Statistical Analysis and Ground Motion Effects on Corner Buildings with Infill Walls Collapsed During the: September 19, 2017 Earthquake in Mexico

Bauhaus Summer School — NextGen 2025 Engineering Program

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Outline

- **Objective:** Vulnerability of corner buildings with infill walls (2017 Mexico City EQ)
- **Approach:** Data collection (ISCDF, digital/public sources)
- **Analysis:** Structural patterns, collapse factors (corner, Ts/T, openings, infills)
- **Seismic Analysis:** Spectral accelerations, SSI effects
- **Structural Assessment:** Asymmetry, torsion, irregularities, facade/infill influence
- **Modeling:** Regular vs. irregular 5-story buildings

Overview on the S19-17 Earthquake in Mexico

- **Event characteristics:**
  - Magnitude Mw = 7.1, depth 48 km
  - Struck between Puebla and Morelos
  - Most devastating intraplate earthquake in Mexico City's history
- **Impact:**
  - Ground motion damaged buildings near epicenter and in Mexico City (120 km away)
  - 44 collapsed buildings + many more with damage
- **Death toll:**
  - 369 total deaths (228 in Mexico City)
  - $>$ 7000 injuries

Overview on the S19-17 Earthquake in Mexico

Figure 1: S19-17 earthquake epicenter

Reasons for the Study

- **Statistical analysis conducted for two main reasons:**
  - Significant information available from ISCDF assessments
  - Mexico City serves as a real-scale laboratory with:
    - Wide variety of structures
    - Observable ground movement effects on buildings
- **Additional advantages:**
  - Extensive instrumentation network in damaged area
  - Well-documented particular geotechnical characteristics
- **High seismic activity due to:**
  - Interaction of five different tectonic plates
  - Most earthquakes from subduction on Pacific Coast:
    - Rivera and Cocos plates with North American plate
- **Unique seismic characteristics:**
  - Subducted oceanic plate generates deep earthquakes
  - Presents significant danger to central Mexico inhabitants

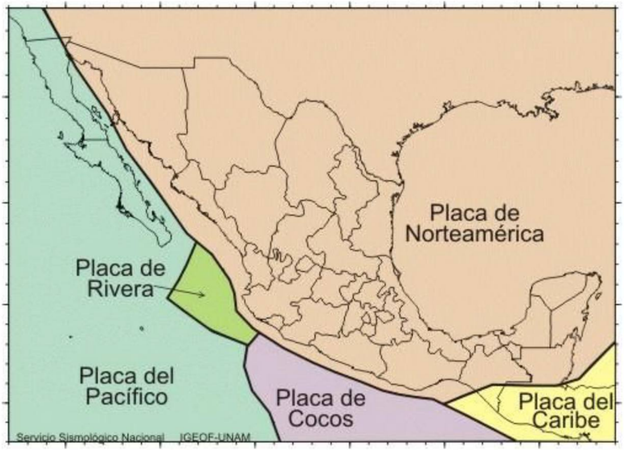
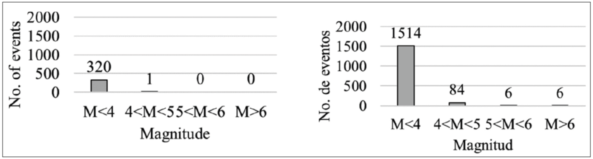
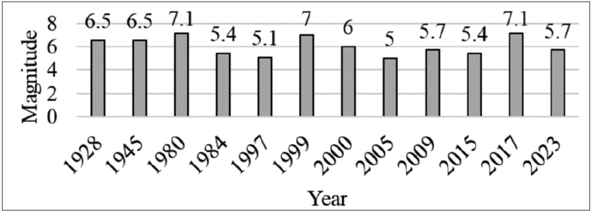


Figura 9. Placas tectónicas que interactúan en territorio mexicano.

Figure 2: Tectonic plate boundary for Mexico region



(a) Number of earthquakes in 2017 in Puebla & Morelos and Mexico City



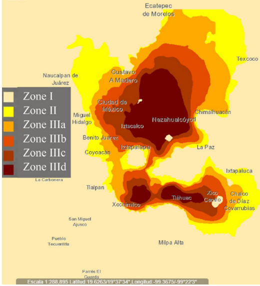
(b) Earthquakes with a magnitude greater than 5.0 in the states of Puebla and Morelos during 1928–2023

Figure 3: Comparison of earthquake activity in Puebla & Morelos vs. Mexico City

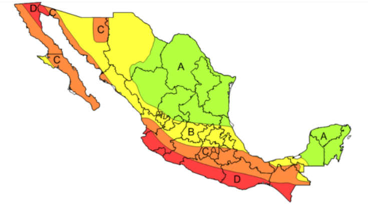
Effects of S19-17 Earthquake in Mexico City

- **Highest intensities recorded in:**
  - Mexico City, Puebla, Morelos, and Guerrero
  - Peak Ground Accelerations (PGA) up to 150 gal
- **Soil-dependent amplification:**
  - Firm soil: PGA range of 53–91 gal
  - Soft soil: PGA of 225 gal ($\approx 3\times$ amplification)
- **Soil characteristics:**
  - Soft soil:
    - Highly compressible and plastic lacustrine clay
    - Variable thickness deposits
  - Firm soil:
    - Primarily soft rock
    - Surrounds the city's compressible zones

Effects of S19-17 Earthquake in Mexico City



(a) Geotechnical zonation of Mexico City



(b) Seismic zonation of Mexico

Figure 4: Zonation of Mexico City and Mexico

The Geotechnical zonation in Code Regulations of Mexico City (NTC 2004) is defined in three zones:

- Zone I is formed by rocks or firm soils.
- Zone II (transition zone); lacustrine deposits not exceeding 20 m in depth.
- Zone III; highly compressible clay deposits up to 50 m deep.

Additionally, IIIa, IIIb, IIIc, and IIId, based on the depth of clay deposits.

Typical Corner Building Configuration

- Corner buildings usually have a seismic-resistant structure composed of reinforced concrete frames and asymmetrically positioned masonry infill walls in two perimetral frames.
- Windows and openings are located on their main facades for ventilation and lighting.
- In contrast, masonry infill walls on the rear perimetral frames delimit the building with neighboring properties.

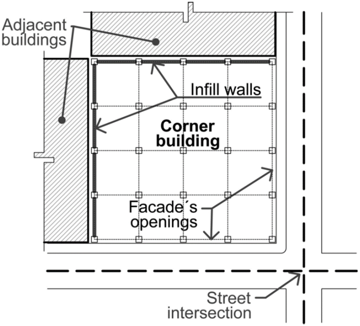


Figure 5: Typical Corner Building

Collapsed Corner Buildings (CCB)

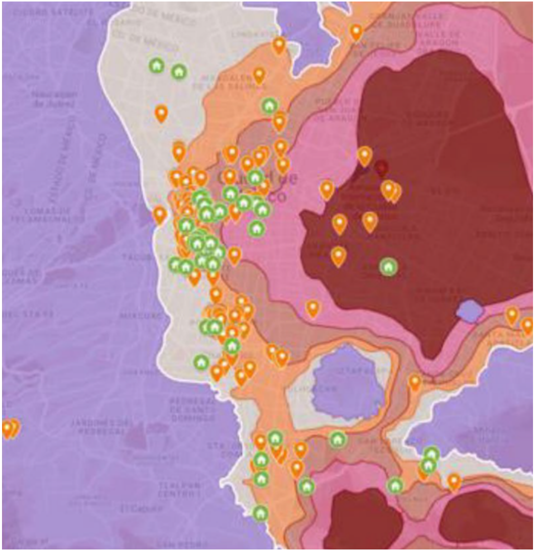


Figure 6: CCB. Green markers being CCB.

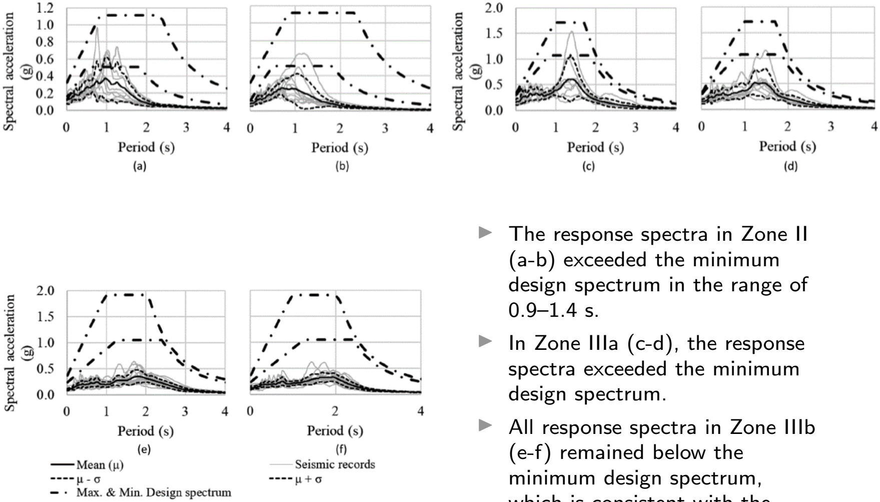


Figure 7: Response spectra analysis for different zones

- The response spectra in Zone II (a-b) exceeded the minimum design spectrum in the range of 0.9–1.4 s.
- In Zone IIIa (c-d), the response spectra exceeded the minimum design spectrum.
- All response spectra in Zone IIIb (e-f) remained below the minimum design spectrum, which is consistent with the limited collapses observed in this zone. SSI.

Current Code Vs. Older Regulations

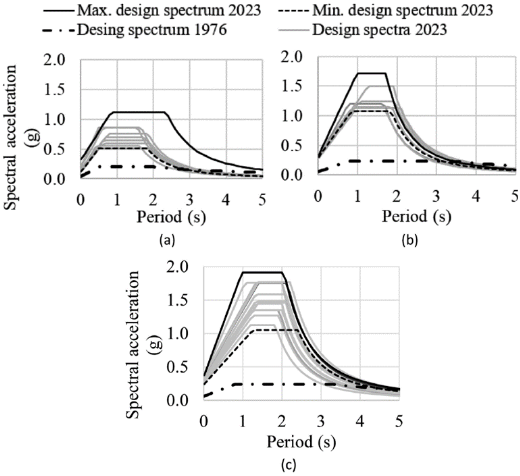


Figure 8: (a) Zone II, (b) Zone IIIa, (c) Zone IIIb

- Most of the damaged buildings were designed according to older codes, which have lower spectral amplitudes.
- 80% of the buildings severely damaged were constructed before 1985.
- 44 buildings collapsed; mostly in Zone II and Zone IIIa.

Corner Effect Characterization – Stiffness Ratio

- It's when buildings on corners have weak front facades (due to large windows/openings), making them less stiff compared to the rear walls. $\frac{\sum k_{\text{Front facade}}}{\sum k_{\text{Rear facade}}}$
- Most collapsed buildings had very low (≈ 0.1) stiffness in the front (sometimes 0%), making them vulnerable.

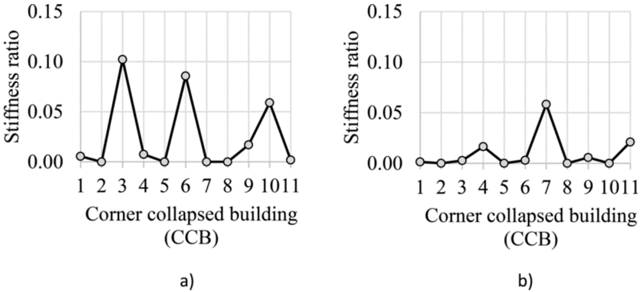


Figure 9: Stiffness ratio in CCB buildings: a Longitudinal direction; b transverse direction

Corner Effect Characterization – Opening Ratio

$$\frac{\text{Total Area of Openings}}{\text{Area of Both Front Facades}} = \frac{\sum A_i}{(b_1 + b_2)h}$$

- **Null**: $r = 0$ (no effect)
- **Low**: $r \leq 0.25$
- **Moderate**: $0.25 < r \leq 0.60$
- **Intense**: $r > 0.60$

Most collapsed corner buildings (8/11) had moderate to intense corner effect — meaning their front walls had large openings and less strength.

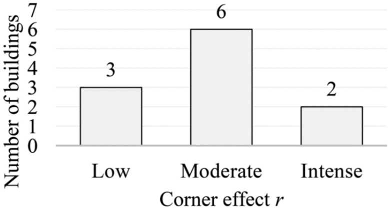


Figure 10: Stiffness ratio in CCB buildings: a Longitudinal direction; b Transverse direction

Corner Effect Characterization – Pounding

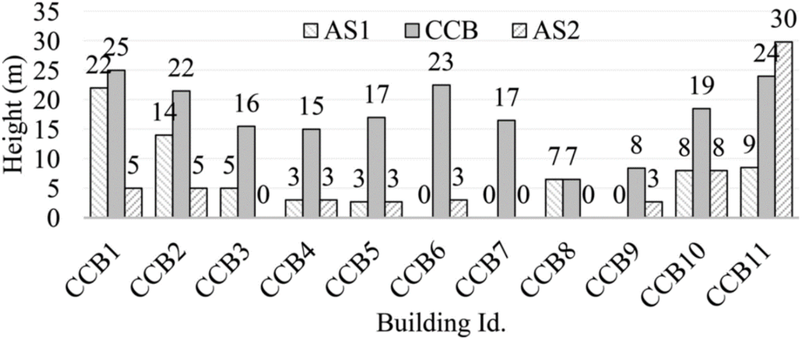


Figure 11: Height of collapsed corner buildings (CCB) and building height of the adjacent structures (AS1 and AS2)

Ts/T Ratio & Seismic Amplification

- **Ts** = dominant period of the seismic shaking
- **T** = fundamental period of the building
- Many collapsed buildings (especially in Zone IIIa) had Ts/T ratios close to 1, suggesting strong amplification.
- For example:
  - CCB5 at 2.56 and 1.34 km had Ts/T = 0.77 and 0.72, respectively.
  - CCB1 at 2.13 km had Ts/T = 0.90.

These **Ts/T ratios** and the **proximity to the two seismic stations** suggest that the buildings must have experienced relevant seismic amplification.

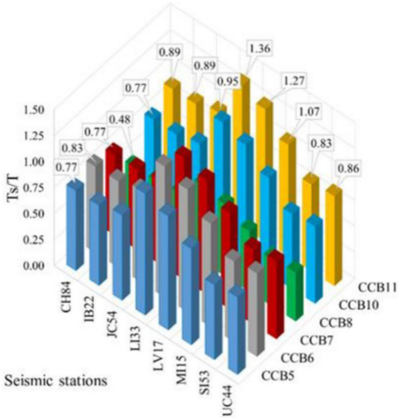


Figure 12: Stiffness ratio in CCB buildings: a Longitudinal direction; b Transverse direction

Ts/T Ratio & Seismic Amplification

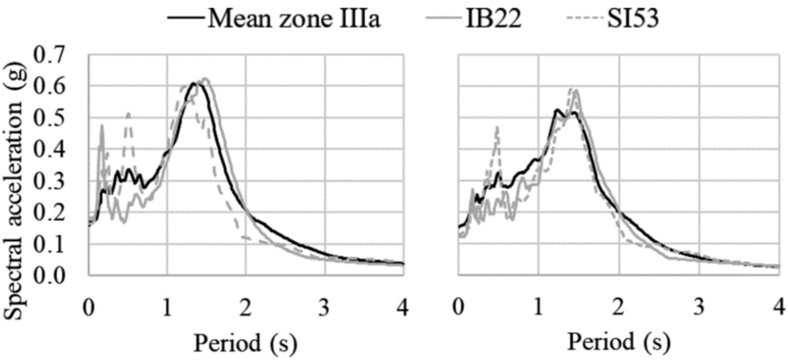


Figure 13: Response spectrum for IB22 and SI53 records, and mean value from the records in Zone IIIa. a E-W; b N-S

Figure 13 shows that the IB22 and SI53 spectra are similar, with maximum amplitudes and dominant periods in the range of 1.2–1.5 s. Buildings CCB1 (≈ 1.30 s) and CCB5 (≈ 1.0 s) fall within high-intensity spectral regions.

Case Study – 5-story Buildings - Inter-Story Drift Ratios

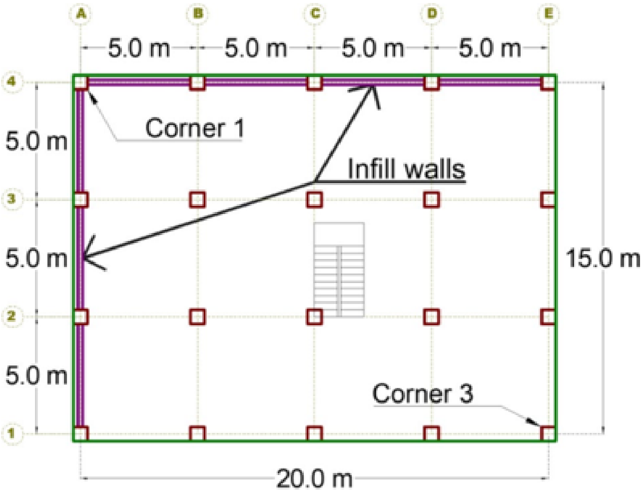


Figure 14: Case study of a five-story RC building. a Irregular building; b regular building

Case Study – 5-story Buildings - Inter-Story Drift Ratios

- C3 exhibited larger inter-story drift ratios compared to C1 due to the effect of walls.
- The maximum inter-story drift ratio in C3 exceeded the limit state of extensive damage.

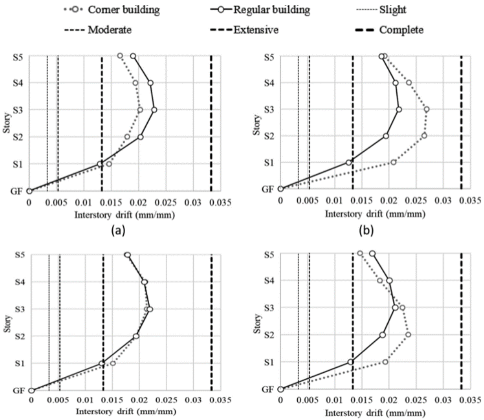


Figure 15: Drift ratio demands in regular and corner buildings subjected to CH84 in the x-direction and MI15 in the y-direction. (a) C1 - X; (b) C3 - X; (c) C1 - Y; (d) C3 - Y.

Conclusions

- The seismic amplification effects on the soft soils in Mexico City significantly contributed to structural damage in corner buildings. The most affected buildings were concentrated in soft (Zone III) and transition (Zone II) soils.
- The statistical analysis revealed that the concentration of collapses in Zone IIIa of Mexico City was primarily due Ts/T.
- The response spectra from the S19-17 were generally lower than the current design spectrum. Still, they exceeded the design spectra from the 1976 regulations, which were used to design most of the damaged buildings.

Conclusions (Cont.)

- Damage in corner buildings. The structural configuration significantly influenced the building's damages. Over half of the collapsed buildings exhibited soft-story, torsion, or a combination of both configurations.
- Connecting infill walls to columns in corner buildings significantly increases the risk of collapse or severe damage during earthquakes.
- Corner buildings with infill walls next to low-rise structures were all collapsed corner buildings had adjacent buildings of lesser height.

Conclusions (Cont.)

- Based on nonlinear analyses, if the building had been designed fully compliant with the regulations in the 1970s, the expected damage would have exceeded the threshold for extensive damage and come very close to the collapse limit state.

Thank you for your attention!

Any questions?