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Study on Seismic Characteristics of Near Fault and Its Influence on Seismic Design of Structures

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Abstract

This paper investigates the significant impact of seismic events on critical urban infrastructure components, including bridges, road networks, and water supply systems. Through detailed case studies and rigorous theoretical analysis, it examines the mechanisms of earthquake-induced damage and consequent service disruptions. The study further conducts an in-depth analysis to identify effective mitigation strategies, culminating in a series of targeted recommendations for enhanced seismic design principles. These proposed measures aim to significantly reduce structural damage, minimize functional losses, and enhance the overall resilience of urban infrastructure against earthquakes.

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Keywords

Earthquake disaster; Urban infrastructure; Seismic design.

1. Introduction

Earthquakes, as a devastating natural disaster, have caused severe impacts on urban infrastructure. Serving as the cornerstone of urban operations, this critical infrastructure includes bridges, roads, water supply systems, and power grids. Damage to these facilities not only results in casualties and property losses but also disrupts normal city functions and socio-economic development. Therefore, studying earthquake-induced damage to urban infrastructure and implementing effective seismic design strategies are crucial for enhancing cities' earthquake resilience and ensuring public safety.

2. The Impact of The Earthquake on Urban Infrastructure

2.1. Bridge

Bridges, vital urban transportation hubs, are particularly vulnerable to earthquake damage. Earthquakes can cause structural deformation, cracks, and collapses in bridges, disrupting normal traffic flow. For example, during the 2008 Wenchuan earthquake, numerous bridges sustained severe damage, leading to complete traffic paralysis and posing significant challenges for rescue operations[1].

2.2. Roadway

Roads, as vital components of urban transportation, are particularly vulnerable to earthquake damage. Earthquakes can cause pavement cracks, subsidence, and roadbed displacement, significantly reducing traffic capacity[2]. For example, during the 1995 Hanshin-Awaji Earthquake in Japan, numerous roads suffered severe damage, leading to massive traffic congestion that posed major challenges for rescue operations.

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2.3. Water supply

As a vital lifeline for urban residents, water supply systems are particularly vulnerable during earthquakes. Earthquakes can cause critical infrastructure failures such as ruptured pipelines and damaged pumps, disrupting normal water services. For example, the 2010 Haiti earthquake caused severe damage to water supply networks, leaving residents without basic drinking water and creating significant challenges for rescue operations[3].

2.4. Power supply system

As a critical infrastructure for urban operations, power systems are particularly vulnerable during earthquakes. Earthquakes can cause transmission line failures and substation damage, disrupting stable electricity supply. A prime example is the 2011 Fukushima earthquake in Japan, where severe damage to power grids triggered nuclear plant leaks, posing significant threats to both environmental safety and public health[4].

3. Seismic Design Strategy

3.1. Aseismatic design of bridge

3.1.1. Reasonable structure selection

The structural selection of the bridge should be comprehensively considered according to the earthquake intensity, site conditions, bridge span and other factors. Generally speaking, the bridge structure with better seismic performance includes continuous beam bridge, arch bridge, cable-stayed bridge, etc..

3.1.2. Strengthen the seismic capacity of piers and abutments

Pier and abutment are important components of bridge structure, and their seismic capacity directly affects the overall seismic performance of the bridge. In the design, the seismic capacity of pier and abutment should be strengthened by adopting reasonable section form, reinforcement method and connection method[5].

3.1.3. Use of seismic isolation devices

Seismic isolation devices are an effective seismic resistance measure that can reduce the impact of earthquakes on bridge structures. In design, appropriate seismic isolation devices such as rubber bearings, lead-core rubber bearings, and friction pendulum bearings should be selected based on factors such as the structural characteristics of bridges and seismic intensity.

3.2. Road seismic design

3.2.1. Optimize road alignment

The optimization of road alignment can reduce the impact of earthquakes on roads. In the design, complex road sections such as sharp turns and steep slopes should be avoided in seismically active areas.

3.2.2. Improve the integrity and stability of the roadbed and pavement

The integrity and stability of the subgrade and pavement are key to road seismic resistance. In design, appropriate subgrade fill materials and compaction methods should be adopted to enhance subgrade strength and stability. Meanwhile, suitable pavement structure forms and materials should be employed to improve pavement integrity and crack resistance[6].

3.2.3. Strengthen the seismic capacity of road ancillary facilities

Road ancillary facilities include street lights, traffic signs, guardrails, etc., and their seismic capacity also directly affects the overall seismic performance of the road. In the design, the seismic capacity of road ancillary facilities should be strengthened by adopting reasonable structural forms and connection modes[7].

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3.3. Seismic design of water supply system

Key design strategies to improve the seismic resilience of water supply network system.

As a lifeline project sustaining urban operations, the seismic resistance of urban water supply networks directly affects the timeliness of post-earthquake emergency rescue and reconstruction. To effectively enhance the functional resilience and recoverability of water supply systems under strong earthquakes, the following core design strategies are crucial:

3.3.1. Select flexible pipe materials to build a resilient foundation

Core Value: Seismic waves induce geological displacement and uneven subsidence during propagation. Rigid pipe materials (e.g., reinforced concrete pipes and brittle plastic pipes) are prone to brittle fractures due to stress concentration. Flexible pipes, with their exceptional ductility and deformation adaptability, effectively absorb and dissipate seismic energy, significantly reducing fracture risks. This makes them the preferred choice for enhancing the seismic resistance of pipeline networks.

Recommended material: Ductile iron pipe. Combining high strength with excellent ductility, its unique spheroidal graphite microstructure provides steel-like strength and superior toughness compared to ordinary cast iron. The reliable socket-type joints (such as T-joints with rubber rings) allow moderate bending and displacement, making it an ideal choice for main pipelines.

Polyethylene (PE) pipes: High-density polyethylene (HDPE) pipes are flexible and lightweight, boasting an exceptionally long fatigue life. Their hot-melt joints form a truly integrated piping system where the joint strength matches or even exceeds the pipe body, allowing coordinated movement with ground deformation. This makes them particularly suitable for areas at risk of liquefaction or uneven settlement[8].

Practical points: In the design, the seismic geological conditions of the site (such as liquefaction potential and fault location) should be systematically evaluated, the types, specifications and connection modes of pipe materials should be selected accordingly, and the specific requirements for pipeline flexibility in relevant seismic design codes should be strictly observed.

3.3.2. Valves and inspection wells should be planned scientifically to ensure controllability after earthquake

Strategic significance: Valves and inspection wells are not only nodes of daily operation and maintenance, but also the core control hub for rapid isolation of damaged pipe sections, implementation of regional leak detection and emergency repair, and maximum maintenance of water supply in some areas after earthquake. The rationality of their layout and structural reliability directly determine the efficiency of emergency response.

Optimized Layout: Zoning Isolation: Based on pipeline network topology and user distribution, valves are strategically deployed to divide the pipeline system into multiple independent "hydraulic zones" that can be isolated. The size of each zone should balance rapid isolation requirements with minimal impact on users. Critical areas such as hospitals, densely clustered fire hydrants, and main pipe intersections require additional valves.

Accessibility design: The location of valve well and inspection well should avoid the threat area of building collapse and potential landslide zone, so as to ensure that roads can be quickly accessible even if damaged after earthquake. The structure design should meet the seismic requirements to prevent the collapse of well body from crushing internal facilities or obstructing operation.

Facility reinforcement: The structure of the well chamber (wall and cover plate) shall be reinforced and constructed according to the seismic grade; the internal valves and their connectors (bolts, flanges) shall be designed to prevent loosening; flexible joints are recommended for large diameter or key valves to absorb vibration[9].

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3.3.3. Strengthen the structure of water pump unit and pool to stabilize the core of the system

System hub function: Pump house and reservoir are the "heart" and "blood bank" of water supply system. Their earthquake damage (such as equipment displacement and damage, structural cracking and collapse) will lead to the overall paralysis of the system, so their seismic performance is the key to maintain the continuous operation of the system.

Seismic Design for Pump Unit: Equipment Selection and Anchoring: Priority should be given to pump units certified for seismic resistance, featuring low center of gravity and compact structure. Foundation design must rigorously calculate seismic forces to ensure sufficient strength and rigidity. High-strength anchor bolts shall be used to securely fasten the equipment to either earthquake-resistant independent foundations or reliably connected to integral base slabs.

Flexible connection: all inlet and outlet pipes connected to the pump and power cable trough must be equipped with clear and reliable flexible joints (such as stainless steel corrugated compensator, rubber flexible joint), and enough displacement compensation is reserved to prevent pipeline tearing or equipment damage due to interlinked force.

Seismic reinforcement of pool structure:

Structural system: According to site conditions and scale, the structural form with good seismic performance is selected (for example, the rectangular pool adopts the frame structure with added shear wall, and the circular pool has better force). The sudden change of structural stiffness is avoided to ensure the integrity and ductility[10].

Key details: Strengthen the connection node structure between the pool wall and the bottom plate, top plate (if any); pipes passing through the pool wall must be equipped with flexible sleeves with water stop and displacement adaptability; pay attention to foundation treatment, especially when located in weak or liquefied soil layers, pile foundation and replacement measures should be adopted.

In conclusion, a comprehensive solution for enhancing the seismic resilience of water supply networks can be achieved through three key measures: scientifically selecting flexible piping materials to construct resilient pipeline infrastructure, strategically optimizing valve and inspection well layouts to improve system controllability and recovery capacity, and implementing rigorous seismic design and reinforcement for critical facilities like water pumps and reservoirs. Only by adopting systematic and meticulous design approaches across these critical components can we effectively mitigate the impact of earthquakes on urban water supply systems, thereby providing robust safeguards for rapid post-earthquake recovery and ensuring the safety and resilience of cities.#

4. Seismic Design of Power Supply System

4.1. Improve the seismic resistance of transmission lines

4.1.1. Reasonable structure selection

The seismic resistance of transmission lines is the key to the seismic resistance of power supply systems. In the design, reasonable tower structure and foundation forms should be adopted to improve the strength and stability of transmission lines; at the same time, protection measures such as lightning arresters and shock absorbers should be strengthened.

4.1.2. Strengthen the seismic resistance of substations

Substations are vital components of power supply systems, and their seismic resistance directly impacts the overall performance of the power grid's earthquake resilience. During design, it is essential to enhance substation seismic capabilities through optimized structural

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configurations and connection methods. Additionally, protective measures such as installing lightning rods and grounding devices should be implemented to strengthen substation safety.

5. Conclusion

Earthquake disasters have a profound impact on urban infrastructure. To minimize losses caused by seismic hazards, we must implement effective seismic design strategies. When designing critical infrastructure such as bridges, roads, water supply systems, and power grids, it is essential to fully consider earthquake resistance by adopting appropriate structural configurations, materials, and construction methods to enhance their seismic resilience. Simultaneously, strengthening maintenance and management through regular inspections and repairs ensures safe operation of these facilities. Only by implementing these measures can we effectively reduce earthquake-related damages and safeguard both the safety and sustainable development of our cities.

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