ACBA 6007

Seismic Design of Buildings

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Introduction

Earthquakes are natural disasters that predominantly lead to the destruction or failure of buildings and other human-made structures. It has been shown that implementing earthquake-resistant regulations for new constructions is crucial in mitigating earthquake-induced damage. The extent of earthquake damage is influenced by various factors, including ground motion intensity, duration and frequency, geological and soil conditions, and construction quality. Building design should ensure that the structure has adequate strength and high ductility and remains intact even when subjected to significant deformation. (Arya, et al., 2014)

The seismic design of buildings requires striking a balance between a structure's seismic capacity and the anticipated seismic demand it will encounter. It aims to minimise the potential risks of earthquakes, including loss of human life, damage to buildings, and economic losses resulting from future seismic events. (Bommer & Strafford, 2016)

The important parameters in seismic design pertain to the material properties of the building, the dynamic characteristics of the building system (including periods, modes, and damping), and the load-deflection characteristics of building components. (Arya, et al., 2014)

Earthquakes impose dynamic and unpredictable forces on buildings, which can lead to catastrophic failures if not properly accounted for in the design process. (Lorant, 2016)

These forces can lead to severe structural and non-structural damage, jeopardising the stability and functionality of buildings. (Saatcioglu, 2013)

When the base of a building shifts, the superstructure and its contents experience irregular shaking and vibration caused by the inertia of the masses. If the building's base moves suddenly to the right, the building moves to the left relative to the base, as though it is being compelled to the left by an imperceptible force known as Inertia Force. Nonetheless, there is no physical pushing involved; the building, owing to its mass, opposes any movement. During an earthquake, the ground moves concurrently in three mutually perpendicular directions: transversely, vertically, and longitudinally. (Arya, et al., 2014)

Earthquakes produce waves that can range from slow and prolonged to quick and sudden. The period of a wave, measured in seconds, represents the duration of a full cycle and is the reciprocal of the frequency. All structures, including buildings, possess a fundamental or natural period at which they sway when subjected to a sudden impact. The natural period is the primary factor in seismic design, although other elements of the building's design may also contribute, albeit to a lesser extent, to mitigation measures. If the shock wave's period aligns with the building's natural period, the building will "resonate," causing its vibration to significantly amplify. (Lorant, 2016)

Ground shaking affects the entire affected area during an earthquake, while other geological effects are limited to specific conditions. Structures near fault lines may experience ground displacement, resulting in shear failure in key structural components such as columns and beams. Liquefaction, on the other hand, is restricted to areas with loose, saturated sands where the soil temporarily loses its strength, potentially causing even settlement and foundation failure. (FEMA U. S. Department of Homeland Security, 2022)

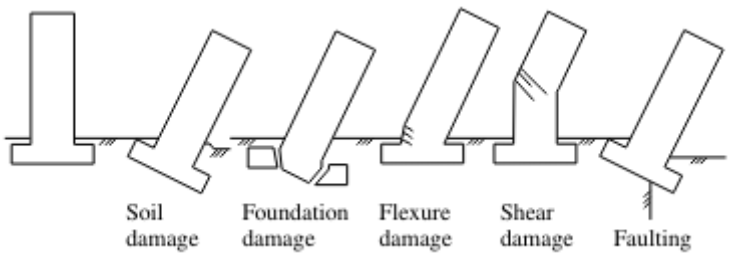

Figure 1 Showing common types of damages during large earthquakes. (Yashinsky, 2006)

Most structural damage during earthquakes is attributed to soil failure or intense shaking. Additional damage can occur due to surface ruptures, lifeline failures, or the collapse of less robust structures. These effects are deemed secondary as they may not always manifest during an earthquake.(Yashinsky, 2006)

The resistance to earthquakes is achieved through the structural design of the building, but the architectural design and decisions also significantly impact the building's ability to withstand seismic forces. The architectural design must allow for effective seismic design while also meeting the functional and aesthetic goals of the building. This can be categorised into three key decisions: building configuration,

structurally restrictive detailed architectural design, and hazardous non-structural components. (Naeim, 2001)

Consequently, understanding the interaction between seismic forces and building components is essential for developing effective design strategies. (FEMA, 2016)

This paper explores the various aspects of seismic design, including structural and architectural considerations, an overview of design codes and an examination of the different structural systems that can be implemented to enhance seismic resistance.

Literature Review

One of the fundamental principles of seismic design is the provision of adequate lateral load resistance to withstand the horizontal forces generated during earthquakes.

Lateral forces can develop significant stresses, inducing lateral movement or triggering vibrations that can lead to structural failure. As a result, it is crucial for the structure to possess adequate strength to withstand vertical loads and sufficient rigidity to counter lateral loads. (Somasekharaiah, et al., 2016)

Lateral force-resisting systems involve incorporating a vertical component of the structure to transmit horizontal forces to the ground. (American Institute of Steel Construction, n.d.)

Three common lateral force-resisting systems used in buildings are moment frames, shear walls and braced frames.

Moment-resisting frames are structural systems that consist of rigidly connected beams and columns to create a continuous load path for transferring lateral loads through bending and shear. These systems can be built using reinforced concrete, structural steel, or a combination of both materials. Reinforced Concrete Moment-Resisting Frames (RC MRFs) rely on the ductile behaviour of specially designed beam-column joints to dissipate seismic energy through inelastic deformations. They provide high lateral stiffness and can be designed for various levels of flexibility based on seismic demand. Steel Moment-Resisting Frames (SMRFs) take advantage of the inherent ductility of steel and the ability of beam-to-column connections to undergo inelastic rotations without significant strength degradation. Careful detailing of the

connections is essential to ensure adequate performance during earthquakes. (Higgins, 1998)

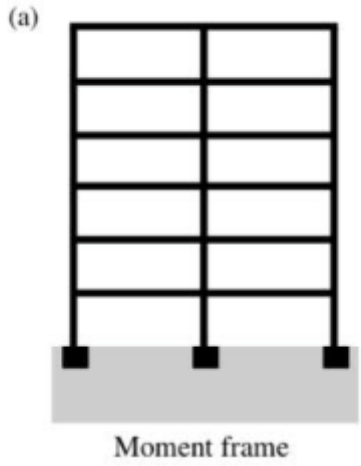

Figure 2 Showing a moment frame. (Hamburger & Scawthorn, 2006)

Shear walls resist lateral forces as a vertical diaphragm through in-plane shear. These walls are usually long compared to their height, utilising plane stiffness and acting as a vertically spanning beam to resist lateral forces. Flexure is resisted by vertical reinforcement along the wall. It is essential to consider opening when calculating a wall's shear capacity because wall sections with openings will be the weakest path of shear resistance. Walls above and below openings act as tie beams that distribute the load between shear walls. To fully transfer shear forces into the substructure, wall vertical bars must be adequately lapped with foundation dowels. For in-plane shear, the wall acts as a cantilevered beam that is fixed at the base. (Gooding, 2017)

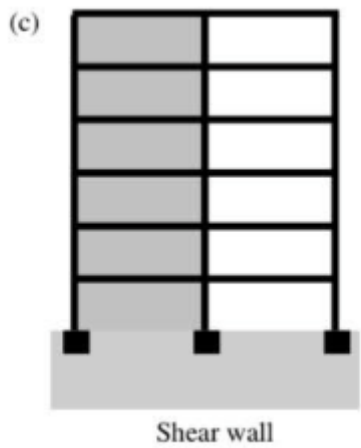

Figure 3 Showing shear wall. (Hamburger & Scawthorn, 2006)

Braced frames are designed to withstand horizontal forces by transferring tensile or compressive forces through diagonal bracing members. These braces play a crucial role in transmitting forces from roof or floor diaphragms through shear connections down to the foundation. There are two main types of braced frames: concentric and eccentric. Concentric frames feature braces that connect at the ends of elements, creating a relatively rigid frame to resist lateral loads. Common configurations include cross-bracing, v-bracing, and single diagonal braces. On the other hand, eccentrically braced frames utilise diagonal braces that eccentrically join the supporting member, resulting in increased ductility similar to a moment frame. These frames are more commonly employed in high seismic regions. (Naqash, et al., 2014)

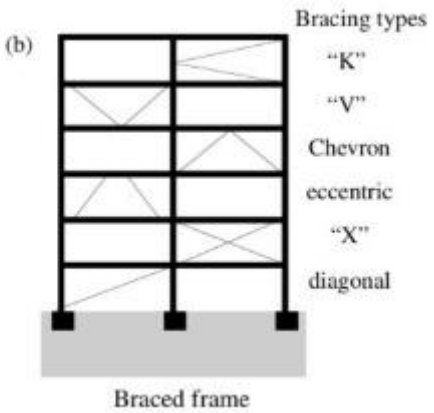

Figure 4 Showing braced frame (Hamburger & Scawthorn, 2006)

(Booth, 2014) highlights another consideration of soil-structure interaction. He states that the analysis of structures built on bedrock assumes that their base is fixed, but this assumption may be incorrect when the soil's translational and rotational restraint is less than rigid. The soil's flexibility typically increases the fundamental period of the structure, which tends to reduce its motion, a phenomenon known as radiation damping. Ignoring these soil-structure interaction effects generally leads to conservative estimates of seismic forces and shear deformations in the superstructure.

In recent years, earthquake-resistant design methods have shifted from traditional ductility-based approaches to more innovative and non-traditional methods, such as seismic base isolation systems. While traditional methods prioritize life safety during earthquakes, they may not effectively control damage to maintain a structure's functionality post-event. This has led to an increased focus on alternative approaches to ensure both life safety and structural functionality. (S., et al., 2016)

Seismic isolation functions by separating a building from the intense ground movements triggered by an earthquake. One key benefit of seismic isolation is its ability to safeguard all components located above the isolation plane. The decrease in accelerations above the isolation plane not only lessens the inertial forces that the structure needs to withstand but also reduces the forces on attachments like water tanks or plant items, making them less susceptible to failure. Additionally, the decrease in structural forces minimises the shear deformations in the structure, thereby reducing damage to cladding, glazing, partitions, and non-structural elements. Therefore, seismic isolation works to protect both the building's structure and its contents, making an isolated building much more likely to resume normal function immediately after a strong earthquake. (Booth, 2014)

Important buildings in New Zealand have been built with base isolation. The benefit of this system was seen when the island was struck by a 6.1 magnitude offshore earthquake. The earthquake showed the benefit of the base isolation system. It was designed to decouple the buildings superstructure from its foundation using flexible bearings to dampen seismic forces. (Hakimian, 2023)

Design codes and Methods.

International Building Code (IBC) The International Building Code (IBC), developed by the International Code Council (ICC), is a widely adopted model code in the United States and other countries. It incorporates provisions from various material-specific codes, such as ACI 318 for concrete and AISC 360 for steel and includes seismic design requirements based on ASCE 7. (AISC 360-16, 2016)

ASCE 7: Minimum Design Loads for Buildings and Other Structures the ASCE 7 standard, published by the American Society of Civil Engineers (ASCE), is a comprehensive document that provides guidelines for determining design loads, including seismic loads, for buildings and other structures. It is a widely referenced standard in the United States and forms the basis for seismic design provisions in the IBC. (AISC 360-16, 2016)

Eurocode 8: Design of Structures for Earthquake Resistance Eurocode 8 is the European standard for seismic design, providing rules and guidelines for the design of buildings and civil engineering structures in seismic regions. It covers various aspects of seismic design, including seismic action, structural analysis, and detailing requirements for different materials. (European Commission, n.d.)

Other National and Regional Codes Many countries and regions have developed their own seismic design codes and standards, such as the National Building Code of Canada, the New Zealand Standard NZS 1170.5, and the Indian Standard IS 1893. These codes are tailored to the specific seismic hazards and construction practices of their respective regions.

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