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Research Paper

A Comprehensive Review on Design Trends in Civil Engineering Structures

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Abstract
The design trends of civil engineering structures have been constantly developed from the early strength-based to the other advanced designs. The safety of structures is still the first priority because the failure and collapses of civil engineering structures can be tragic events, leading to loss of life and serious property damage. Today, with advancements in materials, construction technology, analysis and calculation tools, new design trends have been proposed to meet the increasing needs of users. In this article, four design trends in civil engineering structures including (1) force-based design; (2) capacity-based design; (3) performance-based design; (4) resilience-based design were investigated. In each design direction, the concepts, features and discussion are provided to capture the development trends in the design of civil engineering structures and their potential development.
Keywords: *Civil engineering structures, force-based design, capacity-based design, performance-based design, resilience-based design.*

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I. INTRODUCTION

In the field of civil engineering structures, there are many views on structural design and it can be divided into three main groups: force-based design, capacity-based design, and performance-based design [1]. In the 1960s, the design was based on the load that the strength of the structure must exceed the applied load, so the force-based structure was often large in size and uneconomical [2]. However, in order to evaluate the safety and response of the structure under stress, it is difficult at the system level, especially during earthquakes, so capacity-based design is developed [1]. Capacity-based design refers to the fact that critical areas of structural sections are allowed to deform non-linearly, i.e. plastic hinges are allowed to form to dissipate energy [3]. Thus, with this type of design, a consistent power or capacity hierarchy among the components of the entire system is established [4]. Although a structure designed in this way can maximize operability and minimize repair costs when subjected to earthquake damage [5,6]. During the last years of the 20th century, a new approach to design was performance-based design [7-9], which is the construction of systems that meet specific performance goals predefined by the design of the structure. In fact, the life cycle of an engineering structure is influenced by many other parameters and degrades over time. Impact loads can change over time and maintenance can also be performed. Since then, a resilience-based design approach has been proposed in recent years to assess, reduce risks and quantify resilience after severe damage [10]. However, the research on this direction is still very limited. In recent years, more and more stringent standards and regulations in the construction field have been established in relation to the environment, towards a sustainable building environment. Therefore, infrastructure and structures are also required to be sustainable and minimize environmental pollution. Through the literature review, it is found that some major trends in the design of civil engineering structures include: (1) force-based design (FBD); (2) capacity-based design (CBD); (3) performance-based design (PBD); (4) resilience-based design (RBD) (Figure 1). Following each of these trends, the study will begin with the concept and scope related to the building structure. In addition, there will be a discussion and potential research directions.

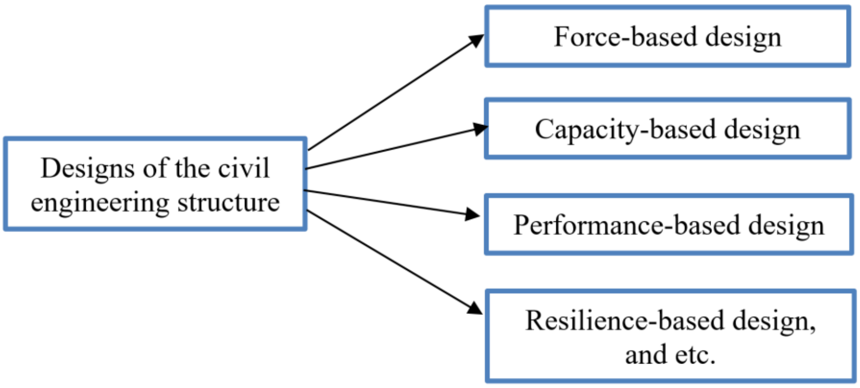

Figure 1. Design trends in civil engineering structure

II. FORCE-BASED DESIGN

Force-based design (FBD) refers to the strength of the civil engineering structure, which must exceed the applied loads. According to ASCE 7-10 [11], there are three options for analytical procedure, including equivalent lateral force analysis (ELF), modal response spectrum analysis (MRS), and seismic response time history analysis (THA) for designing regular concrete moment resisting frame systems (MRF). Among them, ELF and MRS are based primarily on forces, so called force based design (FBD). The displacement in the structures is caused by loads from the earthquake, so these loads have a relation to the elastic stiffness of the system during elastic stage. However, this relation is more complicated in inelastic condition, which also depends on the displacement history during excitation. Accordingly, the strength of civil engineering structure must surpass the applied loads to avoid the structural failure. Until the 1980s, it was recognized that strength was not as important as ductility, i.e. a structure's ability to deform in-elastically in the event of an earthquake without losing its strength. Hence, construction engineers used a force-based design but with a reduced design force level. In the 1990s, the application of FBD showed that there is a major interdependence between the strength and stiffness of the structure. The dimensions of structural sections should be determined in the early stages of the design and distributed to the parts in proportion to the assumed stiffness. However, in this design direction, there are still some disadvantages [6]: (1) The design and the distribution of design forces among the structural elements are based on the initial assumption of stiffness, so it is not determine the durability of elements when the design process is not completed; (2) the initial assumption for the design is not close to the actual load because the seismic force distributed among the elements is not uniform; (3) the strength of the structure must exceed the applied load, so the structure according to this design is often large in size and uneconomical. From there, performance-based design is proposed to overcome some of these disadvantages. This will be discussed in Section 3.

III. CAPACITY-BASED DESIGN

Capacity-based design is a part of a seismic check and ensures that the joint has sufficient deformation capacity. The capacity-based design aims to confirm a building undergoes controlled ductile behavior to avoid collapse in a design-level earthquake. This term became popular in 1970 and has been widely applied up to now. The advantage of this approach can be to maximize capability and minimize repair costs when subjected to earthquake damage. Capacity-based design is of great importance in design, and it has a strong effect on the design process. First, the design begins with balancing the components that are considered "plastic" and continues with storing their capabilities/templates for later review and use. The capacity calculation of each component proceeds in a certain order, retrieved from the information storage required as input during each phase of the capacity design [6]. For example, to balance a concrete beam subjected to shear loads, one needs to know the maximum moments at the end sections not only of the beam itself but also of the columns it is connected to. In fact, the life cycle of an engineering structure is influenced by many other factors and degrades over time. Impact loads can vary with time and maintenance activities, so a further trend in the design of an engineering structure is the performance-based design proposed in the late 20th century, which will be discussed in Section 4.

IV. PERFORMANCE -BASED DESIGN

Performance-based design (*also known as Performance-based building design* (PBBD)) refers to the design of engineering structures for predictable performance for initially investigated loads. This method is used to design a new building or to evaluate an existing structure. In this approach, structural engineers can determine the specific performance of the structures in response to the owner initially and then proceed with the design or evaluation of the existing structure. This design is widely applied with the seismic loads. Evaluation of the existing structure or designing structure of against probable earthquake load is done. However, in modern design now, performance-based design issued in wind designs, earthquake designs, blast analysis and design and progressive collapse analysis [9].

The building facility is a system of numerous components with a very long life cycle. Originated from relevant user requirements, the system design and the more specific design aims of its parts will be clarified. These requirements develop to a set of performance requirements that should be established by a large number of stakeholders (the users, owners, manufacturers, and so on). Figure 2 presents the flow diagram of performance-based design. The main steps in a PBBD process include:

- identifying and formulating the relevant user requirements.
- transforming the identified user requirements into performance requirements and quantitative performance criteria.
- using the appropriate design and evaluation tools to assess whether proposed solutions meet the given criteria at a satisfactory level.

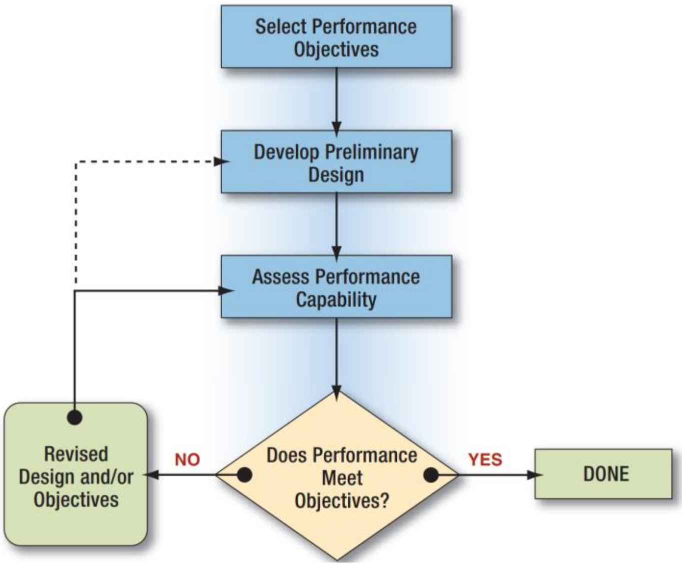

Figure 2. Flow diagram of performance-based design [9]

V. RESILIENCE-BASED DESIGN

In recent years, a new design direction in civil engineering structures is resilience-based design. This design direction has gained much attention of scientists around the world. Resilience-based design is the ability that a structure can quickly restore to its full functions after severe damage. The resilience-based design process is systematically analyzed based on the probability of the structure's resistance to extreme damage expected. In the past, designers and engineers, when calculating the structural design of a building, considered the condition that the work stood independently. Now, that approach has to take into account the fact that the building is part of a group of buildings, so the analysis needs to integrate and take into account many other factors. This is the advantage of RBD over PBD [12]. Over the past decade, earthquake engineers have paid more attention on deformation and life safety during analysis and design, while socioeconomic parameters have received less attention. Today, designs are moving towards developing damage-free structures using tools for risk assessment, from which higher strength structures are proposed with the possibility of recovery is also shorter.

For example, the self-centering capabilities with minimum residual deformations which will allow a faster recovery process were proposed and developed. There are seven dimensions of the RBD [10]:

1. Population and demographics;
2. Environment/ecosystem;
3. Organized government services;
4. Physical infrastructure;
5. Lifestyle and community competence;
6. Economic development;
7. Social-cultural capital.

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VI. CONCLUSION

This paper presents and discusses the development of the design trends for civil engineering structures, namely force-based design (FBD), capacity-based design (CBD), performance-based design (PBD), resilience-based design (RBD). In each design direction, concepts, advantages, and limitations are pointed out and discussed to find out potential development directions of next-generation design trends. Resilience-based design needs further attention and investigation considering the interdependence between different dimensions of the framework that can cause cascading effects. In the future, international cooperation will be needed to exchange information and coordinate the rapid recovery process by adopting common formats and tools. For example, the reports of recent earthquakes should follow the same format so that analysis and damage assessment is quick and the obtained data is consistent.

Acknowledgments

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