Seismic Assessment and Seismic Risk

a. Seismic Assessment

Seismic assessment is a performance-based engineering process used to evaluate how an individual structure—such as a building or bridge—will behave when subjected to earthquake ground motions of varying intensity. It combines structural analysis with seismic hazard understanding to ensure the safety, functionality, and resilience of existing infrastructure. The process begins with essential inputs, including seismic hazard spectra from probabilistic seismic hazard analysis (PSHA), representative ground motion time-histories, and detailed structural information such as material properties, geometry, construction quality, and boundary conditions. Various analytical methods may be used depending on the level of accuracy required—ranging from linear elastic and dynamic analyses for preliminary screening to nonlinear static (pushover) and nonlinear time-history analysis (NLTHA) for detailed evaluation. The structure's response is assessed against predefined performance objectives: Immediate Occupancy (IO), which ensures minimal damage and continued usability; Life Safety (LS), which allows damage but protects occupants; and Collapse Prevention (CP), which ensures the structure does not fail catastrophically. Key outputs include interstorey drift ratios, plastic rotations, deformation patterns, and demand-to-capacity ratios, all compared against component and system-level limit states. In addition, fragility curves are often developed to quantify the probability of reaching or exceeding damage states at different seismic intensities, offering a probabilistic measure of vulnerability. These results guide performance verification, identify structural deficiencies, and help prioritize retrofitting strategies. Ultimately, seismic assessment supports informed decision-making for retrofit design, risk mitigation, and resilience planning, especially for aging infrastructure or buildings constructed under outdated seismic codes. It also serves as a foundational input for seismic risk analysis by supplying building-specific vulnerability data.

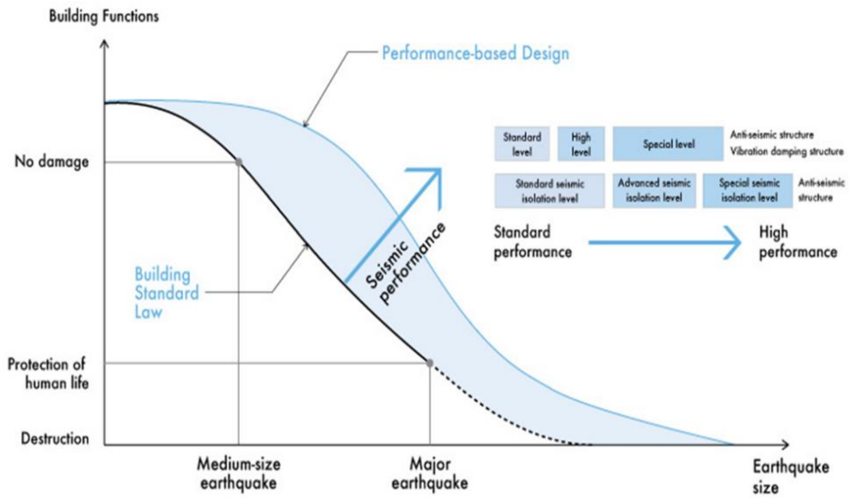


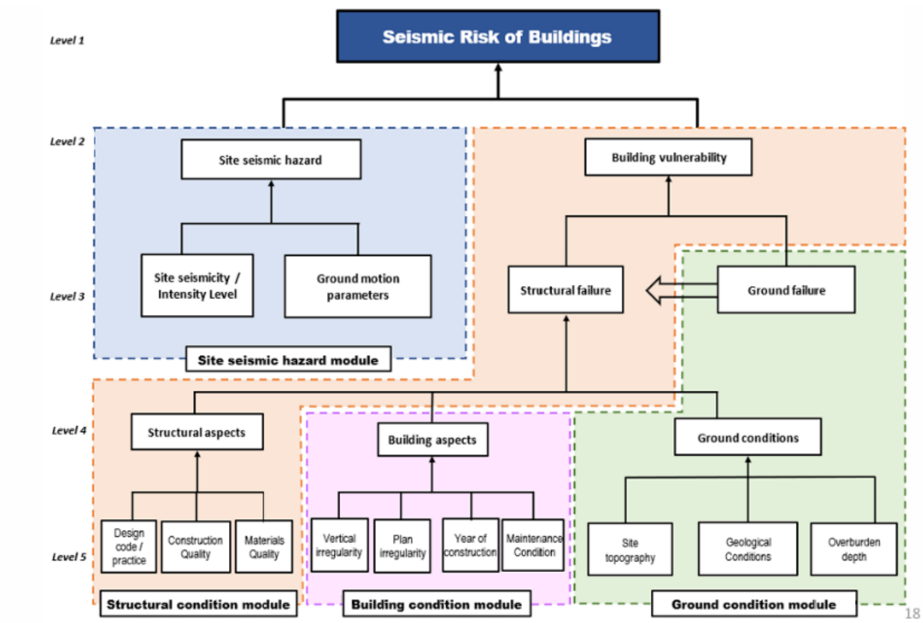
Figure 1:Diagram showing the impact of earthquake size on building functions, emphasizing enhanced resilience achieved through advanced seismic design and isolation techniques.

b. Seismic Risk

Seismic risk is the probabilistic estimation of the potential consequences that earthquakes can have on people, infrastructure, and economic systems at various scales—from individual assets to entire cities or regions. Unlike seismic hazard, which only quantifies the probability and severity of ground shaking at a location, seismic risk incorporates three essential components: hazard, exposure, and vulnerability. Hazard refers to the likelihood and intensity of seismic shaking; exposure represents the population, assets, and systems that may be affected; and vulnerability reflects how susceptible those assets are to damage, often captured through fragility curves derived from seismic assessments. Together, these components enable the quantification of expected losses and impacts in terms of economic cost, casualties, downtime, and damage distributions.

Importantly, seismic risk is not determined by hazard alone. A well-engineered building in a high-hazard zone may still have low risk due to its resilient design, ductile detailing, and compliance with modern codes such as Eurocode 8. In contrast, poorly constructed or inadequately detailed buildings—even in low seismic hazard areas—can face high risk, especially if located on unstable ground prone to liquefaction or landslides. Seismic risk analysis outputs include Expected Annual Loss (AAL), Probable Maximum Loss (PML), Exceedance Probability (EP) curves, and risk maps, which are used by governments, insurers, urban planners, and emergency managers for making informed decisions on mitigation strategies, insurance pricing, and investment in resilience.

A key aspect of seismic risk reduction is the assessment and retrofitting of vulnerable structures, especially in older urban centres or critical facilities such as hospitals and schools. Seismic assessment provides the necessary data to model vulnerability, and risk models in turn identify high-priority areas or structures for detailed evaluation and strengthening. Interventions may include structural retrofitting techniques such as the addition of shear walls, base isolators, or damping systems, all aimed at improving seismic performance and reducing potential losses. Ultimately, seismic risk analysis supports proactive planning and investment, ensuring communities are better



prepared to withstand and recover from major seismic events.

Figure 2: Levels of Seismic Risk of Buildings (Platonas Stylianou – 2020)

c. The differences of the two

Although often conflated in practice, seismic assessment and seismic risk analysis are fundamentally distinct processes, each serving a specific role within the broader framework of earthquake resilience. Seismic assessment is a micro-scale, structure-specific evaluation focused on the engineering performance of an individual building or infrastructure asset under defined earthquake ground motions. It involves detailed analysis—using tools like linear elastic models, pushover analysis, or nonlinear time-history simulations—to determine whether a structure meets predefined performance objectives such as Immediate Occupancy (IO), Life Safety (LS), or Collapse Prevention (CP), in accordance with standards like Eurocode 8 - Part 3. The goal is to verify safety, identify structural deficiencies, and recommend targeted retrofitting if needed.

In contrast, seismic risk is a macro-scale, probabilistic analysis that estimates the potential economic, social, and human consequences of earthquakes across portfolios of structures, urban areas, or entire regions. It synthesizes information from three key components: seismic hazard (likelihood and intensity of shaking), exposure (people, property, and systems at risk), and vulnerability (the expected performance of exposed assets). The output of seismic risk models includes metrics such as Expected Annual Loss (AAL), Probable Maximum Loss (PML), and loss exceedance curves, which are critical for urban planning, insurance pricing, disaster risk reduction, and resilience policy.

Despite their differences, the two processes are deeply interconnected. Seismic assessment provides the technical foundation for risk modelling by generating fragility functions, component vulnerability curves, and performance thresholds. These allow risk analysts to scale up building-level behaviour into regional loss estimates. Conversely, seismic risk analysis helps prioritize which buildings or regions require detailed assessment and retrofitting, especially in resource-constrained contexts by identifying risk hotspots, areas with high potential losses or societal impact. In essence, seismic assessment is diagnostic and technical, while seismic risk is strategic and probabilistic. Engineers, code officials, and building owners primarily use assessment to make decisions about individual structures, whereas policymakers, urban planners, insurers, and emergency managers rely on seismic risk to shape city-wide resilience strategies and investment priorities.

Ultimately, integrating both processes ensures a robust and scalable approach to seismic resilience: assessment informs risk, and risk directs assessment, creating a feedback loop that supports both effective retrofit planning at the asset level and informed risk management at the societal level.

d. Preliminaries / Methodology

A comprehensive structural assessment process begins with the laboratory sampling a desk study involving an archive search to gather all available data, such as drawings and reports, followed by the field study and the site inspections, the assembly of a qualified team including engineers and laboratory technicians, and the preparation of a Risk Assessment and Health & Safety plan. The field study then commences with site inspections aimed at verifying existing drawings, documenting any discrepancies, identifying the structural system and building elements, and, where drawings are unavailable, manually imprinting the structure or complex. External and internal photographs are taken for reference and documentation, and in-situ report forms are completed during the inspection. This phase also includes laboratory sampling and several in-situ testing methods, including core extraction to obtain cylindrical samples of construction materials such as concrete and masonry (Figure 3), and non-destructive methods used for in-situ assessment of concrete, masonry, and mortar, such as the Winsor Pin system (Figure 4) and Schmidt Hammer Rebound tests (Figure 4) for evaluating concrete strength. Additionally, a rebar locator instrument (Profometer) is used to detect and map existing steel reinforcement within concrete structures (Figure 6).

Figure 3: Core extraction

Figure 4: Windsor Pin System Device

Figure 5: Schmidt Hammer Rebound

Figure 6: Profometer Rebar Locator

e. Seismic analysis

Seismic analysis is a subset of structural analysis and the calculation of the response of a structure to earthquakes. It is part of the process of structural design, earthquake engineering or structural assessment, analysis and retrofit in regions where earthquakes are prevalent. A building has the potential to 'wave' back and forth during an earthquake (or even during a severe windstorm or other huge dynamic event). This is called the 'fundamental mode' and is the lowest frequency of building response. Most buildings, however, have higher modes of response, which are uniquely activated during earthquakes. Nevertheless, the first and second modes (and sometimes the third) tend to cause the most damage in most cases.

Category	Structural Model	Seismic Actions	Analysis Method
Linear-static	linear	equivalent load pattern	linear-static, force-control
Linear-dynamic (A)	linear	ground motion spectrum	modal response spectrum
Linear-dynamic (B)	linear	ground motion record	linear time history
Nonlinear static	nonlinear	equivalent load pattern	nonlinear-static, displacement-control
Nonlinear dynamic	nonlinear	ground motion record	nonlinear time history

Table 1: Analysis procedures for seismic design and assessment (Fragiadakis et al, 2014)

f. Analysis Methodology

The structural analysis methodology for seismic evaluation generally includes two primary approaches: (a) modal response spectrum analysis and (b) nonlinear static procedures such as pushover analysis.

Modal response spectrum analysis is an elastic-dynamic technique that takes into account multiple modes of vibration to estimate the response of a structure under seismic excitation. It is particularly effective for complex, irregular, or uncertain structures, especially those lacking diaphragm action (e.g., flexible floor systems), where the seismic response is multi-modal. This method is best suited for low-ductility systems, which are more vulnerable to seismic damage due to their limited energy dissipation capacity, such as unreinforced masonry buildings. The analysis generates maximum expected responses (like displacements and forces) using modal superposition and is commonly used in code-based seismic design and assessment.

In contrast, the nonlinear static procedure, commonly referred to as "**Pushover Analysis**", is a simplified yet powerful tool used to evaluate a structure's performance under seismic loads by explicitly incorporating material nonlinearity and plastic behaviour. It involves applying a monotonically increasing lateral load pattern (typically representing an equivalent earthquake force distribution) while maintaining gravity loads and continues until a target displacement or structural failure is reached. This method generates a Capacity Curve (Pushover Curve), a nonlinear relationship between base shear force and roof displacement, which helps in understanding how the structure transitions from elastic to inelastic behaviour and eventually to collapse. Nonlinear behaviour is captured using plastic hinges at critical locations (e.g., beam-column joints), simulating local yielding or failure.

Pushover analysis is particularly suitable for structures with diaphragm action, and is effective across all ductility levels, but is most accurate for regular, low- to mid-rise RC and steel buildings. It is a key method in performance-based seismic design, where the goal is to assess how a building performs at various levels of seismic intensity, rather than just satisfying minimum code requirements. In existing structures, pushover analysis is widely used in retrofit design, as it helps to identify weak elements and quantify required strengthening.

In the context of vulnerability assessment, the pushover method is used to simulate a structure's response to a scenario earthquake with a defined probability of occurrence commonly the 10% probability in 50 years intensity level. The process involves applying lateral loads incrementally, assessing the distribution of deformation, and tracking damage to individual elements such as columns, beams, and walls. Despite being conceptually straightforward, applying horizontal forces until failure, the analysis requires advanced computational tools and nonlinear structural modelling to accurately capture the real-world behaviour. Modern structural engineering software packages (e.g., SAP2000, ETABS, OpenSees) facilitate this process, incorporating nonlinear material models, hinge definitions, and performance limit states.

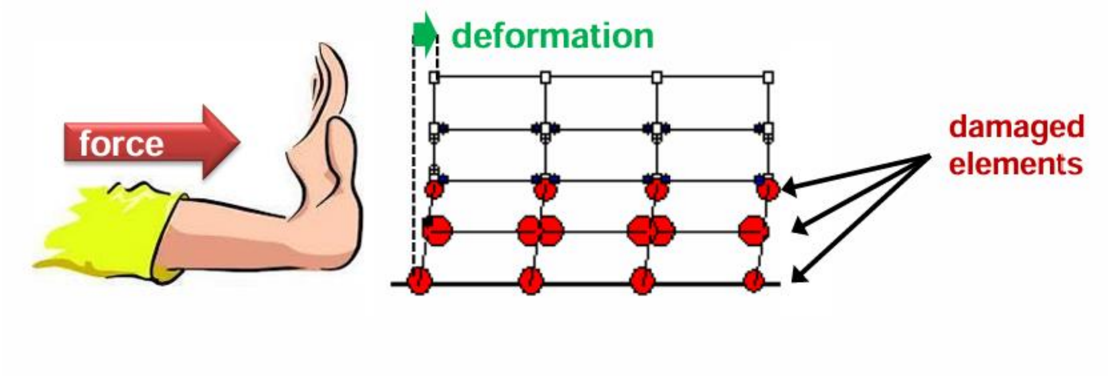


Figure 7: Pushover Analysis

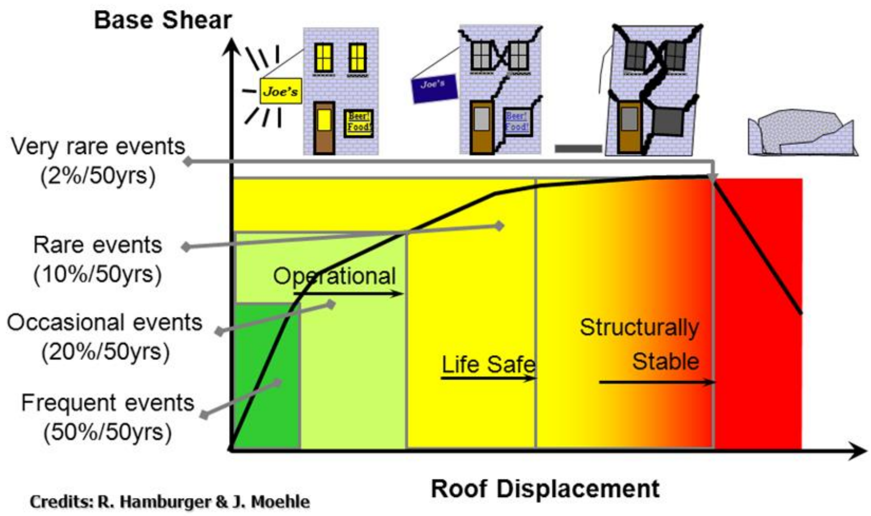


Figure 8: Anatomy of a static pushover curve

g. Assessment

In structural assessment for seismic performance, several key criteria are used to evaluate a building's expected behaviour under earthquake loading, particularly in terms of damage states, performance levels, and probability of exceedance. One such criterion is the Damage Limitation state, typically associated with a 20% probability of exceedance in 50 years (Eurocode 8 - Part 3). This level is used to assess the post-earthquake operability of a structure, focusing on issues such as cracking, minor deformations, or falling debris, which vary depending on the building type, materials, and construction quality. Damage at this level is generally non-structural but may impact the functionality and safety of a building immediately after a seismic event, critical for essential facilities like hospitals or emergency centres.

A more severe level is the Significant Damage state, aligned with a 10% probability of exceedance in 50 years. This level represents life-safety and near-collapse conditions, where structural integrity is compromised, but total collapse is (ideally) avoided. It forms the basis for most international and national seismic design codes (e.g., Eurocode 8, ASCE 7), making it the primary benchmark for design and retrofit evaluations. It provides a more reliable foundation for assessment findings because it reflects realistic worst-case scenarios within the building's expected life, balancing risk and safety. Engineers and policymakers typically base their performance objectives and design thresholds on this return period due to its broad adoption and reliability.

The Peak Ground Acceleration (PGA) return period refers specifically to the loading level, not the structure's response or damage state. While it helps define seismic hazard intensity (often derived from probabilistic seismic hazard assessments), relying on PGA alone is unconservative, particularly for uncertain structures (e.g., with unknown material properties or irregular configurations) and buildings with higher ductility, where actual damage may exceed expectations despite similar ground motions. Therefore, PGA-based assessments are better suited for initial design purposes rather than post-construction evaluation or retrofitting.

In contrast, the Average Useful Lifetime approach pertains directly to the expected damage state over time, integrating both epistemic uncertainty (from lack of knowledge) and aleatory uncertainty (inherent randomness), typically using the hazard curve. This probabilistic measure estimates the expected lifespan before reaching a defined damage state, making it highly valuable for risk-informed assessment and long-term asset management. It provides a more complete picture of a building's performance over its lifetime and is particularly useful when evaluating existing structures or making decisions about repair, retrofit, or replacement. Together, these metrics form a comprehensive framework for seismic assessment, allowing designers and engineers to balance safety, functionality, and economic considerations across different scenarios and timescales.

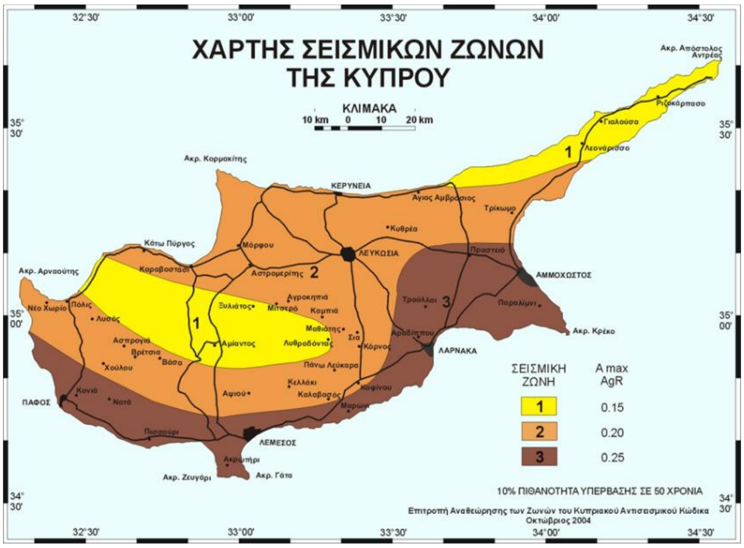


Figure 9: Values of the peak ground acceleration for a PoE of 10% in 50 years, as used to define the design spectra of EN1998 for Cyprus