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Study on Performance Index Quantification of PRC Coupling Beam-Hybrid Coupled Shear Wall System

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Abstract. PRC coupling beam-hybrid coupled shear wall system is a new structural system with plate-reinforced composite (PRC) coupling beam instead of concrete coupling beam in the traditional reinforced concrete coupled shear walls. There is a lack of systematic research on PRC coupling beam-hybrid coupled shear wall system at home and abroad. In this paper, the seismic performance levels of PRC coupling beams and shear walls were partitioned. Combined with the characteristics of PRC coupling beam-hybrid coupled shear wall system, the failure features at different performance levels are put forward. Meanwhile, story drift angle limitation for PRC coupling beam-hybrid coupled shear wall system under different performance levels is obtained. According to the using function and importance of PRC coupling beam-hybrid coupled shear wall system, the seismic performance target of which is given combined with different earthquake action levels.

1. Introduction

This paper summarizes the current research status and principles of seismic levelling of structures at this stage, and classifies the performance levels of PRC coupling beam and reinforced concrete shear wall, combined with the characteristics of PRC coupling beam-hybrid coupled shear wall system, the failure features at different performance levels (good use, temporary use, life safety and near collapse) are put forward. Meanwhile, story drift angle limitation for PRC coupling beam-hybrid coupled shear wall system under different performance levels is obtained. According to the using function and importance of PRC coupling beam-hybrid coupled shear wall system, the seismic performance target of which is given combined with different earthquake action levels.

2. Performance Level and Seismic Fortification Targets of PRC Coupling Beam-Hybrid Coupled Shear Walls

Please follow these instructions as carefully as possible so all articles within a conference have the same style to the title page. This paragraph follows a section title so it should not be indented [1-2].

2.1. Structural performance level

Seismic performance of the structure is the level corresponding to the specific earthquake fortification level, the structure is expected to reach the maximum extent of damage. For the level of structural performance standards, both at home and abroad have a clear definition of norms. The United States
ATC-40 and FEMA 356 two specifications will be the main structural performance is divided into three levels and two control range\textsuperscript{[2,3]}, respectively, immediately restore the use of standards, life safety standards, the level of structural stability and damage control, the limited safety stage. At the same time, the four non-structural performance levels can be expressed as performance, immediate residence, life safety and mitigation level of performance. SEAOC\textsuperscript{[3]} suggested that the performance level (including structural and non-structural) of performance-based earthquake-resistant design should be fully operational, safe and close to collapse. The general rules for design of seismic behavior of building construction (CECS160: 2004)\textsuperscript{[4]} adopted five performance levels of full operation, operation, basic operation, life safety and near collapse.

Based on the current codes, according to the damage characteristics and seismic performance requirements of PRC coupling beam-hybrid coupled shear wall, the performance standards of PRC coupling beam-hybrid coupled shear wall are divided into five parts: good use, temporary use, life safety and approaching the collapse of the four levels, the definition and macro description of the performance level in Table 1.

| Performance level | Macro description                                                                 | Destruction level | Degree of ease of repair |
|-------------------|-----------------------------------------------------------------------------------|-------------------|--------------------------|
| good use          | The structural and non-structural components were not damaged or slightly damaged. The PRC coupling beam did not show any cracks or the first slight curved crack appeared. The PRC coupling longitudinal beam and embedded steel plate did not yield and the wall was intact. The structure was basically under horizontal force in a flexible state, without any residual deformation. | Basically intact  | Intact                   |
| temporary use     | PRC Beam bending cracks appear, even the beam abdomen may appear subtle shear cracks, walls and limbs may appear subtle cracks, the structure has not yet entered the yield state. | Minor damage      | Easier repair            |
| life safety       | The structural components are damaged more severely. The cracks and rifts in the PRC are developing and the width is widened. The structure has entered the yield state and shows obvious plastic deformation under horizontal force. The longitudinal reinforcement of individual walls appears yielding. The middle floor with large beam part of the yield, part of the concrete beam with spalling, but the structure remained stable at the bottom of the wall and the corners did not appear large areas of concrete crushed phenomenon. | Serious destruction | Can be reinforced, repair |
| approaching the collapse | The structure is close to or has been severely damaged. The PRC coupling beams in the middle and lower floors form plastic hinges or severely bent shear failures, and the longitudinal beams and embedded steel plates of the coupling beams yield. Most of the bottom wall reinforcements appear to yield and some concrete walls crumble, but still will not collapse, the structure is in the plastic work stage. | Close to collapse | Local to be removed, the overall reinforcement |

The fourth-level structural performance levels have laid the foundation for the performance-based seismic design theory of PRC coupling beam-hybrid coupled shear walls.
3. Quantification of PRC coupling beams performance

The experimental experience shows that the performance level of the coupled shear walls mostly depends on the seismic performance of the coupling beam. PRC Beam - Hybrid Coupled Shear Wall is the most important lateral load resisting member and load-bearing system of the building. It can be decomposed into reinforced concrete shear wall. Therefore, in this paper, firstly, the allowable values of deformation of PRC-coupling beams and RC shear walls at different performance levels are calculated to obtain the quantification of the performance of PRC-coupling beams. Based on the above analysis, wall performance indicators.

3.1. PRC Coupling Beam damage morphology and performance indicators selected

According to the domestic and foreign research on the PRC beams, the failure modes of the PRC beams can be divided into three types [5]: bending failure, shear failure and bending shear failure.

In the case of coupling beam, generally control the deformation performance by use of component itself, such as plastic zone angle, residual deformation, displacement angle. In this paper, the turn angle is chosen as the index of the deformation performance of PRC beams. The turn angle refers to the ratio of the vertical displacement difference and the net span at both ends after the beam is deformed, as shown in Figure 1.

\[ \theta = \Delta / L \]

![Fig. 1. Schematic diagram of turn angle of coupling beam](image)

3.2. PRC Beam Failure criteria for each performance state

In order to facilitate the research and consistent with the fourth gear performance level of the above-mentioned hybrid composite shear wall structure, the domestic and international experimental research and analysis of PRC beam damage process, based on the PRC Beam performance level is divided into "good use", "Temporary use", "life safety" and "near collapse".

3.3. PRC Coupling Beam Performance Level Deformation Allowable Value Test Statistical Analysis

In order to obtain the turn angle limit corresponding to the four performance levels of PRC beam, In this paper, the seismic performance test data of 45 Chinese and foreign countries [6-9] considering different span-to-depth ratio and plate ratio are analyzed statistically.

In [6] low-cycle reciprocating loading tests of six PRC beams were carried out. According to the experimental skeleton curve to determine the performance level of the four turn angles were: 0.0027 ~ 0.0043, 0.0037 ~ 0.0077, 0.0119 ~ 0.0250, 0.0260 ~ 0.0445.

Literature [7] considering the influence of span-to-depth ratio, reinforcement ratio and steel plate size, the low-cycle reciprocating load test of 8 PRC beams with coupling beams was completed. The measured PRC yielding displacement of the beam, the maximum load corresponding to the displacement and the limit displacement of the turn angle range were: 0.0040 ~ 0.0140, 0.0057 ~ 0.0197, 0.0250 ~ 0.0810.

Literature [8] considered the change of PRC span-to-depth ratio, the rate of steel plate matching and the ratio of longitudinal reinforcement, The measured PRC yielding beam displacement, the maximum load corresponding displacement and the limit displacement of the turn angle range were: 0.0301 ~ 0.0856, 0.0511 ~ 0.1778, 0.0662 ~ 0.1841.
In reference [9], considering the effect of span-to-depth ratio, mixing rate and stirrups reinforcement ratio. The measured PRC yielding displacement of the beam, the maximum load corresponding displacement and the limit displacement of the turn angle range were: 0.0387 ~ 0.0935, 0.0440 ~ 0.0886, 0.0516 ~ 0.0966.

Our research group [10-11] completed the low-cycle repeated loading test of 7 PRC beams with small span-to-depth ratio, mainly considering the influence of the span-to-depth ratio of the spar, the ratio of steel plate and the slab on the shear capacity and ductility of the beam. According to the experimental skeleton curve to determine the performance level of the four turn angles were: 0.0007 ~ 0.0020, 0.0052 ~ 0.0113, 0.0095 ~ 0.0163, 0.0169 ~ 0.0280.

From the above analysis of PRC beam damage process and result analysis, the test beam data in the test data are all PRC beam specimens with a span-to-depth ratio less than or equal to 2.5 and many factors determine the failure mode of PRC beam, the span-to-depth ratio is only one of the factors. By reasonably designing the PRC coupling beam fitting rate, the PRC beam with small span-to-depth ratio can have good deformation performance and energy dissipation capability.

Statistical analysis is made on the turn angles of the PRC coupling beam specimens at the ultimate state of each performance level. The range and distribution of the turn angle angles corresponding to the four performance levels of the PRC coupling beam are shown in Table 2.

| Name          | Good use | Temporary use | Life safety | Near collapse |
|---------------|----------|---------------|-------------|---------------|
| Turn angle    | <1/900   | >1/100        | >1/50       | >1/50         |
| Turn angle   distribution | 900 1/300 300 250 1/100 100 <1/90 1/5 0 1/20 30 |

According to the distribution ratio of the PRC coupling beam turn angle with the four performance levels, when the guaranteed rate is above 80%, PRC strings can be used in good condition, temporary use, life safety and near collapse. The limits are taken as 1/900, 1/250, 1/90 and 1/50.

4. Quantification of performance indicators for reinforced concrete shear wall components

In addition to the overall bending damage, shear failure or bending shear failure will occur, so the value of the performance level should be taken into account the form of damage and hysteresis curve shape the corresponding adjustment. In this paper, the performance level of shear walls is also divided into good use, temporary use, life safety and near collapse, the corresponding performance levels.

Literature [12] through the statistical analysis of the displacement angle distribution of 45 static shear test results of China's shear wall, the limit of displacement angle of the four performance levels of full operation, basic operation, life safety and approach collapse are respectively 1/1200, 1/380, 1/220 and 1/120.

Literature [13] will be divided into good use, continuous use, temporary use, and nearly collapse of the five performance levels, the statistical analysis of the displacement angle distribution of 94 shear wall in China under horizontal load, taking into account the rate of demand, it is recommended that the five performance levels of the force displacement angle limits were: 1/1400, 1/1000, 1/500, 1/300, 1/200.

Literature [14], suggested that the vertex displacement angles corresponding to the three performance levels of the bended high-performance concrete shear walls, which are used well, ensure personal safety and prevent collapse, can be respectively taken as 1/1000, 1/250 and 1/120.

Literature [15] refers to the statistics of Japanese scholars and gives the displacement angle distribution of the corresponding shear wall when the shear wall is cracked as 1/3333 ~ 1/1111. Combining with the test results, the crack limit of the anti-seismic wall is controlled the value of the standard, get the seismic wall elastic layer displacement limit value of 1/1600 (average).
In this paper, according to the description of the four performance levels of reinforced concrete shear walls, taking into account a certain safety guarantee rate, referring to the above literature research results, the four performance levels of good use, temporary use, life safety and near collapse of reinforced concrete shear walls limit state of the displacement angle limit for the 1/1400, 1/380, 1/250 and 1/120.

Table 3. Displacement angle distribution and ratio of each performance level limit state of shear wall

| Name          | Fully operational | Basic operation | Life safety | Near collapse |
|---------------|-------------------|-----------------|-------------|---------------|
| Displacement  | 0.5%              | 1/140, 1/500    | 1.2%        | 1/120         |
| angle distribution | 1/200, 1/150    | 1/60, 1/100    | 1/80        | 1/40          |

5. Quantification of Performance Indexes for PRC Coupling beam-Hybrid Coupled Shear walls

PRC Coupling Beams - Hybrid Coupled Shear Walls are made up of PRC coupling and reinforced concrete wall members. The elasto-plastic displacements between layers include the bending and shear deformation of PRC coupling beams, the bending, shearing, and axial deformation of the wall members, there are more deformation parameters, so the paper still adopts the displacement angle of the comprehensive deformation index as the performance index of the PRC coupling beam-hybrid coupled shear wall, and gives the definition of "good use", "temporary use", "life safety" prevent Collapse four levels of performance of the inter-layer displacement angle limit.

China's "Code for seismic design of buildings" (GB50011-2010) provides the frame-core tube structure of the elastic layer displacement angle limit of 1/800, elastoplastic limit of 1/100.

In the United States, FEMA273 recommended reinforced concrete frame-shear wall structures based on immediate occupancy, life safety and near collapse at three performance levels: 1%, 2% and 4% respectively.

Literature [18] analyzes the experimental results of the seismic performance of the reinforced concrete core tube collected, it is suggested that the limit of story drift angle of "good use", "temporary use", "life safety" and "near collapse" of the general curved or curved shear core structure should be 1/1200, 1/350, 1/150 and 1/80.

Literature [19] collected data on the experimental study on the shear wall structure, and gave the limit of story drift angle of the shear wall under the five performance levels of basic intact, slight damage, moderate damage, severe damage and near collapse, as 1/1000, 1/500, 1/250, 1/150 and 1/80.

Table 4. Displacement angle distribution and distribution ratio of the limit state of each performance level of PRC coupling beam-hybrid coupled shear wall

| Name          | Fully operational | Basic operation | Life safety | Near collapse |
|---------------|-------------------|-----------------|-------------|---------------|
| Displacement  | 1/10              | 1/32            | 1/14        | 1/11          |
| angle distribution | 0.5%              | 1/200, 1/150    | 1/60        | 1/80          |

Therefore, based on the above analysis (Table 4.), this paper proposes that the limit values of the inter-story drift angles of the four performance levels of PRC coupling beam-hybrid coupled shear wall should be 1/1000, 1/320, 1/140 and 1/110.
6. Conclusion
(1) The PRC coupling beam-hybrid coupled shear wall structure performance level is divided into good use, temporary use, life safety and near collapse of four levels, and on this basis to establish seismic fortification target;
(2) It is suggested that the limit of the turn angle for the four performance levels of PRC coupling beams should be $1/900$, $1/250$, $1/90$ and $1/50$
(3) Taking the story drift angle as the performance index of PRC coupling beam-hybrid coupled shear wall system, it is suggested that the story drift angle limits for four performance levels are $1/1000$, $1/300$, $1/140$ and $1/110$, respectively.

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