Analysis of the Existing Seismic-Resistant Concrete Structure

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Abstract. The seismic-resistant concrete structure is an important component in the buildings and plays a key role in many countries, like Japan, Philippine and America. Different from traditional ways, the use of precast concrete in those areas is feasible now. Regardless of the progress in the area of precast concrete, the major problem of joint technology persists. This paper aims to review the existing precast concrete structures and some other seismic-resistant concrete structures. It is concluded from this review that the performance of precast concrete is the same as traditional methods and has its benefits in construction and economic aspects.

1. Introduction

The damage of earthquake has a long history all over the world and has attracted increasing attention in recent years. The normal concrete structure will be easily destroyed in the earthquake, while the seismic-resistant concrete structure can tolerate the damage caused by the earthquake. Previously, the method is to prepare all the materials in the construction site and then work. However, precast concrete has been well-developed now due to its durability, ability to be rapidly built by prefabricated members, cost-effectiveness and high quality.[1]

Smith (2011) proposed a new strategy based on the hybrid precast concrete wall specimen under reversed-cyclic lateral loading for the seismic regions and provided an assessment of the seismic design and analysis of the wall by using the experimental data.[2] Terai (2011) designed a new type of reinforced concrete members which used bamboo. The advantages of bamboo reinforced concrete members are, low cost, fast growing and broad distribution of growth. The test results showed that the performance of bamboo reinforced concrete beams was similar to normal reinforced concrete beams. [3] Using bamboo reinforced concrete beams is far different from traditional methods, but this method is expected to contribute significantly to developing seismic regions. Zhang (2012) suggested a new type of connection-ring beam joints with a discontinuous outer tube between the concrete-filled twin steel tube columns and reinforced concrete beams.[4] The test results showed that the new type of joints can easily achieve seismic-resistant design principles called, strong column-weak beam and strong joint-weak member. This type of column also has good fire resistance. This paper aims to review some seismic-resistant concrete structure cases with both traditional methods and precast concrete.

2. State-of-the-art

2.1. Textile reinforced mortars (TRM)

Previously, fibre reinforced polymer (FRP) was widely used for the strengthening of reinforced concrete structure because of its high strength to weight ratio, good corrosion resistance and minimal change of geometry.[5] However, it also has some drawbacks, like high cost, extreme sensitivity to high temperature, unable to be applied on wet surfaces and incapability with substrate materials. Koutas reported a different solution for strengthening reinforced concrete members which was using textile
reinforced mortars (TRM). TRM combines high-strength fibers in the form of textiles (with open-mesh configuration) with inorganic matrices, such as cement-or hydraulic-lime-based mortars.[6]

![Textile fibre reinforcements: (a) carbon fibre textile; (b) glass fibre textile; (c) basalt fibre textile; (d) polyphenylene bezobisoxazole (PBO) fibre textile; and (e) steel fibre textile.](Source: Koutas, L. 2019. Strengthening of concrete structures with textile reinforced mortars: state-of-the-art review. Accessed 04/2021. Available from Strengthening of Concrete Structures with Textile Reinforced Mortars: State-of-the-Art Review | Journal of Composites for Construction | Vol 23, No 1 (ascelibrary.org))

This method has been well studied in the last two decades. The strengthening of concrete members with TRM is concluded to be an efficient technique to increase the ultimate flexural or shear capacity of RC members with typical geometries. TRM increases their stiffness and their performance under serviceability loads. Additionally, the cracking is better controlled and the thermal resistance is also increased (including high temperature). Although TRM has so many advantages compared with FRP, there are still no reliable design equations available for TRM. This is due to the lack of enough experiment data of TRM and the complexity of the failure modes in TRM systems.

2.2. Hybrid precast concrete wall specimen

In contrast to conventional precast concrete structures, the hybrid precast concrete wall structures have better quality, relatively simple structures and better performance in seismic resistance.[7] Smith investigated a combination of mild (i.e., Grade 400) steel and high strength unbonded posttensioning steel for lateral resistance across horizontal joints.[8] The hybrid wall he studied was constructed by stacking rectangular precast concrete wall panels across horizontal joints at each floor as shown in figure 2.

![Fig.2. Elevation, exaggerated displaced position, and cross section of hybrid wall system](Source: Smith, B. 2011. Design and measure behavior of a hybrid precast concrete wall specimen for seismic regions. Accessed 04/2021. Available from Design and Measured Behavior of a Hybrid Precast Concrete Wall Specimen for Seismic Regions | Journal of Structural Engineering | Vol 137, No 10 (ascelibrary.org))
Overall, this wall specimen performed as designed. It provides the building self-centering and will return to its initial position after the earthquake and energy dissipation to control the lateral displacement. But the rules in America restrict the use of those wall specimen, so only limited experiments can be done. During the experiment, the failure occurred earlier than expected as the strength of the concrete wall was lower than the specified value and the wrong placement of the confinement hoops at the wall toes.

2.3. Steel-concrete composite coupling beams
The steel-concrete composite coupling beams is an alternative way for coupling individual reinforced concrete wall piers, especially for high floors. Compared with traditional reinforced concrete, the steel-composite coupling beams can be designed as a flexural-yielding or shear-yielding member. There are two common issues in designing steel-concrete composite coupling beams, the ratio and detail of the steel-composite coupling beams and the beam-wall connections. In Gong’s (2000) research, the beam-wall connections problem was well studied. He found that most of the input energy would be consumed by inelastic deformation in the connection part, which is not expected from the designer. To solve this issue, the embedment length must be calculated exactly to develop the expected shear capacity of the composite section. Therefore, the energy dissipation, ductility and loading capacity of steel composite coupling beams are significantly improved by using Gong’s method. This method also leads to a longer embedment length.

2.4. Square concrete-filled steel tube beam columns
Steel-concrete composite has become a popular choice for a large number of constructions due to its cost-effective. Most of them are using steel frames combined with steel-concrete composite columns to have better control on the lateral drift. The circular and rectangular are the common shapes of those columns. Varma and his team presented their test results on square concrete-filled steel columns in 2001.

From the test, Varma found that the flexural stiffness and moment capacity of the beam columns was not affected significantly by the cyclic loading, while the post peak moment resistance decreased rapidly under cyclic loading. Also, under the cyclic loading, elastic section flexural stiffness decreases rapidly to the flexural stiffness of the steel tube alone which is caused by the extensive tension cracking of the concrete infill. By the end of his research, both the current ACI code provisions and the modified AIJ method are recommended to predict the strength of such beam columns.

3. Discussion
According to the cases mentioned above, bamboo reinforced concrete members have a good potential in many developing countries due to the advantages of bamboo and the outstanding seismic-resistant
performance of the bamboo reinforced concrete members. In contrast to those conventional materials, bamboo is very competitive due to its cost-effective and large amount. Apart from the advantages, the experimental data of bamboo reinforced concrete strength testing are quite limited at this moment. From the paper, the author found that it had a similar performance to normal reinforced concrete members, but the sample had not been tested in many seismic regions. For instance, Japan, China and some other seismic regions. So, the possibility of widely use of bamboo reinforced concrete structure still needs to be confirmed by more experiment data in different regions.

The precast concrete members will be a more popular choice in the future, such as the hybrid types and the normal precast concrete members. The main reasons are better seismic-resistant performance and simple structures. The precast concrete method can also be applied to bamboo and some other methods introduced in this review paper to improve their quality and the efficiency of the construction buildings. For instance, precast bamboo reinforced concrete structures may have both seismic-resistant performance and a cheaper price. Apart from that, it may also improve seismic-resistant performance. The combination of each method can be proposed in the future and some changes to those applications can also be made to enhance their initial characteristics.

The textile reinforced mortars are going to be studied more in the next few years as their unique benefits compared with fibre reinforced concrete members. The current issue is that the experiments are restricted in some regions due to local laws. Once this issue is solved, it will be developed quite fast in the future. There is a possibility to enhance the seismic-resistant performance by using precast concrete members technology.

Joint connection is the most important part of composite beam-column structures. Many issues affected the research on this technology. For instance, the high cost of the materials and labour, the complicity on the production and the difficulties in construction buildings. It is also the most damaged part during earthquakes, especially in Northbridge of the United States, Hanshin of Japan and Wenchuan of China. The ring beam joints technology proposed by Zhang in 2011 will contribute a lot to the research of joint connection technology.

4. Conclusion
This paper has reviewed some seismic-resistant concrete structures, including conventional methods and some innovations. Especially, the bamboo reinforced concrete structure. This is a brand-new idea which quite different from previous methods. This idea meets the future trend which is continuous, recyclable and clean materials. Precast concrete can be manufactured by mixing materials to enhance its quality and seismic-resistant performance. This technology can also be applied to others to seek better performance. Steel-concrete composite coupling beams need more attraction as it is an alternative way for coupling individual reinforced concrete wall piers, especially for high floors. Overall, the development of seismic-resistant concrete structures is nearly limited at this stage by many factors, like cost, materials, and performance, etc. But the innovations mentioned in this review paper will help the future development of seismic-resistant concrete structures.

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