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RELIABILITY-BASED EVALUATION OF LOSS DUE TO DISTRIBUTION OF NONSTRUCTURAL COMPONENTS IN HEIGHT

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Abstract

Structural and nonstructural components incorporate simultaneously and correspondingly in modern probabilistic performance evaluation to make decision making parameters which is usually economic loss in a predefined level of probability. However, far greater investment, relatively limited seismically design information and dependence of nonstructural components' normative quantities to some architectural, economic and social features contribute to exceeded loss amounts and uncertainties under nonstructural components in comparison to structural ones. This paper addresses the question of how to distribute nonstructural components in height of a building accounting for more reliable economic loss subjected to seismic excitation through application of fully probabilistic reliability approach. This purpose has been captured through proposing a new modified distribution of building nonstructural components in height for three typical steel moment frames and conducting comparative assessments for two alternative distributions of nonstructural components with office occupancy. Dealing with discussions, it could be concluded that more reliable economic losses could be gained and also reduced by more astutely situating building nonstructural components in height considering type of dominated demands in a specific story without requirement to any alternation in component's type or quantity.

Streszczenie

Elementy konstrukcyjne i niekonstrukcyjne występują jednocześnie we współczesnej ocenie prawdopodobieństwa, w celu ustalenia parametrów istotnych w przeprowadzeniu oceny straty wartości przy ustalonym poziomie prawdopodobieństwa. Niemniej jednak, z uwagi na znacznie większe nakłady, relatywnie ograniczone informacje dla projektowania sejsmicznego dla elementów niekonstrukcyjnych, parametry normatywne dla wybranych architektonicznych, ekonomicznych i socjalnych parametrów znajdują odzwierciedlenie we wzroście strat i niepewności dla elementów niekonstrukcyjnych w porównaniu z elementami konstrukcyjnymi. W artykule poruszono kwestię wpływu rozmieszczenia elementów niekonstrukcyjnych na wysokości budynku biorąc pod uwagę bardziej wiarygodną ocenę straty wartości po wystąpieniu oddziaływań sejsmicznych przez zastosowanie podejścia w pełni probabilistycznej teorii niezawodności. W tym celu zaproponowano nowy, zmodyfikowany sposób rozmieszczenia elementów niekonstrukcyjnych na wysokości dla trzech typowych, sztywnych ram stalowych i przeprowadzono ocenę porównawczą dla dwóch alternatywnych rozkładów elementów niekonstrukcyjnych w budynkach biurowych. Po przeprowadzeniu analiz można wnioskować, że bardziej wiarygodny ekonomicznie poziom strat został osiągnięty przez bardziej przemyślane rozmieszczenie elementów niekonstrukcyjnych na wysokości, biorąc pod uwagę funkcję dominującą na konkretnej kondygnacji bez potrzeby ograniczania typu i jakości elementów budowlanych.

Keywords: **Nonstructural components; Cost of damage; Incorporation of stories; Dispersion of loss; Reliability Assessment; Low-rise buildings; Office occupancy.**

1. INTRODUCTION

Application of economic loss as a quantified metric to gauge performance of a specific building subjected to seismic ground motion loads is one of the frequently hired approaches for explicitly quantifying building performance according to some merits explicable to stakeholders [1, 2, 3]. Current performance seismic design practice attempts to control economic loss in a predefined level of probability or specify an acceptable level of occurrence probability for a specific amount of economic loss.

The deviation in each stage of modern performance evaluation causes deviation in decision variables in the final stage and one of researcher's attempts is to reduce deviations in loss as a decision variable [4]. Many approaches have been followed for this purpose like developing new intensity measures or dealing with many different engineering demand parameters to encounter as slight deviation as it is possible. The proposed approach in this study for reducing deviation in decision variable (economic loss) is adjusting the distribution of structural and nonstructural components in height of a building.

While the dispersion of loss is the chief concern of view for reliable decision making, the dispersion of damage cost have not been considered as a decision making parameter so far and few attempts in the previous works devoted to the amounts of loss merely.

The focused subject of this study is to illustrate the significant role of distribution pattern of building nonstructural components in height in magnitude and reliability of the gained loss amounts subjected to earthquake loads and also to propose a new alternate distribution pattern for nonstructural components concluding in more reliable loss amounts.

While picking out location of some nonstructural components is an inevitable feature like the decorating in lobbies or elevator equipment in the roof stories, some of the others could be changed or modified; for example by well-done partition anchoring, they could be assumed as acceleration-dependent components instead of displacement-dependent ones and their cost distributions follow different type of demand.

This study could be very supportive for architectural planning phase of the project and could provide appropriate situating for nonstructural components in low-rise office buildings in view of the cost of damage and its reliability subjected to earthquake loading. The probabilistic cost estimations of this study have been conducted by the means of Performance Assessment Calculation Tool (PACT) code and structural analyzing has been complemented utilizing Open System for Earthquake Engineering Simulation (Opensees) code.

2. THE SIGNIFICANT ROLE OF NON-STRUCTURAL COMPONENTS IN LOSS EVALUATION

Although nonstructural components and systems are not part of a building's structural load-bearing system, they are nonetheless subject to the same dynamic environment during an earthquake and therefore incorporate correspondingly in economic losses. Considering the amounts of damage based on structural and nonstructural components in past earthquakes like the February 28, 2001 Nisqually, Seattle, Earthquake [5] and the 2006 Kona, Hawaii, Earthquake [6, 7], economic losses from damage to nonstructural components constitute far exceeded losses from structural damage in most affected buildings presenting an average factor of 5.7 to 8.4 for the nonstructural to structural damage costs. Moreover, nonstructural damage can severely limit the functionality of critical facilities such as hospitals' facilities, as demonstrated in the 1994 Northridge earthquake [8], the 2001 El Salvador earthquake [9] and the 2006 Kona, Hawaii earthquake [6] or airport operations as it was experienced during the 2010 Maule, Chile Earthquake [10], where two thirds of the Chilean air traffic was interrupted and the total cost for repairs of nonstructural damage at the Santiago airport was estimated as US$40 million. LAN airline alone suffered a loss of revenue of US$10 million as result of damage and business interruption as a result of the earthquake mainly because of failure of suspended air handling units and ceiling tiles and failure of sprinkler piping systems throughout the main terminal [10]. So, the participation factor for integration of this type of components could be different for the structures with diverse occupancy.

The investment in nonstructural components and building contents is far greater than that of structural components and framing. Therefore, it is not surprising that in many past earthquakes, losses from damage to nonstructural components have exceeded losses from structural ones. Furthermore, the failure of nonstructural components can become a safety hazard or can more severely hamper safe movement of occupants evacuating buildings or of rescue workers entering buildings. According to Miranda and Taghavi studies [11], in the United States nonstructural components make up approximately 82%, 87% and 92% of the total monetary investment in office, hotel and hospital buildings respectively (Fig. 1).

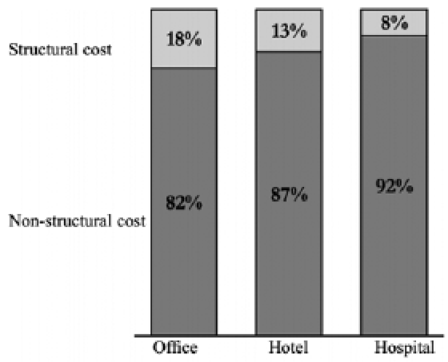


Figure 1.
Relative monetary investment in typical buildings (Miranda and Taghavi, 2003)

Furthermore, damage to nonstructural components occurs at seismic intensities much lower than those required to produce structural damage [11].

In comparison to structural components and systems, there is relatively limited information and specific guidance available on seismic design of nonstructural components for multiple-performance levels. Engineering works are often insufficient to provide the levels of professional service needed for adequate attention to the seismic resistance of nonstructural components [12]. Basic research work in this area has been sparse, and the available codes and guidelines are usually, for the most part, based on past experiences, engineering judgment and intuition, rather than on objective experimental and analytical results. Often, design engineers are forced to start almost from square one after each earthquake event to observe what went wrong and to try to avoid repetitions. This is a consequence of the empirical nature of current seismic regulations and guidelines for nonstructural components [12].

The other point is that nonstructural behavior assessment deals with too huge detailed information which must be classified very well considering very gigantic amounts, types and engineering aspects like response factors to earthquake loads which is very time-consuming varying from one building occupancy type to the other. Summaries of many important aspects of the seismic behavior of nonstructural components as well as the evolution of research and code efforts in the last 30 years can be found in [13, 14].

With development and implementation of the modern performance-based earthquake engineering, harmonization of performance levels between structural and nonstructural components becomes vital as both of them contributed in economic losses. The modern performance-based earthquake engineering methodology that does carefully treat nonstructural components could be quite valuable in risk-management and decision-making, such as choosing between design alternatives for new construction or judging the cost-effectiveness of a seismic retrofit, when decisions affect nonstructural components [15].

The other point is that the type of nonstructural components and their normative quantities for a building by specific occupancy is somewhat an architectural aspect affected by many factors like economic class, big of the city where the building was located, social features, etc. With regard to nonstructural design, most local building jurisdictions in the United States, Europe and most of the other countries designate a project architect with insufficient knowledge about seismic design to have the overall responsibility for the nonstructural portions of the work even these components have very significant role in seismic performance [16]. In some rare specific cases, the architect will designate a structural engineer to be responsible for the seismic design and installation of nonstructural components but it is not common for regular occupancies like residential or office ones [16]. Then, the importance of close collaboration between architects and structural engineers has been desired not only for structural but also for nonstructural components.

3. PERFORMANCE GROUPS AND FRAGILITY FUNCTIONS

In order to provide further comprehend understanding of nonstructural components, building performance codes generally classify nonstructural components using some proposed taxonomies.

Different taxonomies (categorization system) for performance groups in building or story level have been proposed such as taxonomy developed by Antaki, cited in [15], taxonomy developed by Porter [15], HAZUS taxonomy for structural and nonstructural components [17], procurement and contacting requirements from NISTIR 6389 [18], classification of building elements based on UNIFORMAT II and the most commonly applied taxonomy is according to FEMA P-58-1 recommendation [19] that is going to be hired in this study too. Meeting objectives for taxonomic groups ensure meaningful fragility function creation; for more detail refer to [15].

FEMA classification added some detailed subgroups to the NISTIR 6389 classification, for case in point, dividing the structural components based on their ductility to special, intermediate or ordinary groups and dividing nonstructural components to anchored and nonanchored or based on their establishing requirements. The details for each fragility function have been achieved according to some resources:

- Actual demand data: specimens tested with slowly increasing (Engineering Demand Parameter) EDP to failure, EDP at failure is known.
- Bounding demand data: specimens observed in field, some failed, some not. Maximum EDPs are known.
- Capable demand data: specimens tested in laboratories, none failed. Maximum EDP for each is known.
- Derivation: estimate capacity with structural analysis.
- Expert opinion: capacity from engineering judgment [20].

The incorporated attributes cause to reach the number of proposed performance groups up to 700 where for all of them fragility functions and their corresponding cost and repair functions have to be distinguished incorporating quantity of damaged materials, relative difficulties in accessing and conducting repair and quality of finished materials. The given information for each defined performance groups could be classified in basic identifier information, fragility information and consequence information. All of the performance groups in company with their fragility functions are provided in appendix-D of FEMA P-58-1 [19] and appendix-B of ATC-58 [21] or in the files by the name of Fragility Database (Excel file) or Fragility Specifications (PDF file) acting as a supplementary file to the cost estimating program of PACT [22].

A central challenge in such an effort is that the source data can be greatly detailed. These detailed elements must be aggregated by a systematized probabilistic approach considering all structural and nonstructural components. For this purpose, PACT code has been employed. This code is a computer open source software which computes cost of damage, casualties and time delays based on a full probabilistic procedure associated with the PEER approach and according to FEMA P-58-3 seismic performance assessment code [22]. It could be freely downloaded from the site of Applied Technology Council [21]. This code computes probabilistic cost of damage (that is the main concern of this paper) based on the component fragility curves which are by default available based on FEMA P-58-1 [19] or could be manipulated based on any predefined fragility curve by user. Lognormal probability distribution has been considered for both of the collapse and residual drift conditions with statistical parameters defined by user in this code.

Utilizing FEMA specifications have some advantages. The first is the dependence of the proposed fragility functions to large collection of information, reports of earthquakes and experimental data; the second is the possibility of result modification chiefly based on Bayesian approach as well as the most important advantage is covering almost all fragility functions corresponding to structural and nonstructural components by gigantic details. However, inadequacy of the FEMA's proposed group of fragility functions is the overestimation of damage cost resulting from overvaluing in the amounts of standard deviation of fragility functions which affects severely the starting and finishing point of each fragility function. As in practice, limited number of fragility functions considered for a particular prototype building, the mentioned overestimating has been revoked by not covering all the performance groups in a building [19, 23].

4. NORMATIVE QUANTITIES OF NONSTRUCTURAL COMPONNETS

After determining incorporated performance groups, the quantity for each of the groups should be determined. There are two approaches for determining normative quantities of performance groups; the first is deterministic approach working based on specific plan for each story of the model and the second is probabilistic approach operating based on the probability of observing specific amount of a performance group among buildings by the similar type of occupancy.

For selecting a plan for deterministic approach, some attributes should be taken in mind like architectural characteristics; the location of building, how big is the city and social characteristics related to architecture of the model which dominantly affect nonstructural components than structural ones. One of the studies based on deterministic approach in this field is [24] which estimated damage cost of office type buildings subjected to six different earthquake scenarios for big cities of Los Angeles, Salt Lake and Shelby illustrating very great portion of nonstructural components (ceiling, piping and partition) in damage costs of buildings. The other study which delivers very inclusive considerate about the significance of nonstructural components in damage cost of buildings subjected to earthquakes based on some preselected deterministic plans is a work conducted by Aslani and Miranda [3]. This study illustrates noteworthy portion of nonstructural damages subjected to regular ground motions and shows that a slight amplification in quantity of partition-like components could intensely amplify the amounts of damage costs.

Instead of the deterministic approach which is utilized generally in case-studies or benchmark studies, performance codes such as ATC or FEMA P-58-1 prefer to make use of probabilistic approach for obtaining normative quantities for performance groups. The proposed normative quantities of FEMA P-58-1 are based on studies on 3000 models with diverse occupancy types presented according to 10%, 50% and 90% probability of observing the proposed amount for a performance group subjected to certain occupancy of a model. Because of the large number of models, the proposed amounts for performance groups do not hold to a specific plan. The normative quantities in this study are chosen based on the probabilistic approach considering proposed normative quantities by FEMA P-58-1 for 50% probability of observing in a prototype office building.

The point that is fine to be mentioned is that the location of components in a story is an important view for damage cost evaluation that is not going to be considered in many studies because of the required gigantic investigation about possibilities and dependencies of performance groups and it is also beyond the scope of this paper. The concern view of this study is only about the amount of each performance group in each of the stories.

Practically, the source chosen to establish cost estimation and distribution in a building is the RS Means Square Foot Costs codes [25]. These codes provide cost distributions of the entire building components rather than the distributions at each story level for many different types of common building occupancies (ex. residential high-rise, commercial low-rise, hospitals… etc.). Engineering judgment is usually engaged to translate this data into story cost distributions, while maintaining the overall building cost distribution. Translating the building cost distribution into story distributions requires making expectations about the variation of stories' values along building height. This will be highly dependent on how the building components are distributed amongst the different floors, which is typically a function of the building's occupancy as well as it is the subject of this study.

Although different story cost distributions could be generated forever floor, the number of distributions served can be limited by making the following assumptions:

- The entire building will be used for office space (i.e. not a mixed-use facility)
- The value of the first floor has significant differences from the other floors because as the main entrance, the layout, facades and finishes are typically different at this level.
- The value of the top floor, typically the roof of the building, has distinct differences from the other floors because typically this is where most of the buildings mechanical and electrical equipment is located (this floor includes any equipment that may be located in a mechanical penthouse).
- The remaining intermediate floors are all dedicated to office occupancy. These floors will have the same story cost distribution [23].

Under these assumptions, it was decided that there would be three different types of story cost distributions: one for the first floor, one for the top floor, and one for the intermediate floors, which will be referred to as the typical floor.

5. DESCRIPTION OF STRUCTURAL SYSTEMS AND ANALYZING METHODS USED FOR EVALUATION

On account of the need for consideration of varieties in models' characteristics, the selected models should represent acceptably the considered group of the buildings. Studied models in this study take only account of low-rise buildings because of dissimilar distribution of demands and also different cost distribution in mid-rise and high-rise buildings. For mid-rise and high-rise buildings some supplementary studies have to be conducted. In this study, three models with 3, 4 and 5 number of stories have been analyzed through conducting nonlinear dynamic analysis. The height of each story was assumed equal to 3.0 m. The plan of all stories was considered similar with 4 spans in longitude side and 3 spans in the other side and the length of each span is equal to 4.0 m. The fundamental periods of the models are equal to 0.68(s), 0.85(s) and 1.12(s) respectively for the models with 3, 4 and 5 number of stories.

Loading has been accomplished based on ASCE7-05 [26] by consideration of dead load equal to 620 kg/m^2 and live load equal to 200 kg/m^2. Design has been accomplished based on AISC 2005 [27].

For modeling nonlinearity in structural responses, modified Ibarra-Krawinkler (MIK) model [28] has been employed with bilinear hysteresis behavior [29]. This model exhibited very acceptable compatibility between the gained results from analyses and experiments [30]. Modeling has been conducted by the means of the open system for earthquake engineering simulation code (opensees) through using concentrated plasticity in the end joints of each frame component [31]. Critical damping ratios in the first and second modes of vibration are assumed equal to 0.03. Modification of stiffness and damping has been done by consideration of modification factor equal to 10 based on studies conducted by Zareyian and Medina [32]. Geometric nonlinearity considered through consideration of P-Δ effects [33]. Panel zone modeling has been conducted based on nonlinear behavior proposed by Gupta and Krawinkler composed up three linear fragments [34].

The selected engineering demand parameters (EDPs) in performance-based assessment are usually inter-story drift ratios (IDR) and peak floor acceleration (PFA) as well as in this paper. The EDPs have been assessed in three subgroups; responses in near collapse, non-collapse and from residual drift situations. For getting responses near collapse situation, incremental dynamic analysis (IDA) has been utilized for determining median and dispersion of spectral acceleration of collapse fragilities. For obtaining structural responses in non-collapse and residual drift situations, nonlinear dynamic in company with nonlinear static analyses have been applied. All nonlinear dynamic analyses were conducted as Direct Integration Transient time history analyses using direct integration in Hilber, Hughes and Taylor's method. Nonlinear static analyzing used to determine elastic displacement for each story is conducted based on first mode distribution pattern of lateral forces.

6. SELECTED GROUND MOTIONS

The procedure of this paper for record selection is employment of random selection of records by consideration of minimizing deviations around the geometric mean of natural logarithmic spectral acceleration values to reduce the effects of record to record variations in structural responses. The efficiency of this record selection technique has been revealed in an accomplished study by the same authors [35]. Statistical quantities (median and standard deviation) for structural responses could be achieved regarding some ground motion records. Concerning the number of ground motions, typical practice in structural design is to use seven motions according to ASCE05-7 and eleven ground motions according to ATC, but the appropriate number of motions is still a topic of prospect researches.

For ground motion selection, a primarily list of records is required which the records are going to be picked out from it. Many researchers prefer to randomly set records in primarily list and some other recommends choosing records as a list comprises records with all groups of specification subjected to corresponding hazard possibilities.

In this paper, one of very frequently established primarily list of records has been consumed. The 79 earthquake ground motions of this list have been carefully selected by Medina and Krawinkler from the Pacific Earthquake Engineering Research center (PEER) strong motion database and it has been employed in many previous researches in PEER and SAC centers and could be inputted for many studies in this field too [3]. The earthquake magnitude in the list ranges in magnitude from 5.8 to 6.9 with the closest distance to rupture ranging from 13km to 60km. Recorded motions could be derived from databases of PEER NGA database [36], COSMOS [37] or K-NET [38]. All ground motions were recorded on free-field sites classified as site class D according to National Earthquake Hazards Reduction Program (NEHRP) seismic provision [39]. Most of the design codes like ASCE05-7 and seismic performance provisions like ATC-58-1 allow manipulation of this class of soil when the soil specification has not been studied; so, this list could be used when the site class has not been determined too. The eleven selected records are presented in Table 1. It is fine to mention that any arbitrary list of records could be substituted.

The spectrum in the level of design earthquake (DE) representing 10% probability of earthquake occurrence by the adopted intensity measure in 50 years is going to be acquired according to ASCE05-7 procedure for each earthquake. Through calculating geometric mean of design spectrums for different earthquake events, the target design earthquake spectrum will be achieved.

This paper employs a frequently used method for record scaling based on the uniform hazard spectra (UHS) for the models by the fundamental periods of

Table 1.
Eleven selected records

Number	Record ID	Event	Year	Station	Mw	R (km)	Mech	PGA (g)
1	IV79e13	Imperial Valley	1979	El Centro Array #13	6.53	21.90	Strike-slip	0.139
2	MH84g02	Morgan Hill	1984	Gilroy Array #2	6.20	15.10	Strike-slip	0.162
3	PM73phn	Point Mugu	1973	Port Hueneme	5.80	25.00	Reverse-slip	0.112
4	PS86psa	N.Palm Spring	1986	Palm Springs Airport	6.00	16.60	Strike-slip	0.187
5	WN87wat	Whittier Narrows	1987	Carson - Water St	6.00	24.50	Reverse	0.104
6	SF71pel	San Fernando	1971	LA - Hollywood Store Lot	6.60	21.20	Reverse-slip	0.174
7	SH87pls	Superstition Hill	1987	Plaster City	6.70	21.00	Strike-slip	0.186
8	BM68elc	Borrego Mountain	1968	El Centro Array #9	6.70	46.00	Strike-slip	0.057
9	LP89slc	Loma Prieta	1989	Palo Alto - SLAC Lab	6.90	36.30	Reverse-oblique	0.194
10	NR94del	Northridge	1994	Lakewood - Del Amo Blvd	6.70	59.30	Reverse-slip	0.137
11	CO83c05	Coalinga	1983	Parkfield - Cholame 5W	6.40	47.30	Reverse-oblique	0.131

0.68(s), 0.85(s), 1.12(s) located in soil class D. Record scaling associated to a target value of elastic spectral acceleration, from a code-based design spectrum or (Probabilistic Seismic Hazard Analysis) PSHA-based uniform hazard spectrum at the fundamental vibration period of the structure, T1, provides improved results for structures whose response is dominated by their first-mode [40]. Including vibration property of the structure led to improved methods of ground motion scaling; however, scaling only according to fundamental period becomes less accurate and less efficient for structures responding significantly in their higher vibration modes or far into the inelastic range [41, 42, 43]. As the evaluations in this study comprise only low-rise buildings, the procedure of scaling based on first fundamental period of the models seems to be sufficient for consideration of higher modes as well as proceeding nonlinear behavior effects. For more details about the scaling factors and target spectrum, one could refer to [35].

7. RELIABILITY ASSESSMENT

In this study, probabilistic quantification of vulnerability is attempted by means of β-unzipping method for approximating uncertainty. The β-unzipping method is a general strategy for estimating the failure probability of structural systems, initially proposed by Thoft-Christensen and Murotso in 1986 [44]. This interactive, sequential, and iterative strategy relies upon the user to interpret and generate information about the system through the use of appropriate techniques, such as directed experimental design, sampling techniques, response surface, and first- or second-order reliability methods [45]. The basis of FOSM lies in the statement that satisfactory estimates of the parameters of a distribution (which may be unknown and could be given by first-order approximations of Taylor series expansions of second-moment parameters e.g. mean and variance) of a random variable calculated from samples. The FOSM framework addresses and processes uncertainties in input variables to provide estimates of the uncertainty in vulnerability of the system function equation [46].

In operational terms, FOSM analysis requires at least the definition of a central value and a measure of dispersion [47]. Here, the probability distribution has been assumed lognormal for all the cases and the central value is considered as the median value and the measure of dispersion as the logarithmic variance of data similar to many studies in the related fields like [3]. These values in company with their distribution are obtained from analyzing results and are applied to the first order approximation of the failure function in order to carry out the reliability analysis [48]. In the strategy, one tries to obtain increasingly accurate representations of the significant failure regions and use these representations to arrive at an estimate of system failure probability. The goal is obtaining the probability of failure at the level of a hinge or an elementary mechanism, or for the whole structure.

The theoretical, time-invariant structural reliability problem is denoted by the integral:

$$p = \int_{\Omega(x)} f_x(x).dx, \tag{1}$$

where p is the failure probability, $f_X(x)$ is the joint Probability of Density Function (PDF) for a vector of random variables, $X = [X_1; X_2; \_\_\_ ; X_n]^T$ representing uncertain quantities, such as loads, material properties, constants and geometric dimensions, and (x) is the failure domain of the structure in the outcome space, $x = [x_1; x_2; \_\_\_ ; x_n]^T$ of X. For a general structural system, the failure domain may be defined in the form of:

$$\Omega(x) = \cup_k \cup_{i \in C_k} \{g_i(x) \leq 0\} \qquad (2)$$

where $g_i(x)$ defines the failure surface or limit-state function of component i for $i = 1; \_\_\_ ;m$, whereas a set of limit-state functions were formulated, so that $\{g_i(x) \leq 0\}$. In other words, when uncertain response quantity exceeds a specified threshold, $g_i(x)$ takes a negative value and failure is implied, m denotes the number of components, and C_k is the index set for the k^{th} cut set or elementary mechanism, where each cut set represents a minimal set of components, whose joint failure constitutes that cut set.

In this study, the function equation or (g-function) which has been discussed in the prior paragraph could be defined according to Equation (3)

$$L_{Exp} \leq L_{Cal} \qquad (3)$$

Where:

L_{Exp} – is the median amounts of loss which would be expected to occur.

L_{Cal} – is the median amounts of loss which is derived from the analyses.

In the assessments of this paper, only the equality is the accepted area. So, the failure surface coverts to a line. This linear function of g(x) brings about precisely application of FOSM method. If the accepted line has been defined as $L_{Exp} - L_{Cal} = 0$, the other points in the domain have been recognized as the failure domain. Considering FOSM concepts, failure probability and statistical results from the analyses could be connected based on Equation (4)

$$P_f = \phi(-\frac{\mu_{zi}}{\sigma_{zi}});\ or\ 1 - P_f = \phi(\frac{\mu_{zi}}{\sigma_{zi}}); \qquad (4)$$

where:

μ_{zi} – Central value of x (mean or median);

σ_{zi} – Dispersion value of x (standard deviation or logarithmic standard deviation);

$\frac{\mu_{zi}}{\sigma_{zi}}$ – Reliability Index (according to the discussions about failure criteria in FOSM method)

P_f – The probability of failure;

$\phi()$ – The standard normal or lognormal distribution function.

The equation illustrates the significant role of standard deviation in probability of reaching to g-function line or surface. Although the dispersion in loss amounts alone cannot form a measure of decision making factor, its minimizing provides more reliable decision making process and so performance evaluation.

In this study, the amounts of loss for different stories have been considered as independent variable from each other resulting in independency of g-functions and probability of failure for each of the stories.

8. EVALUATION OF STRUCTURAL RESPONSES

As it is mentioned before, the evaluations of structural responses have been conducted in three subcategories; near collapse assessment, noncollpase assessment and residual drift condition.

8.1 Evaluation of structural responses in near collapse conditions

Incremental Dynamic Analysis (IDA) is an emerging analysis method that offers thorough seismic demand and capacity prediction capability by using a series of nonlinear dynamic analyses under a multiply scaled suite of ground motion records. Limit-states, such as the dynamic global system instability, can be naturally defined in the context of IDA, thus allowing annual rates of exceedance to be calculated. In IDA, proper interpolation and summarization techniques for multiple records need to be employed, providing the means for estimating the probability distribution of the structural demand given the seismic intensity [49].

In this study, IDA analyses have been accomplished utilizing both N-S and W-E direction of ground motion sets in each of the x and y direction of the models to derive collapse fragility curves. The diagrams of IDA analyses for the models are presented in Figure 2. The collapse condition has been recognized as reaching to these three limit-states: local tangent of the diagram reaches 20% of the elastic slope, maximum drift of the roof reaches to 10% or global dynamic instability illustrating as reaching to flatline condition in the diagrams, whichever occurs first in IM terms [49]. Distinguishing spectral acceleration amount in collapse point for each of the IDA diagrams and supposing Lognormal distribution for collapse fragility curves, the collapse fragility curves could be obtained and presented in Figure 3. The statistical parameters for collapse fragilities are exhibited in Table 2; where, $S_{CT}(T_1)$ is the median amount of spectral acceleration at collapse point and β is the logarithmic amount of dispersion.

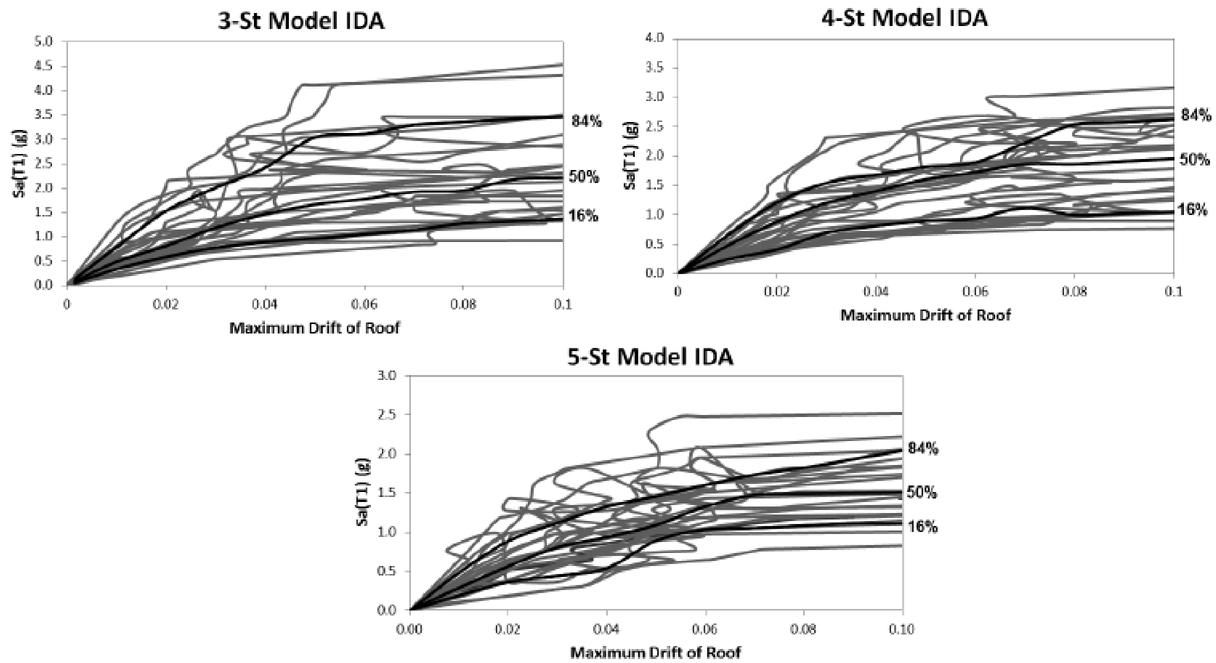
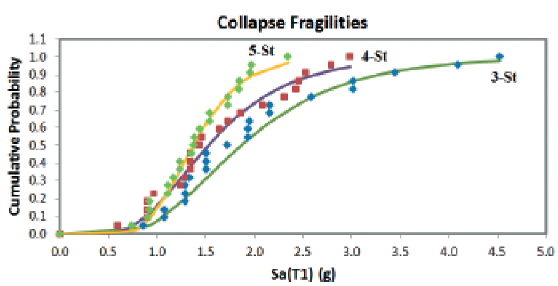


Figure 2.
Incremental dynamic analysis results, spectral acceleration amount according to maximum drift of the roof story, for different models



	3-St Model	4-St Model	5-St Model
$S_{CT}(T_1)$ (g)	1.863	1.526	1.372
β	0.440	0.422	0.311

Figure 3.
Collapse fragilities of the models

Table 2.
Collapse fragility parameters

	3-St Model	4-St Model	5-St Model
Median of $S_{CT}(T_1)$ (g)	1.863	1.526	1.372
β	0.440	0.422	0.311

8.2 Evaluation of structural responses in noncollapse condition

For assessing non-collapse conditions, record scaling has been done according to five scaling levels corresponding to design level earthquake (DLE) which was calculated based on first fundamental period and consideration of the design target spectrum. The level of scaling is selected as (0.5 DLE, 1.0 DLE,…, 2.5 DLE). Nonlinear dynamic analyzing has been conducted according to the both N-S and E-W factors of the records; so, the models have been analyzed subjected to 22 records in each direction of x and y. Maximum level of scaling has been selected so that the models do not experience collapse at the most under half of the records. All EDPs are extracted for each story of the models with different number of stories under different scaling levels for each ground motion record. For case in point, EDPs of the roof story in 3-story model have been presented in Figure 4 in scaling level of 1.5 DLE under San Fernando record.

The dispersion amounts of the EDPs (β) are calculated by consideration of lognormal distribution of responses in all of the scaling levels according to the recommended procedure in ATC-58 [21]. According to this code, deviation parameter of the system could be separated into three major parts incorporated in β

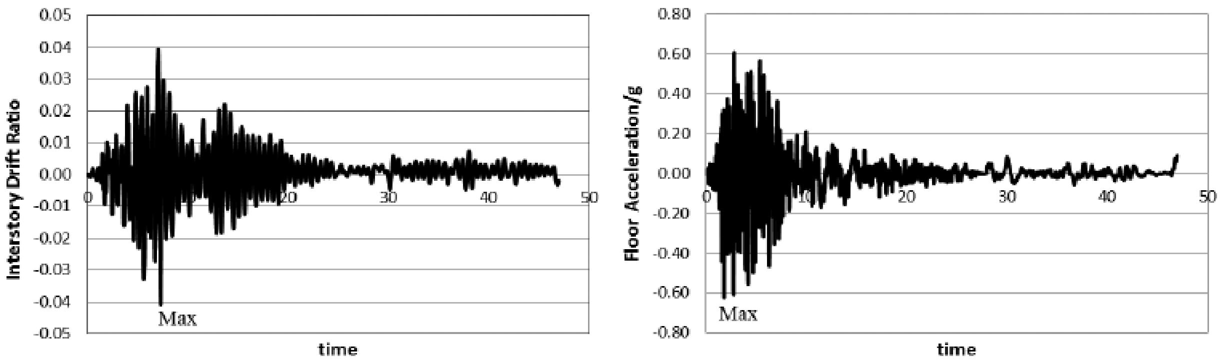


Figure 4.
Structural responses of the roof story in 3-story model in scaling level of 1.5 DLE

computation by the help of Equations (5) and (6).

$$\beta_m = \sqrt{\beta_c^2 + \beta_q^2} \qquad (5)$$

$$\beta_m = \sqrt{\beta_c^2 + \beta_q^2} \qquad (6)$$

Where

β_m – Modeling Dispersion (which could be considered based on ATC-58 recommended values).

β_c – Dispersion associated to definition of the building, characteristics of the materials and available information of the building (which could be considered based on ATC-58 recommended values).

β_q – Dispersion associated to modeling strategy (which could be considered based on ATC-58 recommended values).

β_{aEDP} – Dispersion associated to structural responses calculated in two distinct groups of peak floor acceleration and interstory drift ratio (which could be derived from the analyses results).

The ultimate calculated dispersion amounts for three selected models are presented in Tables 3 and 4.

Fragility functions for non-collapse condition are derived from FEMA P-58-1 specification. Selected fragility functions and associated performance groups and their normative quantities were discussed earlier in this paper.

Table 3.
Calculated amounts of dispersion for peak floor acceleration (PFA)

T(s)	0.5 DL	1.0 DL	1.5 DL	2.0 DL	2.5 DL
0.68	0.28	0.29	0.31	0.31	0.33
0.85	0.28	0.29	0.31	0.32	0.32
1.12	0.28	0.29	0.32	0.32	0.33

Table 4.
Calculated amounts of dispersion for interstory drift ratio (IDR)

T(s)	0.5 DL	1.0 DL	1.5 DL	2.0 DL	2.5 DL
0.68	0.31	0.38	0.38	0.40	0.44
0.85	0.30	0.35	0.38	0.41	0.43
1.12	0.32	0.39	0.41	0.41	0.45

8.3 Evaluation of structural responses for consideration of residual drifts

Residual drift plays very significant role in loss evalaution. The effect of considering this factor in loss estimation reaches up to 50% of the loss amounts in some cases especially systems with high ductility [50]. Diverse equations have been proposed by some researchers commonly based on ultimate nonlinear displacement and yield displacement of story. One of very frequently applied equations in researches [51] and also in codes [21] as well as in this study is the mentioned equations of (7).

$$\begin{aligned} &\Delta_r = 0 && \Delta \le \Delta_y \\ &\Delta_r = 0.3(\Delta - \Delta_y) && \Delta_y < \Delta < 4\Delta_y \\ &\Delta_r = (\Delta - 3.1\Delta_y) && \Delta \ge 4\Delta_y \end{aligned} \qquad (7)$$

Where:

Δ_r – Estimated median residual story drift in a story.

Δ – Computed median ultimate drift in a story gained from nonlinear dynamic analysis.

Δ_Y – Median value for elastic drift of a story gained from static nonlinear analysis.

Static nonlinear analyzing has been performed based on ASCE/SEI 41-06 recommendation [52] by utilizing gravitational load combination of

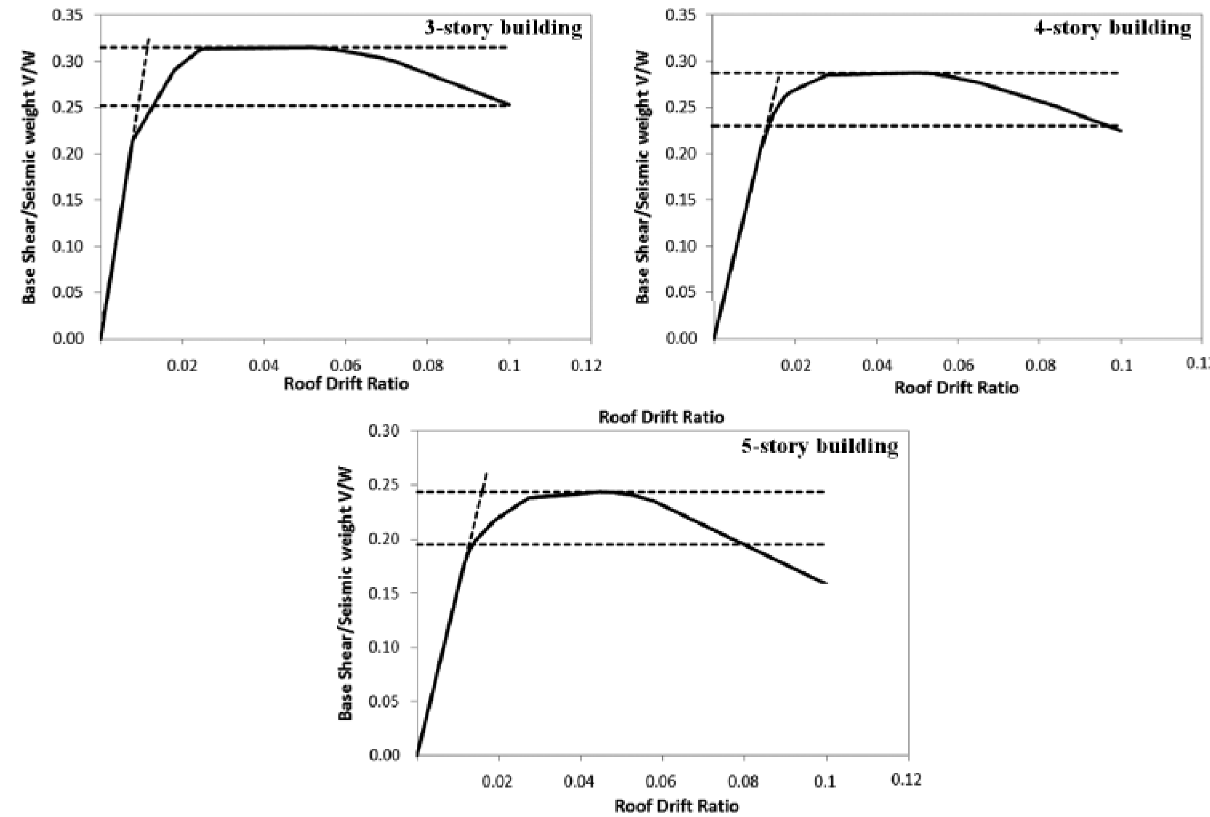


Figure 5.
Pushover diagrams for different models

Table 5.
Elastic drift for each story of the models in both x and y direction

	3-story Model		4-story Model		5-story Model	
	x dir	y dir	x dir	y dir	x dir	y dir
Story 1	0.011	0.013	0.014	0.014	0.016	0.017
Story 2	0.013	0.012	0.015	0.016	0.017	0.017
Story 3	0.013	0.011	0.016	0.017	0.017	0.018

(1.05DL+0.25LL). Target drift has been considered equivalent to 0.1 and distribution of lateral load was based on the first mode of vibration in accordance with the recommendations of FEMA P695 [53]. Moreover, yield shears and their corresponding yield drifts for entire and each story of the building have been defined regarding to FEMA P695 [53]. The pushover diagrams for the entire building and the results of elastic drifts for each story of the models have been presented in Figure 5 and Table 5.

Availability of nonlinear dynamic analysis results in company with elastic drifts and utilizing Equation (7) contribute to the residual drift ratios for the models under each of the 22 records. The dispersion values are calculated according to the Equations (5) and (6) by consideration of the deliberated residual drifts values.

For consideration of residual drifts in loss calculations, a repair fragility with lognormal distribution, median value of 1% and dispersion of 0.3 has been hired similar to most of the works by consideration of this aspect like [21] and [54].

9. DEFINITION OF THE COST MODEL IN PACT

The Performance Assessment Calculation Tool (PACT) computes probabilistic cost of damage (that is the main concern of this paper) based on the component, collapse and repair fragility functions. This program has been conducted on the foundation of Monte Carlo simulation in each try called in this program as one realization. The numbers of realizations in this study have been assumed equal to 200 which could impact on accuracy of the results as well as time of analyzing. There are too many non-structural components in a building and containing them all is not feasible in terms of time and effort. The type and normative quantities of the applied performance groups in this study are developed based on the FEMA P-58-1 [19].

The estimated amounts of damage cost for the models have been available through conducting analyses according to the earlier mentioned clarifications about the EDPs and performance groups and have been presented for the each of the stories of the models in two subcategories; costs dependent on IDR and costs dependent on PFA in Tables 6 to 8.

Providing damage cost for all the models subjected to different scaling levels, the contribution portion of each story in entire building's damage cost have been calculated and presented in Table 9. For illustrating the impact of component distribution in height on total damage cost of building the ratio of DR has been defined as the amount of total damage cost of building to the amount of total replacement cost of building. The amounts of this factor are also going to be presented in Table 9.

It could be observed that by increasing intensity level of spectral acceleration, the incorporation of displacement-dependent components has been decreased resulting in reduction of contribution portion of first story in the damage cost. However, ampli-

Table 6.
Median amounts of damage cost for each story according to different intensity levels for the 3-story model with fundamental period of 0.68(s) based on the frequently used component distribution mentioned by FEMA P-58-1

Intensity Levels	Story damage cost to the cost of each story %						Total damage cost to the cost of entire building %
	First Story		Typical Story		Roof Story		
	IDR	PFA	IDR	PFA	IDR	PFA	
0.5 DLE	4.30	7.37	5.27	7.03	2.85	8.65	8.39
1.0 DLE	15.58	14.54	15.38	14.59	7.76	11.59	20.55
1.5 DLE	26.91	25.07	28.07	23.42	28.22	18.01	35.14
2.0 DLE	34.78	37.10	35.98	31.93	40.78	24.18	47.36
2.5 DLE	37.98	39.71	38.40	34.30	45.20	26.32	50.93

Table 7.
Median amounts of damage cost for each story according to different intensity levels for the 4-story model with fundamental period of 0.85(s) based on the frequently used component distribution mentioned by FEMA P-58-1

Intensity Levels	Story damage cost to the cost of each story %						Total damage cost to the cost of entire building %
	First Story		Typical Story (2^{nd}+ 3^{rd} Stories)		Roof Story		
	IDR	PFA	IDR	PFA	IDR	PFA	
0.5 DLE	7.06	5.69	8.74+6.72	6.13+6.18	3.79	5.79	12.61
1.0 DLE	17.43	16.78	16.86+9.84	16.89+17.42	5.09	13.38	28.66
1.5 DLE	30.46	27.67	31.36+27.41	25.87+25.61	24.89	20.29	53.59
2.0 DLE	40.70	34.43	39.19+32.47	31.19+31.35	34.89	24.68	67.38
2.5 DLE	45.78	38.05	46.82+35.98	34.88+34.17	38.44	27.34	75.57

Table 8.
Median amounts of damage cost for each story according to different intensity levels for the 5-story model with fundamental period of 1.12(s) based on the frequently used component distribution mentioned by FEMA P-58-1

Intensity Levels	Story damage cost to the cost of each story %						Total damage cost to the cost of entire building %
	First Story		Typical Story (2^{nd}+ 3^{rd}+ 4^{th} Stories)		Roof Story		
	IDR	PFA	IDR	PFA	IDR	PFA	
0.5 DLE	1.45	4.61	4.16+5.59+4.37	4.46+4.51+5.08	2.04	3.94	8.14
1.0 DLE	7.32	11.67	22.58+21.23+15.94	11.98+11.81+12.18	8.67	9.46	26.98
1.5 DLE	21.76	19.04	27.87+26.85+21.46	18.18+17.93+17.87	16.12	14.20	40.65
2.0 DLE	34.72	26.51	40.29+40.72+31.98	21.09+20.87+19.89	32.51	19.70	57.84
2.5 DLE	42.42	32.04	46.78+46.71+34.38	29.48+29.42+29.39	36.03	23.21	70.36

Table 9.
Percentage of incorporation for each story in the total damage cost and the percentage of total damage cost to the total replacement cost of building (DR) according to different fundamental periods and different scaling levels based on the frequently used component distribution mentioned by FEMA P-58-1

Periods	3-story (T=0.68 (s))				4-story (T=0.85 (s))				5-story (T=1.12 (s))			
Scaling levels	1^{st} St.	Typ St.	Top St.	DR %	1^{st} St.	Typ St.	Top St.	DR %	1^{st} St.	Typ St.	Top St.	DR %
0.5 DLE	0.326	0.333	0.339	8.39	0.215	0.261	0.257	12.61	0.177	0.202	0.217	8.14
1.0 DLE	0.297	0.349	0.351	20.55	0.212	0.255	0.275	28.66	0.175	0.204	0.213	26.98
1.5 DLE	0.310	0.339	0.349	35.14	0.216	0.254	0.272	53.59	0.173	0.199	0.230	40.65
2.0 DLE	0.307	0.336	0.358	47.36	0.214	0.249	0.281	67.38	0.166	0.201	0.231	57.84
2.5 DLE	0.313	0.328	0.360	50.93	0.209	0.257	0.272	75.57	0.164	0.198	0.242	70.36

Table 10.
Logarithmic standard deviations values (β) for the damage costs of the models subjected to different intensity levels based on the frequently used component distribution mentioned by FEMA P-58-1 based on the case of 50% probability of observing in a low-rise office building

Periods	3-story (T=0.68 (s))				4-story (T=0.85 (s))				5-story (T=1.12 (s))			
Scaling levels	1^{st} St.	Typ St.	Top St.	Entire Building	1^{st} St..	Typ St.	Top St.	Entire Building	1^{st} St.	Typ St.	Top St.	Entire Building
0.5 DLE	0.49	0.31	0.33	0.38	0.30	0.27	0.26	0.28	0.1	0.14	0.21	0.15
1.0 DLE	0.29	0.29	0.29	0.29	0.23	0.28	0.29	0.27	0.32	0.21	0.22	0.25
1.5 DLE	0.32	0.37	0.37	0.35	0.40	0.31	0.25	0.32	0.37	0.33	0.36	0.35
2.0 DLE	0.27	0.21	0.26	0.25	0.33	0.33	0.31	0.33	0.44	0.35	0.34	0.38
2.5 DLE	0.25	0.19	0.21	0.22	0.30	0.36	0.28	0.31	0.33	0.36	0.45	0.38

fication of intensity level consequents intensification of contribution portion for acceleration-dependent components which are generally situated in top story. Contrariwise, by increasing the number of stories and consequently the period of structure, the involvement of the typical stories increased bringing about reduction in portion of top and first floors, where by increasing the intensity level, the impact of fundamental period of the models decreased. Thus, the strategies of situating displacement or acceleration-dependent components could be determined according to various factors such as intensity level of earthquake, number of stories, building's fundamental period and etc. …

Denoting to the obtained results explained above, it could be understood that in small earthquake intensities by transferring acceleration-dependent elements to the lower stories, the cost of damage could be reduced according to less gained accelerations in these stories and also according to further incorporation of lower stories in building damage costs. In the other hand, by increasing the scaling level of intensities, if one could distribute displacement-dependent component in a way to afford larger portion of contribution to the upper stories, or by altering the type of components from displacement-dependent to acceleration-dependent by well-done component anchoring, the cost of damage has been decreased.

Logarithmic standard deviations values (β) for the obtained damage cost of the models have been presented in Table 10. Different trends of changes could be observed for each of the story types in each of the models illustrating different participation portion of each story in reliability of the entire building. In scaling levels with greater differences of dispersions in loss amounts, the significant role of component distribution would be evidently recognized.

10. PROPOSED MODIFIED PATTERN

Procedures for modifying the stories' incorporations could be classified as modifications in structural responses and modifications in distribution of components.

By ductiling roof story and strengthening first story, the acceleration demands trend from roof story to the below ones as well as displacement demands trend from first story to the upper ones, causing less participation of roof story and first story in damage cost induced by acceleration-dependent and displacement–dependent demands respectively. There are lots of structural design approaches for making this

Table 11.
Modified distribution of the presumed performance groups

COMPONENT SUMMARY MATRIX							
Occupancy	Fragility	Fragility Name	Assumed Quantity per component	Quantity	Actual Quantity		Fragility Quantity Beta
Floor Name	Number		within PACT	Non Directional	Value	Unit	(Lognormal Distribution)
1st	D3031.011a	Chiller-Capacity:<100 ton- Unanchored equipment that is not vibration isolated-Equipment fragility only	75 Ton	1.0	3.3	Ton	0.1
1st	D3031.021a	Cooling Tower- Capacity:<100ton- Unanchored equipment that is not vibration isolated-Equipment fragility only	75 Ton	1.0	3.3	Ton	0.1
1st	D5012.013a	Motor Control Center- Capacity: all-Unanchored equipment that is not vibration isolated-Equipment fragility only	1 Each	1.0	0.0	Each	0.5
2nd	E2022.012	Fragility Contents on shelves in storage cabinets with latches.	15 Each	2.89	45.0	Each	0.4
2nd	E2022.021	Electronic equipment on wall mount brackets	1 Each	1.0	1.0	Each	0.4

type of modification up which are not the concern view of this paper. The focused feature of this paper is on modifications in distributions of components bringing about adjustments in incorporation of stories in total damage cost which contribute in more reliable loss with less magnitude without any alternation in the presumed quantity for each performance groups. The proposed modifications are based on formerly discussions about the obtained results and are not statically allowing for the easy addition or modification of groups as future testing or other dictated developments. The proposed component summary matrix by FEMA P-58-1 could be revised in some cases as mentioned in Table 11.

Conducted modifications in this paper are as follow:

- Moving chiller equipment (D3031.011a) from roof story to the first story.
- Moving cooling tower (D3031.021a) from roof story to the first story.
- Moving motor control center (D5012.013a) from roof story to the first story.
- Decreasing decorating expenses in first story by moving them to the 2nd story or completely anchoring the components; so, they could be removed from the first story.
- Moving electronic equipment from first story to the 2nd story.

For reference purposes, the codes of performance groups have been listed in Table 11 as the same codes by FEMA P-58-1 [19].

Table 12.
Percentage of incorporation for each story in the total damage cost and the percentage of total damage cost to the total replacement cost of building (DR) according to different fundamental periods and different intensity levels subjected to the proposed modified pattern of nonstructural components

Periods	3-story (T=0.68 (s))				4-story (T=0.85 (s))				5-story (T=1.12 (s))			
Scaling levels	1st St.	Typ St.	Top St.	DR %	1st St.	Typ St.	Top St.	DR %	1st St.	Typ St.	Top St.	DR %
0.5 DLE	0.335	0.341	0.324	7.99	0.233	0.268	0.231	7.85	0.182	0.210	0.188	7.86
1.0 DLE	0.323	0.354	0.323	16.39	0.230	0.261	0.248	26.52	0.187	0.211	0.180	26.04
1.5 DLE	0.344	0.342	0.314	31.51	0.242	0.263	0.232	48.96	0.178	0.207	0.201	39.20
2.0 DLE	0.340	0.341	0.319	43.32	0.258	0.257	0.228	60.83	0.181	0.206	0.201	55.74
2.5 DLE	0.337	0.348	0.315	45.36	0.264	0.262	0.212	74.17	0.170	0.207	0.209	67.78

10.1. Evaluation of the results subjected to the modified pattern

As the modifications are not as structural type, the previously gained structural responses could be utilized for new analyses too. The amounts of damage cost and the portion of contribution of each story in the damage cost of the models based on the modified distribution of components are presented in Table 12 for different models subjected to diverse intensity levels demonstrating prominent standing of the performance group's distribution in height of models.

The cost of damage in all of the models has been declined subjected to all assumed fundamental periods and all intensity levels by the help of the straightforward proposed modifications without any alternation in the amounts of performance groups or in structural characteristics of the models. Although this reduction is not too considerable in the percentage of total damage cost of building in some cases; assuming the amount of building cost in dollars, this reduction could save great expenses particularly for the models with large areas and thus large initial costs. As for models with larger areas, both of the initial cost and normative quantities for performance groups are too greater than the presumed amounts for the considered typical models of this study. For complementing the analyses results, the percentages of total damage costs could be compared in different intensity levels before and after application of the proposed modifications for different models by the help of the diagrams in Figure 6.

The more important impact of the proposed modifications is on the portion of incorporation of each story in the total damage cost of building. By conducting the proposed modifications, the portions of incorporation for the first and typical stories increase especially in low scaling levels of intensities. This amplification is more intense in the first floor than the typical ones and further in 3-story building than the 4 or 5-story ones; because of fewer number of typical stories permits to the first floor to play more significant role in making cost of damage. In addition,

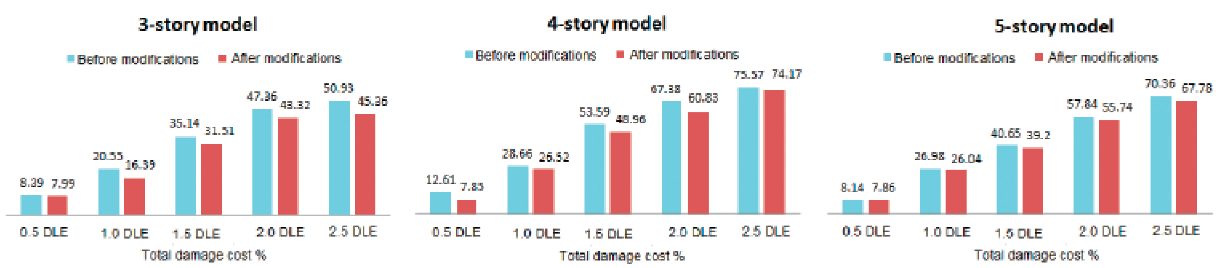


Figure 6.
Percentage of total damage cost for models with different number of stories before and after conducting the proposed modifications for components' distribution in height

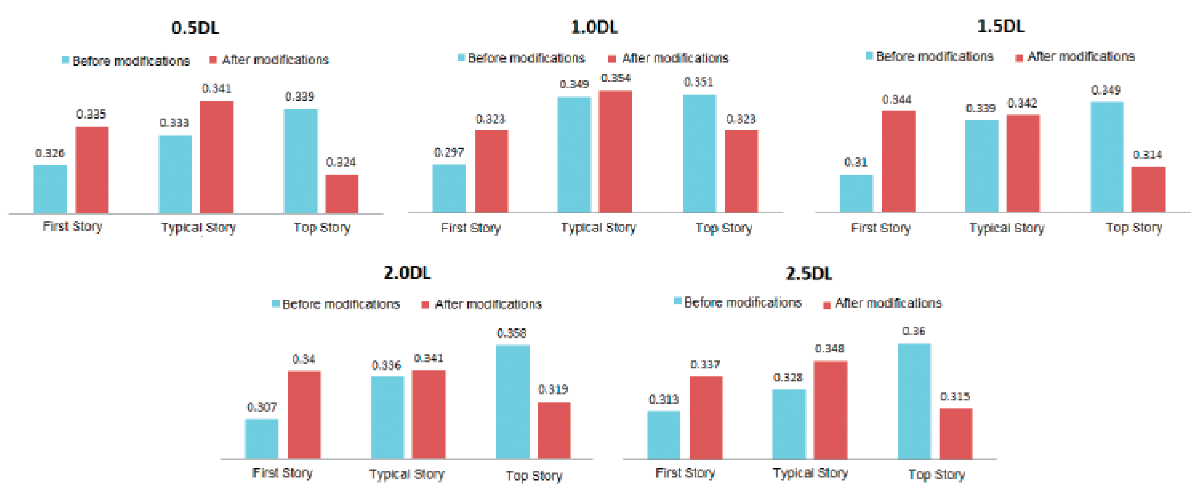


Figure 7.
Percentage of incorporation of stories in total damage cost for 3-story model subjected to different scaling intensity levels for two alternative nonstructural distributions

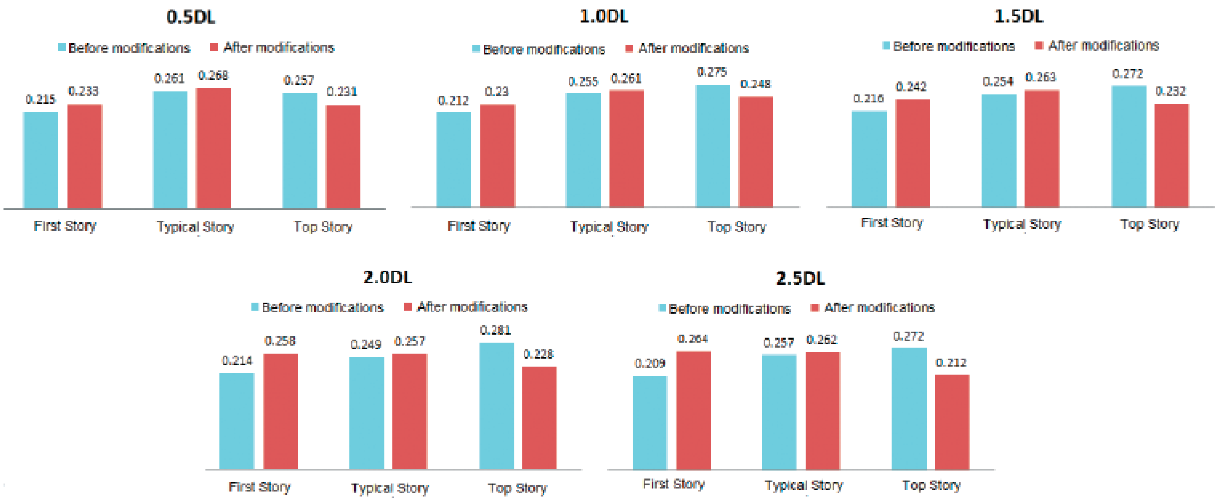


Figure 8.
Percentage of incorporation of stories in total damage cost for 4-story model subjected to different scaling intensity levels for two alternative nonstructural distributions

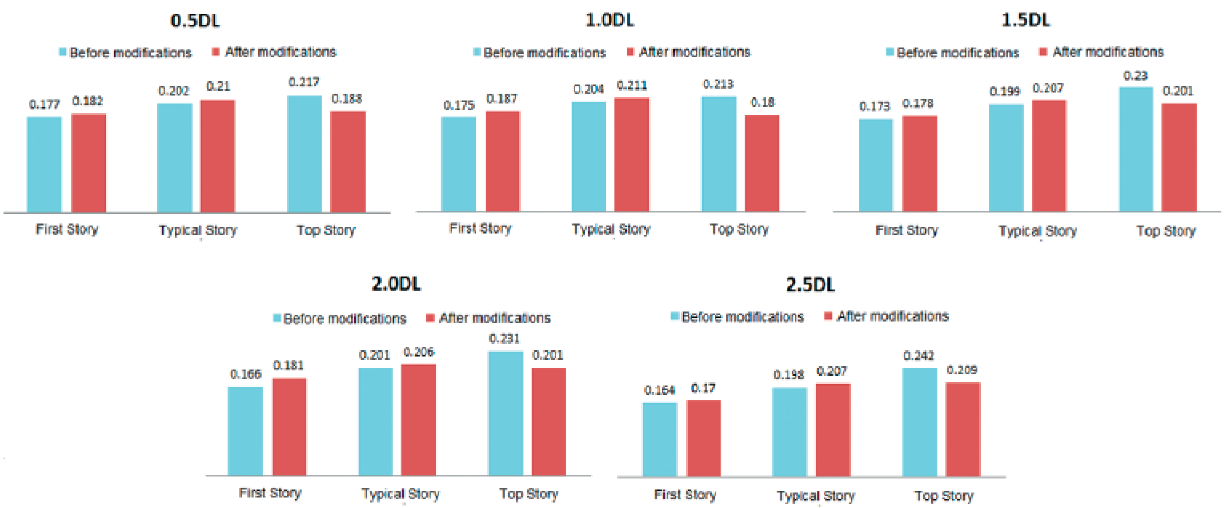


Figure 9.
Percentage of incorporation of stories in total damage cost for 5-story model subjected to different scaling intensity levels for two alternative nonstructural distributions

new proposed distribution pattern of components indicates in almost near to equivalent portion of incorporation for all types of stories. For more evidently demonstration of the proposed modified components' distribution effects on the portion of contribution for stories of the models, Figures 7 to 9 could be very supportive presenting intensification in participation part of lower stories and reduction in participation part of upper stories in the total damage cost particularly subjected to low intensity earthquakes.

In some levels of intensity, the contribution portions of stories go across equality like the intensity of 0.5DLE for the 3-story model or 1.5DLE for the 4-story model according to FEMA nonstructural distribution which was presented in Table 9. Although this situation is very ideal for investment, its occurrence would not guarantee the least amount of damage cost subjected to seismic excitation in all cases; because of the diverse structural responses and unalike component distributions in different stories. For example, for a model near to collapse, the strategy for reduction of total damage cost and for preventing collapse is to decrease incorporations of lower stories in damage; though the equivalent incorporation of stories in damage costs could insure the profitability of the built investment in each story, noticing the fact that nonstructural components

Table 13.
Logarithmic standard deviations values (β) for the damage costs of the models subjected to different intensity levels based on the proposed modified pattern of nonstructural component

Periods	**3-story (T=0.68 (s))**				**4-story (T=0.85 (s))**				**5-story (T=1.12 (s))**			
Scaling levels	1^{st} St.	Typ St.	Top St.	Entire Building	1^{st} St..	Typ St.	Top St.	Entire Building	1^{st} St.	Typ St.	Top St.	Entire Building
0.5 DLE	0.48	0.30	0.32	0.365	0.29	0.26	0.25	0.266	0.09	0.13	0.20	0.141
1.0 DLE	0.28	0.28	0.28	0.281	0.23	0.27	0.28	0.262	0.29	0.19	0.20	0.225
1.5 DLE	0.31	0.36	0.36	0.342	0.39	0.30	0.24	0.308	0.35	0.31	0.34	0.332
2.0 DLE	0.26	0.20	0.25	0.239	0.32	0.32	0.30	0.318	0.41	0.33	0.32	0.353
2.5 DLE	0.24	0.18	0.20	0.210	0.29	0.35	0.27	0.305	0.31	0.34	0.43	0.362

account for most of the total investment in a typical office building.

Equality in stories incorporation in damage cost could be commonly assure less entire building damage cost and also profitability of investment only in non-collapse situation. Hence, it is the wisdom of designer to keep in mind the cost of damage induced by seismic excitation as a decision making issue for determining the situation of nonstructural components. For the models of this study, the evaluations exhibit reduction in total amounts of damage costs in all situations just by employment of the modified pattern of component distribution in height without any alternation in specification or quantity of the incorporated components.

Logarithmic standard deviation values (β) for the obtained damage cost of the models based on the proposed modified pattern of nonstructural components have been presented in Table 13.

Comparing dispersion amounts subjected to the frequently used component distribution mentioned by FEMA P-58-1 based on the case of 50% probability of presence in office buildings and according to the modified nonstructural distribution proposed in this paper (the modified distribution pattern mentioned in detail in Table 11), it has been understood that almost in all of the cases utilizing the proposed modified pattern concludes in reduction of dispersion amounts and therefore more reliable evaluation of loss values.

Considering standard deviation and median amounts for entire building, the failure probability could be computed based on Equation (4). It is fine to mention that failure in this study indicates not reaching to

Table 14.
The reliability index and failure probability in each of the scaling levels for different systems subjected to the component distribution mentioned by FEMA P-58-1

Scaling Levels	**Reliability Index**			**Probability of Failure**		
	3-story (T=0.68 (s))	4-story (T=0.85 (s))	5-story (T=1.12 (s))	3-story (T=0.68 (s))	4-story (T=0.85 (s))	5-story (T=1.12 (s))
0.5 DLE	2.65	3.61	6.67	3.97E-03	1.50E-04	1.31E-11
1.0 DLE	3.45	3.75	4.00	2.82E-04	8.84E-05	3.17E-05
1.5 DLE	2.83	3.13	2.83	2.33E-03	8.89E-04	2.33E-03
2.0 DLE	4.05	3.09	2.65	2.52E-05	9.91E-04	3.97E-03
2.5 DLE	4.62	3.19	2.63	1.96E-06	7.08E-04	4.25E-03

Table 15.
The reliability index and failure probability in each of the scaling levels for different systems subjected to the modified component distribution proposed in this paper

Scaling Levels	**Reliability Index**			**Probability of Failure**		
	3-story (T=0.68 (s))	4-story (T=0.85 (s))	5-story (T=1.12 (s))	3-story (T=0.68 (s))	4-story (T=0.85 (s))	5-story (T=1.12 (s))
0.5 DLE	2.74	3.76	7.09	3.07E-03	8.52E-05	6.60E-13
1.0 DLE	3.56	3.82	4.44	1.86E-04	6.76E-05	4.41E-06
1.5 DLE	2.92	3.25	3.01	1.73E-03	5.84E-04	1.30E-03
2.0 DLE	4.18	3.14	2.83	1.43E-05	8.31E-04	2.31E-03
2.5 DLE	4.76	3.28	2.76	9.59E-07	5.21E-04	2.87E-03

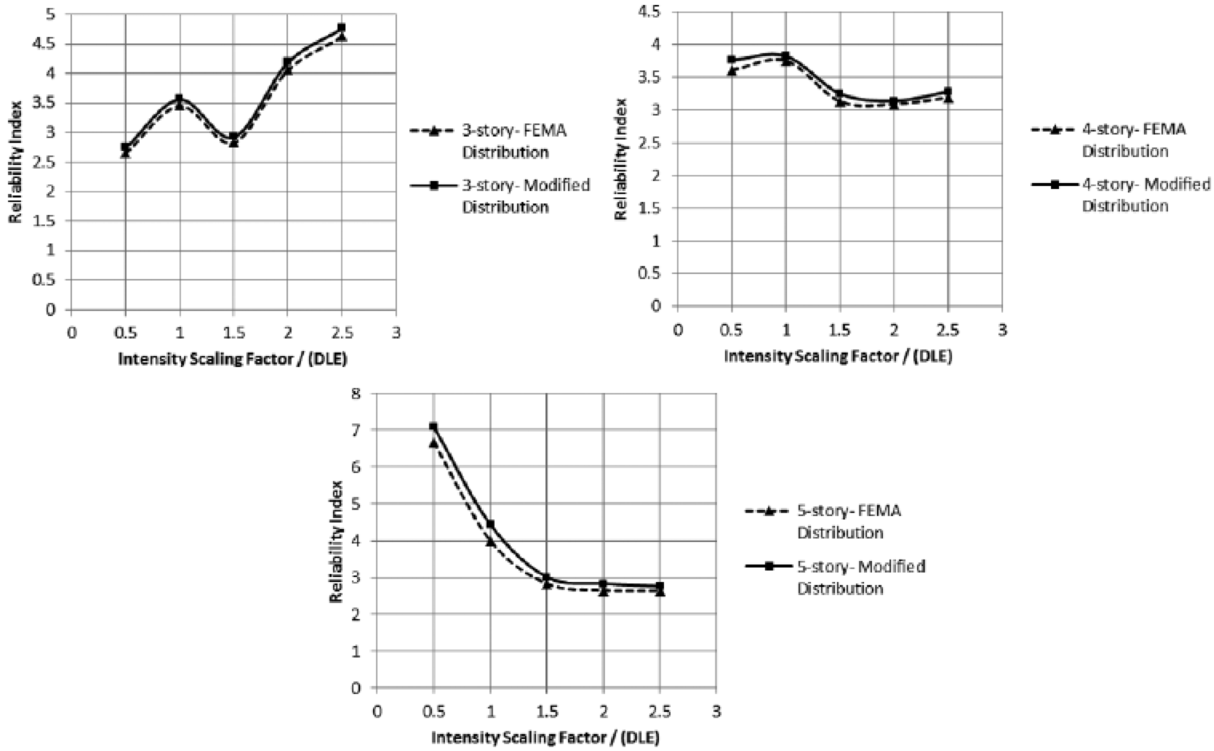


Figure 10.
The reliability index according to intensity scaling levels for the models subjected to the component distribution mentioned by FEMA P-58-1 and the modified component distribution proposed in this paper

the evaluated median amount of loss located on the g-function line (this feature has been previously discussed in section 1.2). The reliability index and failure probability in each of the scaling levels for different models subjected to the component distribution stated by FEMA P-58-1 and also according to the proposed nonstructural distribution in this paper are presented in Tables 14 and 15.

The presented diagrams of Figures 10 and 11 could be very supportive in illustration of the role of modified component's distribution pattern in amplification of reliability index for loss evaluation for the models.

These diagrams exhibit that almost in all of the cases using modified pattern of component distribution proposed in this paper could amplify the reliability index for the obtained loss amount and decrease the failure probability of the systems; where failure of the system has been indicated in this study as obtaining different amount of loss from which expected.

Although the amplification of reliability index is diminutive, the reduction in failure probabilities could very well demonstrate the significant role of utilizing the modified nonstructural components' distribution in amplification of system reliability which was presented by means of diagrams in Figure 11. The point of notice is that all of these preferment in reducing the amount and dispersion of loss only gained by changing the pattern of distribution of nonstructural components in height of building without any requirement to do any changes in type or amounts of these components presenting very significant role of considering amount and dispersion of loss as decision factors for determining the location of nonstructural components.

11. CONCLUSIONS

This paper illustrates the significant role of nonstructural performance group's distribution in height of models and its impact on stories incorporations and thus profitability of investments and also in the amounts and dispersions of the total damage costs by assessing the cost of damage as a performance merit for two alternative nonstructural distributions (first is the commonly used and recommended in associated codes and second is the modified and proposed distribution by the authors).

Some of the obtained conclusions from the paper

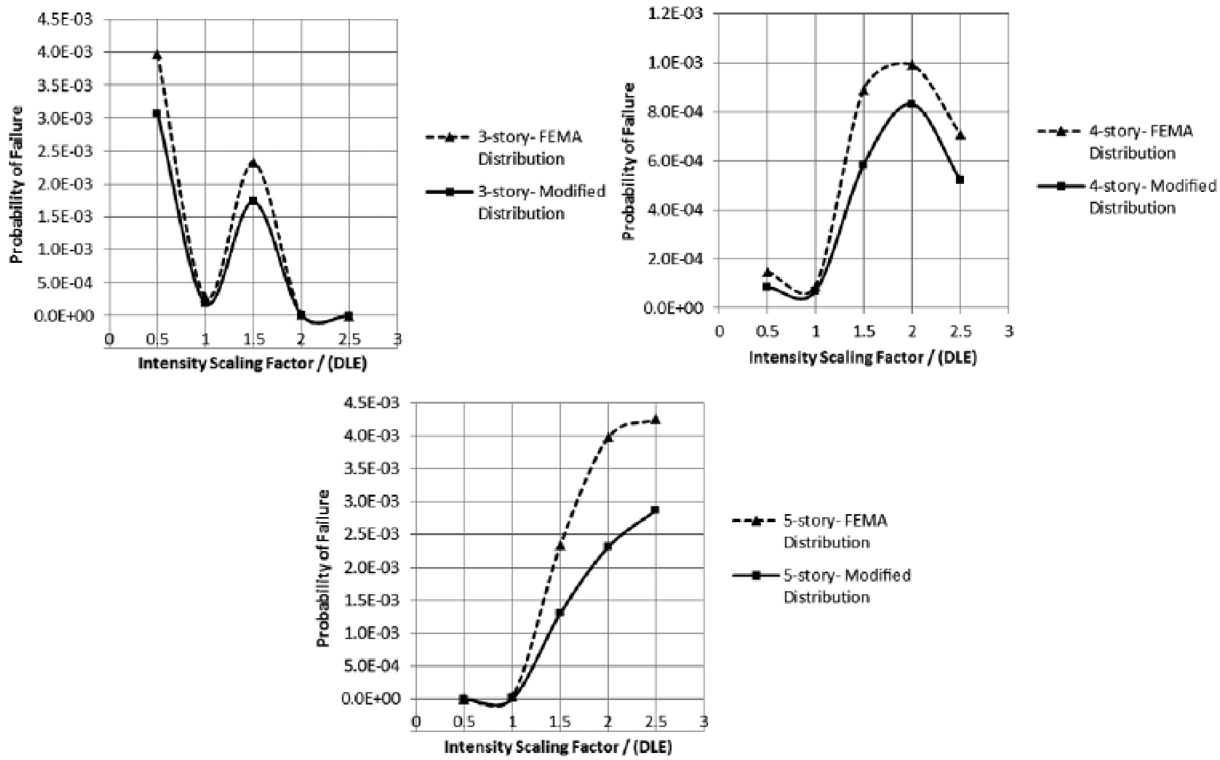


Figure 11.
The probability of failure according to intensity scaling levels for the models subjected to the component distribution mentioned by FEMA P-58-1 and the modified component distribution proposed in this paper

could be formulated as:

- The strategies of situating displacement or acceleration-dependent components could be determined according to some factors like intensity level of earthquake, number of stories and fundamental period of the building.
- In small earthquake intensities by conveying acceleration-dependent elements to the lower stories, the cost of damage could be reduced according to less gained accelerations in these stories and also according to further incorporation of lower stories in building damage costs. On the other hand, by increasing the scaling level of intensity, if one could distribute displacement-dependent component in a way to afford larger portion of contribution to the upper stories, or by altering the type of components from displacement-dependent to acceleration-dependent by well-done anchorage of the components, the cost of damage has been decreased.
- Application of the straightforward proposed modifications without any alternation in the amounts of performance groups or in structural characteristics of the models, the cost of damage in all of the models has been declined subjected to all assumed fundamental periods and all intensity levels. This reduction could save great expenses particularly for the models with large areas and thus large initial costs.
- By conducting the proposed modifications, the portions of incorporation for the first and typical stories increase especially for low scaling levels of intensities. This amplification is more intense in the first floor than the typical ones and also in 3-story building than the 4 or 5-story ones; because of fewer number of typical stories permits to the first floor to play more significant role in making cost of damage.
- New proposed distribution pattern of nonstructural components indicates in almost near to equivalent portion of incorporation for the stories in the total damage cost of building. Although uniformly distributed costs in height of building do not assure less total damage cost in all cases, the equivalent incorporation of stories in damage costs could guarantee the profitability of the built investment in each story, noticing the fact that nonstructural components account for most of the total investment in a typical office building. While

for the models of this study, the evaluations exhibit reduction in total amounts of damage costs in all situations just by application of the proposed modifications in the pattern of component distribution in height without any alternation in specification or quantity of the incorporated components.

- Modified pattern of distribution proposed in this paper considering type of dominated demands in a specific story could amplify the reliability index for the obtained loss amount and decrease the failure probability of the systems. Although the amplification of reliability index is diminutive, the reduction of failure probability could very well demonstrate the significant role of utilizing the modified nonstructural components' distribution in height in amplification of system reliability.

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