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Seismic design methods for concrete buildings

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Abstract. Earthquake is a devastating natural disaster that can easily cause buildings to collapse, posing a serious threat to human life. Concrete, as a widely used building material, is of significant concern for its seismic performance. This paper mainly presents how seismic resistance can be considered in concrete building design and proposes two main solutions, the use of high-performance materials and rational structural placement. Through comparison and analysis, it finds that rationalization of the structural placement is the preferred and feasible solution for the future between the two. The successful development of computer software has dramatically reduced the workload of structural modeling and analysis. At the same time, the combination of considering the use of high-performance materials and rationalizing the structural placement is a highly effective approach, which requires more time from the researcher to solve the difficulties and challenges. This paper provides a clear direction for research into seismic problems in concrete buildings.

Keywords: earthquake, concrete building, high-performance materials, structural placement.

1. Introduction

For the following reasons, it is thought that earthquakes, unforeseen natural disasters brought on by the movement of the earth crust, must be prevented in the structural design of buildings: to reduce the loss of human life and property, and to significantly reduce the cost of materials incurred by using traditional construction techniques. Indeed, Gioncu and Mazzolani claim that without preparation, earthquakes can destroy big portions of cities and cause significant damage to residential areas all over the world [1]. Due to the significant cost needed to properly withstand an earthquake's impacts on a structure, Ibrahim and Sumunar argue that earthquake design is largely focused on averting fatalities and minimizing damage [2]. Consideration of earthquake effects on concrete buildings remains a matter of concern to members of society. Most residential buildings are constructed with concrete as the preferred building material [3]. Therefore, the seismic performance and design of concrete structures are of great relevance to the safety of people. The advancement of communication technology can alert people to the impending arrival of earthquakes, but this has limitations and consequences. The consideration of the majority of groups and surroundings needs to be improved because the communication technologies are not very impressive in terms of seismic efficacy and are only now accepted by a tiny portion of the community [4]. To avoid greater damage caused by earthquakes, the center of efforts for seismic resistance of buildings should be brought together into the structural design [5]. This paper outlines two different seismic design options and primarily

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discusses how to take earthquake effects into account when designing concrete buildings' structural integrity. These options are critically examined in the paragraphs that follow, first in isolation and then in comparison to one another, summarizing the benefits and drawbacks of each choice. At the same time, this paper will concentrate on the effects of earthquakes in common concrete buildings to avoid a lack of clarity on the subject.

2. Two seismic design methods

2.1. The use of high-performance materials

The use of high-performance materials for structural elements is one potential solution for taking earthquake effects in concrete buildings into consideration. This typically pertains to the primary load-bearing component of the building, such as shear walls, beams, and columns. It makes concrete buildings significantly more seismically resilient, postponing the building's collapse and providing residents more time to escape. Currently, there are four main types of high-performance materials, Ultra-High-Performance Concrete (UHPC), Carbon Fiber (CF), Sodium Silicate Microspheres (SSM), and Self-Healing Concrete (SHC). Ultra-High-Performance Concrete (UHPC) improves the strength, durability, and crack resistance of concrete structures. It usually has a high cement content, a high fineness modulus, and high resistance to cracking. Figure 1 illustrates a toll station built with UHPC in France. Carbon Fiber (CF) can be used as an alternative to steel to strengthen concrete structures, providing high tensile strength and low weight, significantly increasing the strength and stiffness of concrete structures. Sodium Silicate Microspheres (SSM) improve the thermal insulation of concrete buildings and reduce cracks and shrinkage in concrete. Self-Healing Concrete (SHC) can enhance the durability and longevity of concrete structures by creating tiny crack repairs on the surface of the concrete with special microorganisms and additives. This shows that the use of high-performance materials can reduce the negative effects of environmental factors and improve the resistance of buildings to corrosion [6]. Additionally, the use of high-performance materials in the construction of structures has a wealth of experience and is well-accepted worldwide [7]. There are, however, two obvious drawbacks to this approach. First, because high-performance materials tend to shrink during manufacturing, more water must be sprayed on the surface to prevent this phenomenon. This lowers productivity, especially during the winter [8]. Second, the problem of resource use requires more development. The global construction market has a high demand for raw materials and uses a lot of energy [9]. As a result, governments and researchers will need to make more investments in the future to reduce energy use and increase raw material quality.

Figure 1. The toll station built with UHPC in France [10].

2.2. The proper structural placement

The proper structural placement of the building is another method for accounting for the effects of earthquakes on concrete structures. This includes the building's regular symmetry in its plan and its uniform mass distribution in its vertical floor structure. Meanwhile, it is achieved mainly through the structural placement of beams and columns, the span placement of the concrete structure, the foundation placement, and the placement of the prestressed concrete structure. The primary advantage of this strategy is that it can reduce the effects of irregular eccentric twisting and avoid concentrated

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earthquake effects on weak floors in the building, minimizing seismic damage [11]. Figure 2 shows that the building is destroyed by an earthquake due to a weak floor. Besides, a sound structural layout will bring down the material costs of the building [12]. However, this approach has the following shortcomings. First, there is a discrepancy between the goals of architectural design and the placement of the structures [13]. This means that while the structural placement is safety-focused and the building form is anticipated to be simple, the architectural design concentrates mainly on the comfort and aesthetic shape of the structure, making the work of the structural engineer more challenging. Second, the structural placement is a little bit biased, emphasizing the lives of individual safety while neglecting other significant signs of economic loss [14]. This demonstrates that when designing the structure, engineers must work as closely as possible with architects to maintain the building's aesthetics and meet the requirements for seismic resistance, while also taking other crucial factors into account, like estimated costs, which will make the structure more appealing to customers.

Figure 2. The weak floor in a building suffers earthquake damage [11].

3. The comparison of two seismic design methods

While both solutions can provide outstanding seismic resistance in the design of concrete buildings, with high-performance materials often having properties such as higher strength, toughness, and durability, and proper structural placement resulting in a more compact and stable concrete building, neither is the best choice for seismic resistance. They prioritize optimizing only one aspect while ignoring the others, giving the building a shorter service life than anticipated [7]. However, of the two, proper structural placement appears to be the most workable for the long term. The resource consumption of High-performance materials is a problem that needs to be addressed, as was previously mentioned [9]. This would have a negative impact on today's international situation of sustainable development. Contrarily, a sound structural design would result in a decrease in the amount of building materials needed [12]. Furthermore, with the development of the internet, data on structural placement can be modeled and analyzed by computer software [7], as shown in Figure 3. The workload of staff has been greatly reduced as a result. The issue of the incompatibility between structural placement and architectural design still exists, which is almost inevitable [13]. This needs to rely on structural engineers and architects to actively interact and attempt to make the building constructed successfully under the condition of satisfying the design concepts of both sides.

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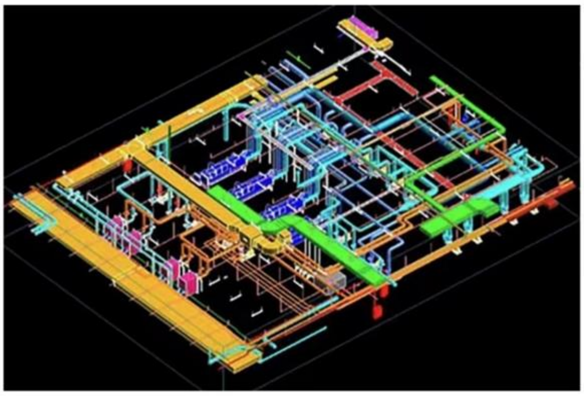

Figure 3. The construction engineering model using BIM software [7].

4. The combination of two seismic design methods

Considering the combination of high-performance materials and structural placement is a more efficient approach. It can make concrete buildings more compact, stable, and robust, thus enhancing the overall seismic stability, as well as reducing the risk of damage and injury to the structure, enabling the building to remain stable and safe during strong earthquakes. For instance, the use of UHPC can improve the stiffness and strength of the building and reduce the generation and extension of cracks, while the use of the rational column network and beam-slab placement can result in a uniform distribution of seismic loads on the structure and reduce local damage. This will enable concrete buildings to minimize damage caused by earthquakes. It is undeniable that the usage of new materials has sparked the invention of new building structures with the advancement of science and technology. The requirement for varied high-performance buildings has also encouraged people to investigate building materials in the interaction of various disciplines. Wang et al. believe that this is a challenge and an unavoidable prerequisite for technological advancement [7]. It implies that additional research is required to determine the best ways to integrate the two.

5. Conclusion

In conclusion, the paper discusses the issue of seismically resistant structural design for concrete buildings, finds two options, and suggests the best one. This issue is mostly caused by earthquakes, which may seriously harm urban building structures, particularly those in residential areas [14], with consequences for the death and injury of people as well as the loss of local physical resources [2]. The two viable solutions mentioned above are the use of high-performance materials and the proper placement of structural elements. Because the placement of the structural elements has no impact on the environment and can be incorporated with the expansion of the internet, the second option seems to be the most realistic in terms of long-term development. Nevertheless, this approach may contradict the concept of architectural design [15]. To achieve an aesthetically acceptable form and arrangement without compromising the safety of buildings, between the structural designers and those involved in the architectural design, there is active contact and cooperation are necessary. Combining these two solutions is another choice for future consideration, but it requires further research by the government and academics to meet the challenge.

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References

[1] Gioncu, V. & Mazzolani, F. (2014). Earthquake Engineering for Structural Design. London: Taylor & Francis Group.

[2] Ibrahim, Y. & Sumunar, D. R. S. (2019). Analysis of Earthquake Resistant House Characteristics as Optimization of Earthquake Victims. IOP Conference Series: Earth and Environmental Science, 271 (1), 012036.

[3] William, B., Skidmore., Owings. & Merrill. (2001). BUILDING SYSTEMS AND CONCEPTS - Structural Innovation. CTBUH Research Paper, pp. 481-493.

[4] Verrucci, E., Perez-Fuentes, G., Rossetto, T., Bisby, L., Haklay, M., Rush, D., Rickles, P., Fagg, G. & Joffe, H. (2016). Digital engagement methods for earthquake and fire preparedness: a review. Natural Hazards Review, 83 (3), pp. 1583-1604.

[5] Spence, R. (2007). Saving lives in earthquakes: Successes and failures in seismic protection since 1960. Bulletin of earthquake engineering, 5, pp. 139-251.

[6] Li, V. C. (2019). Engineered Cementitious Composites (ECC) Bendable Concrete for Sustainable and Resilient Infrastructure. Berlin, Heidelberg: Springer Berlin Heidelberg.

[7] Wang, X., Li, F. & Chen, S. (2020). Application of Conceptual Design and Structural Measures in Coastal Architectural Structure Design. Journal of coastal research, 115, pp. 10-12.

[8] Golias, M., Castro, J. & Weiss, J. (2012). The influence of the initial moisture content of lightweight aggregate on internal curing. Construction & building materials, 35, pp. 52-62.

[9] Li, Z. (2011). Advanced concrete technology. Hoboken, N. J: John Wiley & Sons.

[10] Ming, X., Huang. J. C. & Li, Z. (2022). Materials-oriented integrated design and construction of structures in civil engineering—A review. Frontiers of Structural and Civil Engineering, 16, pp. 24-44.

[11] Feng, N. (2009). Development and Application of High Performance Concrete and Ultra-high Performance Concrete. CONSTRUCTION TECHNOLOGY, 4 (34): 1-6.

[12] Grant, D. & Booth, E. (2020). Earthquake Design Practice for Buildings (4th Ed). London: ICE Publishing.

[13] Ye, J., Shepherd, P., He, L., Gilbert, M., Davison, B., Tyas, A., Gondzio, J., Weldeyesus, A. G. & Fairclough, H. (2017). Computational layout design optimization of frame structures. Hamburg, Germany: International Association for Shell and Spatial Structures (IASS).

[14] ZHANG, Y. & MUELLER, C. (2017). Shear wall layout optimization for conceptual design of tall buildings. Engineering structures, 140, pp. 225–240.

[15] O'Reilly, G. J. & Calvi, G. M. (2019). Conceptual seismic design in performance-based earthquake engineering. Earthquake engineering & structural dynamics, 48 (4): 389–411.