Business Continuity in Data Centers and Seismic Isolation Applications

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ABSTRACT

Economic losses from earthquakes raised many questions regarding the adequacy of the current seismic design and seismic isolation in data centers. Organizations accommodated new explicit seismic isolation applications in their business continuity and disaster recovery plans. These applications aim acceptable damage levels that correspond to acceptable business interruption for data centers in case of an earthquake. In this study, the authors aim to discuss the importance of seismic isolation applications that can be implemented for data centers within business continuity and disaster recovery planning contexts. To provide a clearer aspect on seismic isolation applications, the topic has been discussed within the framework of international standards. They conclude that GSA, ASCE, and Uptime Institute provide internationally recognized standards which make raised floors a good option for data centers. These standards provide technical documentation for service functioning with high levels of availability during an outage.

KEYWORDS

Business Continuity, Data Centers, Information Technologies, Seismic Isolation

INTRODUCTION

Data storage capabilities of businesses depend on the characteristics of computer components and storage infrastructure as well as demand for data traffic and high-speed access. To protect the data properly and enable businesses to operate towards business needs, controlled environments with suitable infrastructures are essential (Lemahieu et al., 2018). These environments are consolidated with computer and network hardware including web and application servers, storage subsystems and application software for suitable management of gathering, storing, processing, recovering and distributing the data. Information technology (IT) initiatives can lower the costs of business operations and sustain the functions in data storage environments. In accordance with international standards, an architectural approach that relies on the design of location and arrangement of energy, telecommunication, climatization and automation is required (Dutta et al., 2015). These applications are utilized under “data center” framework. Cocchiara et al. (2008) state that most business systems are mission-critical and there is an increasing need for investments in data center facilities and related technologies.

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Data centers play a vital role to respond data services requests of businesses. They provide a flexible environment and constant communication for all types of large quantities of data to meet the demands of both traditional and internet based companies. These massive networking infrastructures are complex, well secured facilities to house all of the information related to the business operations. As shown in Table 1, Cisco (2018) reports that global data center traffic is estimated to quadruple by 2021 and the data center workloads will nearly triple by 2021. These strategic computing resources have various areas that connect physical components such as high performance computers, servers, caches, switches, firewalls and other networking hardware with cables and fibers. As an IT initiative, the business goals of the data centers include business continuance, security, integration of applications and data storage consolidation (Arregoces and Portolani, 2004). These goals address a strategic direction for businesses and provide a quantifiable impact on operations.

The primary purpose of the data centers is to provide suitable storage conditions and access to data in desired time and speed (Inmon et al., 2019). Hardware, software, electrical and mechanical infrastructure, cooling and fire extinguishing systems, direct current physical environment safety, and disaster scenarios are considered critical facilities to support data server resources and network infrastructure. IDC (2018) also points out that the annual growth rate of global investments in data center infrastructure will reach almost 30 percent by 2021. Some appropriate precautions should be set for 24/7 data flow and access in case of a possible disaster. The most common precautions for disaster scenarios are data center resilience and redundancy infrastructure systems, applications, and data center restore systems (Schmidt, 2006).

Risk management in IT and associated computing services are fundamental requirements for the continuity of the operations and communication capabilities of an organization. Engemann and Henderson (2012) propose a management plan that focuses on exploring the threats to IT services resilience. The plan assesses the risks that impact business operations and enables the businesses to continue their critical functions and operations during or after the crisis, resulting the field of Business Continuity (BC) management.

Physical and software assets of a data center are the main source of the risk that cause damage to the organization. The risks and related threats should be managed before the strike and they should be mitigated with different precautions on data center infrastructure. Unexpected threats or natural disasters such as earthquakes, floods, and hurricanes negatively affect a data center and its facilities, resulting in business failure. For example, serious hardware or environmental damages may occur after a seismic activity in the data center location. This may cause an important data loss or unavailability of systems and services. In such cases, being unable to provide access to data may prevent businesses

Table 1. Global Data Center Statistics

Year	Number of cloud data centers	Number of traditional data centers	Total number of data centers	Total data stored in data centers (in exabytes)	Data center total workloads (in millions)
2016	5991	828	6819	286	241.5
2017	8190	897	9087	397	303.8
2018	10606	952	11517	547	371.8
2019*	13127	997	14124	721	432.4
2020*	16086	1030	17116	985	495.4
2021*	19509	1046	20555	1327	566.7

*estimated numbers
Source: Cisco, 2018

from meeting the service level agreements with both internal and external clients and therefore cause penal sanctions, loss of reputation, and market share of the business.

The impacts of disasters on key business resources can affect an organization's critical operations. According to Sahebjamnia et al. (2015) potential negative impacts of earthquakes on business facilities, equipment, and manpower are significantly higher than the impacts of other disruptive events such as flood, fire, sabotage, and epidemic diseases in possible optimistic, realistic and pessimistic damage scenarios. Prolonged downtime and reduced production capacity caused by such a disaster may have direct or indirect disruptive consequences on both economy and social community (Brown et al. 2015). BC planning aims to take resilience actions including building contents and nonstructural elements that are closely related to the flow of goods and services before and after such an event.

The top regions and countries that have the most active seismic zones with a number of data centers are listed in Table 2. Earthquakes are generally based on the geographical area and can be significant or catastrophic in nature. They are grossly underestimated by businesses in terms of buildings and infrastructure technology. If the businesses do not have valid BC and Disaster Recovery (DR) plans, the precautions to be taken after the disaster may be inadequate and powerless. For this reason, implementing earthquake-proof buildings and appropriate architectures are the key components of risk and BC management that can avoid or minimize the losses (Miller et al., 2006). Although the cost of building and operating data centers in seismic zones is 24 to 27% higher than in nonseismic zones (Bowman, 2008), the number of companies interested in constructing data centers with seismic isolation technologies is rising significantly since 2011 - Japan megathrust earthquake (Kwon et al., 2015).

A secure data center should preserve the integrity of business operations and functions. Seismic isolation can be applied for eliminating the impacts of vibrations and minimizing the harm to servers, storage device units and related components by absorbing the seismic movements in the geographical area in which the data center is located.

This paper is organized as follows. Section 2 provides the operational efficiency and overview of data center tiers. Then, it summarizes the factors affecting data center buildings and BC/DR planning. Section 3 introduces seismic isolation and its applications in data centers. Finally, section 4 discusses the significance of seismic applications and concludes the research.

Table 2. The most active seismic zones & data centers between 2016-01 and 2019-09

Country*	Number of earthquakes**	Region	Data center average workload in the region (in millions)	Total number of data centers***
Indonesia	5708	Asia Pacific	78.7	42
Peru - Chile	4272	Latin America	11.7	11
Japan	1981	Asia Pasific	78.7	44
China	1365	Asia Pasific	78.7	79
Iran	680	Middle East	8.6	21
United States	398	North America	135.8	1869
Turkey	339	Southeast Europe	8.6	52

*The closest country to earthquake
*Magnitude ≥ 4
*** As of 2019-09. Only traditional data centers are included.
Source: USGS, 2019

OPERATIONAL EFFICIENCY OF DATA CENTERS

In today's business environment, companies cannot afford hard-dollar costs of IT requirements, regardless of unplanned or unexpected changes in IT infrastructure. Data centers have become important IT devices for businesses to support their operations. Table 2 shows how much data is stored and how many workloads are deployed in data centers. Decision makers must ensure that IT infrastructure design and solutions for data centers are able to solve availability, cost, and performance issues.

To decide the type of information stored and managed in a data center may vary depending on the importance of information and technology utilization. For example, a data center of a bank may strictly monitor threshold levels of customer accounts and it may not attach the same importance to mail archive databases. Likewise, a GSM operator may strongly consider utilization and network connections between cell towers, however, network connections used for cash management transfers between banks may be less important for business priorities. Moreover, big data centers' processing systems employ continuous operations for critical data and they are backed up by employees working in shifts. On the contrary, a small data center may not employ any personnel working in night shift. These instances may also vary depending on business needs and data center infrastructure.

Operational efficiency states a condition that provides an optimum level of output. According to Stewart et al. (2012) operationally, efficient data centers can allocate at least 50% more of their IT resources to new projects and those are a valuable part of business processes and agile scalability.

To establish a strategic approach for business operations, IT management should take proactive steps for service delivery before, during, and after disruptive events. Some companies can tolerate outages, regardless of various risks or threats, while others require their operations run continuously. To ensure operational efficiency and provide assurance for data services, there are four main strategic characteristics (Carey et al., 2017):

- Managed infrastructure such as computing hardware, storage, power, cooling, physical space, and related environments.
- Flexible business operations design.
- Automation for improving service levels.
- Ability to upgrade virtual and physical platforms.

Data Center Tiers

The Telecommunications Industry Association (TIA) and the American National Standards Institute (ANSI) bring international quality standards (ANSI/TIA-942-2005) for the data centers to provide solutions for global challenges. ANSI/TIA-942-2005 is audited by TIA and specifies guidelines and characteristics that cover site location and layout, access control, security and safety, design, cabling infrastructure environmental arrangements, and tiered reliability. These standards can help the data centers to reach their objectives and allocate resources for risk management and corporate governance (TIA-942, 2019).

TIA-942-2005 draws attention to tiered reliability that is classified by Uptime Institute into four levels. The classification has been made in accordance with the availability rate of the data center and the importance of data storage. The availability states a condition of being operable at a random time and it is typically associated with a data center's infrastructure and the applications that are expected to continue to function in case of an outage. For example, a maximum of 0.8 hours of an outage is acceptable for mission-critical Tier 4 data centers in a year and the construction costs would reach $2,250 and up per square foot. While Tiers 1 and 2 can meet small companies' needs that do not work 24/7, Tiers 3 and 4 are generally dedicated to companies that are less prone to failures (Bowman, 2008). Table 3 indicates the Uptime Institute's requirements such as possible values of maximum

Table 3. Uptime Institute requirements summary

Variables	Tier I	Tier II	Tier III	Tier IV
Number of redundant components	N	N+1	N+1	2N or S+S
Power supply	Single	Single	Double-One Active	Double-Active-Active
Cooling	N	N+1	2N	2N
Building	Tenant	Tenant	Single	Single
Personal	Non	1 Shift	1+Shift	7x24
Available critical load amount (% of N)	100	100	90	90
Output power intensity (grossw/sq. Ft)	20-30	40-50	40-60	50-80
Maximum power intensity (grossw/sq. Ft.)	20-30	40-50	100-150	150+
Raised floor height	12 inches	18 inches	30-36 inches	30-36 inches
Weight intensity (lbs/sq. Ft.)	85	100	150	150+
Utility voltage	208,480	208,480	12-15 kV	12-15 kV
Construction ($/raised sq. Ft.)	$650	$850	$1850	$2250 +
Months to implement	3	3-6	15-20	15-20
Single point of failure reasons	Human factors	Human factors	Human factors + natural disasters	Human factors + fire + emergency power off
DC electric interruption/year	28,8 h	22,0 h	1,6 h	0,8 h
Availability rate	99,671%	99,741%	99,982%	99,995%
Launch year	1965	1970	1985	1995

Source: Uptime Institute, 2019

power intensity, output power intensity, a minimum height of raised floor in inches and, a number of redundant components which is the amount of equipment to keep the system running.

In Tier I standards, uninterruptible power supply (UPS) systems are dedicated to sudden power outages and voltage irregularities. In this Tier, the power of IT devices should be supplied from a single source without any redundancy. Cooling and generator systems are also necessary to protect the IT systems from power outages and overheating problems. The generator system should have a tank capacity of 12 hours of operation at maximum load. Systems supplying the data center may be shut down during infrastructure maintenance. A single distribution pipeline (piping and cabling) is adequate for electrical and mechanical systems.

Tier II standards are composed of critical power and cooling system components, which are backed up with redundant modules in the event of power outages. Precautions are taken by using more devices than necessary devices. Generator and UPS systems of a data center should have an N+1 redundant structure. The generator systems should have a tank capacity that will allow 12 hours of full-load operating. Data center operations do not cease in planned or ad-hoc maintenance on redundant components and failure of a component. Tiers III and IV have a high level design with building and their support areas. In Tier III, the entire devices are used by the IT staff and can be maintained synchronously. The IT equipment should be supplied by multiple power and cooling distribution paths without interruption. Generators should have a tank capacity that allows 12 hours of full-load operation to supply power for all energy-consuming equipment. Generators should also have an N system for each energy line and a 2N system in total for each independent energy line. UPS should be N+1 fault tolerant. In case of any power outage, a redundant source should carry the entire load with 72 hours of power outage protection. It is not required to use UPS for the second energy line. Cooling equipment is independently dual-powered and meets the N+1 system requirement. Tier IV data center consists of the IT equipment with high capabilities for concurrent maintainability goals.

Fault-tolerant functionality provides uninterrupted service during unplanned failure of one or more components in Tier IV data centers. To provide synchronous maintenance and fault tolerant design, the electrical and mechanical systems are physically separated and the power supply of the IT devices has an active-active structure for both sources.

Factors Affecting Physical Space of Data Centers

Data centers consist of many facilities to utilize physical links for reliable and uninterrupted storage of data. In general, an effective operation relies on these facilities and allocated equipment that are a consolidation of technical and energetic resources including location and building site, network layout, power distribution, and cooling systems (CISCO, 2014).

Data centers are secure locations to house many physical and virtual devices. To minimize associated losses or damages from natural disasters, data center location should be chosen away from fault lines, and data center building infrastructure should follow the principles of seismic design. The principles are realized by the following factors:

- **Geographical location:** Companies can balance their IT budgets and the scale of the disaster by monitoring disaster occurrences and their potential impacts on business operations. A data center should be built at the correct location for business continuity and recovery objectives. Climatic or tectonic conditions of a geographical location can cause natural hazards such as hurricanes, floods, earthquakes, and volcanic eruptions. For example, climate-related risks such as excessively high or low temperature or humidity in the geographical location may lead to corrosion and defects in electronic equipment and pose safety concerns. Moreover, dust, gases, particles, biological molecules, static electricity, and other contaminants that originate from the location can damage the electronic circuits of the devices. The International Organization for Standardization (ISO) (2017) provides risk management standards for organizations to identify their risks and allocate resources for risk treatment.
- **Energy:** A power system is a critical infrastructure. The operating facility of a data center consumes a large amount of electricity. Environmental Protection Agency (EPA) estimates that the data center industry consumed 1.8% of the total domestic U.S. electricity consumption in 2014 and it comes at a cost of $7 billion a year (EPA, 2017). Due to the workloads, high computation time, cooling – lighting systems, and thereby uninterruptible power generation demand for powerful computing machines, energy management becomes apparent in data centers. The proximity of a data center to alternative energy sources such as wind, solar, wave, hydroelectric, biomass, and geothermal will ensure both power generation and lower carbon emission.
- **Telecommunication infrastructure:** Telecommunication pathways are important components of a data center. Geographic nearness to telecommunication systems implies good network connections. For example, closeness to a fiber optic backbone network can support ease of connectivity with nearly limitless bandwidth capacity. The data center's distance to the backbone will help to deliver reliable, and high-capacity communication between widely distributed locations. The type of fiber, service provider, and transaction latency will affect speed and transmission capabilities of telecommunication.
- **Construction costs:** To determine the construction costs of a data center, decision-makers should develop a roadmap that meets operational requirements. Depending on the data center's ICT vision and strategic plan, considerations for construction costs can vary from construction plan

(e.g. hard and soft costs including architectural planning and landscape costs, fees, insurance, local tax, loans, and off-site costs), industry life cycle (e.g. industry maturity, inflation, production efficiency, market penetration) and labor markets (e.g. unemployment rate, cost of living, availability of workforce) to topography (e.g. accessibility of the site, proximity to public utilities). Furthermore, many organizations allocate their physical servers in multiple locations and seek cost-efficient opportunities for building construction. EPA (2017) states that 83% of the companies with more than 2000 servers have data centers in multiple locations and about 80% of these are midtier and enterprise-class data centers.

Table 4 shows the facilities and the estimated number of servers per facility. The physical size of the data center facility is an important element of construction costs and is measured by computing space or rack yield. The estimated construction cost of the base building of a data center is approximately 20.9% of the initial capital expenditures and $200 per square foot (Forrester, 2011).

- **City level and Staffing considerations:** Accessibility of the data center, commute times, crime rates, state laws, political environment, cost of living, and quality of life (e.g. educational opportunities, attractions, entertainment) identify main concerns of organizations when searching for a physical space of a data center. For example, state or federal regulations may restrict or prohibit some goods or technologies through quotas, public licensing, etc. for protecting public security or interests. This may mean a limit on the equipment purchases and delay or failure in IT investments of the companies. Data centers are dynamic working environments that depend on the technical expertise, business acumen, and communication skills of employees. IT professionals are driven by technical skills and knowledge to understand how technology can maximize business outputs and maintain its operations. They can identify business needs and analyze the feasibility of strategies and objectives to validate decisions; therefore, it is vital to recruit suitably skilled staff with the highest level of competence. The factors including unit labor costs, labor productivity and staff turnover in the industry may also have an impact on the site selection of a data center through staffing considerations.

BC and DR Planning

In today's business environment, companies are dependent on their IT services, which are crucial for business decisions. These services are usually restricted by limited resources or disruptive events. The stability of the IT infrastructure is the key requirement of the IT services for continuous operation. BC refers to a methodology that identifies risks and threats with alternatives and losses before, during, and after disruptive events. It is a system design approach that integrates all mission-critical functions of the businesses and ensures operational performance during or after catastrophic events.

Table 4. Data center specifications

Facility	Estimated servers (per facility)	Typical size (sq. ft.)	Estimated number of facilities (thousands)
Server closets	1-2	<200	1000-1500
Server rooms	3-36	<500	50-100
Localized data center	36-300	<1000	10-13
Midtier data center	300-800	<5000	2-4
Enterprise-class data center	800-+	5000-+	1-2.5

Source: Geng, 2015

Outages are expensive problems for the IT industry. Some companies may have a tolerance for business failures and downtime and they can ignore the losses with severe consequences. However, for some companies, continuous availability and serviceability are essential and they cannot tolerate the cost of downtime. BC planning allows businesses to function normally and deal with challenges, regardless of potential risks and threats. For example, outage duration, backup, and recovery times are vital for data centers and spare parts or units should be easily available in times of emergency. Outages may have major effects on the data center's operations and they may require several hours or days to resolve. The data center manager should assess the impact of outages on business functions by considering the type of services or tasks.

Table 5 shows the categorization of minor and major outages in a data center environment. According to Gartner (2014) the average cost of IT outages depends on the company's size, budget, IT infrastructure, and how the company operates. The average cost of downtime might reach $140,000 or even $540,000 per hour. Uptime Institute (2019) states that outages will continue to disrupt IT services, despite technological developments. However, the number of business-critical outages is falling, while minimal and negligible outages that have a lower impact on operations grew.

The ISO provides principles on business continuity management for organizations. ISO22301 enables large and small businesses to respond to disruptive and threatening events. It establishes the continuity and recovery objectives by assessing the impact of the event and specifies an effective framework for minimizing losses and critical functions of businesses by placing the emphasis on how IT management system elements are being operated. Top management responsibilities to support business continuity policy, awareness and communication for internal and external parties, and the performance evaluation based on business objectives are the key points that require attention in ISO22301 (Drewitt, 2013).

DR is a subset of BC that is used in maintaining or restoring the systems and all critical processes of an organization with IT resilience. It defines the abilities and processes of the businesses to deal with the immediate impacts of major outages, with reduced performance. This might include stopping the effects of unexpected events as quickly as possible when components are damaged and business operations can not be resumed. DR aims to recover sensible business objectives in restricted service levels under unusual circumstances that seldom happen.

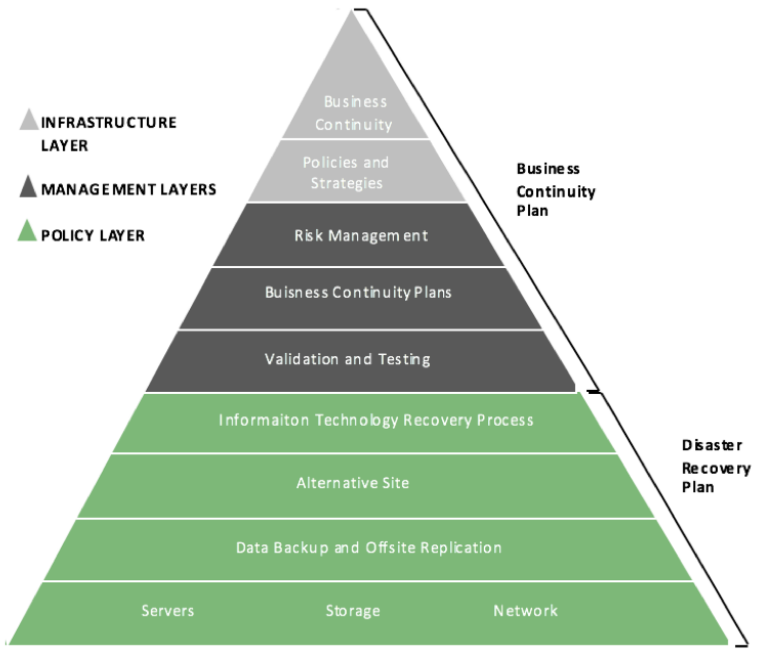
People, processes, and technology are considered as the main purposes of the BC and DR cycle (Snedaker and Rima, 2014). An infrastructure is a part of a technology component and it refers to facilities, utilities, buildings, and other services pertinent to business operations. As shown in Figure 1, the BC plan includes all of the tasks related to owners, deliverables, and success criteria in both management and infrastructure layers. However, DR planning is concerned with IT service functionality in major outages or disasters and it is aligned with BC process (ITIL, 2019). DR focuses on minimum IT resources, such as applications, servers, or sites, required for operating essential business functions. Minimizing the effects of threats including geophysical, hydrological, and meteorological events that cause harm to infrastructure, is the main concern of DR planning.

Table 5. Services and Outage Categories

Services	Maximum minor outage	Maximum major outage
Continuous availability	1 minute	2 hours
Mission-critical	10 minutes	8 hours
Business-important	1 business hour	3 days
Business-foundation	1 business day	1 week
Business-edge	> 1 week	>1 month

Source: Schmidt, 2006

Figure 1. BC plan



Haag et al. (2008) point out that only 6% of the companies with a BC and DR plan can survive over a long-term period after a major data loss. 51% of the companies without a plan are out of business within two years. Before implementing recovery strategies, a risk assessment and impact analysis can help mitigate losses and prevent contingencies or redundancies in place. All strategies and procedures (recovery, restoration, maintenance, notification, etc.) should be documented comprehensively to preserve integrated and networked business environments. Procedures should address the priorities of information services and the continuity of the critical functions of the data center.

Data center buildings are not only a capital expense for companies but also mission-critical infrastructures that achieve better utilization and a solid BC plan. Failures in the physical environment of a data center may have serious consequences, especially for the hardware components. CISCO (2014) underlines that the building site and architecture are the main components of the data center's physical safety and data center design should be made for minimizing possible impacts of natural disasters and failure durations. There is no explicit architecture model for data centers in both ISO and ITIL standards.

SEISMIC ISOLATION AND ITS APPLICATIONS IN DATA CENTERS

Earthquakes are the second costliest type of natural disasters with losses amounting to more than $30 billion per year (UNISDR, 2018). These losses can be from disaster's physical damages to assets or indirect consequences of disasters such as the cost of business interruption or the increase in companies' liabilities. For example, the Japan earthquake of 2011 is estimated to be the costliest natural disaster in the world history. It caused losses over $150 billion (Norio et al., 2011). The loss of technological infrastructure had widespread catastrophic impacts on businesses with interrupted supply chain and power outages in the aftermath of the earthquake. The disaster disrupted IT resources including facilities and communications infrastructure. The data centers were heavily damaged and not accessible.

Earthquakes cause significant damage to property and have a direct impact on business cycles and investments. Uptime Institute (2019) states that external vibrations such as nearby constructions, heavy traffic and railways, the sound of evaporative coolers, fans and cooling units, electric generators, and earthquakes having less than 4.0 magnitude can cause data corruption. Communications and power infrastructure can fail following an earthquake and the entities of the supply chain network can all be impacted. To provide the availability and functionality states for IT resources and services immediately after an earthquake, a viable IT-centric risk management process should be followed by businesses.

Disaster risk reduction is a part of the business risk management process in most companies. It is also a fundamental issue in BC and DR planning, which is primarily focused on ensuring business operations. To sustain data center operations and maintain business continuity in the case of disasters, data center design should consider critical components of the system. Technical infrastructure, especially building design and its related elements, should be strengthened with considerations of an appropriate BC plan (Lykou et al., 2018).

Nonstructural components including architectural, mechanical, and electrical items are important as much as the physical structure of the data center building and they may require attention to seismic isolation. In a typical building, anchorage of nonstructural equipments are generally required to resist the effects of an earthquake, if the data center building is in a seismic zone. However, the anchorage avoids the equipment from moving or toppling, it does not assure the functionality of the equipment after an earthquake. It is essential for data centers to be aware of the requirements and infrastructure redundancy and take all feasible precautions to reduce, remove or avoid possible risks or impacts of seismic vibrations. For instance, Tier III data centers are always operative and concurrently maintainable with no break. For Tier IV, the level of availability is 99.995% and reduced performance of the equipment is only possible in case of an intentional failure, natural hazard or intermittent fault, which occurs simultaneously. As a part of BC and DR planning, seismic isolation is risk mitigation and earthquake protection strategy that relates to data center building and infrastructure. It consists of the mechanisms decoupling the motion structure from earthquake-induced ground with a sufficient load-carrying capacity (Makris, 2019).

During an earthquake, the amount of damage to the data center building and the facilities may vary significantly depending on ground motion intensity, type and quality of physical infrastructure, anchorage and bracing stability, reliability, and ruggedness of components (Bonneville and Pekelnicky, 2015). Data centers are designed to meet their client's needs and secure the infrastructure by fulfilling seismic regulation requirements in which the services are running. TIA-942 (2019) provides an outline for the data center's building, electric systems, air conditioning, security, and communication equipment and it classifies infrastructure redundancy into different levels. The levels are based on risk categories that require consideration of the intended occupancy of the data center building and the hazard level of the data center's region. The outline also evaluates probable maximum loss from potential damages to identify risks that relate to seismic design and it provides guidance on building structure by utilizing Seismic Performance Level Design methodology. Furthermore, Federal Emergency Management Agency (FEMA) proposes FEMA P-58 approach to allow seismic performance assessment on the design and construction of buildings, considering potential damages from earthquakes. It includes analytical procedures with information of structural and nonstructural components of a building and statistical information on earthquakes for decision-making purposes (FEMA, 2018).

According to Uptime Institute, an acceleration bigger than 0.8 m/s2 (0,08g) is evaluated as a "higher risk" in Natural Disaster Risk Category (see Table 6). In the event of such seismic movement, data corruption can occur during writing, reading, storing, or accessing data. Due to increased latency for the data transmission incurred by power, hardware, or environment failures (e.g. total loss of power,

Table 6. Site Location-Natural Disaster Risk Category

Natural Disaster Risk Category	Scale of Risk	
	Higher	Lower
Flooding (river, lake, reservoir, canal, pond, etc.) and Tsunami	< 100- Year Flood Plan	> 100- Year Flood Plan
Hurricanes, Tornadoes and Typhoons	High	Medium
Seismic Activity	> 0.8 m/s2	< 0.8 m/s2
Active Volcanoes	High	Medium

Source: Uptime Institute, 2019

drop in voltage, electro static mischarge, raised floor collapse, hard drive head crash), the data center cannot be able to maintain its operations and service availability, resulting in significant time and cost.

Seismic isolation systems are specially designed and installed at or near the base of the structure. These systems provide support for mitigating damages from earthquakes as well as a clean room environment and robust equipment and service management system. Shape, place of use, the type of materials used, and construction mechanisms are essential criteria that must be taken into consideration when classifying isolators in seismic isolation applications.

In general, elastomeric bearing systems, slider and rubber bearings, steel spring isolators, and rolling systems have been widely used for seismic isolation in buildings and mega structures (Kamrava, 2015). In this study, following the classification of Warn and Ryan (2012), we only focus on the most suitable seismic isolation mechanisms in terms of basic construction and mechanical behavior for data centers. Raised floors, Ball-N-Cone isolators, and seismic base isolation mechanisms are the recent approaches to protect the data center infrastructure and allow the data center equipment to ride out with minimal vibrations.

Raised Floor

Early data centers were designed in different sizes and shapes regardless of a suitable environment and equipment. Heat removal and air distribution were one of the most essential issues in these data centers. Today, with the transformation of the IT industry, modern data center designs consider an efficient cooling system to allow IT equipment to exhaust air for overheating problems and establish an uninterrupted power supply and well-designed, adaptive cabling infrastructure. The need for cooling IT equipment, cabling pathways, utility piping systems, and grounding of equipment caused the raised floor to be suitable for data centers. Tajirian (2009) states that raising the floors are undeniably important measures that can be taken to maintain data centers operational following an earthquake.

Raised floors are the first point of contact to take acceleration caused by consecutive seismic movements coming from the base floor. Such flooring is designed to lift vertical imposed loads and to resist horizontal earthquake-induced forces. The key factors that affect raised floor installation are equipment's height and weight, wall and floor system, anchoring and bracing options for equipment, cabling, wiring, thermal management, and power supply requirements of the data center, seismic zone, and cost. American Society of Civil Engineers (ASCE) Minimum Design Loads for Buildings and Other Structures Standards provide various specifications on structural materials, allowable stress, and load limits for buildings (ASCE, 2010). Resistance to extraordinary events such as strength, stress, and reliability for materials of construction and integrity of structural – nonstructural components are considered within the standards. Moreover, General Services Administration (GSA) introduced a guideline for the facilities with raised floor systems. It presents design criteria for the selection of the most suitable raised flooring products, modular panels and understructure by considering economic, architectural, mechanical, and electrical conditions (GSA, 2019).

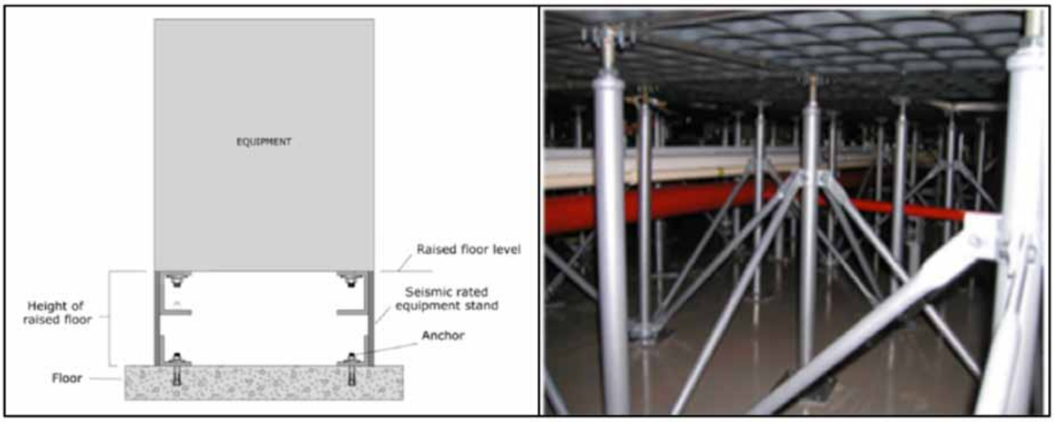
Typically, a raised flooring system consists of modular panels and understructure components as shown in Figure 2. Floor panels are solid or perforated and constructed from aluminum or formed steel. Understructure components include pedestals and base plates, stringers, and braces. The components are accommodated under the panels. Pedestals are integral and height adjustable which should be adhered or anchored to the floor slab. Pedestals are available for a wide range of imposed loads and seismicity with supplemental bracing or anchorage if needed. To ensure the floor's loading capability, lateral strength should be increased by floor tiles in accordance with cabling pathways. Stringers are fastened to the pedestals with a connection to the pedestal head or floor tile to provide lateral stability by transmitting seismic loads.

Installation of raised floor systems may vary widely in terms of manufacturer, equipment racks, building codes, and construction, functional spaces, special requirements, and cost. Design professionals verify that ceilings, walls, floors, and all tied partitions are designed to resist forces caused by earthquakes. For example, as shown in Figure 3, in presence of the equipments that exceeds the specified maximum weight or height capacity, the equipment may need to be relocated or should be mounted directly to the concrete floor. Although stringerless raised floors provide greater accessibility to underfloor in which the spaces are used as plenums for air supply, they are significantly weaker in supporting lateral loads. However, diagonal bracing provides lateral resistance for data centers in high seismic zones (see Figure 3).

Despite the possibility of the equipments sliding or overturning in an earthquake, the critical equipments should be tethered through anchoring methods that have sufficient ductility and strength. For places in which the floor height is less than 30.5 centimeters high or harbor low or moderate seismic risk, it can be feasible to adhere the pedestals to the floor slab rather than anchoring them (FEMA, 2018).

Figure 2. Braced pedestal, stringers and braced raised floor with panels

Figure 3. Understructure for raised floors (Source: FEMA, 2011)



(a) Direct installation of equipment (b) Diagonal bracing for heavy-duty pedestals

For seismic resilience of data centers, all raised floors shall comply with ASCE standards as follows:

- The height of raised floor shall be convenient for additional space to accommodate cable interconnection between related equipment in accordance with structural integrity, seismic loading, safety, power distribution, cooling, cleaning, and cost issues.
- Stringers and pedestals shall be sufficiently robust for the loads and the pedestal pads shall be bolted to the slab for the buildings located in zones that have relatively high seismic activity.
- Floor system shall be supported with additional horizontal restraints or appropriate bracing for the data centers in which the pedestal height is 30.5 centimeters and the data center building is in a high seismic zone.
- Bolted stringer systems shall be used for resistance to heavy loads with pedestal pads welded or bolted rather than glued to the floor slab.
- The installation of raised floor systems shall be tested near-fault regions.
- Heavy equipments shall be anchored to the concrete floor. The raised floor around the equipment should be arranged with bolted assembly to support pedestals in case of collapses.

Ball-N-Cone Rolling Isolation

The floor motion may cause toppling or displacement of equipments in an earthquake. Anchoring or bracing equipments can prevent toppling and decrease displacements. However, this increases the seismic and other loadings sustained by the equipment. Rolling isolation systems became a popular method with numerous installations and it has been considered as a well-performing method for seismic protection. The system has been used widely in data centers by isolating entire floor or data center components such as racks and cabinets.

There is considerable research on rolling isolation system over the last decade (Harvey et al., 2013). The system includes two concave surfaces and a hardened steel ball located between the surfaces. The geometry of isolation bearings and the gravity are important factors to achieve seismic isolation success. Movement capacity of the platforms or cabinets can be doubled through the mechanism between conical surfaces.

Typical shape of Ball-N-Cone isolator and its setup are shown in Figure 4. In this technology, conical surfaces produce lateral resisting force that is equal to the gravity-induced restoring force [see Figure 4(a)]. The steel ball tracks through the solid conical surfaces to bear the loads and provides damping. The isolator can resist uplift while vertical forces become negative and gives satisfactory results in the protection of fragile equipments during an earthquake (Tsai, 2012). Vertical load carrying capacity depends on the strength of the plate and its supporting components. The steel ball is not expected to be a limiting factor even if the vertical load increases.

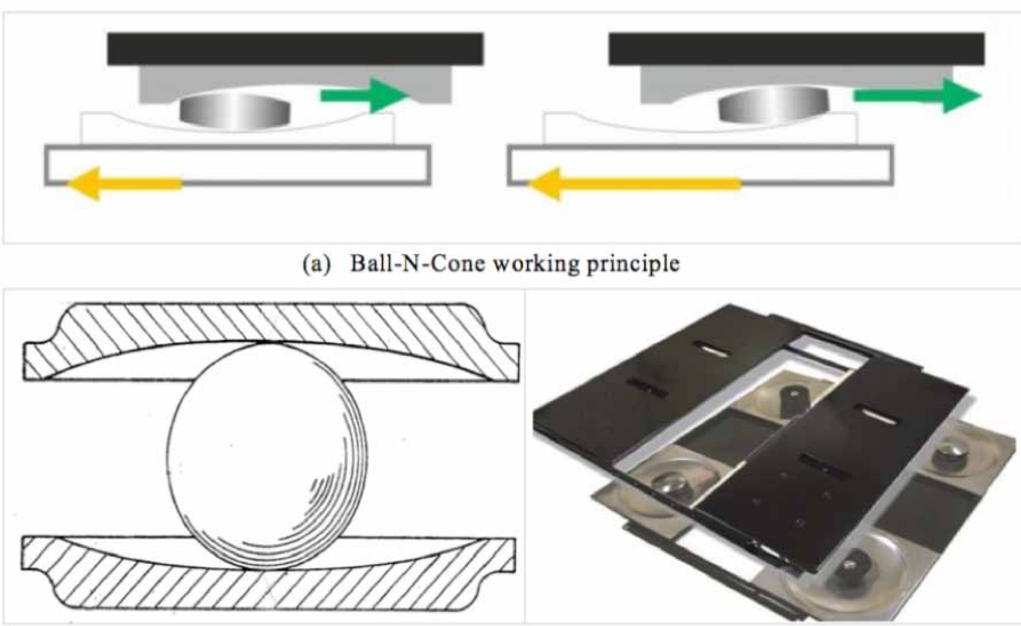
Unlike other seismic isolators, Ball-N-Cone has small and negligible damping which is originated from the rolling friction. Its cone apex enables the system to deal with different gravitational restoring forces with minimal lateral accelerations. The period of system is independent of equipment's weight but it depends on the slope of solid plates and displacement length (Nacamuli and Sinclair, 2011). Generally, the solid plate consists of a cone with a slope of 1:10 and, displacement capacity reaches up twice the radius of the plate.

Ball-N-Cone isolators can usually be assembled as a seismic isolation platform for computer racks in data centers [see Figure 4(c)]. Each plank consists of two interconnected plates with steel ball bearings. The platform is adjustable and easy-mount for a variety of structural systems. Ease of implementation without cumbersome mechanical anchors, having no fundamental natural period for the bearings, compliant equipment design, modular nature of the mechanical system and cost effectiveness are the advantages of the system (Kesti, 2005). However, the effect of the steel ball rolling on the surfaces of the plates can cause permanent deformation and affects the isolation efficiency.

Base Isolation

Traditional seismic design of structures focuses on the concepts of structural mechanics that increase the resistance capacity of buildings. These methods are generally concerned with the quality and strength of materials and framing system for strong foundation and building construction. In traditional methods, the size of structural elements expands due to the strength –dependent stiffness. They show structural deflection under loads, while reduction in ductility can cause inelastic deformation capacity as well as additional stress induced by the earthquake [Figure 5(a)]. This often results floor

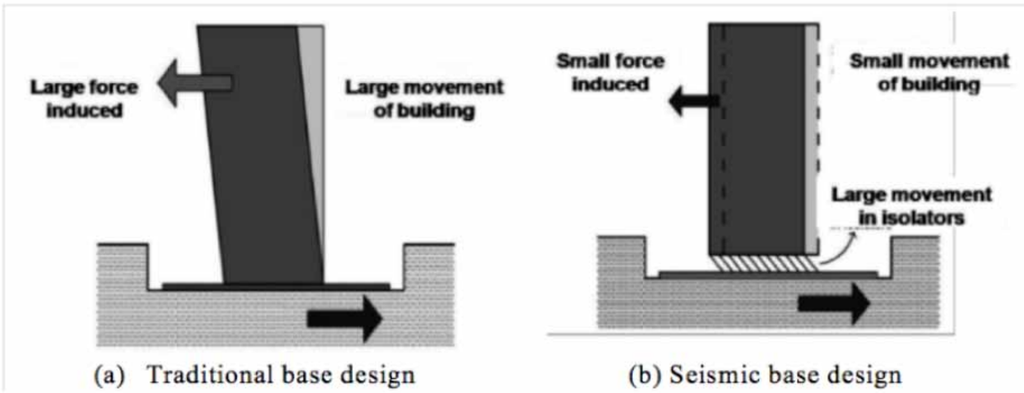
Figure 4. Conical surface resistance



(a) Ball-N-Cone working principle

(b) Mechanical system (c) Base plank

Figure 5. Structural deflection under load



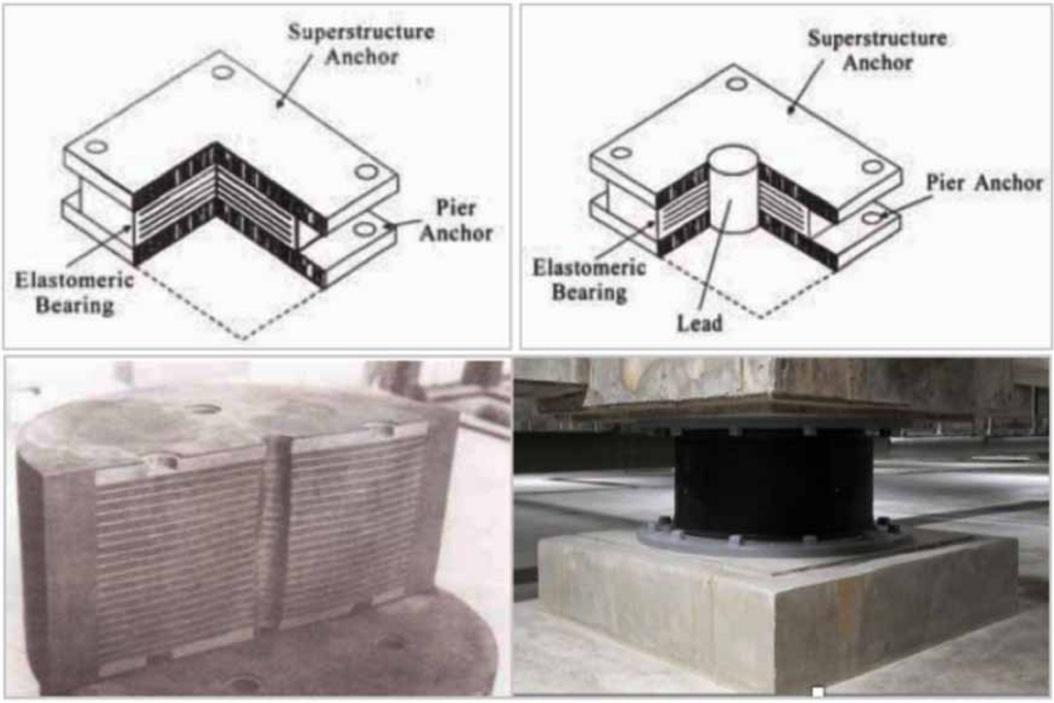
shattering, intrestory drifts of building structures or serious damages to nonstructural components. If damages occur in the buildings that contain vital facilities and assets, business operations may be substantially or completely interrupted, resulting heavy costs in time, money and equipment. Moreover, earthquake incidents show that the buildings with traditional earthquake-resistant design are only able to respond to ground accelerations at some specific levels during ground shaking (Ambrose and Vergun, 1999). These buildings have an inelastic response to earthquakes and displacements are subject to the rigidity of structural elements. Due to different displacements between the floors during an earthquake, beam to column connections can be severely damaged. For this reason, seismic base isolation systems have been in use to enhance seismic performance of the structures in earthquake zones over the past 20-25 years.

Many studies have shown that besides technical advantages, seismic base isolation is cost-prohibitive and well proven method in practice and it can significantly reduce seismic accelerations transmitted to the building (Guo et al., 2009). In this method, structural response to seismic vibration is reduced by decoupling the structure from the ground. As shown in Figure 5(b), the isolation mechanism does not absorb seismic energy but allows the fundamental natural period of the structure to be increased by isolation layer, resulting in lower acceleration. Furthermore, investment costs of structures can be decreased by 5-10% and structural safety can be increased by 4-12 times with base isolation in high seismic zones (Peng et al., 2019). Despite wide variation in seismic base isolation devices (e.g. hysteresis bearings, tuned mass dampers, viscous dampers, active magnetic bearings), the most commonly used bearings are classified in elastomeric and sliding bearing systems (Warn and Ryan, 2012).

Elastomeric bearings, also known as rubber bearings, are passive control technologies in seismic base isolation. The bearings are placed to certain points of the building's structure to minimize the transmission of shear forces that are induced by earthquakes. This technology consists of steel and rubber plates in layers as load-carrying component of the system. Steel plates provide stiffness in vertical direction and flexibility in horizontal direction. Manufacturing and installation of the bearings are easy and the mechanism has a low level of environmental degradation.

Elastomeric bearing is formed by a vulcanization process, combining the steel and rubber layer under high pressure and temperature. Installation of the bearing is achieved through superstructure and pier anchors which are bonded to building's structure. Lead plugs such as steel bars or steel coins, hydraulic dampers can be inserted to the mechanism through the holes on anchors in order to provide energy dissipation and control the use of elastomeric bearing. This results an increase in energy absorptive capacity of the bearing. Lead provides homogeneous resistance to reversible loads since it is in the middle region of the isolator and has a vertical cylindrical structure.

Figure 6. Elastomeric bearings (Source: Chopra, 2001; Kelly, 2004)



Sliding isolators are conceptually simplistic isolation systems that work on principle of friction. This system consists of two stainless steel plates or concave sliding surfaces between the foundation and base of the structure. The working principle of sliding isolators depend on the attenuation of the seismic energy through frictional surfaces. This limits the shear force at the insulator interface and this reduces the destructive effect of the earthquakes on the structure. The performance of the sliding isolation is dependent on sliding velocity, pressure, temperature, and travel distance on the coefficient of friction between the surfaces.

Changes in stiffness due to sudden shifts can cause high frequency vibrations in the structure. This generates floor accelerations and increases the likelihood of structural damages. Therefore, the sliding systems may not be sufficient to maintain the physical properties and equipments within the structure. To ensure sliding structure's ability to return back to its original position, additional bearings as an auxiliary mechanism can be implemented to the isolator. On the other hand, the vertical stiffness of sliding isolators is expected to be larger than elastomeric bearings due to strengthened stainless steel plates in the system. However, the isolator does not sustain resistance to tensile forces and uplift.

Following the principle of yielding under axial stress of metallic plates, conventional metal braces (e.g. steel, lead, aluminum, copper or alloys) have been adopted to seismic base isolation mechanisms for improving absorption of seismic energy. Due to inelastic nature of solid metallic elements, metallic dampers possess excellent lateral strength and energy dissipation for improving the effectiveness of seismic response. The hysteretic behavior of metal materials allows the isolator to yield and soften at various stress levels. This means that the material follows its initial stiffness until the yield stress exceeded.

Metallic dampers are often formed with a bracing system. Generally, these devices are comprised of shaped steel bar or layered steel plates anchored to top and bottom of frame structures and damping performance is dependent on constitutive material. As shown in Figure 8, various types of metallic

Figure 7. Sliding Isolation working principle (Source: Maurer, 2019)

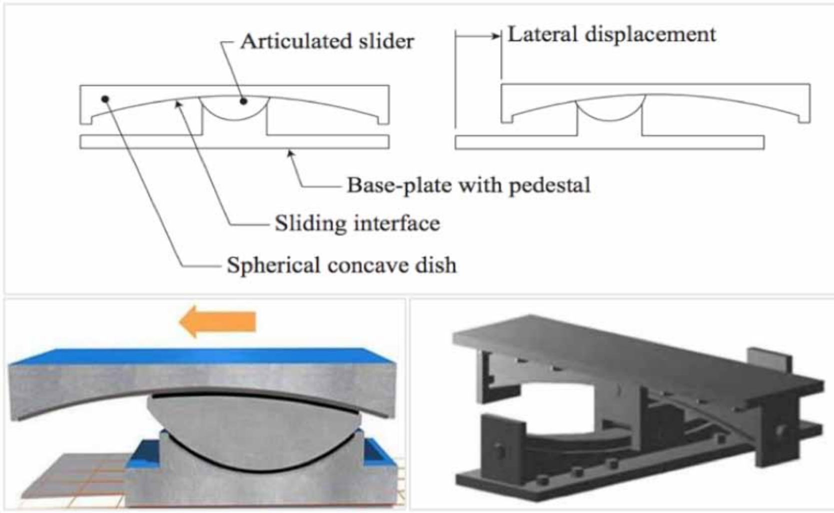
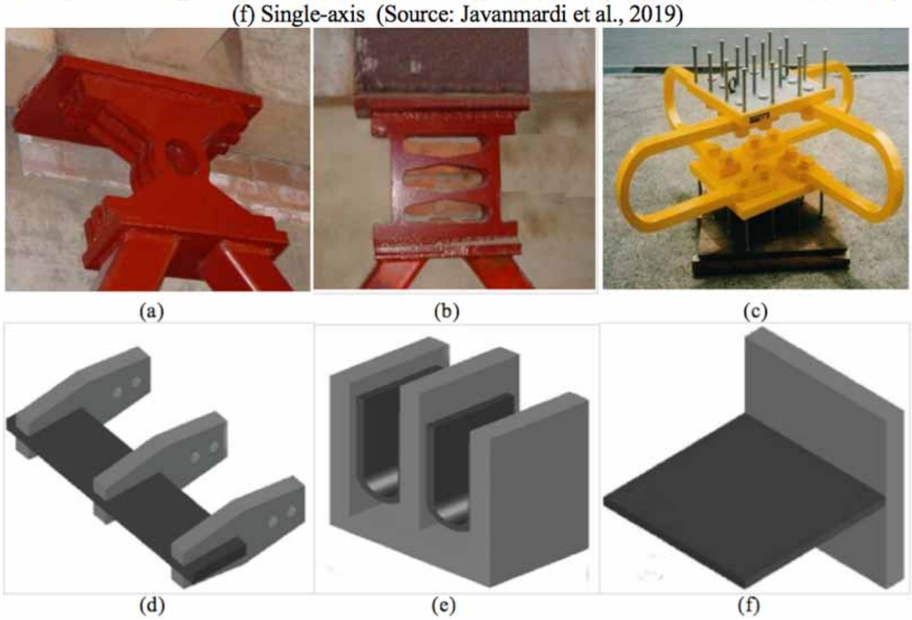


Figure 8. Various metallic dampers (Source: Javanmardi et al., 2019)

Metallic dampers: (a) Single round-hole (b) Double X-shaped (c) U-strip (d) Torsional beam (e) U-shaped steel (f) Single-axis (Source: Javanmardi et al., 2019)



dampers (e.g. X-shaped, single round-hole, U-strip, torsional beam, tapered cantilever, single axis and steel panel-based) have been proposed in accordance with place of use, ease of installation and type of frame structures.

Metallic dampers provide seismic resistance for both building and equipment. Capability of dissipating energy, stable hysteresis behavior, resistance to thermal conditions, low manufacturing costs and suitability for use as a part of bracing system are the main advantages of metallic dampers

(Javanmardi et al. 2019). However, high energy absorption can cause severe yield deformation due to inelastic deformation of metallic. The damper should be replaced after an earthquake.

CONCLUSION

Information technologies become integrated with organizational capabilities to support value creation from new technologies. Organizations balance operational agility with being utilized more widely and they customize their working environments by addressing a resilient and scalable foundation for performance and reliability. As specialized organizations, data centers use physical and virtual computing resources for delivering services and they can operate with an appropriate design that involves architectural, structural and mechanical systems. These mission-critical organizations incorporate some essential strategies in their operational plans to manage the massive data generated, stored and retrieved every day.

Availability, reliability and serviceability are the main functions of a data center's environment, business requirements and objectives that can help ensure maximum uptime and minimal outages. When building and operating a sustainable and efficient data center through accessibility, some globally accepted standards have been set. These standards cover site location, building structure and all other mechanical and architectural aspects of data center.

Due to large scale business activities, companies are increasingly moving to bigger data centers. Data centers should assess all kind of risks related to critical business functions. Seismic isolation of data centers focuses on high availability of IT systems and infrastructure and service functionality of IT services in case of outages. To the best of our knowledge, none of data center management studies assess architecture and DR for IT service continuity. In this study, we discuss BC and DR through seismic isolation technologies to maintain continuous business operations in data centers. We assess the concept of operational efficiency in data centers within the framework of international tier standards. The conclusions of the study are as follows:

- Based on recent developments in seismic design methodologies, the structures are expected to resist low-magnitude earthquakes (M<4.5) without damages. For moderate (M= 4.5-6.5) and major (M>6.5) levels of ground motion, the seismic design philosophy should be very explicit and it should target appropriate performance levels such as collapse prevention or reparable damages with acceptable business interruption. Therefore, it is essential to clarify the role of BC in risk mitigation and disaster avoidance. BC strategies should reflect the capabilities of the data center and it should be aligned to its performance or risk acceptance levels.
- DR serves as a risk assessment and mitigation function in BC planning. It describes critical business functions at the time of event. DR planning focuses the operability of necessary and desirable functions of the business during and after a disruption. Data center manager should determine the scope of threats and evaluate the likelihood of risks with potential damages, cost of downtime including tangible and intangible costs. All IT equipments should be assigned to a risk category in accordance with DR plan.
- Data system equipments and resources can help understand the best approach for BC/DR planning. Regardless of the complexity of IT environment, organizations should develop comprehensive BC/DR plans for business disruptions that include failure scenarios. The plans should contain additional procedures regarding the immediate response to disaster, especially for the companies located in active seismic zones. The basic steps in BC/DR should involve business impact analysis, risk management approaches with testing and implementation, auditing and plan maintenance.
- In data centers, seismic isolation requires significant investment depending on base building construction, IT equipment and the tier level. The construction costs increase with the redundancy level of tier facilities. Data center planning and design will be costly in Tier III and Tier IV compared with Tier I and Tier II.

- Seismic isolation of a data center can be performed in two ways. Structural isolation includes all structural elements such as walls, floors, support columns and utility connections. For example, floor planning is vital step for the performance of data centers in terms of IT equipment capacity, power density capability and IT equipment costs. The structural design must consider variations in structural and seismic load effects, displacement, stiffness, and building material properties. Besides that, nonstructural seismic isolation is applied for furnitures, temporary or movable equipments to sustain continuous operations of the facilities during the event of downtime and outages. ASCE provides minimum design criterias in accordance with seismic requirements for both buildings with bearings and nonstructural components.
- The majority of existing structures are not earthquake-resistant in active seismic zones (Takagi and Wada, 2019). For this reason, it is expected to have a slight number of BC/DC plans for IT companies. Data center managers should make decisions on seismic isolation applications by considering tectonic, geophysical, geological, seismological data and the costs. Environmental conditions, wind forces, fire resistance, lateral forces, vertical load stability and displacement must also be considered as non-ignorable factors for seismic design.
- Raised flooring system is evaluated as an important measure for data centers in Tier standards set by Uptime Institute. The main advantages of installing a raised floor is the ease of wire management (e.g. underfloor data and power cabling, piping), efficient air distribution, clean room environment and the accessibility of IT equipments for maintenance and repair. For earthquake resilience, it is important to bolt or anchor heavy equipments to concrete floor or structural supports. Raised floor pedestals and stringers should meet load requirements and floor tiles should be installed for the strength of the system. The floor system have to be integrally designed with the walls to withstand seismic forces.

FUTURE RESEARCH DIRECTIONS

Seismic activities can be disruptive for data center building and IT equipments. Seismic isolation application should be chosen by determining the impacts of the earthquake to data center infrastructure rather than broad scenarios. Physical design and underlying support systems of data centers can be arranged in different Tier levels as stated by Uptime Institute. The levels should be designed by service capabilities to host from basic to advanced mission-critical systems and to withstand a fault. Seismologists and engineers may develop innovative retrofitting techniques to minimize damages from seismic activities. Electronic sensors can be useful to detect seismic shaking and allow the data center to react suitably with the shaking. Prestressed laminated building materials and engineered isolators can also help mitigate or prevent damages during an earthquake. Improved building design with a systematic seismic evaluation may be less expensive than retrofitting.

Data corruption is an important cost for businesses. Regulatory organizations should impose seismic isolation as an obligation for entire locations that render data center services for businesses even if they are not built as a data center. Seismic isolation is an integrated issue and it cannot be separated from IT development and innovation, geographical location, city level and staffing considerations, design and construction and organizational culture. Equipment sitting and layout are the management of physical substances. In a data center, positioning of devices, racks, floor-tile systems, and other components should be implemented in accordance with equipment geometries, floor planning, architecture and seismic design of the building.

An efficient IT service delivery ensures a better organizational value. In an operationally efficient data center, the systems should be running all the time for the delivery of IT services. Service level agreement of the data center for minor or major outages should be specified in BC/DR plans. Disaster declaration, roles, responsibilities and risk escalation processes should be described with a layered solution.

Due to a few numbers of manufacturers in seismic isolation technologies, seismic isolation seems costly for all parties. Some policies (e.g. exemption from taxes, duties and fees, credit allocation, customs tax, investment allowances, public loans and guarantees, R&D incentives or the regime of intellectual property rights) must be envisaged to enhance competition, innovation and production efficiency.

In most earthquake-prone countries, there is a huge gap in research on engineering and management of data centers including DR and high availability of data services. Universities, public research institutions, governments and manufacturers play important roles in creating information and seismic isolation applications. Coordinated actions are necessary for developing an unified seismic hazard model for data centers in active seismic zones. There are also no government agencies or professional advising offices to improve awareness and take precautions for data protection in most of the earthquake region countries.

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