17th World Conference on Earthquake Engineering, 17WCEE
Sendai, Japan - September 13th to 18th 2020

THE SURA POST-EARTHQUAKE ASSESSMENT METHODOLGY. CASE STUDY: M7.1 MEXICO EARTHQUAKE, 2017

M.J. Barrera(1), V. Gonzalez(2), E. Cardona(3), G.M. Estrada(4), J.D. Rendon(5)

(1) *Structures Specialist, Suramericana S.A., mbarrera@sura.com*
(2) *Director of Geophysical Risk, Suramericana S.A., vgonzalezp@sura.com*
(3) *Manager Department of Geosciences, Suramericana S.A., ecardonar@sura.com*
(4) *Vice President Risk, Suramericana S.A., gestradaa@sura.com*
(5) *Structures Specialist, Suramericana S.A., jrendonb@sura.com*

Abstract

The 25 January 1999 magnitude 6.2 (Mw) Earthquake in Armenia (Colombia) highlighted SURA’s need to develop an inhouse methodology for a Post-Earthquake Structural Assessment of the insured assets. Even though SURA, an insurance company, had a team of specialized structural engineers carrying out these assessments, a methodology that guaranteed homologation and unified criteria for the assessment of damaged structures was a necessity to follow the company’s desire to contribute in the construction of more resilient and less seismically vulnerable cities.

This article introduces SURA’s Post-Event Structural Assessment Methodology, which focuses on establishing procedures and evaluation criteria that facilitate the repair, rehabilitation and reconstruction decisions for SURA’s clients [1]. The methodology, which is to be applied by structural engineers, establishes standard quantitative criteria to classify structural damage into three main damage states: minor damage, special damage, and severe damage.

A case study is presented based on the response to the M7.1 Puebla, Mexico Earthquake of 19 September 2017, where SURA applied its Post-Event structural assessment methodology to evaluate the damage of its insured assets. As a result, a statistical analysis of the building stock under study is presented and showing the influence of material type, structural configuration, and local site effects on the appearance of certain damage conditions. Moreover, some characteristics of the internal earthquake care protocol are summarized. This article relies upon the experiences of this event to show the application of its methodology, its results, and to reflect on the lessons learned and on the necessary improvements to the methodology’s content and applications.

Keywords: Earthquake, Insurance, Damage Assessment, Damage Classification, Post-Earthquake Methodology

1. Introduction

Suramericana S.A. (SURA), founded in 1944, prides itself on being in the business of Risk and Trend Management and is considered one of the major players in the Insurance Industry in Latin America, with operations in nine countries of the region. As part of its strategy to maintain its relevance to its clients, and compromised with the seismic resilience of Latin America, SURA saw the need to develop an in-house methodology for the assessment of structural damage as a result of natural phenomena. The aim of the methodology is to diagnose and classify damage with engineering criteria and provide adequate intervention solutions in accordance with the observed structural and non-structural damage.

The first version of the methodology was developed between 2006 and 2008 and it has been applied to assess SURA's building stock damaged by natural disasters, such as the 2010 Maule, Chile earthquake and the 2017 Puebla, Mexico earthquake. The experiences of these events, along with the lessons learnt from earthquakes and other natural phenomena around the world that can cause structural and non-structural damage, have been used as feedback for the continuous improvement of the SURA Post-Event Structural Assessment Methodology.

This paper introduces the methodology and its application in the assessment of 2214 structures damaged in the 19 September 2017 M7.1 Puebla, Mexico earthquake. A statistical analysis of the building stock under study is presented as a result of this study.

2. SURA Post-Event Structural Assessment Methodology

The SURA Post-Event Structural Assessment Methodology establishes criteria and standard procedures for the inspection, diagnosis and damage classification of structures. It also provides guidance on the definition of intervention solutions and on the technical supervision of the repair, retrofit and reconstruction of structures affected by natural phenomena. This criteria and solutions are in accordance with the applicable construction codes and the state-of-the-art advances in structural engineering around the world [2].

2.1 Premises

The SURA Post-Event Structural Assessment Methodology has been developed under these premises:

The application of the methodology should be done by structural and geotechnical engineers to ensure a correct understanding of structural and geotechnical damage, in order to obtain trustworthy data.

The methodology establishes standard quantitative criteria, based on structural and seismic engineering knowledge, for the classification of damage in buildings affected by natural phenomena. This ensures a uniform and professional application of the methodology, resulting in diagnosis, damage classification, and intervention proposals built under a unified criterium.

The methodology allows for the application of special non-conventional procedures for structures whose occupation type or characteristics require specific vulnerability studies and special intervention design solutions.

2.2 Background

The 25 January 1999 magnitude 6.2 (Mw) earthquake in Armenia (Colombia) highlighted SURA's need to develop an inhouse methodology for a Post-Earthquake Structural Assessment of its insured assets. Even though SURA had a team of specialized structural engineers carrying out these assessments, a methodology that guaranteed homologation and unified criteria for the objective assessment of damaged structures was a necessity.

Several studies from around the world, such as those developed by FEMA (Federal Emergency Management Agency), NEHRP (National Earthquake Hazard Research Program) and AIS (Colombian Society of Earthquake Engineering), were considered for the development of the methodology, which initially focused only on earthquakes. The contribution of the SURA methodology was to accomplish a diagnosis and damage classification based on quantitative data. This provides an objective view of damage data that can be used to understand priorities and make decisions on the required interventions for damaged structures.

The methodology was first tested a few weeks after the 27 February 2010 magnitude 8.8 (Mw) earthquake in Maule (Chile), when a team of engineers from SURA and EAFIT University were sent to the affected areas to assess structural damage. Because of its dynamic nature, the methodology is updated with the lessons learnt from earthquakes around the world and with the scientific advances in structural and earthquake engineering.

The methodology was updated in 2019 so that it could be applied in the assessment of structures damaged by other natural phenomena such as floods, windstorms and hurricanes. Some of the recommendations found in the ATC-45 Field Manual: Safety Evaluation of Buildings after Windstorms and Floods [2], were considered in this update of the methodology [3].

SURA has trained external teams of structural engineering specialists all around Latin America to prepare them for the implementation of the methodology. In 2008, SURA had a network of 60 structural engineering specialists in Colombia. Today, SURA counts on a vast network of structural engineering specialists in Colombia, Chile, Mexico, United States of America, New Zealand, Panama, Dominican Republic and El Salvador which are trained to apply the methodology.

2.3 Damage Classification Procedure

In order to ensure an adequate treatment of damaged structures, the SURA Post-Event Structural Assessment Methodology defines the following phases:

2.3.1 Phase 0: Identification of areas affected by the event

A detailed analysis of the event is performed in order to understand its characteristics and to obtain a list of potentially affected clients. This first step allows for a strategic prioritization of the structures that need to be assessed and facilitates the assignment of engineers required for inspection in each of the affected zones.

2.3.2 Phase 1: Damage diagnosis and classification

The structural engineer in charge fills out a survey that requires a visual inspection of the structure and asks for the input of data regarding general building information, safety conditions for its occupants and habitability conditions. The results of this survey allow for the classification of damage into three categories:

Category 1 – Risk of collapse: buildings that collapsed or that have a high risk of collapse and should be immediately evacuated. Demolition and new construction are suggested for this category.

Category 2 – Minor damage: buildings with minor or conventional damage that does not require further vulnerability studies or design of special intervention solutions. The damage in these buildings can be classified easily and standard intervention procedures can be assigned for their repair. These repair measures have no impact on the structural performance of the building.

Category 3 – Special damage: buildings that cannot be classified in either of the first two categories. These buildings don't present and evident risk of collapse, but the observed damage could have serious implications in its structural performance. A more detailed inspection is required in order to quantify damage severity, the percentage of the building that is affected and habitability conditions. This second inspection is performed by a structural and geotechnical engineer (when required) and the structure is evaluated according to the following criteria: risk of collapse, risk of global instability, risk of local instability, differential settlement, risk due to damage of structural elements, risk due to damage of non-structural elements that can affect the building performance (e.g. non-structural walls and partitions) and risk due to geotechnical issues. For this category, further studies are required to define and design an adequate intervention. In some cases, damage can be irreparable or too costly so demolition and reconstruction may be recommended.

2.3.3 Phase 2: Assignment of intervention solutions for each building according to damage classification

In this phase, repair, retrofit or reconstruction methods are assigned to each building depending on the results of the damage assessment and classification. Where needed, more in depth studies for the analysis and design of solutions are performed by specialized engineering firms. The results of this phase vary depending on the needs of each structure and they can include:

- Recommendations and detailed drawings with repair procedures
- Structural analysis, design, and detailed structural drawings for structural retrofit
- Demolition and reconstruction recommendations for new structure if retrofit is not considered technically or economically viable

3. Application of the SURA Post-Event Methodology for the evaluation of structures damaged in the 19 September 2017 Puebla, Mexico Earthquake

The most important test of this methodology was during the assessment of structures belonging to SURA's clients, affected by the 19 September 2017 magnitude 7.1 (Mw) Puebla, Mexico earthquake. Many invaluable lessons were learnt during this experience, the main one being the importance of channeling efforts towards the seismic resilience of our region, aiming at the retrofit and reconstruction of buildings in accordance with the most recent engineering developments.

2114 structures were assessed during the implementation of the SURA Post-Event Structural Assessment Methodology in Mexico. Most of these structures were located in Mexico City, while a smaller portion were located in the states of Mexico, Morelos, Puebla and Tlaxcala. Fig. 1 presents the geographic distribution of the assessed structures.

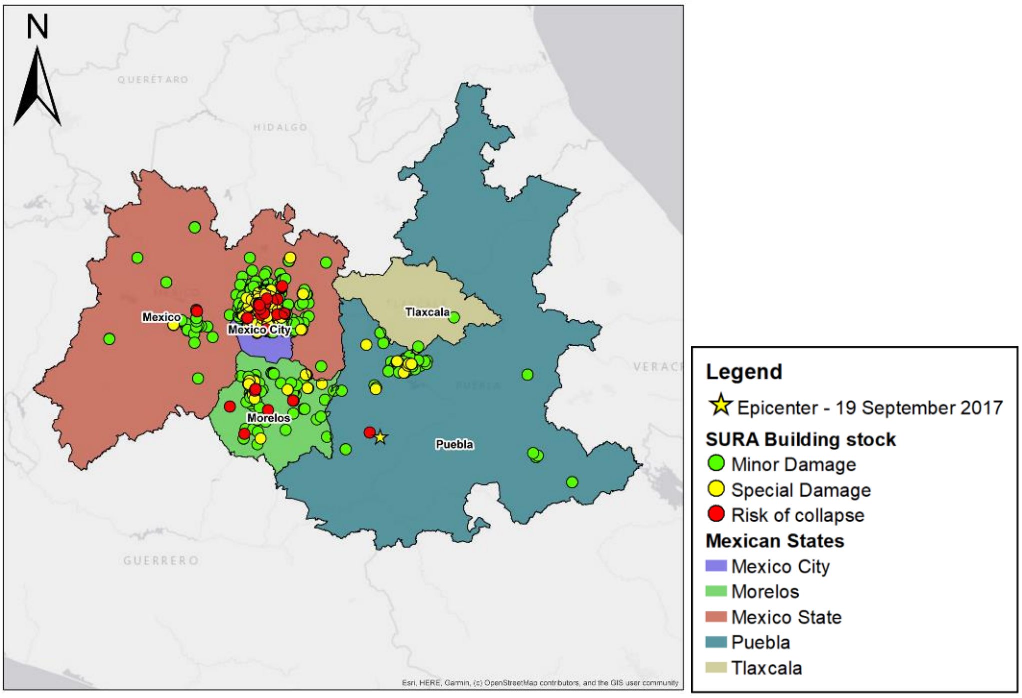
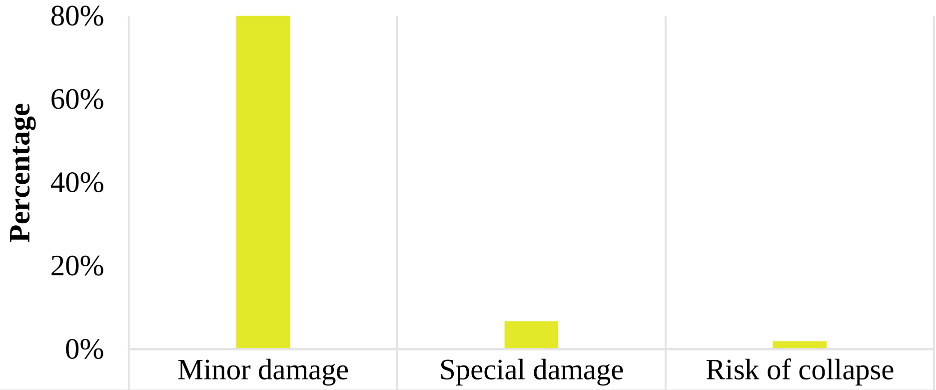


Fig. 1 – Location of structures assessed by SURA according to damage classification

3.1 Results according to damage classification

The results from the application of the SURA Post-Event Structural Assessment Methodology on 2214 structures show that 91% of the structures were categorized as having minor damage, 6.7% as special treatment structures, and 1.9% were classified as presenting risk of collapse. Fig. 2 shows the percentage of structures classified under each category.



	Minor damage	Special damage	Risk of collapse
Buildings (%)	91.1%	6.7%	1.9%
Total buildings	2016	151	47

Damage classification

Fig. 2 – Percentage of inspected buildings classified under each damage category

Fig. 3 shows the percentage of buildings classified in each damage category for three different structural materials. Of the assessed structures classified as having risk of collapse, 61% were masonry structures, while of those classified as having special damage 71% were reinforced concrete structures. Fig. 3 higlights the superior performance of steel structures, which presented no risk of collapse, and represented only 11% of those classified as having minor damage.

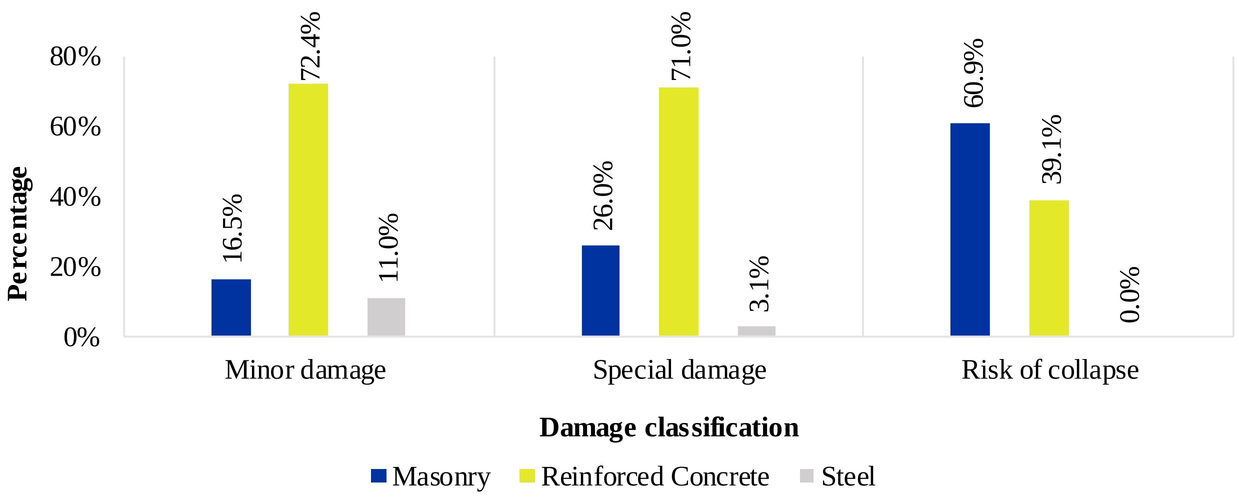
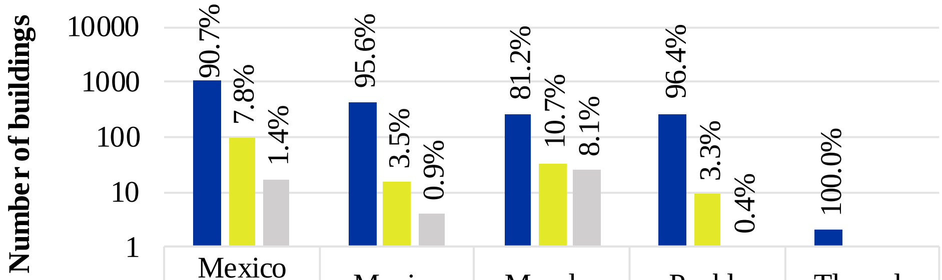


Fig. 3 – Damage classification of inspected building stock by structural material

Although most of the claims received were filed in Mexico City, Morelos was the state with the most structures that presented a high risk of collapse (see Fig. 4). An important part of these structures were constructed in adobe.



	Mexico City	Mexico	Morelos	Puebla	Tlaxcala
Minor damage	1088	412	250	264	2
Special damage	94	15	33	9	
Risk of collapse	17	4	25	1	

Mexican States

Fig. 4 – Damage classification of inspected building stock by state

3.2 Site effects in Mexico City

The influence of local geology and site conditions on ground motion intensity has been proven by many earthquakes around the world. Among the local site effects, the amplification associated with soil profile characteristics, which has the potential of modifying the intenisty, frequency content, and length of ground motions, was especialy important in this event.

Fig. 5 presents Mexico City's seismic zones, along with the distribution of buildings belonging to each damage state for two different data sets: Fig. 5a shows data for the structures insured and assessed by SURA for the 19 September 2017 event under the methodology being presented, while Fig. 5b shows data from official sources for structures damaged by the 19 September 1985 event.

(a)

(b)

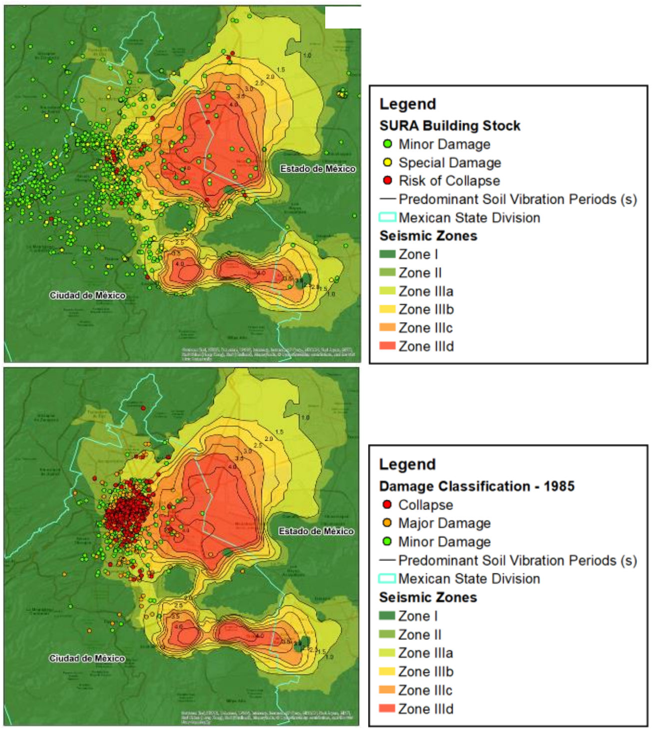


Fig. 5 – Damage distribution over Mexico City's seismic zones for (a) the 19 September 2017 event and (b) the 19 September 1985 event [4]

Fig. 5 shows that most of the structures assessed by SURA that were damaged by the 19 September 2017 earthquake in Mexico City were concentrated in zones I, II and IIIa, with 40% of collapses occurring in zone IIIa. For the 19 September 1985 earthquake, Zone IIIb presented the most structures classified in all damage levels.

When comparing the two events, most of the damage resulting from the 2017 event was primarily located in soils with a vibration period lower than 2.0 seconds, while in the 1985 event, damage was concentrated on soils with vibration periods between 1.0 and 3.0 seconds.

Of all the structures assessed by SURA in the six seismic zones shown above after the 2017 event, 92% were located in soils having periods of 2.0 seconds or less. Of these structures, 85% presented minor damage, 6% were classified as having special damage, and 1% were classified as having risk of collapse.

3.3 Damage classification by structural typology

Fig. 6 shows the percentage of buildings pertaining to each identified structural typology that were classified in each of the three damage categories. 35% of the structures classified as having risk of collapse were unreinforced masonry structures, while 22% where confined masonry structures. For the structures classified as having special damage, 51% were found to be reinforced concrete frames in two directions. Among the structures that presented good seismic performance, steel structures and shear wall reinforced concrete structures were in no case classified as having risk of collapse, and only 3% and 2.3%, respectively, were classified under the special damage category.

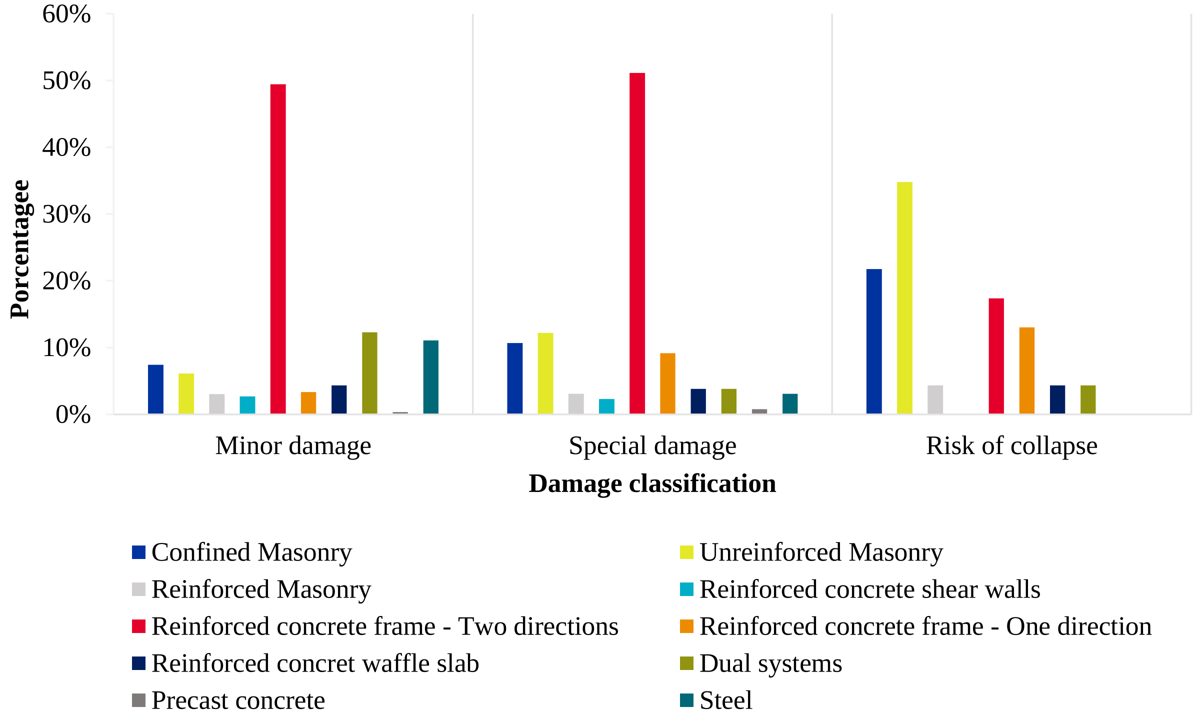
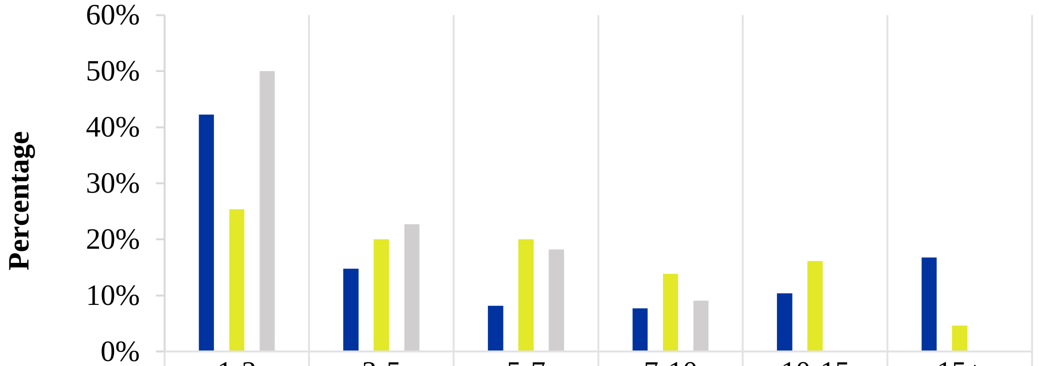


Fig. 6 – Damage classification of inspected building stock by structural typology.

3.4 Damage classification by number of stories

Of the inspected building stock, 57% had 5 stories or less, 17% had between 5 and 10 stories, and 26% had over 10 stories. Fig. 7 presents the percentage of buildings pertaining to each story range that were classified in each of the three damage categories. This shows that most of the damage was found in low-rise buildings (1-2 stories), which correspond to 42.3% of the buildings classified in minor damage, 25.4% of those classified in special damage, and 50% of those classified as collapse or having risk of collapse. None of the high-rise structures (10 or more stories) were classified as having risk of collapse.



	1-2	3-5	5-7	7-10	10-15	15+
Minor damage	42.3%	14.8%	8.1%	7.7%	10.4%	16.8%
Special damage	25.4%	20.0%	20.0%	13.8%	16.2%	4.6%
Risk of collapse	50.0%	22.7%	18.2%	9.1%	0.0%	0.0%

Story Range

Fig. 7 – Damage classification of inspected building stock by story range

Of the structures classified as having risk of collapse (see Fig. 8), 36% were unreinforced masonry structures, of which 23% were low-rise and 13% were mid-rise (3 to 5 stories). This same analysis was done for reinforced concrete frames, which represent 23% of the structures classified as having risk of collapse. Of these, 9% were low-rise structures, another 9% had 5 to 7 stories, and 5% had 7 to 10 stories.

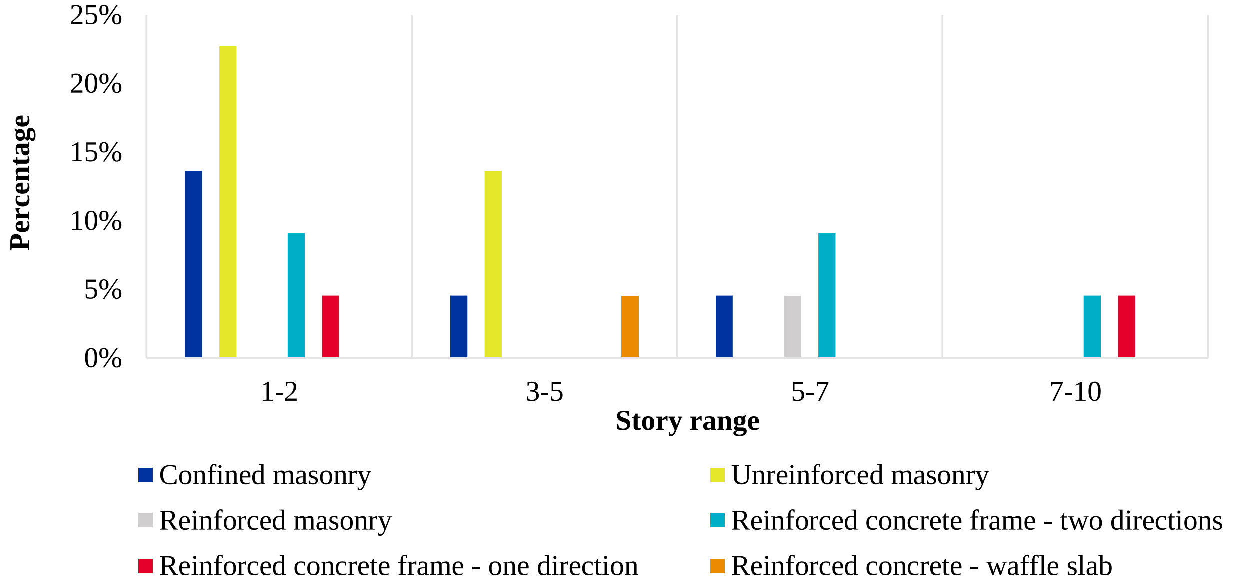
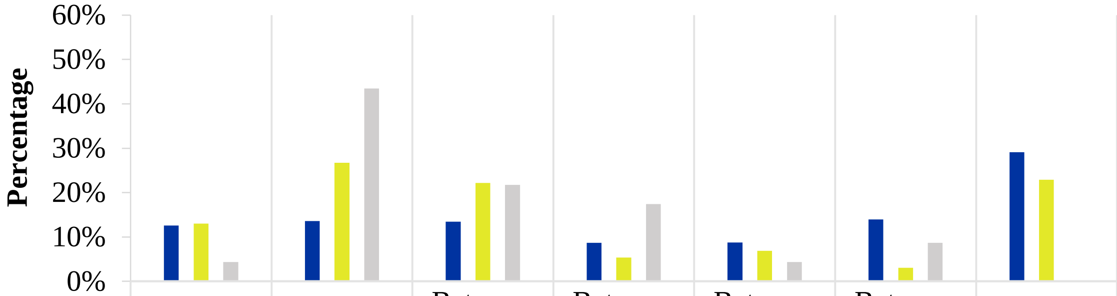


Fig. 8 – Inspected buildings classified with risk of collapse by structural typology and number of stories

3.5 Damage classification by year of construction

When crossing damage classification with year of construction, of all the structures classified as having risk of collapse, 43% corresponds to structures built before 1976. For buildings classified under special damage, 27% were built before 1976. 29% of buildings classified under minor damage were built after 2004 and this damage could be explained by an unfavorable interaction between structural and non-structural components (see Fig. 9).



	Unknown	Before 1976	Between 1977 & 1987	Between 1988 & 1993	Between 1994 & 1997	Between 1998 & 2004	After 2004
Minor damage	13%	14%	13%	9%	9%	14%	29%
Special damage	13%	27%	22%	5%	7%	3%	23%
Risk of collapse	4%	43%	22%	17%	4%	9%	0%

Year of construction

Fig. 9 – Damage classification of inspected building by year of construction

3.6 Damage classification by building use

Fig. 10 shows the percentage of buildings pertaining to each use that were classified in each of the three damage categories. The building use defined as "services", which include hotels, healthcare facilities, prisons, religious centers, restaurants and sports facilities, represent only 5% of the assessed building stock. However, it also corresponds to 30% of the structures classified under risk of collapse and 9% of the structures classified as having special damage. The commercial buildings, which make up 21% of the assessed building stock, represent 22% of the structures with special damage and 17% of those with risk of collapse.

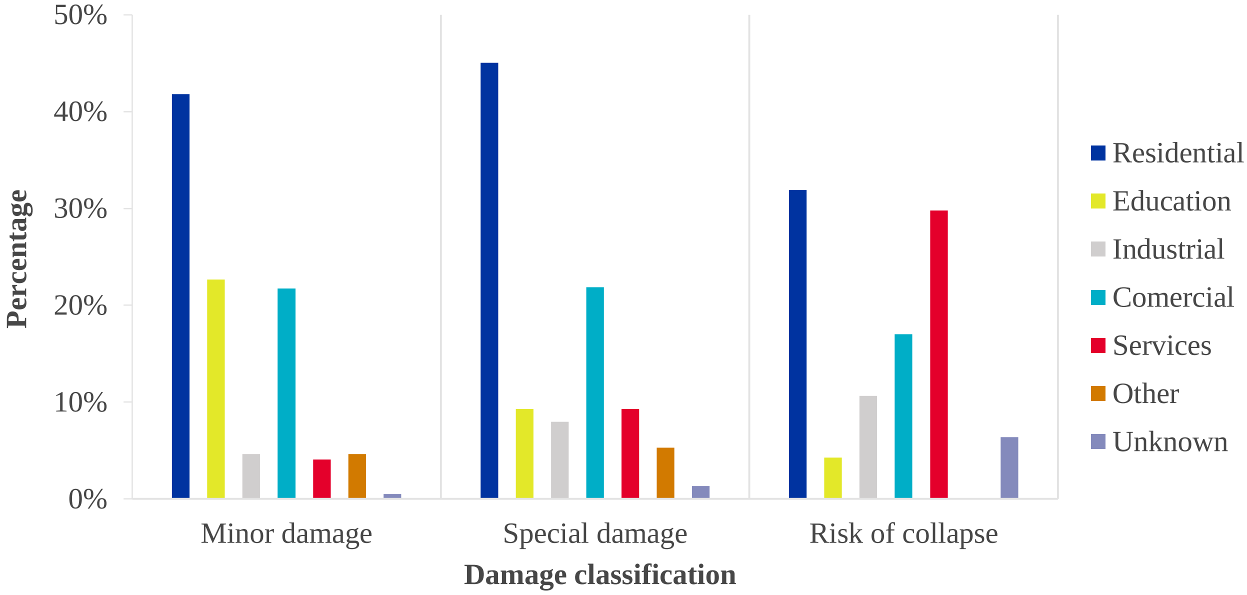
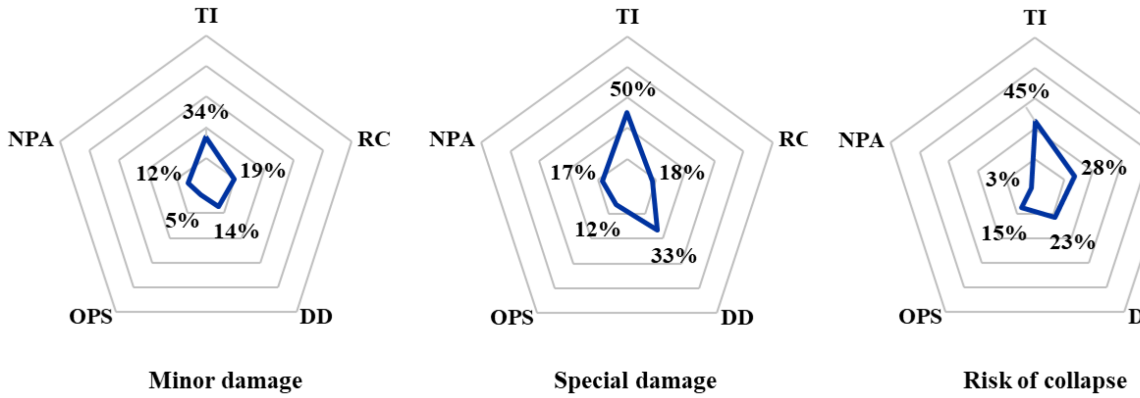


Fig. 10 – Damage classification of inspected buildings by use

3.7 Damage classification by presence of structural irregularities

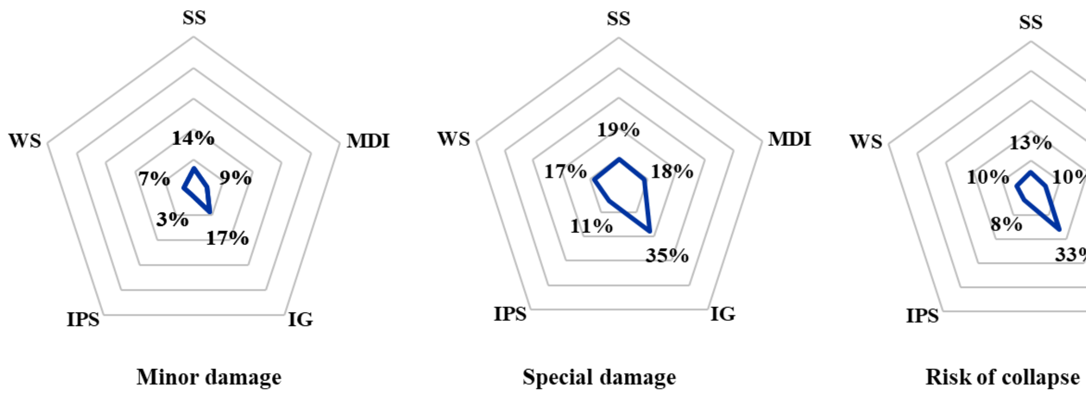
Structural irregularities in plan and height have been proven to have considerable effects on the seismic performance of a structure. Fig. 11 presents the distribution of irregularities in plan for each of the three damage classifications. Torsional irregularity is the most commonly observed in all three damage states, but its influence is predominant in structures presenting special damage and risk of collapse. Reentrant corners also influence seismic performance, with 28% of structures with risk of collapse presenting this irregularity, and a lower percentage seen in buildings with minor or special damage.



TI: Torsional Irregularity RC: Reentrant Corners DD: Diaphragm openings
OPS: Out-of plane setback NPS: Non-parallel systems

Note: The same building may have none, one or several plan irregularities
Fig. 11 – Damage classification by plan irregularities

Fig. 12 presents the distribution of irregularities in height for each of the three damage classifications. 35% of buildings having special damage and 33% of buildings having risk of collapse present geometric irregularities, which was the most observed. Soft story and weak story irregularities represent 23% of the structures having risk of collapse and 36% of structures classified as having special damage.



SS: Soft story MDI: Mass distribution irregularity IG: Irregular geometry
IPS: In-plane setback WS: Weak story

Note: The same building may have none, one or several height irregularities
Fig. 12 – Damage classification by height irregularities

4. Conclusions

SURA's Post-Event Structural Assessment Methodology was developed as part of SURA's compromise with the resilience of Latin America. It was applied in response to the 19 September 2017 Puebla, Mexico earthquake and it was essential for the adequate treatment of affected structures, becoming an effective mechanism for the support of SURA's clients.

The diagnosis and damage classification data resulting from the application of the methodology in Mexico highlight the fact that most of the damage was highly influenced by structural typology, configuration and site affects associated to building location. When analyzing damage among different structural typologies, the best structural performance was observed in reinforced concrete shear wall and dual structures, and in steel structures.

Out of all the structures that were classified as having risk of collapse, 35% were found to be unreinforced masonry structures, while 22% were found to be confined masonry structures. These two structural typologies had the most unfavorable structural performance and explains why low-rise structures were the most affected by the earthquake. Among the structures classified as having special damage, 51% were reinforced concrete frame buildings. Many of these reinforced concrete frame buildings had masonry infills which were highly damaged during the earthquake but in some cases, they were also seen to protect structural elements in highly flexible buildings.

When analyzing damage among different structural uses, 30% of the structures assessed by SURA that presented risk of collapse belonged to the “Service” use category. This use includes hotels, healthcare centers, religious centers, among other type of uses, which concentrate a considerable amount of people.

Structural irregularities in plan and height were seen to have considerable influence in the damage levels observed. Out of the building sample analyzed, a large percentage of buildings classified as having risk of collapse had torsional irregularities in plan, followed by reentrant corners y diaphragm discontinuities. The most common irregularities in height were geometric irregularities, followed by soft story and weak story.

The 19 September 2017 Mexico earthquake shows a positive influence of all the investigation efforts put into effect after the 1985 earthquake. The 2017 event highlighted the importance not only of site conditions but also of structural systems and their configuration on structural performance. The lessons learnt in this earthquake provided key feedback for the methodology and were important input for the repair and retrofit design decisions.

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