unit quantity of the i^{th} component for a given value of EDP ($L_{c,i|EDP}$) can be computed deterministically as,

$$L_{c,i|EDP} = \sum_{j=1}^{n_{DC}} \left[\left\{ P\left(D_j \mid EDP\right) \right\}_i \times l_{c,i|D_j} \right] \tag{1}$$

where, $l_{c,i|D_j}$ is the mean repair cost per unit quantity/density of the i^{th} component for the damage state D_j; and n_{DC} is the number of discrete damage states considered in the component fragility. $P(D_j \mid EDP)$ is the probability of damage being in the j^{th} damage state for the given EDP value (e.g. edp) which is computed as,

$$P\left(D_j \mid EDP = edp\right) = \Phi\left(\ln\left(\frac{edp}{\theta_j}\right) \Big/ \beta_j \right) - \Phi\left(\ln\left(\frac{edp}{\theta_{j+1}}\right) \Big/ \beta_{j+1} \right) \qquad \text{for } j \neq n_{DC} \tag{2a}$$

$$P\left(D_j \mid EDP = edp\right) = \Phi\left(\ln\left(\frac{edp}{\theta_j}\right) \Big/ \beta_j \right) \qquad \text{for } j = n_{DC} \tag{2b}$$

where, θ_j and β_j are the median and logarithmic standard deviation of the capacity for a component type to resist its j^{th} damage state, respectively; and Φ is the standard normal cumulative distribution function. Eq. 2 assumes lognormal representations of the component fragility functions for different damage states. The contribution from probability of collapse in the component loss is neglected due to the fact that the chances of collapse for buildings designed as per modern code guidelines are slim. As the repair cost of a component can vary within a range, it is convenient to represent those using probability distributions. Therefore, the expected (mean) loss due to a component can be obtained using Monte Carlo (MC) simulation in terms of the mean replacement cost (C_i) of that particular component as,

$$\bar{L}_{c,i|EDP} = \frac{1}{C_i} \times \frac{1}{n_{sim}} \sum_{k=1}^{n_{sim}} \left[\sum_{j=1}^{n_{DC}} \left\{ P\left(D_j \mid EDP\right) \right\}_i \times \chi_k\left(l_{c,i|D_j}\right) \right] \tag{3}$$

where, $\bar{L}_{c,i|EDP}$ is the mean seismic loss for the i^{th} component at a given EDP, normalized with the component replacement cost; $\chi_k\left(l_{c,i|D_j}\right)$ is the randomly generated repair cost per unit quantity/density of the i^{th} component corresponding to D_j damage state; and n_{sim} is the number of simulation. Fig. 4 shows the mean seismic losses, normalized with respect to the respective replacement costs, for typical drift sensitive and acceleration sensitive components using 2500 simulations. Here, the fragility functions and cost distributions of these components are taken from earlier reported works [5, 15, 16]. It is observed that the non-structural components lose their values more than the structural components even at lower levels of *EDPs*. For example, at 2% inter story drift, the partitions are completely lost (requiring replacement), whereas the loss of the beam-column joint and slab-fame connection are up to 40% and 55% of their replacement costs, respectively. Once, an exhaustive list of component level loss functions and weightage factors are established, the expected floor level loss ($L_{F|EDP}$) can be estimated as,

$$L_{F|EDP} = \sum_{i=1}^{N_{FC}} \left(w_i \times \bar{L}_{c,i|EDP} \times A_{c,i} \right) \tag{4}$$

where, $A_{c,i}$ is the total quantity/area of the i^{th} component in a floor; and N_{FC} is the total number of component contributing to the floor loss. Note that Equation 4 directly compiles the component losses to obtain the floor losses (without going at the group level); hence the weighting factors should be normalised with respect to the floor value.

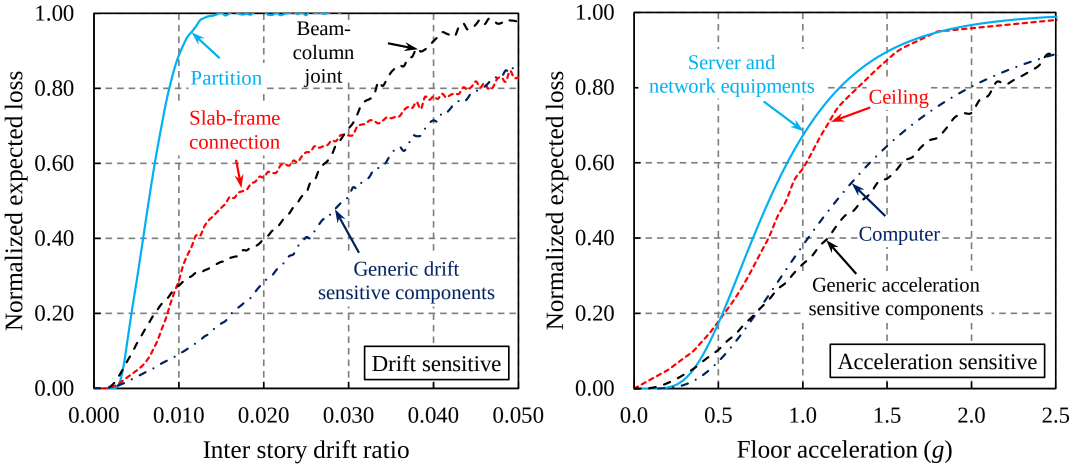


Figure 4 – Normalized expected losses (with respect to respective replacement costs) of typical drift and acceleration sensitive components.

The expected component level loss can also be normalized further with respect to the total construction cost per square meter of the floor area. This will remove any effect of temporary surge in the component/construction cost in a particular region, and can provide more generic idea of the expected seismic loss. To develop such generic component level loss functions, the information required are: (i) database of component fragility functions, (ii) component quantity/density distribution for a particular building category; (iii) distribution of repair/replacement costs for different damage states for each component; and (iv) distribution of overall construction cost of the particular building category in consideration.

Once these information are available, the expected loss for a component, normalized with respect to total construction cost, can be expressed as,

$$\bar{\chi}_k\left(L_{c,i|EDP}\right) = \frac{\chi_k\left(A_{c,i}\right) \times \sum_{j=1}^{n_{DC}} \left[P\left(D_j \mid EDP\right)_i \times \chi_k\left(l_{c,i|D_j}\right) \right]}{\chi_k\left(C_T\right)} \tag{5}$$

where, $\bar{\chi}_k\left(L_{c,i|EDP}\right)$ is the seismic loss corresponding to i^{th} component per square meter of floor area normalized with respect to total cost of the building; $\chi_k\left(A_{c,i}\right)$ and $\chi_k\left(C_T\right)$ are the random realizations of component quantity/density per square meter of floor area and total construction cost per square meter of floor area, respectively. Here, it can be noted that the earlier mentioned weightage factors (w_i) are alternatively considered in the form of normalization with respect to the total building cost, i.e. $\left(l_{c,i|D_j}/C_T\right) = \left(l_{c,i|D_j}/C_i\right) \times \left(C_i/C_T\right)$. Thereafter, the normalized mean, $\bar{\mu}\left(L_{c,i|EDP}\right)$, and the standard deviation $\bar{\sigma}\left(L_{c,i|EDP}\right)$ of the expected loss for the i^{th} component per square meter of floor area at a given *EDP* are computed as,

$$\bar{\mu}\left(L_{c,i|EDP}\right) = \frac{1}{n_{sim}} \sum_{k=1}^{n_{sim}} \bar{\chi}_k\left(L_{c,i|EDP}\right) \tag{6}$$

and

$$\bar{\sigma}\left(L_{c,i|EDP}\right) = \sqrt{\frac{1}{n_{sim}} \sum_{k=1}^{n_{sim}} \left[\bar{\chi}_k\left(L_{c,i|EDP}\right) - \bar{\mu}\left(L_{c,i|EDP}\right)\right]^2} \tag{7}$$

where, n_{sim} is the total number of simulations. This process is to be repeated for different values of *EDP* to develop the generic component loss functions.

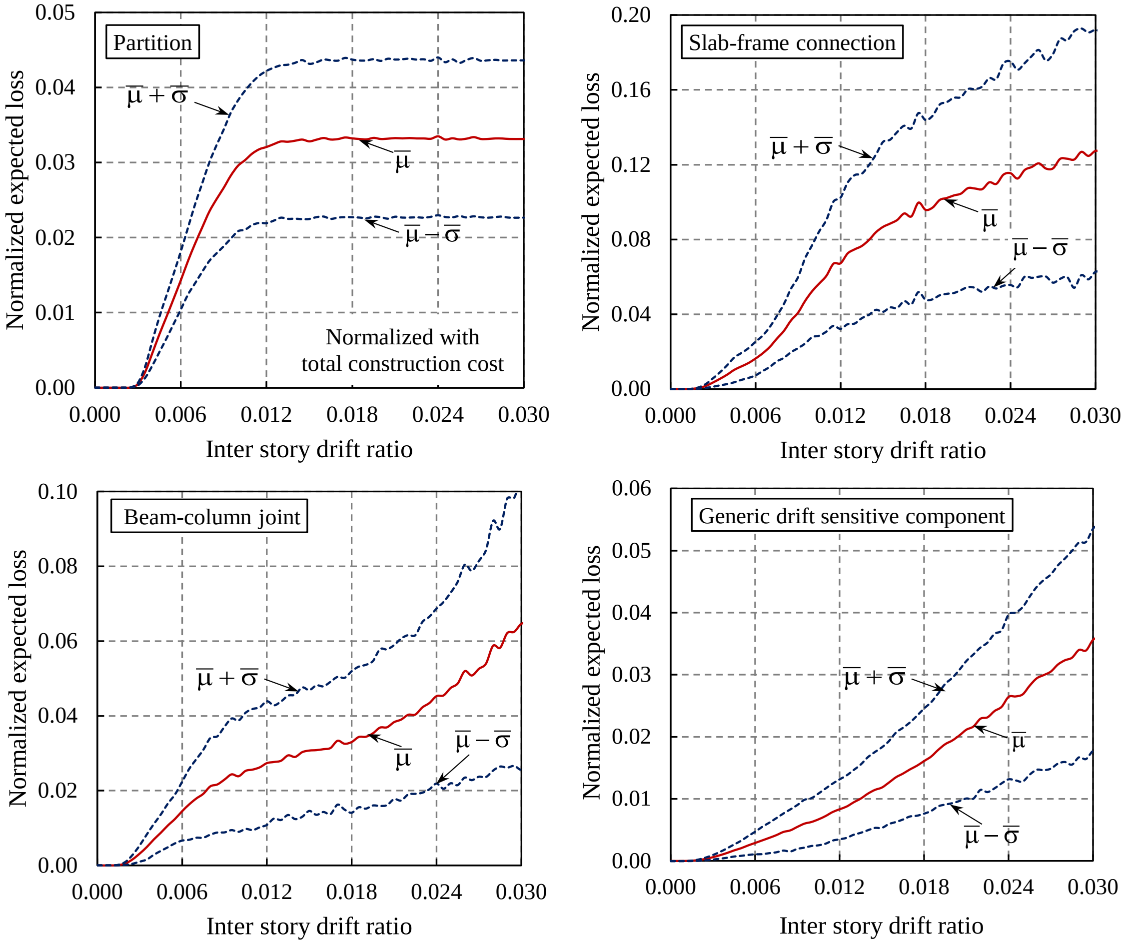


Figure 5 – Generic normalized (with respect to total building construction cost) loss functions for typical drift sensitive components

Extensive component inventory data is necessary to develop the probability distributions of different component quantity/density and repair cost for a typical building category. Some examples of generic loss functions, normalized with respect to the total building cost per square meter of floor area, for drift and acceleration sensitive components corresponding to typical RC office buildings in New Zealand are presented in Figs. 5 and 6, respectively. The generic drift sensitive components are considered to include vertical piping, toilet/wall fixtures, ducts etc., and the generic acceleration sensitive components are considered to include fire protection system, heating and HVAC equipment's, pumps and plumbing etc. [5]. Here, the normalized mean expected loss ($\bar{\mu}$) along with the $\bar{\mu} \pm \bar{\sigma}$ losses are presented. The normalized expected losses for the partition and ceiling are computed based on the field data collected from Christchurch CBD, New Zealand as reported by Dhakal et al. [16]. The generated normalized loss functions suggest that the loss from suspended ceilings and partition damage in typical RC office buildings could be up to 4.5% and 3.4% of the total cost of the floor, respectively. For other components, the average component quantity/density prescribed by other researchers [7, 8] are assumed, and normal distribution with coefficient of variation (CV) as 0.25 is assumed. It is observed that the spread of the expected loss for the presented drift sensitive structural components is larger. It is probably due the crude assumption of the component quantity and cost distributions. Specially, the assumed CV of the repair cost corresponding to the different damage states is significantly higher (in the order of 0.5 ~ 0.7 [15]). These discrepancies can possibly be overcome with more realistic data collection in terms of repair cost, component quantity and cost per square meter of the floor area. It is further observed that the normalized loss due to acceleration sensitive content such as server is considerably high as compared to other components.

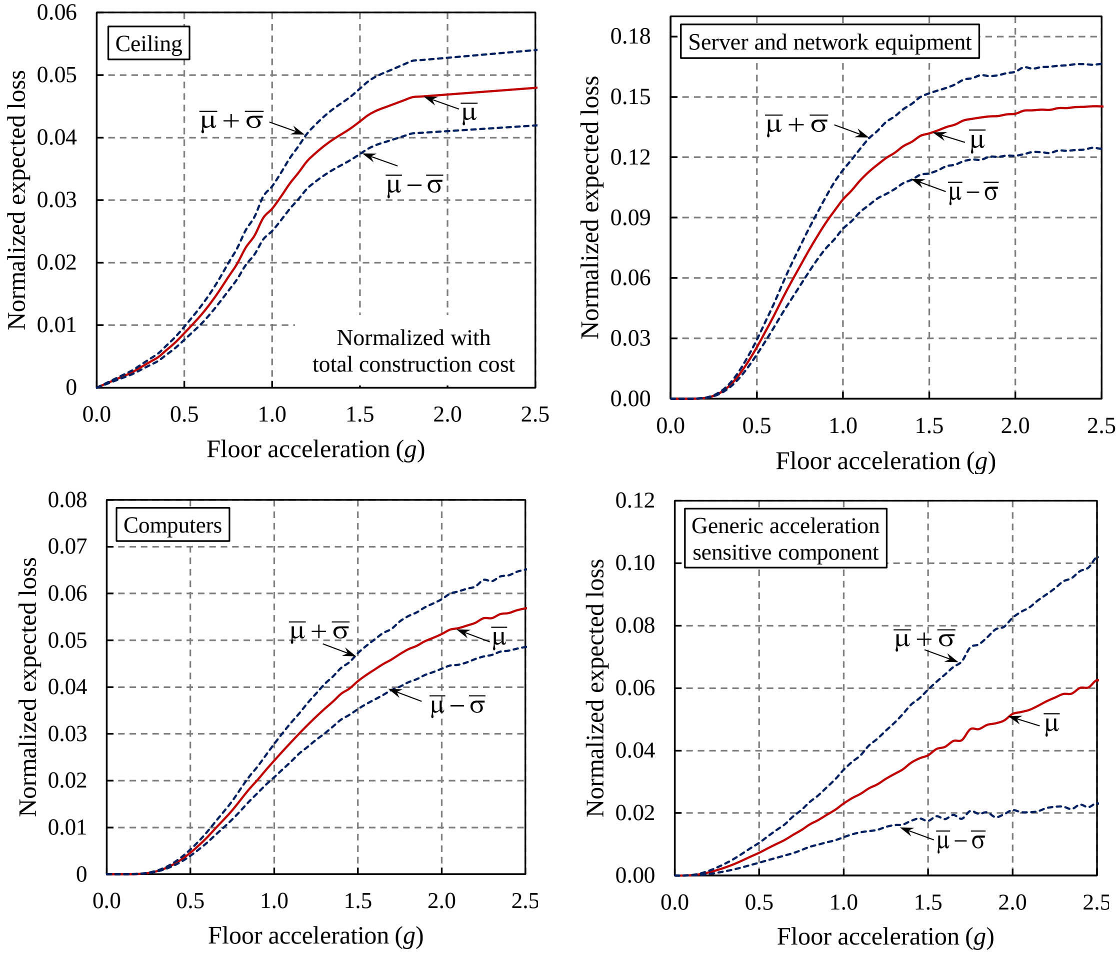


Figure 6 – Generic normalized (with respect to total building construction cost) loss functions for typical acceleration sensitive components

3.2 Generalized floor level loss functions

Once the generalized loss functions for various structural and non-structural components are established for a typical building category, one can develop the generalized floor level loss function based on the contributing components. Mathematically, the normalized mean, $\bar{\mu}_{L_{F|EDP}}$ and standard deviation, $\bar{\sigma}_{L_{F|EDP}}$ of the expected seismic loss per square meter of the floor area are expressed as,

$$\bar{\mu}_{L_{F|EDP}} = \sum_{i=1}^{N_C} \bar{\mu}\left(L_{c,i|EDP}\right) \tag{8a}$$

and

$$\bar{\sigma}_{L_{F|EDP}} = \left[\sum_{i=1}^{N_C} \bar{\sigma}^2\left(L_{c,i|EDP}\right) + 2\sum_{i_1=1}^{N_C}\sum_{i_2=1}^{i_1-1}\left\{\bar{\rho}\left(L_{c,i_1|EDP}, L_{c,i_2|EDP}\right)\bar{\sigma}\left(L_{c,i_1|EDP}\right)\bar{\sigma}\left(L_{c,i_2|EDP}\right)\right\}\right]^{1/2} \tag{8b}$$

where, N_c is the total number of component considered in a group; $\bar{\rho}\left(L_{c,i_1|EDP}, L_{c,i_2|EDP}\right)$ is the correlation coefficients among different component losses. For simplicity, the correlation coefficients are assumed insignificant here. However, there can be few cases where correlation is significant based on the necessary repair steps [5].

As damage to various components of a building depends either on peak inter story drift ratio (*IDR*) or peak floor acceleration (*PFA*), the floor level loss functions are generated with respect to these two *EDPs*. However, selection of contributing components is a key step for successful implementation of the generic component loss functions (i.e. *Loss vs. EDP* plots) to develop the floor level loss function. Moreover, several researchers have reported that the relative contributions of various components to the total seismic loss vary with different seismic hazard levels [7, 17]. Therefore, there is a need to investigate loss deaggregation for several buildings to identify components that significantly contribute towards the total seismic loss of a building category. Combining the significantly contributing components, the weightage factor of the group as percentage of total building cost (cost per square meter of floor area) can be computed, and expressed as floor level loss function. For example, when all the drift sensitive and acceleration sensitive components, presented in the previous section, are considered to be contributing towards the total expected seismic loss of a building floor, the generalized floor level loss functions are presented in Fig. 7. The seismic loss due to the drift sensitive components (structural and non-structural) at 1% inter story drift ratio is expected to be within the range of 8% to 15% of the total cost of the floor. Similarly, the seismic loss due to the acceleration sensitive components (non-structural) at 1*g* floor acceleration is expected to be within the range of 16% to 19% of the total cost of the floor. It can be observed that spread of the expected loss due the drift sensitive components is found to be significantly high as compared to the acceleration sensitive components. This is because of large variation in the repair cost considered for the structural components as discussed earlier in Fig. 5. It can be further noted that the combined normalized expected loss of the components (acceleration and drift sensitive) are not summing up to 1 within the considered range of *EDPs*. This is primarily because of the fact that the normalization is carried with respect to the total value of the building, which is necessarily more than the summation of the component replacement costs.

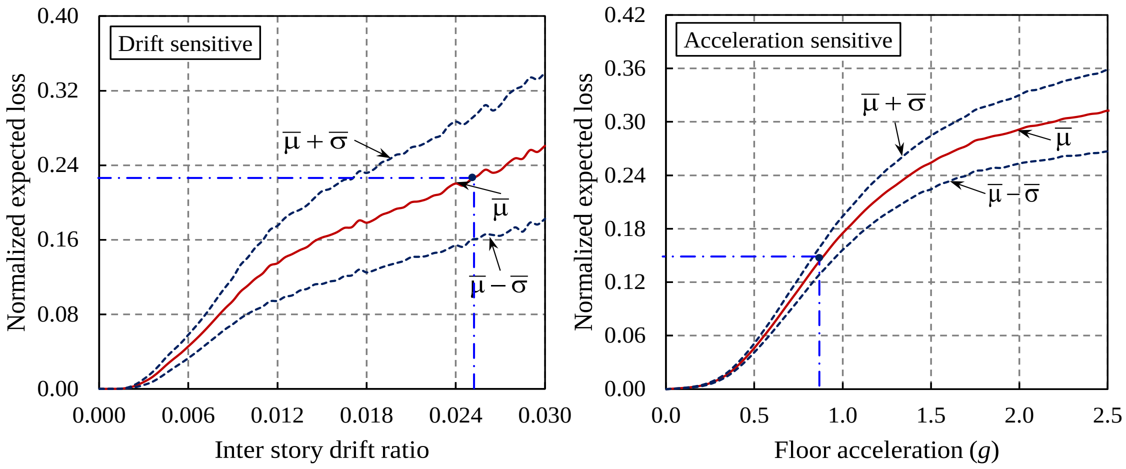
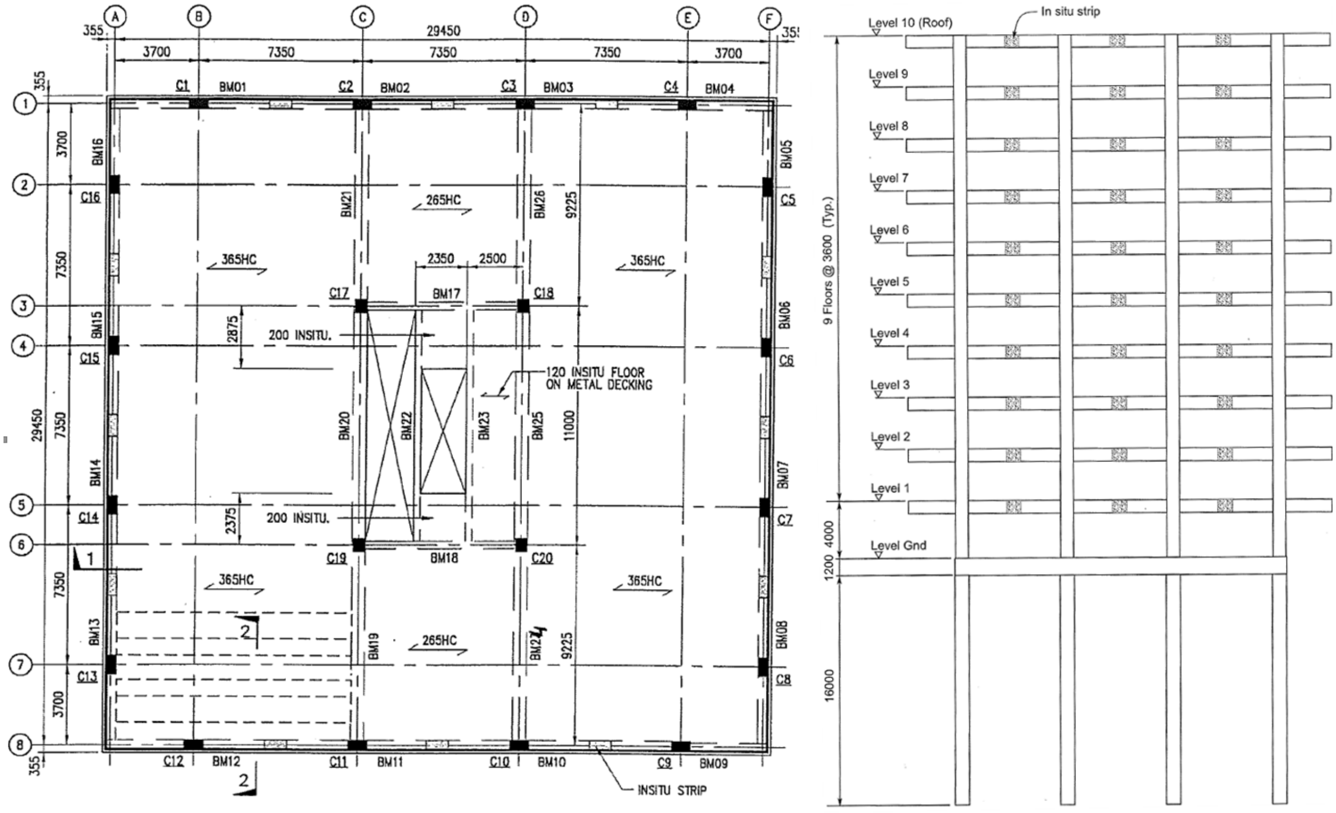


Figure 7 – Generic normalized floor level loss functions

4. Case Study

A reinforced concrete (RC) framed building, used as a design example in the Red Book [18], is considered for the present work to verify the developed generic floor level loss functions for estimating the expected seismic loss. Fig. 8 shows the plan and elevation of the 10 story building, supported on pile foundation, having four moment resisting frames at the perimeter as the lateral load resisting system. Four internal columns are deigned to carry the gravity load of the building. The RC building was designed as a conventional office building as per the New Zealand concrete code [19]. The fundamental period of vibration of this building is computed as 1.5 sec. Bradley et al. [7] performed seismic analysis of this building to explain the theoretical development of the seismic loss estimation methodology, and presented the expected seismic loss along with deaggregation of the loss due to various components. Therefore, the estimation of expected seismic loss using the generic loss functions can be compared with the earlier published results. The seismic analysis and loss estimation were carried out considering a site comprising stiff soil in Christchurch, New Zealand.



(a) (b)

Figure 8 – (a) Plan and (b) elevation of the Red Book building [18]

As per detail component based loss estimation [7], contributions of various components to the total expected seismic loss at a given seismic intensity level (S_a = 0.5g at T = 1.5 sec; 2% annual frequency of exceedance in 50 years) are presented in Table 2. The contributions from the elevator and paint to the total expected loss are neglected while developing the floor level loss functions. It can be noted here that the server and network equipment were considered to be located only at three floors in the earlier study. However, the floor level loss functions presented in preceding section are applied to all the floors uniformly. This will probably compensate the contributions from other components, which are not included in the floor level loss functions. The estimated mean seismic loss at each floor level is presented in Table 3. For example, the inter story drift ratio and the peak floor acceleration at the 2nd floor are 0.025 and 0.86 g, respectively. From Fig. 7, the corresponding normalized expected losses at the 2nd floor level due to the drift and acceleration sensitive components are obtained as 0.225 and 0.141, respectively. As the total cost of the 10 story building was reported as about NZ$ 14M [9], the cost of each story can be assumed to be $ 1.4M. Therefore, the expected loss due to the drift and acceleration sensitive components in the 2nd floor are calculated as NZ$ 0.31M and NZ$ 0.20M, respectively. The reported seismic loss at this hazard level for the whole building is about NZ$ 4M. Whereas, using the presently developed floor level loss functions, the range of the expected seismic loss for the whole building is computed to be between NZ$ 3.2M to NZ$ 3.7M with the mean at NZ$ 3.45M. This level of seismic loss amounts to be around 25% of the building cost, which is not acceptable as per the assumed repair limit (μ_R = 10%) in Table 1. As the objective of this preliminary study is to present the methodology, the result obtained from the case study is satisfactory given the fact that there exist several crude assumptions in developing the generic loss functions. Once, the generic loss functions for major components are established from the ongoing inventory data collections, more reliable floor level loss functions can be generated.

Table 2 – Contribution of seismic loss for various components from detailed loss assessment [7]

Sl. No.	Component	% of Total Loss
1	Partitions	20
2	Server/Network Equipment	19
3	Ceiling	14
4	Beam-Columns Joints	14
5	Slab-Frame Connections	11
6	Generic Acceleration Sensitive Components	6
7	Generic Drift Sensitive Components	6
8	Computers/Desktops	6
9	Elevator	2
10	Paint	2
	Total	100

Table 3 – Expected seismic loss computation using generic floor level loss functions

	Structural Response [7]		**Loss due to Component (NZ$)**	
Floor No.	***IDR***	***PFA* (*g*)**	**Drift Sensitive**	**Acceleration Sensitive**
Roof	0	0.54	0	78476
9	0.0022	0.47	3103	55353
8	0.0043	0.45	31289	49124
7	0.0057	0.48	57650	58468
6	0.0137	0.61	210300	103416
5	0.0226	0.64	290846	114816
4	0.0243	0.68	306574	130045
3	0.0256	0.76	322249	160246
2	0.025	0.86	314375	198048
1	0.0246	1.12	307129	279132
Ground	0.013	0.76	202488	160246
	Total (NZ$)→		**2.05M**	**1.39M**

5. Summary and Research Needs

There is a growing demand from non-engineering stakeholders of building stocks to gauge the building performance during earthquakes not only against the life safety and collapse prevention criteria, but also in terms of financial losses due to repair, downtime and injury (or causalities). A framework for a loss targeted seismic design of structures, called Loss Optimisation Seismic Design (LOSD), has been envisaged, wherein; the structural engineer can estimate the expected seismic loss for a building in its lifetime during the design phase without involving any rigorous computational effort or time, and revise the structural design to meet the prescribed loss limits.

Herein, the basic elements of this LOSD framework are explained, and typical floor level loss functions are developed based on preliminary studies. The effectiveness of the framework is assessed for a case study office building. The results are found to be promising in terms of rapid estimation of a range of total expected seismic loss for a building using the generic floor level loss functions. However, there exists significant research needs to fully develop and successfully implement the LOSD framework. Combining the fragility functions and repair/replacement costs of each component, generalized loss functions can be developed for all major contributing components in various building categories. It is necessary to derive the appropriate weightage factors for the group of components from the collected construction inventories and loss deaggregation analyses. Once these two tasks are completed, more reliable floor level generalised loss functions can be developed, which will tremendously simplify the estimation of direct seismic loss in buildings.

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