

Entry

Earthquake Resilience in Japanese Cities: Reactive and Proactive Approaches

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Definition

Urban resilience to earthquakes refers to the capacity of cities to anticipate, absorb, and adapt to seismic shocks through a combination of structural, institutional, and social mechanisms. In the context of Japan, one of the world’s most seismically active countries, this concept has evolved through both post-disaster learning and anticipatory planning. This entry examines two complementary trajectories of urban resilience in Japanese cities: reactive resilience, which develops through adaptation after a destructive event, and proactive resilience, which is embedded in preventive policies and preparedness strategies before a shock occurs. The city of Kobe, following the 1995 Great Hanshin Earthquake, exemplifies a reactive trajectory shaped by institutional reform, community mobilization, and regulatory change. In contrast, Tokyo represents a proactive resilience model based on stringent seismic standards, advanced monitoring and early warning systems, and a widespread culture of disaster preparedness. By comparing these trajectories, the entry outlines a conceptual framework for understanding urban seismic resilience as a dynamic process that integrates social adaptation, governance, and technological innovation.

Keywords: reactive/adaptive resilience; proactive/preventative resilience; earthquakes; Japan; Kobe; Tokyo

1. Urban Resilience: Definition and Scope

Urban resilience is the capacity of a city to anticipate, absorb, and recover from shocks and stresses, such as extreme climatic events or social and economic crises, through strategies of continuous adaptation and transformation. Rather than merely withstanding adverse events, a resilient city may also turn disruption into an opportunity for innovation, fostering sustainable social, economic, and environmental responses.

The emergence of resilience as an analytical concept reflects a major theoretical evolution. Originally developed in ecology, resilience was defined by Holling as the capacity of a system to absorb disturbance while maintaining its basic functions and structure [1]. This perspective was later extended to the social domain, where social resilience came to describe the ability of groups and communities to cope with external stresses and adapt to change [2]. In disaster studies, and particularly in seismic contexts, this shift proved crucial, since resilience could no longer be understood only in terms of physical resistance, but



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also in relation to the adaptive capacities embedded in society itself. As noted by Norris et al., community resilience depends on a network of resources and capacities—including social capital, information and communication, economic development, and community competence—that shape a society’s ability to absorb shocks and reorganize after disaster [3]. In this sense, earthquake resilience is not limited to the structural performance of buildings and infrastructure but is also rooted in the social capacity to respond, adapt, and recover. In the Japanese context, moreover, urban resilience also depends on governance arrangements, public–private partnerships (PPPs), and policy instruments aimed at reducing vulnerability in densely built-up areas exposed to seismic and fire risk [4]. More broadly, the Japanese understanding of resilience has been shaped by repeated large-scale disasters, which have reinforced the importance of preparedness, institutional learning, and coordinated response capacities [5]. Against this background, this paper explores different approaches to urban resilience through two examples. The first focuses on the city of Kobe, before and after the Great Hanshin earthquake of 1995, as an example of reactive resilience. The second examines proactive resilience through the case of Tokyo and its preparation for the anticipated “Big One.” Rather than ranking Kobe and Tokyo as alternative models, this comparison is intended to show that urban seismic resilience is a dynamic process that evolves over time, shifting from reactive post-disaster adaptation toward proactive prevention, continuous preparedness, and the progressive integration of social, institutional, and technological capacities (Figure 1). Rather than a rigid binary, reactive and proactive resilience are understood here as positions along a continuum, which may be observed through the timing of regulatory upgrading, the extent of retrofit interventions, and the degree of investment in preparedness measures. In line with the encyclopedia format, this entry addresses a broad interdisciplinary readership, while being particularly relevant to urban planners and disaster risk researchers concerned with the social, institutional, and technological dimensions of seismic resilience.

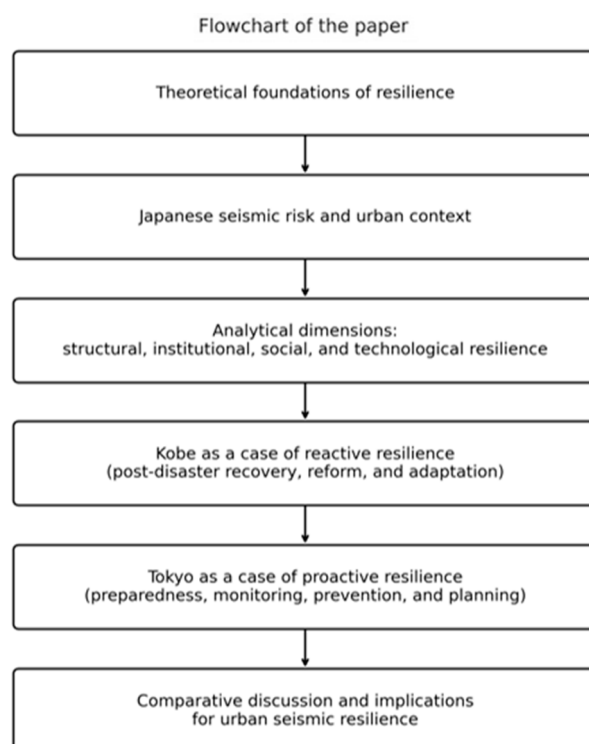


Figure 1. Flowchart diagram.

2. Seismic and Environmental Context of Japan

Japan is situated within a complex plate boundary system in which the Pacific Plate and the Philippine Sea Plate converge and subduct beneath adjacent continental and domains, generating a spectrum of seismic sources that include subduction interface (megathrust) earthquakes, intraslab events, and shallow crustal earthquakes that can directly affect major urban agglomerations (Figure 2) [6].

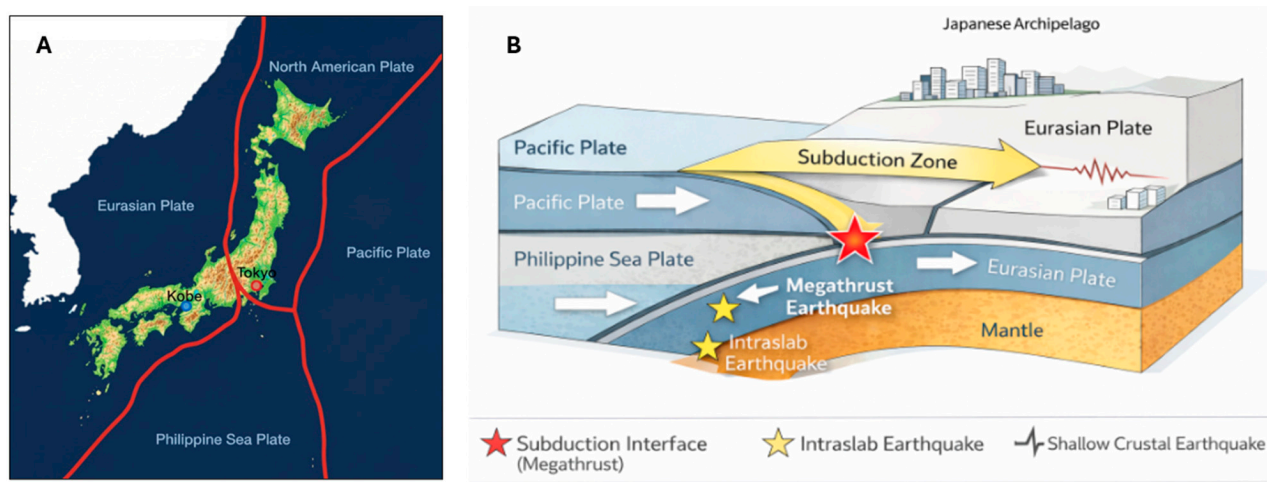


Figure 2. Simplified schematic representation of the tectonic setting of Japan. **(A)** Tectonic map of Japan. The intersections of the four major tectonic plates (the Eurasian Plate, the North American Plate, the Pacific Plate, and the Philippine Sea Plate) are shown in red. **(B)** The figure illustrates the convergence and subduction of the Pacific Plate and the Philippine Sea Plate beneath the Japanese archipelago, generating a spectrum of seismic source mechanisms that include megathrust earthquakes along the plate interface, intraslab earthquakes within the descending oceanic plates at intermediate depths, and shallow crustal earthquakes within the upper crustal crust beneath densely urbanized areas. These coexisting seismic sources reflect the complex plate boundary environment responsible for Japan's high and spatially heterogeneous seismic hazard. For clarity, the tectonic configuration is presented in a simplified form: although the region is influenced by additional microplates (e.g., Okhotsk and Amur), and subduction geometries vary along different margins (e.g., Japan Trench, Nankai and Sagami troughs), these complexities are not explicitly shown, as the schematic is intended to highlight the dominant processes relevant to urban seismic risk rather than detailed geodynamic structures.

This tectonic configuration underpins Japan's persistently high seismicity and has motivated the development of dense national monitoring capabilities; for example, the National Research Institute for Earth Science and Disaster Resilience (NIED) integrates nationwide land and seafloor observation systems (MOWLAS) to support rapid monitoring, early warning, and hazard assessment across the archipelago and its offshore zones [7]. Institutional seismic observation has deep historical roots: the Tokyo Meteorological Observatory (now the Japan Meteorological Agency, JMA) began formal observations in 1875, providing a long baseline for operational monitoring and risk communication. Against this geophysical background, exposure and potential impact are amplified by the spatial concentration of population and economic activity in dense metropolitan regions and along coastal plains, where critical infrastructure networks and essential services are highly interdependent [8].

In public-facing preparedness guidance, Japan is commonly described as experiencing on the order of ~1500 earthquakes per year in and around the archipelago, referring to recorded seismic events rather than only damaging or widely felt earthquakes (Table 1).

This frequent seismic activity underscores the routine nature of earthquake hazard in everyday life and the consequent emphasis on continuous readiness [8].

Table 1. Major damaging earthquakes in Japan over the last ~50 years (1975–2025).

Year	Earthquake (Common Name)	Location	Magnitude *	Fatalities **	Estimated Direct Economic Damage ***	Primary Source
1978	Miyagi-ken-oki Earthquake	Offshore Miyagi Prefecture	Mw ~7.7	~28	~US\$2.9 billion	JMA; Cabinet Office of Japan
1983	Nihonkai-Chūbu (Sea of Japan) Earthquake	Offshore Akita Prefecture	Mw ~7.8	~104	~US\$0.8 billion	JMA; NIED
1993	Hokkaidō Nansei-oki (Okushiri) Earthquake	Offshore Hokkaidō	Mw ~7.7–7.8	~185	~US\$0.6 billion	JMA; USGS
1995	Great Hanshin-Awaji (Kobe) Earthquake	Hyōgo Prefecture (Kobe)	Mw ~6.9	>6400	~US\$100 billion	JMA; Cabinet Office of Japan
2004	Niigata-ken Chūetsu Earthquake	Niigata Prefecture	Mw ~6.8	~68	~US\$27.7 billion	JMA; Cabinet Office of Japan
2007	Noto Peninsula Earthquake	Ishikawa Prefecture	Mj 6.9 (Mw ~6.7)	1	~US\$0.55 billion	JMA; Cabinet Office of Japan
2007	Niigata-ken Chūetsu-oki Earthquake	Offshore Niigata Prefecture	Mw ~6.8	14	~US\$12.8 billion	JMA; ADRC
2011	Great East Japan (Tōhoku) Earthquake and Tsunami	Pacific coast of Tōhoku	Mw 9.1	>15,000	~US\$300 billion	JMA; Cabinet Office of Japan; USGS
2016	Kumamoto Earthquake Sequence	Kumamoto Prefecture	Mw ~7.0	>50 †	~US\$22–42 billion	JMA; Cabinet Secretariat of Japan; ADRC
2018	Hokkaidō Eastern Iburi Earthquake	Hokkaidō	M 6.7	~41	~US\$1.5 billion	JMA; Cabinet Office of Japan
2024	Noto Peninsula Earthquake (Reiwa 6)	Ishikawa Prefecture	Mj 7.6	>500	~US\$10 billion	JMA; Cabinet Office of Japan; reinsurance loss assessments

Notes: * Magnitude values are reported according to the issuing authority (Mw, Mj, or M) and may vary slightly across agencies. ** Fatalities may include direct and disaster-related deaths, depending on official post-event revisions. *** Economic damage refers to direct losses as reported by governmental or authoritative analytical bodies; figures are not inflation-adjusted and are therefore not directly comparable across events. † For the 2016 Kumamoto earthquakes, official fatality counts were revised over time to include disaster-related deaths. List of Abbreviations: Asian Disaster Reduction Center (ADRC); Japan Meteorological Agency (JMA); National Research Institute for Earth Science and Disaster Resilience (NIED); United States Geological Survey (USGS); Moment Magnitude (Mw); Japan Meteorological Agency Magnitude (Mj); generic earthquake magnitude (M); United States Dollar (USD); Japanese Yen (JPY); and Disaster Risk Reduction (DRR).

3. The “Kobe Lesson”

3.1. The Great Hanshin Earthquake (阪神 淡路大震災) of 17 January 1995

Kobe is located in western Japan and serves as the capital of Hyōgo Prefecture. It is among the ten most populous cities in the country, with approximately 1.5 million inhabitants. It lies in a strip of land between the Rokko mountain range and the Seto Inland Sea. Structurally, the city is constituted of an older city core which, at the time, was surrounded by newer districts. The older parts of the city were inhabited largely by elderly residents and were not efficiently connected with the newer areas of Kobe. Furthermore, in order to adapt to the local topography, large populations were concentrated in limited spaces, resulting in overcrowded neighborhoods and narrow streets [9,10]. These urban characteristics were not only morphological constraints, but also direct factors in the human toll of the disaster: aging building stock increased the likelihood of collapse and entrapment, narrow streets slowed rescue operations and restricted fire-fighting access, and dense urban fabric facilitated the spread of post-earthquake fires.

On the 17 January 1995, at 5:46 a.m. (local time), the earthquake struck the city. The epicenter was in the Strait of Akashi, near Awaji Island, around 15 km southeast of Kobe. The magnitude on the JMA scale was 7.3 and the ground shook for about 20 s [11]. In the days before the earthquake, some small tremors were recorded, but they were not considered foreshocks, only normal occurrences given the seismic nature of Japan. The combination of no real signs that a major earthquake was about to happen and the early morning hour caught the population completely off guard [12]. Many buildings in Kobe had been constructed before the revision of Japan’s seismic building code in 1981 and therefore did not meet modern earthquake-resistant standards [13]. In addition, numerous traditional wooden houses in the central districts were both structurally fragile and highly flammable, so that their collapse was often followed by widespread fires. Many of the traditional houses in central Kobe were built with heavy tiled roofs, weighing up to two tons, supported by only a few wooden pillars and lacking adequate lateral bracing [11]. This structural configuration made them highly vulnerable to horizontal seismic forces: once the pillars failed, the roof collapsed onto the lower parts of the house, producing a rapid, layered failure. This vulnerability was not limited to residential areas. The structural failure also severely crippled the city’s transport network: long sections of the elevated Hanshin Expressway collapsed or toppled over, cutting off vital transport and supply routes. The damage to highways was the most renowned and associated image of the earthquake, appearing on front pages worldwide, as most people believed these steel-reinforced concrete structures to be relatively safe [11]. However, it was later revealed that most of the collapsed structures were built correctly according to the older codes in force during the 1960s and 1970s. The steel-reinforcement specifications in those older regulations were inadequate for the seismic intensity experienced, demonstrating that the massive loss was a systemic failure of pre-1981 building codes which did not apply retroactively to existing critical infrastructure [13]. At several locations, severe fires broke out, and 7000 buildings were completely consumed, resulting in more than 800,000 m² of burnt areas [11]. The direct financial loss was estimated at approximately 10 trillion yen [9]. The disaster claimed over 6400 lives, injured 43,000 people, and displaced more than 300,000 residents, who had to find temporary shelter [10]. Numerous public facilities were destroyed such as hospitals, schools and offices. Electricity, water, and gas services were disrupted across the city, and approximately 25% of telephone lines were inoperative. The restoration of critical lifelines progressed at different rates. While some services were reestablished within a few days, complete restoration across the city took up to three months [10]. At the time of its occurrence, it represented the second most lethal earthquake of the twentieth cen-

ture in Japan, exceeded only by the 1923 Great Kantō Earthquake, which resulted in over 105,000 fatalities [9].

3.2. *Post-Disaster Adaptive Trajectories: From Immediate Response to Long-Term Civic Recovery*

3.2.1. The Role of Community Rescue

A great number of people immediately after the earthquake were helped or rescued by their families and friends. This spontaneous intervention marked the first step that defined the start of adaptive resilience. Different tools, such as crowbars and saws, were utilized by local residents to reach casualties through the wreckage [10].

A case study conducted in the Nishi Suma area, located in the western part of the city, clearly illustrated this reliance on self-help and social capital, a key determinant of community resilience in disaster contexts [10,14,15]. Nishi Suma was characterized by having many old residences and strong community bonds. Drawing on interviews and group discussions conducted as part of the case study, the authors estimated that 60 percent of residents were evacuated through their own efforts, and approximately 20 percent were rescued by neighbors [10,14]. This rapid community response was of fundamental importance and provided crucial partial support to the government and authorities, who were faced with a catastrophe of extreme magnitude on a city-wide scale, which significantly slowed down official mobilization. The authorities' actual slowness in mobilizing aid, due to the magnitude of the seismic impact on the entire city, highlighted that the pre-1995 protocols were completely inadequate for managing a modern urban disaster. This institutional gap acted as a catalyst for adaptation, dividing the post-disaster recovery process into two distinct but interconnected approaches, which converged in the city's adaptive resilience.

The government, as direct answer for the failure of the protocols and the necessity of raising prevention standards, launched a series of top-down (centralized) measures. First and foremost was the strengthening of building codes.

Japanese building regulations underwent a critical overhaul in 1981, prompted by the earthquake that struck in 1978 in Miyagi, a Japanese prefecture with approximately 2.4 million inhabitants, located in the Tōhoku region.

This regulatory evolution established two distinct classifications [13]:

- **Kyu-Taishin (旧耐震, Old Seismic Standard):** Buildings whose Construction Confirmation Certificate was issued prior to June 1, 1981. These structures were engineered to resist collapse during shaking corresponding to an intensity five on the Japanese Shindo scale.
- **Shin-Taishin (新耐震, New Seismic Standard):** Applied to construction projects initiated thereafter. This standard requires structures to withstand major structural damage from seismic events measuring six to seven in intensity on the Japanese Shindo scale, with the principal objective being the preservation of life.

The superior performance of the Shin-Taishin code was empirically demonstrated by post-event analyses, notably after the 1995 Great Hanshin Earthquake, where structures built following this principle showed higher survival rates [9].

A further revision to the seismic code was introduced in 2000, specifically targeting wooden residential buildings and reflecting the lessons learned from the 1995 Kobe earthquake. Although many timber houses built under the 1981 code were formally compliant, their extensive collapse and fire damage revealed the inadequacy of pre-2000 requirements. The 2000 revision therefore introduced much stricter performance criteria, so that only structures certified after this date can be considered significantly more earthquake-resistant. Consequently, most timber dwellings constructed between 1981 and 2000 do not meet the enhanced post-2000 standards [13] (Figure 3).

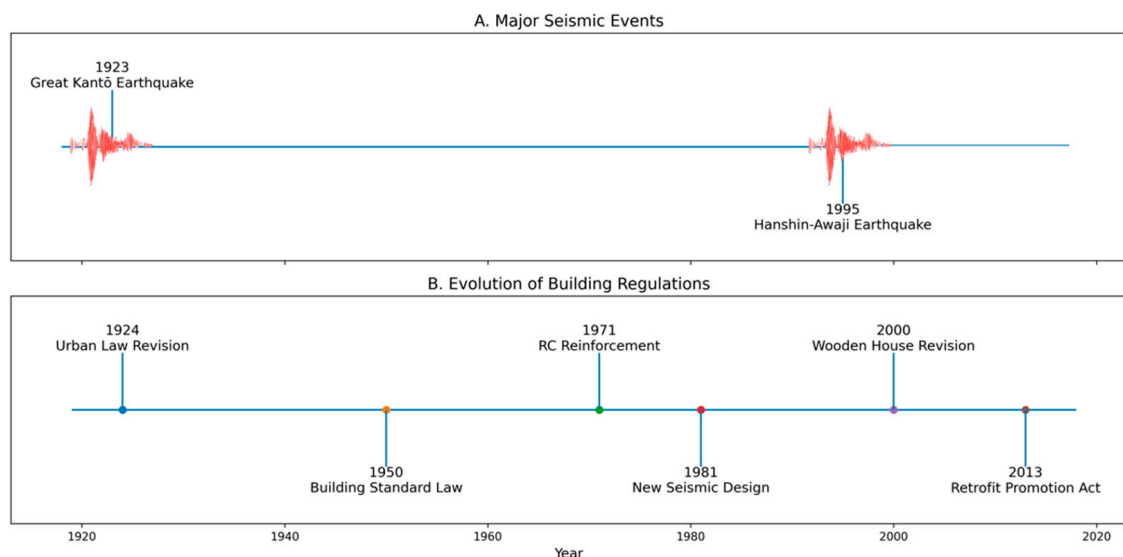


Figure 3. Major seismic events (A) and subsequent regulatory evolution (B) in Japan.

It is important to notice that the stability of a structure does not only depend on the design of it, but also depends on subsoil characteristics or conditions. Foundations situated on weak soil bases can significantly amplify ground motion, leading to substantial damage even in well-engineered structures [16].

Simple, robust, and regular (square or rectangular) building geometries generally demonstrate favorable dynamic responses. The port area in Kobe was severely affected by soil liquefaction, a phenomenon in which saturated, water-logged ground loses its strength and stiffness during intense seismic shaking and begins to behave like a fluid [16]. This loss of bearing capacity caused quay walls, cranes, and other port structures to tilt or deform, severely disrupting cargo operations and making vessel docking difficult, thereby hampering economic recovery efforts [11].

3.2.2. Technological Leap: From Resistance to Control and Isolation

While the Shin Taishin standard, also known as Taishin (耐震), mandates basic structural resistance primarily achieved through the rigid reinforcement of columns and shear walls, developments following the 1995 Great Hanshin Awaji (Kobe) earthquake spurred the adoption of advanced seismic technologies that today constitute the core design principles of antiseismic construction. In the case of reinforced concrete (RC) structures, this transformation did not consist merely in increasing structural strength, but in a broader shift in design philosophy. The lessons of Kobe showed that life safety alone was no longer considered a sufficient objective, particularly for residential and urban buildings. As a result, seismic design increasingly incorporated capacity design principles intended to control the location and nature of inelastic deformation, promote ductile failure mechanisms, and prevent brittle modes such as shear failure, beam–column joint failure, and soft-story collapse. In this framework, the objective was no longer limited to collapse prevention, but extended to maintaining damage within repairable limits under design-level earthquakes, thereby preserving residual structural capacity and improving post-earthquake functionality [17–19]. This paradigm shift therefore moved beyond mere collapse prevention towards ensuring rapid functional recovery and enhanced protection of non-structural elements [11]. In this context, functional recovery refers to the capacity of a building or infrastructure to resume acceptable use after an earthquake, even if limited repairs are still required.

As summarized in Table 2, Japanese seismic design evolved from resistance-based approaches, referred to as Taishin, to vibration-control systems, known as Seishin (制震), and base isolation strategies, referred to as Menshin (免震). Each approach is characterized by distinct mechanical principles and specific post-Kobe applications in both new construction and retrofitting strategies. Figure 4 provides a graphical overview of the three design configurations.

Table 2. Overview of the three main categories of Japanese seismic design systems—quake-proof (Taishin), seismic control (Seishin), and quake-absorbing/base-isolated (Menshin)—including their underlying engineering principles, fundamental mechanisms, and typical applications following the 1995 Kobe earthquake.

Structure	Japanese Term	Principle and Fundamental Mechanism	Kobe/Reactive Application	Tokyo/Proactive Application
Quake-proof	耐震 (<i>Taishin</i>)	Rigid structural resistance through strengthened columns, beams, and shear walls to withstand seismic forces.	Post-disaster strengthening and code-compliance reconstruction.	Baseline life safety solution for ordinary buildings.
Seismic control	制震 (<i>Seishin</i>)	Vibration damping through energy-dissipating devices that reduce structural motion during shaking.	Retrofit strategy to improve vulnerable structures after 1995.	Vibration-control solution for high-rise and dense urban buildings.
Quake-absorbing	免震 (<i>Menshin</i>)	Base isolation through bearings or sliding devices that decouple the structure from ground motion.	Limited but strategic use for critical reconstruction.	Preferred continuity-oriented solution for critical and high-performance buildings.

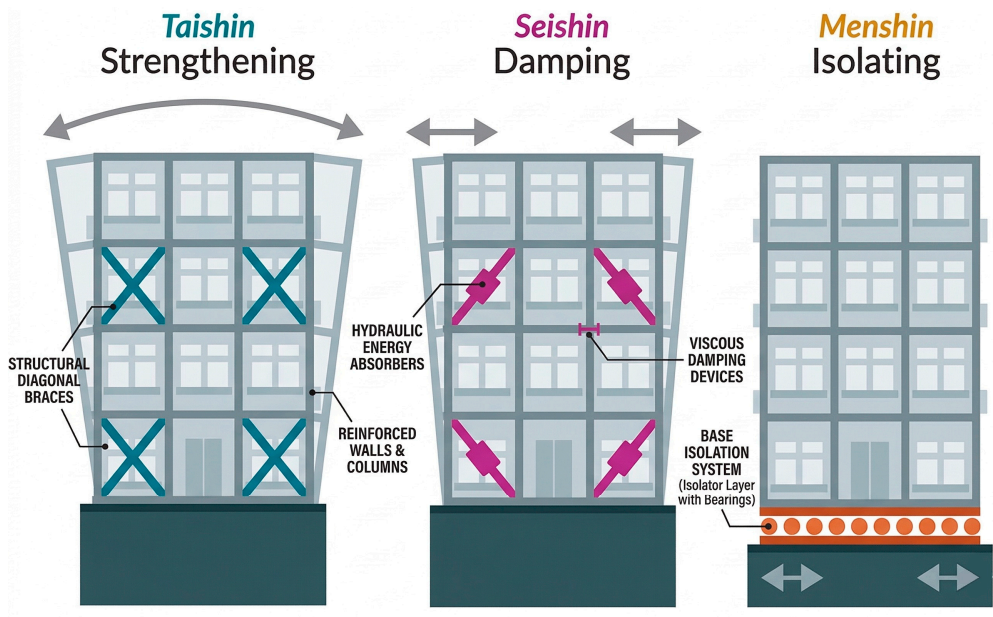


Figure 4. Graphic representation of the three main categories of Japanese seismic design systems.

Table 2 provides an overview of the three main categories of Japanese seismic design systems, namely quake-proof, seismic control and quake-absorbing structures, outlining their underlying engineering principles, fundamental mechanisms and typical applications following the 1995 Kobe earthquake.

In general, buildings that did not comply with the updated standards were either demolished and reconstructed or retrofitted to meet the revised codes, with interventions of varying intensity. Particularly stringent requirements were introduced for the reconstruction of lifelines and critical infrastructures, such as the Hanshin Expressway. These principles were embedded within an aggressive, no-compromise approach to structural reinforcement, characterized by robust and comprehensive regulatory measures [11].

3.2.3. Other Institutional Adjustments

Several institutional revisions were also introduced, particularly concerning protocols and assistance policies. Among the most significant was the revision of the Basic Disaster Prevention Law, which expanded the responsibilities of both local and central governments, making it mandatory to develop more detailed emergency plans and to establish strategic stockpiles of supplies [9]. In addition, responding to public discontent, fueled also by the fact that no mechanism existed to compensate individuals for disaster-related losses, the Act on Support for the Livelihood Recovery of Disaster Victims was introduced in 1998 [9]. Moreover, January 17 was officially designated as the national “Day of Volunteerism and Disaster Prevention,” not merely as a symbolic commemoration but as an institutional commitment to education-based preparedness. On this day, schools, communities, and local governments conduct seminars, training sessions, and public awareness activities, underscoring the idea that effective disaster prevention fundamentally relies on widespread instruction and civic engagement [10].

3.2.4. Bottom-Up Mobilization: Civic Discontent and Community Self-Empowerment

Parallel to governmental action, a strong bottom-up dynamic emerged as citizens reacted to the shortcomings of the official recovery narrative. Although authorities claimed that 80% of the physical reconstruction had been achieved—primarily in terms of infrastructure and lifelines—this statistic failed to account for the profound internal and social damage experienced by residents [10]. Many perceived a loss of community cohesion, a weakening of social bonds, and a deep psychological disorientation that physical reconstruction alone could not address. One of the main drivers of civic discontent was the bipolarization of affected districts. Reconstruction policies tended to prioritize certain “supported areas”, where public investment and technical assistance were concentrated, while leaving “unsupported areas” to rely largely on resident-led efforts. This uneven distribution of resources amplified frustration and reinforced the perception that recovery was progressing inequitably [10].

3.2.5. Socio-Economic Rehabilitation

Beyond physical rebuilding, many households struggled to regain economic stability. The absence of adequate financial support mechanisms (prior to the 1998 reforms) made socio-economic recovery slow and uneven [9]. For many communities, revitalization depended on the creation of new livelihoods, grassroots initiatives, and mutual aid networks capable of compensating for institutional gaps.

3.2.6. Reconstructing Fragmented Communities

The earthquake had disrupted long-established neighborhoods. Relocation policies, temporary housing arrangements, and the demolition of damaged districts contributed to the fragmentation of social networks [13]. Rebuilding “broken communities” became a

priority for residents, who viewed social cohesion as essential to long-term recovery. To address these challenges, civic organizations (NPOs and NGOs) assumed an increasingly central role. The spontaneous volunteer groups that emerged in the immediate aftermath of the disaster gradually evolved into structured entities.

The 1998 NPO Law provided a legal framework for these organizations, enabling them to operate formally, receive funding, and participate in policy discussions [10].

3.2.7. The People's Rehabilitation Plan (PRP, 1998)

Three years after the earthquake, citizens drafted the People's Rehabilitation Plan (PRP), a comprehensive proposal aimed at accomplishing the "remaining 20% of recovery": the social, economic, and communal dimensions that top-down policies had not addressed [9].

The PRP emphasized community-based planning, livelihood diversification, participatory decision-making, and the formation of a more active civil society. It represented one of the most significant examples of bottom-up recovery planning in postwar Japan.

At its core, the bottom-up response reflected a collective need to regain agency and restore a sense of control over the future, something that official reconstruction alone could not provide.

The case of Kobe illustrates how urban resilience can emerge after catastrophe through processes of learning, institutional reform, and civic self-empowerment. The Great Hanshin Earthquake of 1995 exposed the structural, social, and regulatory vulnerabilities of a modern Japanese city, triggering a profound transformation that unfolded through both top-down policy adjustments and bottom-up community mobilization. In this sense, Kobe represents a paradigmatic example of adaptive (or reactive) resilience: a form of resilience constructed retrospectively, shaped by damage, loss, and post-disaster experience.

In analytical terms, this adaptive trajectory can also be understood through recovery-based models of resilience, which define resilience not only by the capacity to withstand shock, but by the extent of functional loss, the duration of disruption, and the path through which urban systems return to acceptable levels of operation [20,21]. From this perspective, the Kobe case reveals that post-earthquake recovery was neither uniform nor linear: infrastructure, housing, local economies, and community networks recovered at different speeds and through partially overlapping phases. Frameworks such as Bruneau et al.'s "Resilience Triangle" are particularly useful in this regard, as they conceptualize resilience through the temporal evolution of functionality after disruption [20]. Applied to Kobe, such an approach highlights that urban resilience was expressed not as an immediate return to equilibrium, but as a staged and uneven process of restoration shaped by both institutional reform and civic self-organization [21].

4. From Field Lessons to the Tokyo Experience

The lessons derived from Kobe did not remain confined to the city itself. Instead, they became embedded in Japan's national approach to disaster risk governance, contributing to a broader shift from reactive adaptation toward anticipatory and preventive strategies [22]. This transition is particularly evident in the case of Tokyo, where resilience is increasingly conceived not as a response to a realized shock, but as a continuous process of preparation for a future, highly probable, catastrophic event.

This future-oriented perspective is closely linked to what is commonly referred to as the "Big One": a major megathrust earthquake expected to occur along the Nankai Trough, a subduction zone where the Philippine Sea Plate is converging beneath the Eurasian Plate along Japan's Pacific coast [6]. Scientific consensus does not frame the Big One as a spec-

ulative or hypothetical scenario, but rather as a probabilistic certainty within a defined temporal horizon. Historical records indicate that large-scale earthquakes in this zone recur cyclically, and contemporary seismic models estimate a high likelihood of a magnitude 8–9 event within the coming decades [9].

The anticipated characteristics of such an earthquake—including prolonged and intense ground shaking, widespread infrastructural disruption, and the generation of destructive tsunamis—pose systemic risks not only to coastal regions but to the entire national economy. The Tokyo metropolitan area, as the political, financial, and logistical core of Japan, would be indirectly but profoundly affected by such an event, even if the epicenter were located hundreds of kilometers away. For this reason, Tokyo’s resilience strategy cannot be understood through post-disaster recovery alone; it must instead be analyzed through the lens of pre-disaster planning and mitigation [23].

This approach corresponds to what can be defined as proactive resilience: a model in which urban systems are designed, regulated, and continuously upgraded to reduce vulnerability before a shock occurs. In Tokyo, proactive resilience manifests through stringent seismic building codes, large-scale retrofitting programs, advanced early warning systems [5], redundancy in critical lifelines, and a pervasive culture of disaster preparedness embedded in everyday urban life. Unlike Kobe, where resilience emerged as a response to institutional failure and social disruption, Tokyo’s resilience framework is built on institutionalized foresight, scenario-based planning, and the deliberate internalization of past disasters into present governance [23].

4.1. *From the Static City to the Adaptive City*

The transition from the static city to the adaptive city reflects a substantial transformation in the way urban environments are conceived and governed. The static city is grounded in an idea of stability and permanence: its forms, infrastructures, and functions are designed as fixed elements, intended to operate under predictable and relatively unchanging conditions. Within this model, urban planning responds to needs defined a priori, and risk is treated as an exception, to be addressed through corrective interventions after the critical event has occurred.

By contrast, the adaptive city recognizes change and uncertainty as structural conditions. It is not conceived as a finished object, but as a process in continuous evolution, capable of modifying itself over time in response to human needs, social transformations, and environmental risks. In this sense, adaptability does not merely coincide with formal flexibility, but with the ability of the urban system to absorb, reorganize, and transform its structures without collapsing.

This vision finds an important interpretative key in the distinction between the “static” city and the “dynamic” or “kinetic” city, in which the urban condition is not defined exclusively by permanent elements, but also by relationships, interactions, and continuous transformations. The dynamic city does not replace the static one, but rather reveals its limits, showing how urban intelligence increasingly lies in the capacity to manage transformations, interdependencies, and adaptation processes, rather than in the preservation of rigid spatial arrangements [24].

Within this perspective, the adaptive city aligns fully with the concept of evolutionary or proactive resilience: a form of resilience that is not activated only after a crisis, but that integrates risk into ordinary processes of planning, governance, and design [25]. The objective is not merely to withstand shock, but to anticipate it and reduce its systemic effects, acknowledging that the contemporary urban condition is inherently unstable and complex.

Modern urban infrastructures (electricity networks, transportation systems, and telecommunications) are in fact complex and highly interdependent systems. A localized failure, such as a blackout, can rapidly propagate to other systems, compromising the functioning of essential services such as water supply or communications [26]. As highlighted in contemporary resilience and disaster studies, systemic risks cannot be effectively addressed through individual responses alone, but require coordinated, collective action across infrastructures, institutions, and communities [15,26].

4.2. Integrated Version—Smart City and Six Enabling Technologies for Seismic Resilience

As defined by Murrone et al., a Smart City (SC) is a municipality in which communication networks and traditional urban services are made more efficient through digital and real-time solutions [27]. Within this framework, smartness is not an abstract technological condition, but a functional one: it depends on the coordinated use of a set of enabling technologies that operate as an integrated ecosystem. In seismic contexts, this ecosystem becomes particularly relevant, as it supports not only urban efficiency but also proactive earthquake prevention, monitoring, and response.

The Internet of Things (IoT), together with advanced connectivity infrastructures such as 5G, constitutes the city's nervous system, enabling the continuous connection of physical assets across the urban fabric. Through dense sensor networks embedded in buildings, bridges, and critical infrastructure, these technologies allow for real-time data acquisition of structural behavior, environmental conditions, and system performance [27]. Recent studies on IoT-based Structural Health Monitoring show that, in seismic environments, connected sensing systems can provide continuous information relating to vibrations, displacements, and structural anomalies, thereby supporting near-real-time damage identification and the prioritization of post-earthquake inspections [28,29]. In the context of seismic risk, this layer enables Structural Health Monitoring (SHM) and damage detection, providing immediate information regarding the integrity of the built environment before, during, and after an earthquake.

Sensors play a crucial role within this system by converting physical parameters—such as vibrations, displacements, and accelerations—into digital signals that can be interpreted by autonomous systems. Their integration into utilities and infrastructure networks supports early warning mechanisms and the rapid identification of critical failures, contributing to the reduction in cascading effects across interdependent urban systems. This function is consistent with recent research on earthquake-oriented IoT monitoring platforms, which emphasizes their value for rapid situational awareness and continuity planning in critical infrastructure [30].

Structural Health Monitoring (SHM) systems are the main framework through which sensor technologies are integrated into conventional buildings and infrastructure. In seismic applications, SHM uses devices such as accelerometers, displacement sensors, and strain gauges to collect data on the behavior of structures during and after earthquakes. In infrastructure such as bridges, viaducts, and transport networks, sensors are installed on key components including decks, piers, bearings, joints, and foundations. In buildings, they are distributed across structural elements such as floors, cores, columns, and beams, and, where present, on base isolation or damping devices. These systems allow for continuous or event-based data acquisition, providing a basis for rapid post-earthquake assessment, design verification, and long-term performance evaluation [31,32]. The high-fidelity records collected after the 2011 Tohoku Earthquake were especially important, as they documented the actual behavior of monitored buildings and bridges under strong ground motion and helped refine seismic design assumptions, retrofit strategies, and the understanding of controlled and isolated structural systems [32,33].

The massive volume of data generated by IoT and sensor networks, commonly referred to as Big Data, is processed through Artificial Intelligence (AI), which functions as the city's analytical core. AI enables pattern recognition, forecasting, and predictive modeling, allowing urban systems to anticipate potential damage scenarios and optimize resource allocation. In seismic risk management, this capability is central to forecasting, simulation, and scenario analysis, including the use of digital twins to model earthquake impacts and test mitigation strategies in advance. More specifically, recent studies demonstrate that machine learning and deep learning can be used for rapid post-earthquake structural damage assessment, including the classification of component-level and building-level damage states in reinforced concrete and other building types, thus significantly accelerating emergency assessment workflows [34–36].

Cloud and Edge computing provide the computational backbone required to process and distribute this information efficiently, either remotely or locally, ensuring systems' functionality even under degraded conditions. Their role is particularly critical during seismic events, when real-time processing and redundancy are essential to maintain operational continuity, particularly in critical infrastructures such as transportation networks, whose post-disaster performance has proven decisive in past events such as the 1995 Kobe earthquake [37]. Complementing this layer, Blockchain technologies introduce secure and transparent data management mechanisms, supporting trust, decentralization, and reliability in the governance of essential services, such as energy distribution and emergency coordination [27]. At the same time, these technologies do not all have the same degree of operational maturity. Sensor networks, SHM systems, and early warning infrastructures are already embedded in contemporary seismic risk management, whereas other tools—such as AI-supported predictive platforms, digital twins, and Blockchain-based governance applications—remain more unevenly implemented and, in some cases, are still being developed through pilot or experimental initiatives.

Together, these enabling technologies do not operate as isolated tools, but as interconnected layers of a single system aimed at enhancing urban resilience. Their combined function supports emergency communication, decision-making processes, and the rapid mobilization of resources, ensuring that the city's critical “nervous system” remains operational under extreme stress. In this sense, the Smart City model is not only a framework for urban efficiency, but also a seismic-specific architecture for rapid damage assessment and automated response. Research on earthquake early warning and automated alerting systems further shows that digital networks can directly activate protective actions and shorten the interval between seismic detection and infrastructural response [38].

As outlined in [23], Tokyo is pursuing a Smart City model explicitly oriented toward resilience and disaster preparedness, supported by interdisciplinary and industry-academia collaborations aimed at enhancing metropolitan-scale disaster resilience [23,39]. Rather than prioritizing convenience alone, advanced technologies are strategically deployed to secure the city against earthquakes, floods, and large-scale power disruptions, with the declared objective of guaranteeing “safety for the next 100 years.” By reinforcing digital and physical infrastructures and ensuring the continuity of communication and power networks during crises, Tokyo exemplifies a defensive Smart City, where technological innovation functions as a protective layer designed to safeguard human life and maintain systemic stability in the face of seismic risk.

4.3. Earthquake Early Warning (EEW) and J-Alert: Reducing Latency Between Detection and Response

At the core of Tokyo's communication strategy lies the Earthquake Early Warning (EEW) system, operated by the Japan Meteorological Agency. The primary objective of this protocol is the minimization of latency between seismic detection and population re-

sponse. When seismic sensors detect the arrival of primary (P) waves, preceding the more destructive secondary (S) waves, the system instantaneously triggers a J-Alert message that is broadcast directly to personal devices within the affected area [9].

The alert is designed to be impossible to ignore; smartphones emit a distinctive, high-intensity sound and display a short, standardized message instructing citizens to remain calm and seek immediate shelter nearby. The effectiveness of the protocol lies precisely in its simplicity. Rather than overwhelming users with technical information, the system prioritizes clarity, urgency, and behavioral guidance, ensuring that even a few seconds of warning can be converted into life-saving action [9].

Simultaneously, the protocol activates a series of automatic safety measures that operate independently of human intervention. Elevators are halted at the nearest floor, high-speed trains such as the Shinkansen are automatically decelerated and stopped, and gas valves are shut off to prevent fires—one of the primary causes of fatalities during the 1995 Kobe earthquake. In this way, the alert system functions not only as a communication tool, but as a coordinated mechanism linking human behavior and infrastructural response [23].

4.4. Managing Interdependencies: From Monitoring to Decision Support

Beyond early warning, Tokyo's proactive resilience strategy addresses the interdependence of urban systems, recognizing that seismic risk extends far beyond ground shaking. Through IoT-based sensor networks, buildings and infrastructures continuously report their structural condition to centralized control centers, enabling real-time Structural Health Monitoring and rapid damage assessment [27].

These data streams are processed by decision support systems (DSS), which analyze incoming information to prioritize emergency actions: determining which roads must be closed, which hospitals require immediate energy supply, and how resources should be distributed across the metropolitan area [23]. Acting as a form of “digital brain,” these systems support authorities in managing cascading failures and preventing localized damage from escalating into systemic collapse (Figure 5) [26].

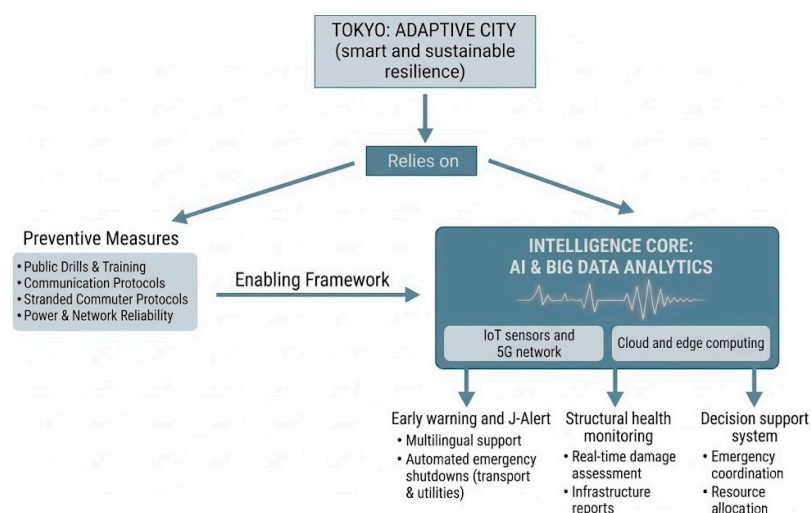


Figure 5. Smart City resilience in Tokyo: integrated technologies for seismic risk management. Conceptual framework of an adaptive, resilience-oriented Smart City for seismic risk management, using Tokyo as an illustrative case. The figure depicts the transition from a static to an adaptive urban model and the integration of enabling technologies (IoT, 5G, AI, Big Data, and Cloud/Edge computing) into a unified socio-technical system. Earthquake early warning, Structural Health Monitoring, and decision support systems are represented as interconnected layers supporting proactive resilience, infrastructure continuity, and the mitigation of cascading failures within complex urban systems.

A particularly significant example of protocol-driven resilience is the management of stranded commuters (*kitaku konnan-sha*). Recognizing that millions of people could be unable to return home after a major earthquake, Tokyo has established mandatory protocols requiring public and private buildings to stock food, water, and basic supplies for non-residents [23]. This measure directly addresses social vulnerability and prevents secondary crises generated by mass displacement and infrastructural paralysis.

4.5. Limits and Critical Issues of Proactive Technological Resilience

However, the effectiveness of proactive seismic resilience does not depend solely on the availability of advanced technologies, but on their capacity to be translated into clear, rapid, and actionable human responses. Technological systems remain ineffective if they are not supported by well-defined communication protocols capable of transforming technical data into collective behavior under extreme conditions [40]. In this sense, communication, training, and institutional preparedness are as critical as sensing and monitoring technologies.

A central challenge in highly prepared urban contexts is the management of overconfidence in and over-reliance on technology. In cities characterized by advanced infrastructures and long periods without major disasters, there is a latent risk that citizens may assume that automated systems alone will ensure their safety. Tokyo explicitly seeks to counter this tendency through continuous public information campaigns, evacuation drills, and emergency simulations [23]. Schools, workplaces, and public institutions regularly conduct training exercises to maintain disaster awareness and ensure that alerts are immediately associated with appropriate behavioral responses.

A further limitation concerns the long-term feasibility of proactive seismic technologies across the building lifecycle. Systems such as seismic control and, above all, base isolation offer superior performance in terms of damage reduction and functional continuity, but their effectiveness depends on regular inspection, maintenance, and, where necessary, replacement of key components over time [40,41]. Their adoption therefore requires not only technical expertise, but also sustained financial and institutional capacity. From a lifecycle perspective, higher initial costs may be offset by lower repair costs, reduced downtime, and improved continuity of critical services, especially in strategic buildings such as hospitals, emergency facilities, and major headquarters [40,42]. However, this cost-benefit balance is not uniform across all building types. In ordinary buildings or in contexts with limited maintenance capacity, highly sophisticated systems may prove less feasible in the long term than more conventional reinforcement strategies [40,41].

In addition to these behavioral and economic constraints, proactive systems also face operational limitations during extreme events. In the case of inland earthquakes with epicenters located very close to the urban area, the time gap between detection and strong shaking may be reduced to only a few seconds, limiting the effectiveness of human-centered response protocols [7]. Similarly, widespread power outages or network congestion may partially disrupt digital communication, potentially returning the city to conditions of informational isolation.

The Tokyo case thus demonstrates that proactive resilience is not a purely technological achievement, but a socio-technical balance. Technology can reduce vulnerability and support rapid response, but only when embedded within clear protocols, informed populations, and a continuous culture of preparedness. The transformation of technical data into effective human action remains the decisive factor in preventing systemic collapse during a major seismic event [43].

5. Perspectives: Urban Seismic Resilience Through the Lens of Disaster Risk Reduction Policy

The comparative trajectories of Kobe and Tokyo can be critically reinterpreted through the framework of the international Disaster Risk Reduction (DRR) policy, particularly the Sendai Framework for Disaster Risk Reduction 2015–2030. Adopted by the United Nations General Assembly in 2015, the Sendai Framework represents a paradigmatic shift from disaster response toward proactive risk governance, emphasizing prevention, preparedness, and resilience as core objectives of sustainable development [44].

5.1. Aligning Reactive and Proactive Resilience with the Sendai Framework

The Kobe case exemplifies the Sendai principle of “Build Back Better”, articulated under Priority 4 (Enhancing disaster preparedness for effective response and to “Build Back Better” in recovery, rehabilitation and reconstruction) [44]. Post-1995 reconstruction policies, strengthened seismic codes, institutional reforms, and the legal recognition of civil society organizations reflect a concrete operationalization of this principle, even before its formal codification. Kobe’s trajectory illustrates how post-disaster recovery can serve as a laboratory for institutional learning, regulatory upgrading, and social innovation, transforming catastrophe into a driver of systemic resilience [45].

Tokyo, by contrast, aligns more closely with Priority 1 (Understanding disaster risk) and Priority 2 (Strengthening disaster risk governance) [44]. Its extensive seismic monitoring networks, probabilistic hazard modeling, early warning systems, and scenario-based planning reflect an advanced capacity to translate scientific knowledge into policy and operational preparedness. The integration of Earthquake Early Warning (EEW), automated infrastructure response, and population-wide training exercises demonstrates how anticipatory governance can reduce exposure and vulnerability before disaster occurs [22], consistent with Sendai’s emphasis on prevention rather than reaction.

5.2. Governance, Institutions, and Multi-Level Responsibility

A core lesson emerging from the Kobe–Tokyo comparison is the centrality of risk governance as defined by the Sendai Framework. Effective urban resilience depends on coordinated action across national, metropolitan, municipal, and community levels, with clearly defined roles and accountability mechanisms. The failure of pre-1995 emergency protocols in Kobe revealed the consequences of fragmented governance and insufficient local preparedness, whereas subsequent reforms strengthened the coordination between central government, local authorities, and civil society [22].

Tokyo’s resilience strategy further demonstrates the importance of institutional continuity and regulatory enforcement, particularly in land-use planning, building regulation, and infrastructure management. These measures directly address one of the Sendai Framework’s core concerns: the reduction in disaster risk drivers, including poorly planned urban development, aging infrastructure, and systemic interdependencies [44].

5.3. Technology as an Enabler of DRR, Not a Substitute for Governance

From a policy perspective, the Japanese experience underscores that advanced technologies—such as IoT-based monitoring, AI-driven decision support systems, and digital early warning platforms—should be interpreted as enablers of DRR policy, rather than as standalone solutions. The Sendai Framework explicitly calls for the use of science and technology to support decision-making, while warning against technocratic approaches disconnected from social realities [44].

Tokyo’s Smart City-oriented resilience model illustrates this balance: technological systems are embedded within legally defined protocols, public communication strategies,

and continuous training programs. This socio-technical integration mitigates the risk of over-reliance on automation and addresses a recognized challenge in DRR policy—namely, the translation of technical risk information into timely, appropriate human action [4].

5.4. Social Capital, Participation, and Inclusive Resilience

A further policy-relevant perspective concerns the role of social capital and community participation, which are explicitly recognized in the Sendai Framework as essential components of resilience [44]. Kobe's bottom-up recovery processes, including volunteer mobilization, NPO institutionalization, and the People's Rehabilitation Plan, demonstrate how civic engagement can compensate for institutional gaps and enhance long-term recovery outcomes.

This dimension resonates with a growing body of DRR literature emphasizing that resilience is unevenly distributed and socially constructed. Policies that neglect community agency risk reinforcing vulnerabilities rather than reducing them [15]. Japan's post-Kobe evolution illustrates how participatory mechanisms can be progressively formalized within governance structures, transforming spontaneous solidarity into durable institutional capacity [12].

5.5. Implications for Global Urban DRR Policy

Taken together, the Kobe and Tokyo experiences suggest that effective urban seismic resilience requires hybrid DRR strategies combining (a) anticipatory risk governance and scientific forecasting, (b) robust regulatory and institutional frameworks, (c) socio-technical systems capable of managing interdependencies, and (d) sustained investment in public awareness and civic participation.

Rather than offering a universal model, the Japanese case provides a transferable policy logic consistent with the Sendai Framework: resilience must be embedded in everyday governance, urban planning, and infrastructure management, while remaining adaptable to local contexts and evolving risks [29]. For rapidly urbanizing regions exposed to seismic hazards, these insights reinforce the need to shift from emergency-centered disaster management toward integrated, prevention-oriented DRR policies. At the same time, the transferability of Tokyo's proactive resilience model must be approached with caution. Many of its defining features—advanced sensor networks, large-scale retrofitting programs, redundant lifelines, and highly institutionalized preparedness protocols—depend on long-term public investment, strong regulatory enforcement, and a high degree of coordination across government, infrastructure operators, and private actors. These conditions may be difficult to reproduce in lower-income or rapidly urbanizing cities, where financial resources, maintenance capacity, data infrastructures, and planning continuity are often more limited. For this reason, the global relevance of the Tokyo case lies less in the direct replication of its technological sophistication than in the broader policy logic it embodies: integrating risk reduction into everyday governance, prioritizing critical infrastructures, strengthening preparedness culture, and aligning technological tools with realistic institutional and social capacities.

5.6. Urban–Architectural Foundations of Reactive and Proactive Seismic Resilience

The divergence between reactive and proactive resilience in Kobe and Tokyo is rooted in fundamentally different urban and architectural paradigms, which shape not only how damage propagates during seismic events, but also how cities are expected to function spatially and operationally in their immediate aftermath. In Kobe, the pre-1995 urban fabric was characterized by compact morphology, narrow street sections, limited open-space redundancy, and a heterogeneous building stock developed incrementally over time. While efficient under ordinary conditions, this configuration proved highly vulnerable un-

der seismic stress: evacuation routes were easily obstructed, fire spread was facilitated by spatial continuity, and emergency access was severely constrained. The urban system, conceived primarily for everyday efficiency rather than disruption, exhibited a limited capacity to absorb shock, resulting in a resilience trajectory that emerged retrospectively through reconstruction, retrofitting, and selective spatial reconfiguration.

By contrast, Tokyo's proactive model is grounded in an anticipatory urban logic in which seismic risk is treated as a permanent design condition rather than an exceptional event. Metropolitan-scale planning integrates hierarchical street networks, distributed open spaces, and infrastructural redundancy as intrinsic spatial attributes, while architectural typologies are conceived to retain partial functionality during strong ground motion. Solutions such as base isolation, refuge floors, and structurally legible forms are not add-on safety measures, but core components of an urban system designed to operate under disruption. As a result, the expected seismic response differs substantially: Kobe's resilience is activated after damage has occurred, through spatial correction and institutional learning, whereas Tokyo's is designed to function during and immediately after the shock, limiting systemic disruption and preventing cascading failures.

This contrast illustrates that seismic resilience is not solely a matter of engineering performance, but a spatial property embedded in urban form, architectural typology, and the temporal horizon of planning itself. Table 3 synthesizes these differences across key urban–architectural dimensions.

Table 3. Reactive and proactive urban–architectural seismic resilience models in Kobe and Tokyo. Comparative synthesis of reactive (adaptive) and proactive (anticipatory) seismic resilience in Kobe and Tokyo across key urban and architectural dimensions, including planning temporality, urban morphology, infrastructural redundancy, architectural typologies, and expected post-event functionality.

Analytical Dimension	Kobe Reactive (Adaptive) Resilience	Tokyo Proactive (Anticipatory) Resilience
Temporal logic of planning	Ex post adaptation following catastrophic failure; resilience constructed after the seismic event	Ex ante planning based on probabilistic seismic scenarios; resilience embedded before the event
Urban morphology	Compact, fine-grained fabric with narrow streets and limited spatial redundancy	Hierarchical, multi-scalar urban structure with planned redundancy
Street network	Discontinuous and highly vulnerable to blockage due to collapse and debris	Designed as a resilient lifeline system with multiple alternative routes
Open-space system	Insufficient and unevenly distributed; redefined after 1995 as evacuation and firebreak infrastructure	Strategically planned, hierarchical evacuation spaces integrated into the metropolitan structure
Building stock composition	Heterogeneous and aging, largely pre-1981, developed incrementally	Strongly regulated, continuously retrofitted, and performance oriented
Architectural typologies	Low-rise wooden houses and mid-twentieth-century reinforced-concrete buildings with limited seismic legibility	High-rise and mixed-use typologies incorporating refuge floors, base isolation, and clear structural expression

Table 3. Cont.

Analytical Dimension	Kobe Reactive (Adaptive) Resilience	Tokyo Proactive (Anticipatory) Resilience
Design philosophy	Collapse prevention as the minimum objective; frequent loss of functionality after impact	Functional continuity and rapid post-event operability as core objectives
Building city relationship	Buildings dependent on external rescue and post-event intervention	Buildings conceived as semi-autonomous resilience units
Role of redundancy	Introduced retrospectively through reconstruction and selective urban widening	Embedded structurally and spatially at building, district, and metropolitan scales
Expected seismic response	Delayed recovery dominated by debris clearance, rebuilding, and social reorganization	Immediate response with reduced disruption and controlled degradation
Resilience activation	Triggered by damage and institutional learning	Activated during the event through design, form, and spatial logic
Urban resilience model	Adaptive and corrective; resilience as a learning outcome	Preventive and evolutionary; resilience as a permanent urban condition

From a theoretical standpoint, the divergence between reactive and proactive seismic resilience reflects a deeper shift in how urban form is conceptualized in relation to risk. Kevin Lynch's theory of urban legibility emphasizes that clearly structured systems of paths, nodes, edges, and districts enhance everyday orientation and spatial understanding, with important implications for cognitive and physical performance under stress conditions [46]. In seismic contexts, legible urban environments facilitate intuitive movement, rapid evacuation, and effective emergency response, whereas fragmented and morphologically dense fabrics—such as those characterizing pre-1995 Kobe—tend to lose intelligibility once disrupted, amplifying disorientation and delay.

This interpretation is further reinforced by spatial syntax theory, which demonstrates that the configurational properties of street networks—particularly levels of integration and connectivity—directly condition movement potential and accessibility [47]. Earthquake damage disproportionately affects poorly integrated secondary networks, intensifying spatial isolation and delaying rescue operations. From this perspective, the post-Hanshin reconfiguration of Kobe's street hierarchy can be interpreted as an *ex post* correction of syntactic vulnerabilities, whereas Tokyo's anticipatory planning embeds spatial integration and redundancy as structural prerequisites of resilience.

This transition aligns with Bernardo Secchi's interpretation of the contemporary city as an open and adaptive system, in which resilience arises from the capacity to absorb uncertainty, tolerate partial failure, and reorganize without systemic collapse [48,49]. Within this framework, the city is no longer conceived as a stable artifact, but as a relational field in continuous transformation.

Such a theoretical evolution is fully consistent with the principles of the Sendai Framework for Disaster Risk Reduction, which explicitly identifies urban form, land-use planning, and infrastructure concentration as key drivers of disaster risk [44]. Seismic resilience therefore emerges not as a purely engineering outcome, but as an urbanistic property produced through form, connectivity, and multi-scalar redundancy, positioning architecture and urban design as central instruments of disaster risk governance rather than as ancillary post-event responses.

5.7. Multi-Hazard Seismic Scenarios and the Resilience of Critical Infrastructure

A realistic understanding of seismic resilience requires moving beyond the assumption of a single earthquake event. In practice, critical infrastructures may be exposed to compound, sequential, and time-dependent hazards, whose interaction can substantially modify structural performance and post-event functionality. This perspective is especially relevant in earthquake-prone contexts such as Japan, where urban resilience depends not only on resistance to ground shaking, but also on the continuity of transport networks and other interdependent systems.

A key implication of recent studies is that vulnerability is not static. It evolves over time because of deterioration processes, such as corrosion, and because damage caused by an initial event may reduce residual capacity before a subsequent one occurs. This is evident in earthquake–scour interactions, where flood-induced scour may weaken bridge foundations before seismic shaking takes place, and in earthquake–corrosion conditions, where aging and material degradation progressively reduce structural strength and ductility [50,51]. A further issue concerns mainshock–aftershock sequences, in which the aftershock acts on a structure already damaged by the main event, increasing the probability of severe damage, collapse, or prolonged service interruption [52]. In coastal areas, earthquake–tsunami interactions further show how hydrodynamic loading may amplify the effects of prior seismic damage [53]. More generally, recent multi-hazard fragility studies confirm that damage accumulation, aging, and coupled hazards may significantly alter vulnerability patterns [54].

In the context of this article, this perspective reinforces the idea that urban seismic resilience in Japan depends on the capacity to anticipate cumulative damage, cascading effects, and infrastructure interdependencies through planning, monitoring, maintenance, and preparedness. The main multi-hazard scenarios and their principal effects are summarized in Table 4.

Table 4. Multi-hazard seismic scenarios relevant to critical urban infrastructure. Comparative synthesis of major coupled and sequential hazards—such as earthquake–scour, earthquake–corrosion, mainshock–aftershock sequences, and earthquake–tsunami interactions—and their principal effects on structural vulnerability and resilience.

Multi-Hazard Scenario	Main Effect
Earthquake + scour	Scour weakens bridge foundations before shaking occurs, which can significantly increase seismic fragility, displacement demand, and the probability of local or global failure compared with earthquake-only conditions [50].
Earthquake + corrosion	Corrosion progressively reduces stiffness, strength, and ductility over the lifecycle; when combined with seismic loading, it leads to higher fragility and lower residual structural capacity than assumed in non-deteriorated models [51].
Mainshock–aftershock sequences	Sequential seismic events produce cumulative damage, reduce residual capacity after the mainshock, and may markedly increase collapse probability and recovery time relative to single-event assessment [52].
Earthquake + tsunami	In coastal settings, tsunami loading may act on structures already damaged by the earthquake; this sequential interaction can intensify loss of stiffness, damage accumulation, and disruption of transport connectivity and emergency access [53].
Other coupled or cascading conditions (e.g., earthquake + flood, liquefaction, power/network failure)	Combined hazards and cascading failures can extend damage beyond the initial shaking, affecting interdependent lifelines, delaying emergency operations, and reducing overall urban recovery capacity [54].

In relation to the comparative framework developed in this paper, the inclusion of a multi-hazard perspective strengthens the distinction between reactive and proactive resilience. A reactive model may be effective in reconstruction after a major event, but it remains limited if it does not account for the possibility of cascading and compound disruptions. By contrast, a proactive model incorporates multi-hazard knowledge into planning, retrofitting, monitoring, and emergency management before disaster occurs.

5.8. Health Emergency Preparedness as Urban Risk Governance

The Kobe–Tokyo comparison has direct implications for health emergency and disaster risk management (Health EDRM): Kobe (1995) showed that earthquake mortality and morbidity are strongly shaped by health system fragility in the acute phase, not only by hazard intensity. Post-event reviews from Japan’s Ministry of Health emphasized that “preventable deaths” occurred when medical needs outpaced the available surge capacity, compounded by lifeline failures, uneven injury distribution, and delayed external medical support—highlighting the central public health priority of time-critical continuity of care. These gaps catalyzed the development of a national disaster medical architecture, including disaster base hospitals, emergency medical information systems, aeromedical evacuation, and rapid-deployment clinical teams (DMAT) as core components of Japan’s National Disaster Medical System [55,56]. In practical terms, Kobe reframes “preparedness” as a measurable capability: (i) hospital functional resilience (power, water, and communications), (ii) rapid field triage and inter-facility coordination, and (iii) wide-area patient distribution to avoid local collapse—capabilities now embedded in training and doctrine for Japan’s DMAT model [56,57].

Tokyo’s preparedness model operationalizes these lessons through a people-centered risk communication + system continuity approach consistent with the Sendai Framework (Priority 4: preparedness and “Build Back Better”) [44] and WHO’s Health EDRM framework (whole-of-system, multi-sectoral prevention–preparedness–response–recovery) [43,58]. First, Tokyo’s public health risk governance explicitly plans for a high-probability, high-impact scenario (e.g., metropolitan planning assumptions including major shaking and secondary risks) [23]. Second, Tokyo leverages early warning as a health intervention: JMA’s Earthquake Early Warning system is built on the rapid detection of P-waves and dissemination before stronger S-waves arrive, converting seconds into preventable-injury reductions when coupled with standardized protective actions [59]. Third, Tokyo tackles a distinctly “urban” public health threat revealed by past disasters: mass stranded populations that can obstruct emergency response and generate secondary harms (injuries, exposure, and interrupted access to medicines). The Metropolitan Tokyo ordinance on stranded individuals institutionalizes a 72 h “stay” principle and shared responsibilities across public and private sectors (temporary sheltering, supplies, information), which is best interpreted as population health surge management rather than simple crowd control.

Finally, the Kobe experience also clarifies that preparedness is not purely technical: social capital and organized civic participation measurably strengthens survival and recovery, and Kobe is a canonical case of how volunteerism and community organization can become durable capacity after institutional stress [10,15]. For Tokyo, the implication is that advanced systems (codes, sensors, warnings, and logistics) must be paired with equity-focused community readiness—targeting older adults, people with disabilities, tourists/commuters, and those dependent on chronic therapies—so that continuity plans and “stay” policies do not inadvertently shift risk onto the most vulnerable.

6. Conclusions

This paper has examined urban seismic resilience in Japan through a comparative analysis of two emblematic cases: Kobe, shaped by reactive adaptation after the 1995 Great Hanshin Earthquake, and Tokyo, characterized by a proactive and anticipatory resilience strategy oriented toward future catastrophic risk. The comparison shows, first, that urban seismic resilience is neither spontaneous nor static, but rather the outcome of cumulative processes involving institutional reform, technological innovation, spatial adaptation, and social transformation. Kobe demonstrates how disaster can expose latent structural, regulatory, and social vulnerabilities, thereby triggering profound changes in building codes, governance frameworks, and civic participation. Tokyo, by contrast, illustrates how past disasters can be internalized into continuous preparedness, advanced monitoring systems, and a pervasive culture of risk awareness.

Second, the study identifies a significant conceptual distinction between reactive and proactive resilience. Kobe exemplifies a predominantly reactive and adaptive model, in which resilience emerged after catastrophe through reconstruction, regulatory change, and strong community mobilization. Tokyo instead represents a more proactive and anticipatory model, in which resilience is embedded before disaster through planning, redundancy, monitoring systems, and long-term risk governance. In this respect, one of the main contributions of the paper is to show that the transition from a static urban condition to an adaptive city is central to understanding resilience in seismic contexts.

Third, the Japanese case confirms that urban seismic resilience should be understood as a socio-technical achievement rather than a purely engineering outcome. Resilience depends not only on structural safety, but also on the interaction between governance capacity, civic participation, technological systems, and infrastructural continuity. Social capital and community networks remain indispensable, since they often provide the first layer of support, rescue, and recovery when institutional systems are under stress. At the same time, redundancy across infrastructures, communication systems, and decision-making arrangements is essential to prevent localized damage from escalating into wider urban failure.

Finally, the broader significance of this study lies in showing that earthquake resilience should not be interpreted simply as the capacity to return to a pre-disaster condition. Rather, resilient cities evolve toward safer, more inclusive, and more adaptive urban systems capable not only of withstanding shocks, but also of learning from them. In this sense, the Japanese experience offers lessons of wider relevance for other seismic regions facing increasing uncertainty, infrastructure interdependence, and compound risks.

This study also has some limitations, which help indicate promising directions for future research. The analysis is primarily comparative and interpretative, rather than quantitative, and it focuses on two emblematic Japanese cases that have strong heuristic value but cannot fully represent the diversity of seismic urban contexts. Future studies could therefore extend the comparison to a broader set of Japanese and international cities, develop more structured indicators for the comparative assessment of urban seismic resilience, and further explore the relationships among urban governance, infrastructural interdependence, and multi-hazard conditions.

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