GIS Graduate Student Final Project Report

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Geographic Information Systems Applications – Dr. Atsushi Nara

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Project Background

National City was established in 1887, making it the second oldest city in San Diego County. Many buildings were built before modern seismic building codes were adopted. Seismic provisions began to be implemented after the 1971 San Fernando earthquake. Significant Uniform Building Code (UBC) updates were later seen after the 1989 Loma Prieta earthquake (Legal Clarity, 2024). National City lies in proximity to active fault lines. The Rose Canyon fault line on the coast and beneath downtown, and the eastern La Nacion fault line. As a result, many homes in National City face a greater risk in the event of an earthquake. Certain building types are particularly vulnerable to earthquake damage, including cripple wall buildings, unreinforced masonry structures, soft-story buildings, older concrete buildings, and buildings with crawl space and raised foundations. However, these structures can be made safer through seismic retrofitting, which can be done through programs like the California Earthquake Authority's Brace & Bolt (CEA BB) program. Apart from its structural vulnerability, National City has an economically vulnerable population. One of the most pressing socioeconomic challenges facing National City is its low median household income, reported at $51,735 in 2021. 63.5% of National City's 18,541 housing units are renter-occupied (SD County, 29). Retrofitting older housing is costly and provides financial barriers to renters who do not qualify for the same retrofitting programs homeowners do. Renters living in older housing are in a more vulnerable state when it comes to preparing for natural hazards. National City has partnered with the Sage Project, a program within the Center for Regional Sustainability at San Diego State University (SDSU), to combat these challenges. They establish multiple partnerships within the San Diego community for SDSU students to apply their class skills to issues impacting the community.

Problem Statement / Objectives

Our objective is to comprehensively assess the building types in National City to identify the structures most vulnerable to earthquake damage. Our assessment focuses on residential structures built before 1980. Our teams were tasked with determining the structural material and the number of stories of each building. Identifying this criterion would give us a glimpse into a parcel's vulnerability based on infrastructure, listing potential trends. Weighted analysis would focus on slope percentage, distance from the fault line, and soil type. These three data sources would allow us to see areas vulnerable to liquefaction during seismic events.

Data Sources

Dr. Atsushi Nara provided our residential parcel layer, which was retrieved from the San Diego County Assessor (SDARCC.com). All parcels shown on the "Parcels25_NC_work" layer are parcels built before 1980. Each parcel listed its building age, making it easier to fill out information on structure type using the flow chart provided by the SDSU engineering department.

The United States Geological Survey (USGS) provided the California Fault Lines feature layer, containing information on fault lines associated with folds in the United States that demonstrate a history of seismic activity over the past 1.6 million years.

The soil layer was retrieved from the United States Department of Agriculture (USDA) Web Soil Survey. The area of interest was set to San Diego County and was downloaded as a ZIP file to be extracted into ArcGIS Pro. The Map Unit Legend pictured to the left of the soil map clarified the acronyms' meanings and the soil content found in each listed soil type.

A high-resolution Digital Elevation Model was downloaded from the USGS ScienceBase Catalog, offering a spatial resolution of 1 meter suitable for building-level topographic analysis. Although LiDAR data was initially considered, it was deemed unsuitable for slope modeling in this context because it includes surface features such as trees and buildings, rather than representing the bare-earth terrain needed for accurate slope evaluation.
The DEM was imported into ArcGIS Pro, where it was clipped to the National City boundary using the Extract by Mask tool to isolate the study area. Following this, the Slope tool in the Spatial Analyst toolbox was applied, with the output configured to percent rise (rather than degrees), which is more directly relevant to structural and engineering risk modeling. The result was a raster dataset expressing slope values at each cell within the study area, forming the basis for further parcel-level aggregation.

The Liquefaction Potential feature layer data set was retrieved from the San Diego Association of Governments (SANDAG) Regional Data Warehouse. This feature layer is composed of polygons of areas with potential for liquefaction in San Diego County, last update being December 11, 2024 (Geo SANDAG). The dataset is a combination of existing liquefaction areas provided by local maps, the National Earthquake Hazards Reduction Program (NEHRP), which rates soils from hard to soft, and known hydric soils from the USDA Soil Survey to identify the potential areas where liquefaction may occur.

We were given a flow chart provided by the SDSU Engineering Team that was used to assist us in identifying the building material based on its building age. First, we analyzed whether the building was used for residential or non-residential purposes. Next, we identified the number of stories in the building. The team was provided visual examples of each structure material at Step 3 to better understand what the parcels were observed.

Methods

The study area was within the National City Boundary line, consisting of only residential parcels built before 1980. These parcels were subdivided into ten sections, each assigned to a group project member (Appendix, Figure 1). Each student was responsible for analyzing and annotating between 500 and 800 parcels in the parcel layer. We used an ArcGIS Online group to retrieve the feature layer “Parcels25_NC_work” and utilized ArcGIS Pro to make our edits and analysis. For each parcel, we identified the building’s structure, the number of stories, and the presence of a crawl space. We determined the building’s structure using the flow chart that SDSU’s engineering team provided. To identify crawl spaces, we looked for vents, raised foundations, access panels, and steps or ramps up to the front door. We examined each parcel using Google Street View by looking at the physical characteristics of the building. We referenced realtor sites such as Redfin, Zillow, and Realtor.com to retrieve additional information on the building if available. A note field was created to report potential errors that we faced, including instances of incorrect building age found on the parcel layer.

To see which parcels fell in the liquefaction risk zones, we overlaid the liquefaction risk zone layer with our “Parcels25_NC_work” layer. We created a new field labelled “In_liquefaction”. This is a binary field where 0 corresponds to not in the risk zone and 1 corresponds to yes in the risk zone. Using the Select By Location Tool, our target layer was “Parcels25_NC_work,” and our source layer was the Liquefaction Risk Zone. These selected parcels intersected with the liquefaction layer. To assign the values in the binary field, we calculated the field In_liquefaction=1, switched the selected parcels, and calculated the field In_liquefaction=0. The output is a map of parcels annotated 1 to be structures located in the liquefaction risk area (Appendix, Figure 2).

We calculated the shortest distance from each parcel to the nearest fault line to incorporate fault proximity into our earthquake vulnerability analysis. First, we created new fields on the “Parcels25_NC_work” attribute table and labeled them “Near_Dist” and “Norm_Dist”. Using the Near Spatial Analyst tool, we derived the shortest straight line distance from each parcel to the closest fault line, La Nacion or Rose Canyon Fault. Once we had our near-distance measurements, we standardized the values from 0 to 1 using the following script: (!NEAR_DIST! - min_value) / (max_value - min_value), where 0 corresponds to closer values and 1 corresponds to farther values. Finally, we used the script to eliminate null values with an output of -1: (None if !NEAR_DIST! == -1 else !NEAR_DIST! / max_value) (Appendix, Figure 3).

Soil type plays a significant role in the success of structures that remain standing during and after natural hazards (earthquakes and flooding). We identified the soil types present throughout National City. Sand, silt, and clay are the three basic classifications, and a combination of these three produces different bases. We overlaid our soil layer with our “Parcels25_NC_work” layer and combined soil types by grouping soil as “Not Ideal” and “Ideal” (Appendix, Figure 4).
The soils grouped as the “Not-Ideal” soils were Made Land (Md), Olivenhain-Urban land complex (OkE), Terrace Escapements (TeF), Urban Land (Ur), Linne clay loam 30-50 percent slopes (LsF), Huerhuero loam 9 to 15 percent slopes (eroded) (HrD2), Huerhuero loam 15 to 30 percent slopes (eroded) (HrE2), and Gaviota fine sandy loam 9 to 30 percent slopes (GaE). Soils grouped as “Ideal” were Salinas clay loam 0 to 2 percent slopes, Huerhuero-Urban land complex 2 to 9 percent slopes, Huerhuero-Urban land complex 9 to 30 percent slopes, Olivenhain cobbly loam 9 to 30 percent slopes, Linne clay loam 9 to 30 percent slopes, and Chino silt loam saline 0 to 2 percent slopes.

The slope gradient impacts the ground motion amplification and potential for soil movement. Gravity, shaking, and weak ground can result in landslides, sliding foundations, or building collapses where hills are present in National City. Identifying and assessing slope exposure is one of the initial steps to determining the structural resilience of residential buildings in seismic vulnerable zones. We used the Zonal Statistics tool, with the National City’s building footprints as the zone-layer and slope as the value raster to calculate the mean slope per building. The mean slope values ranged from 0-50% and were visualized in five classified categories (Appendix, Figure 5). The mean slope values were normalized to a 0-1 scale suitable for the weighted analysis.

The DEM was clipped to the National City boundary using the Extract by Mask tool to prepare the slope raster for parcel analysis. Then, the slope tool within the Spatial Analyst toolbox in ArcGIS Pro was run with the option to calculate slope as percent rise, which is best suited for our vulnerability analysis. Since LiDAR-based DEMs usually consist of surface features such as buildings and vegetation, a bare-earth DEM was employed to obtain the proper slope values of the ground itself. Once the slope raster was created, the Zonal Statistics as Table tool was run with the pre-1980 building footprints as the zone layer. This assigned the slope values to each building's footprint and provided the average slope per parcel. The relevant statistics table was joined to the parcel polygon layer on the OBJECTID field so that slope data could be added directly to each parcel.

To allow for easier map reading and additional classification, we added a new attribute field breaking up slope values into five ranges: 0–10% (white), 10–20% (light yellow), 20–30% (orange), 30–40% (pink), and 40–50% (dark red). The layer was symbolized using graduated color symbology, with more steeply sloping areas in warmer colors.

The slope exposure map (Appendix, Figure 5) was exported from layout view with a legend, scale bar, and title for inclusion in the report. A pie chart was also generated from attribute statistics to show the proportion of parcels in each slope class, emphasizing areas of high terrain-related seismic vulnerability.

We conducted a Weighted Linear Combination (WLC) for our final analysis. We determined that the three key geophysical factors for our final analysis were fault proximity, soil type, and slope. The residential parcel layer was also used. We used the following script to derive our earthquake vulnerability composite scores: (!NormSlope! * .33 + !soil class! * .33 + (1- !Norm_Dist!) * .33). Each factor was normalized from a scale of 0-1 and given equal weights of .33. Once the composite scores were calculated, we converted them into percentages to make it easier to interpret and compare across parcels, with higher percentages indicating greater vulnerability (Appendix, Figure 6).

Results

Inspecting 5,131 pre-1980 parcels revealed key geophysical hazard characteristics and structure type differences throughout National City. The overwhelming proportion consisted of wood-frame buildings (98.9%), with minimal contribution from other buildings, including manufactured homes (0.4%), reinforced masonry (0.2%), and concrete (0.1%). There were no steel or unreinforced masonry buildings. The most prevalent building height was one story (4,169 parcels), and the second most prevalent was two- to three-story buildings (962), with few taller buildings (Appendix, Figure 8). Importantly, 2,817 buildings were found to have crawl spaces, a structural characteristic well documented to increase hazard through foundation instability when earthquakes strike.

In terms of terrain, the slope analysis (Appendix, Figure 5, Appendix, Figure 10) revealed that the overwhelming majority of residential parcels (over 80%) are situated on relatively flat land (0–10% slope). However, a significant proportion of buildings (~15%) were in the 10–20% category, and small but notable concentrations were present in steep terrain at over 20% slope. The parcels with high slopes were spatially concentrated in the eastern and southeastern parts of the city. They are of specific interest because of their collective hazard to ground failure during seismic activity.

A Weighted Linear Combination model was employed to integrate slope, soil, and seismic proximity into a single vulnerability score. The final scores were the result of these three normalized geophysical inputs and were used to classify parcels into five percentage-based risk groups. These vulnerability percentages ranged from 4.82% to 95.84%, with most parcels falling between 24% and 59% (Figure 6). The parcels most at risk, those in the higher ranges of scores greater than 58%, are grouped in various clusters. The high-risk zones match up with zones of increased terrain slope, poorer soil conditions, and proximity to active faults, especially in the northeastern and southeastern parts of the city. These zones were frequently found in HrE2 and TeF soil and known liquefaction areas. The spatial overlap of risk factors suggests potential hotspots for seismic-induced structural damage. In contrast, lower-risk parcels are found near the western city boundary, particularly along the waterfront and flat, inland housing areas. Here, the slope is frequently near zero. Also, the soil tends to be more stable, and fault lines are relatively distant.
The final vulnerability map may be employed for sound proactive measures to mitigate seismic related hazards in National City, particularly for building structures.

Discussion

This project aimed to identify residential parcels in National City vulnerable to seismic impact. The civil engineering professors at San Diego State University suggested using correct semantics in our presentations, specifically knowing when to use the words “risk” and “vulnerability” appropriately. Seismic risk is the probability that loss or damage will be inflicted on the built environment if seismic events occur (Wang, Z). Earthquake vulnerability refers to the susceptibility of a building to be impacted by an earthquake and is determined by factors such as soil type.

As a result, our analysis looks at earthquake vulnerability rather than earthquake “risk.” We plan to edit the terminology for all our figures and maps for the final Sage Project report. The earthquake vulnerability scores were determined by a composite score based on three geophysical factors: fault proximity, soil type, and mean slope. It was brought to our attention that fault proximity is not a significant factor in determining earthquake vulnerability. Thus, we plan to look into other geophysical factors that play a larger role. To ensure our soil type layer is fit for seismic vulnerability analysis, a future change would be to use seismic soil grades over the US Department of Agriculture’s soil grading system for our research. USGS soil data provides us with more relevant data when determining the seismic vulnerability of parcels.

Our decision to apply equal weights to our WLC analysis resulted in a broad overview analysis that does not truly reflect real-world conditions. In reality, not all geophysical factors impact earthquake vulnerability similarly. Some factors might play a more significant role in how a building reacts in a seismic event and thus should be weighted differently. Future analysis will incorporate realistic weight distributions that can give us a better direction of what areas in National City should be prioritized for future planning. The amount of the weighting will depend on scientific studies and expert knowledge.

The original residential parcel data provided us with the building age. However, issues with recording accurate data through our visual surveys arose as some parcels were hidden due to homeowners' requests for privacy or were obstructed by vegetation. Identifying crawl spaces was particularly difficult for these reasons. Suggestions for refining the accuracy of our results revolve around using different data sources, analyzing more parcel components, and refining results with experts. More field work is suggested to ground truth our data by verifying the building structure in person to ensure more accurate findings.

Future research on vulnerability in National City parcels will benefit from including crawl spaces. Crawl spaces provide spaces dedicated to plumbing, HVAC, electrical wiring, and other utilities that are easily accessible for repairs and maintenance. Houses with crawl spaces are more vulnerable to the housing foundation due to their susceptibility to weakened wood and insufficient support (LRE Foundation Repair).

Conclusion

As part of the SAGE project, this assessment evaluated the seismic vulnerability of pre-1980 buildings in National City. The analysis combined building types and structures with local slope, soil type, and proximity to active faults. Based on these factors, the results include a weighted vulnerability map identifying the most vulnerable zones in National City, CA.
Most buildings are single or double story wood frames on a rather flat surface. Nevertheless, the analysis identified numerous buildings in seismically highly vulnerable locations or hotspots. Some of the neighborhoods in the northeast and southeast sections of the city are notable for their slopes, hazardous soil type, and relative proximity to fault lines. Crawl spaces were also common, particularly in mid-century dwellings, introducing additional structural weakness.
The combined vulnerability assessment's outcome should urge local decision makers to focus on areas where the different risk factors overlap, as shown in Figure 6, Weighted Earthquake Vulnerability Percentages in National City. Buildings in these areas will benefit most from structural retrofitting. These neighborhoods should also consider public policy updates, increase preparedness among the population, and raise general awareness. Future analyses may improve the assessment by using seismic modeling, soil classification, verified crawlspace data, geological features to estimate the influence of fault proximity, and a more sophisticated model to determine factor weights.

Acknowledgements

We would like to acknowledge the many team members and classmates who have contributed to this analysis.

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Lastly, we also wish to express our gratitude to the Sage Project, led by Dr. Jessica Barlow, for providing SDSU students with this opportunity to apply their skills to uplift San Diego communities.

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"What Causes Crawl Space Damage?" *LRE Foundation Repair, LLC*, www.lrefoundationrepair.com/crawl-space-repair/what-causes-crawl-space-damage.html.

Appendix

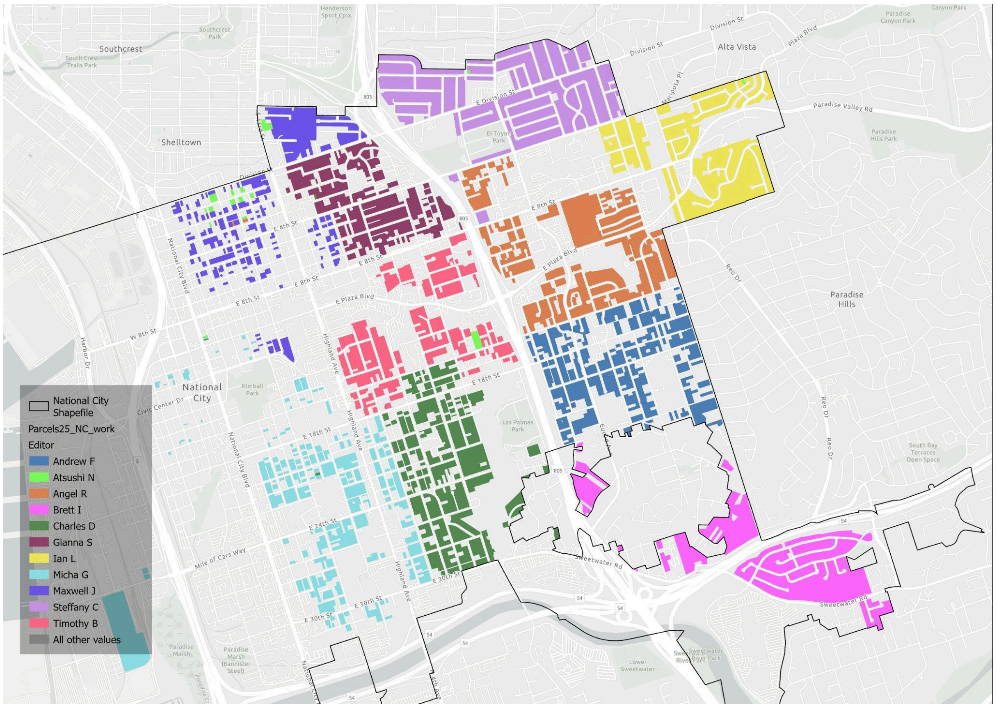

Figure 1. *National City Building Parcels*

Figure 2. *National City Liquefaction Zones*

Figure 3. *National City Proximity to Fault*

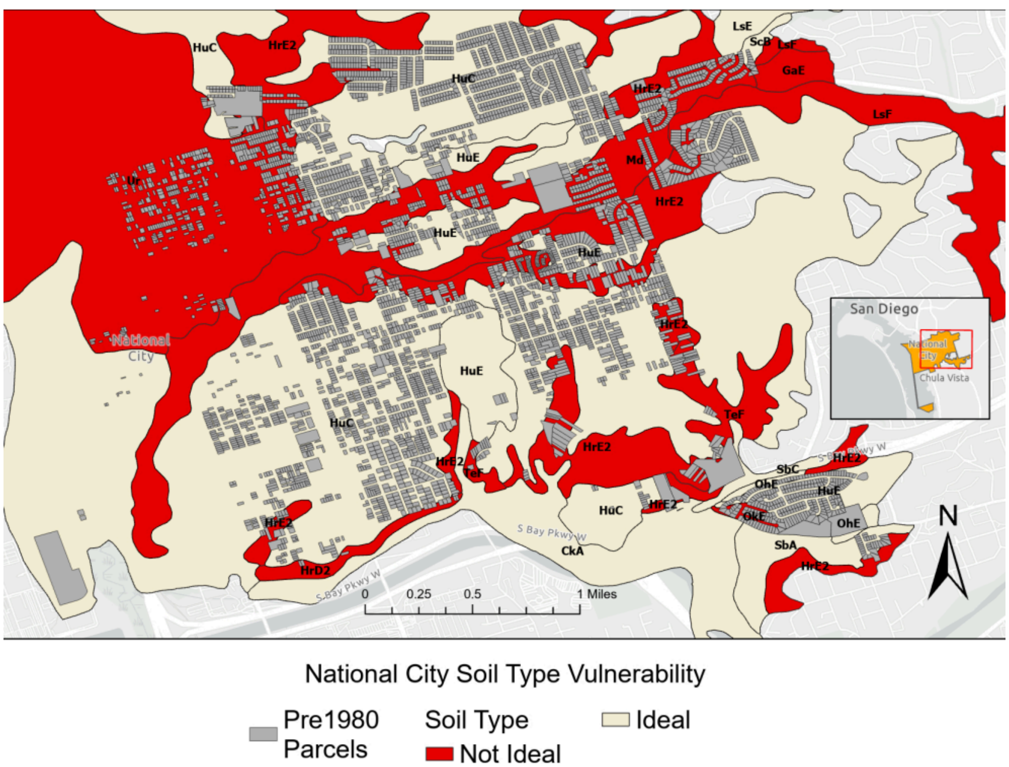

Figure 4. *National City Soil Types Vulnerability Areas*

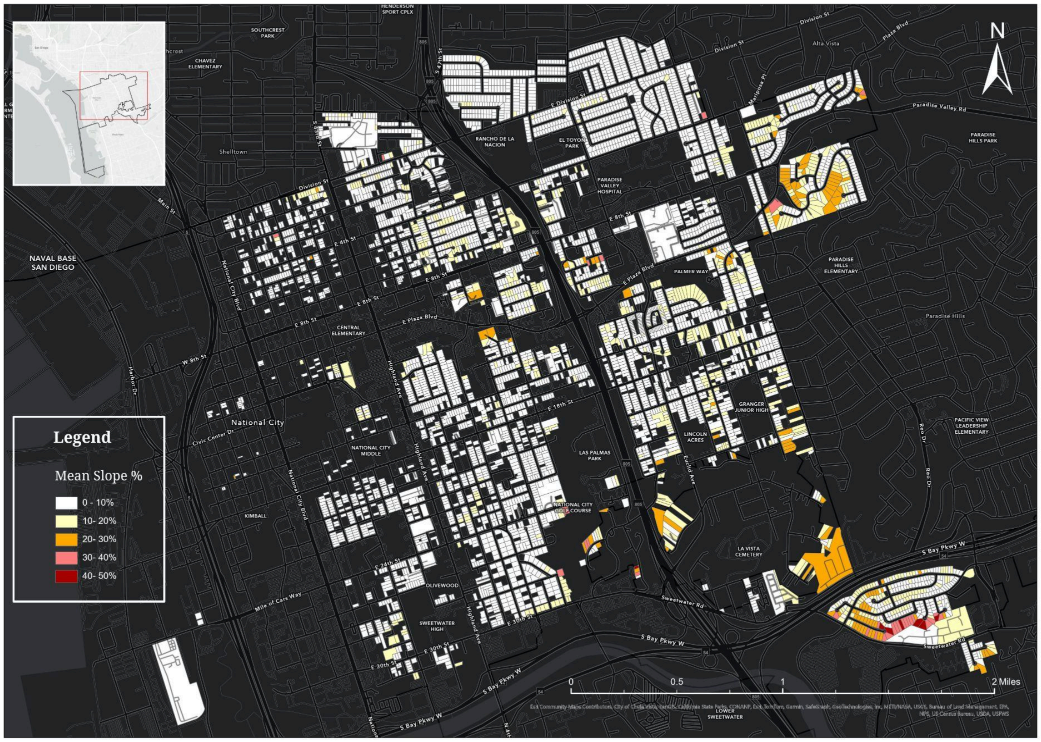

Figure 5: *National City Slope per Building*

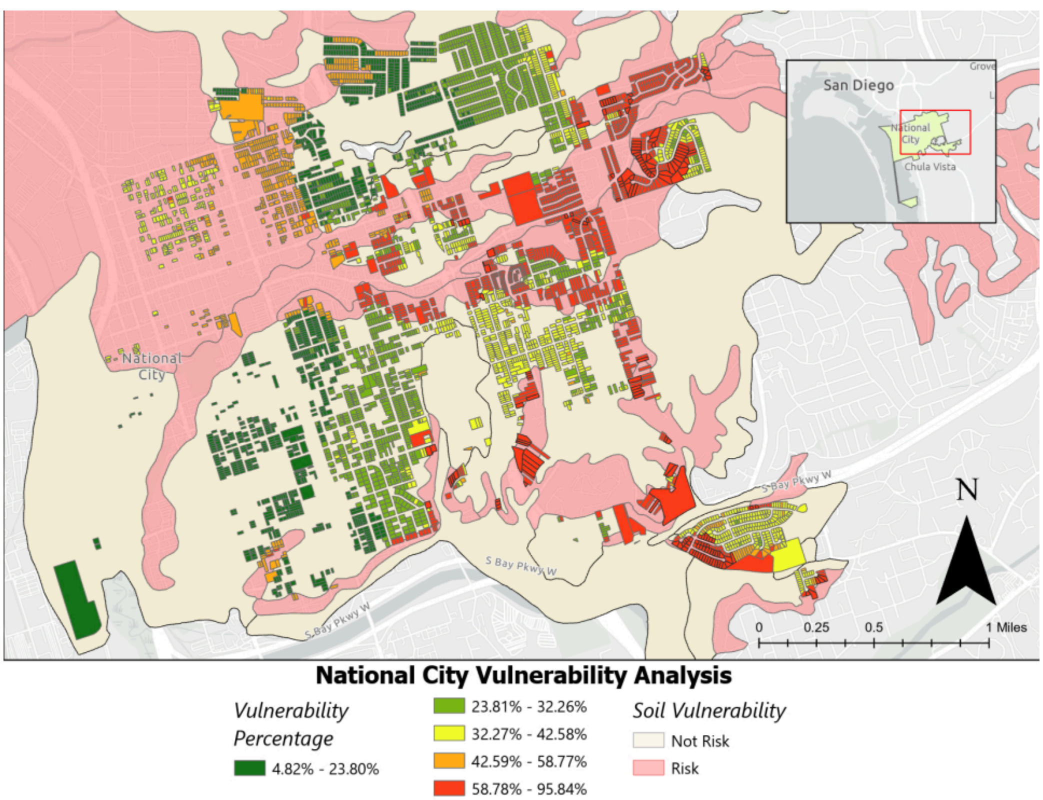

Figure 6. *Weighted Earthquake Vulnerability Percentages in National City*

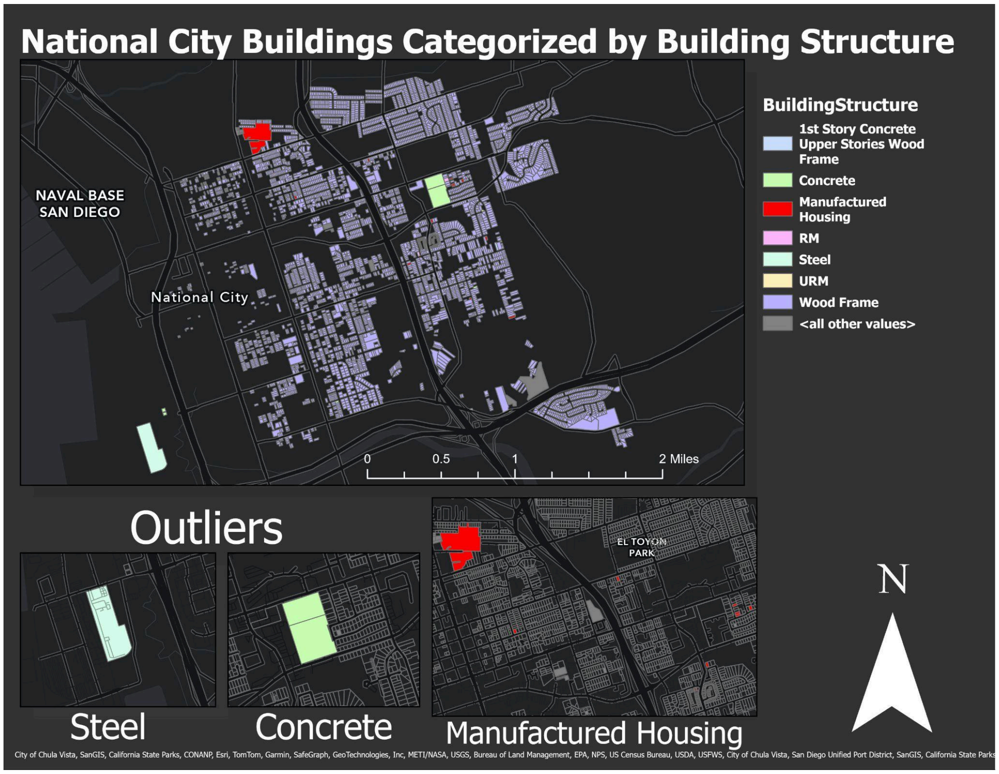

Figure 7: *National City Buildings by Building Structure*

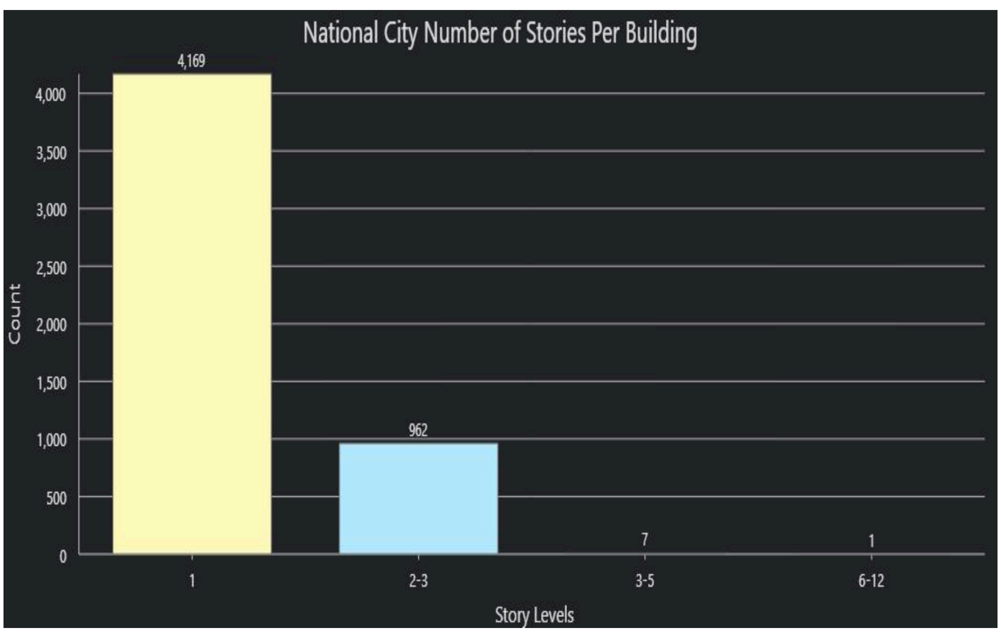

Figure 8. *National City Number of Stories per Building*

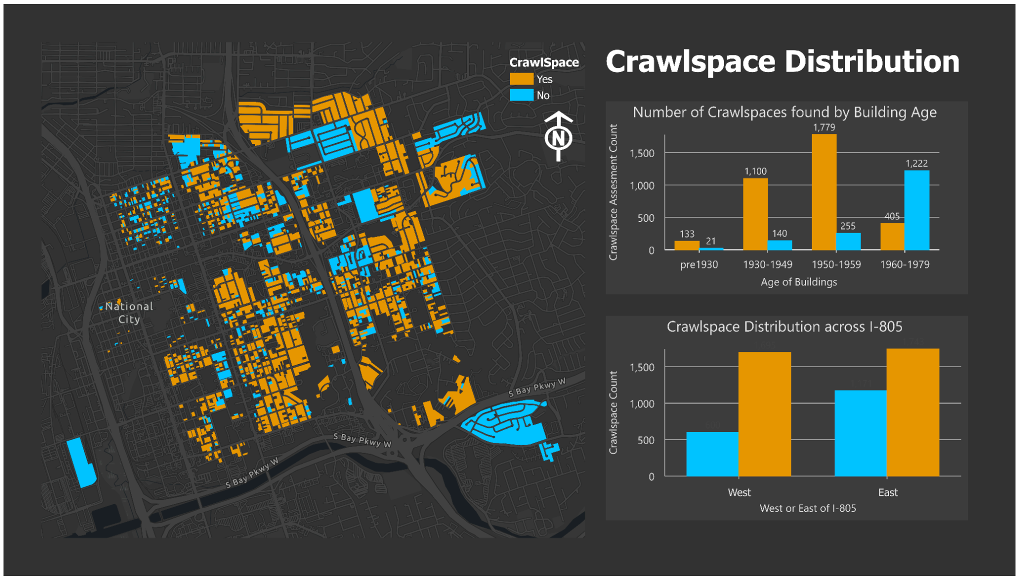

Figure 9. *National City Number of Stories per Building*

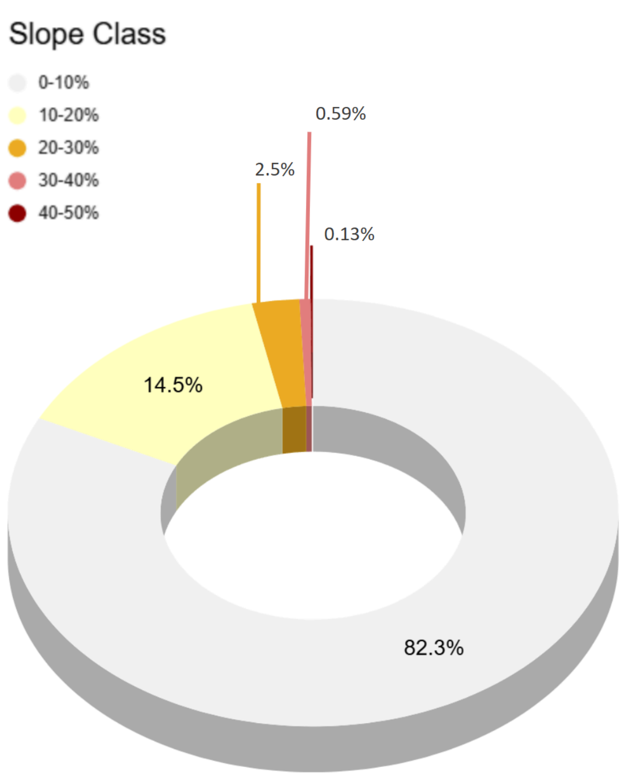

Figure 10. *National City Building Slope Class Distribution*