Seismic Performance Analysis of PEC Structures

Abstract: Partially-Encased Composite Steel and Concrete Members (PEC members for short) consists of H-shaped cross-section of the main steel and concrete filling between the flange and the web, compared with the pure steel structure, the PEC structure has the advantages of high stiffness, high bearing capacity, good fire resistance and so on. The arrival of an earthquake may cause damage to building structures. The use of PEC structures can effectively improve their bearing capacity and seismic performance, and the method of post earthquake repair is relatively easier and more economical.In recent years, PEC components have been gradually popularized and applied in building structures.

Keywords: pec structures, seismic performance, post-earthquake repair

Introduction

Earthquakes are a natural phenomenon resulting from tectonic movements of the earth's crust. China is located in the intersection of the world's two major seismic tectonic systems, and has historically been one of the most earthquake-prone countries. 2011.2.22, New Zealand's second-largest city, Christchurch, was hit by a strong earthquake of magnitude 6.3 on the Richter Scale, and since then, "post-earthquake recoverability" has become a new requirement for seismic design, and "resilient cities" has become a new development direction for the world's earthquake engineering research. "In 2017, China listed "resilient cities and towns" as one of the four major programs of the "National Earthquake Science and Technology Innovation Project", in order to improve the ability of China's cities to withstand earthquake risks, and to safeguard the implementation of major national strategies and the implementation of the national earthquake strategy. ensuring the implementation of major national strategies and the safety of people's lives and property. Seismic resilience: On the basis of guaranteeing earthquake safety, to realize the post-earthquake maintenance function or rapid recovery function of engineering structures, cities and even the whole society. At present, China's building seismic technology is basically able to meet the "small earthquake is not bad, medium earthquake can be repaired, large earthquake does not fall" defense requirements, but did not pay attention to post-earthquake structural repair and functional restoration, resulting in serious damage to non-structural components after an earthquake, building

UNDER PEER REVIEW

repair difficulties, building function for a long time can not be restored, which affects the city's functional recovery. Recovery. Especially for key buildings such as hospitals and emergency command centers, the lack of function seriously affects the earthquake relief and post-quake recovery work.

Figure1 Earthquake damage

In recent years, there is a new type of combined structure that is filled with concrete between the two flanges of H-beam and become a new type of partially wrapped concrete combination of components called partially encapsulated steel-concrete combination of structures referred to as PEC, as shown in Fig. I. The concrete between the flanges of the PEC components can bear a large portion of the load, and strengthen the local stability of the components, and compared with the traditional steel frame, the cross-section size of the PEC components is significantly reduced. Compared with the traditional steel frame, the cross-section size of the PEC member is significantly reduced, increasing the effective use area of the room, so it has good mechanical properties and superior economic performance, and has a good application prospect.

UNDER PEER REVIEW

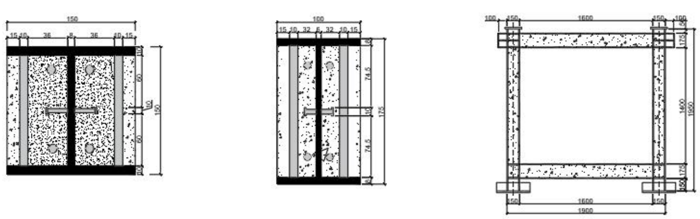

Figure 2Flanges of the PEC components

1 Research progress of PEC column at home and

abroad

The current domestic and international studies on PEC columns are as follows:

1.1 Progress in foreign research:

In 2003, Chicoine et al [8] designed five 300 × 300 mm and two 450 × 450 mm short column specimens in order to investigate the performance and strength of PEC columns made of thin-walled welded H-sections with transverse tie bars. The four specimens were loaded for five months until failure according to the prevailing construction sequence, and the axial deformation due to concrete shrinkage and creep was recorded and compared with the predictive model. The tests showed that the relatively high stresses in the steel sections did not have a significant effect on the damage mode and ultimate capacity of such columns due to loading, shrinkage and creep of the concrete. The transverse stresses in the web of the sections were low in the specimens subjected to long-term loading. It was found that the axial stresses in the transverse links under peak loads caused by transverse expansion of concrete did not depend on the loading sequence.

In 2013, Begum [9] et al. performed a finite element analysis of the force properties of a high-strength concrete thin-walled PEC column. The numerical model takes into account both the nonlinear material behavior and the geometric nonlinearity due to large deformations. In order to simulate the nonlinear material behavior of high-strength concrete, an intrinsic model including post-peak softening branch and residual strength was chosen, and the axial load carrying capacity of the PEC columns was greatly improved (by 55% on average) by using high-strength concrete (60 MPa) instead of 30 MPa concrete for different parameters with a relatively small increase in cost. However, the load-deformation of the high-strength concrete PEC columns exhibited greater brittle damage than the normal-strength concrete columns, and the residual capacity after damage was similar to that of the normal-strength concrete columns.

In 2021, Patrick et al [10], in order to investigate a more practical alternative to welded steel reinforcement in PEC columns, introduced steel fiber concrete as an alternative to conventional concrete with connectors, and mechanically investigated the fiber concrete composite columns through numerical simulations, which revealed superior ductility and better post-flexural performance of the fiber concrete compared to the conventional

UNDER PEER REVIEW

concrete.

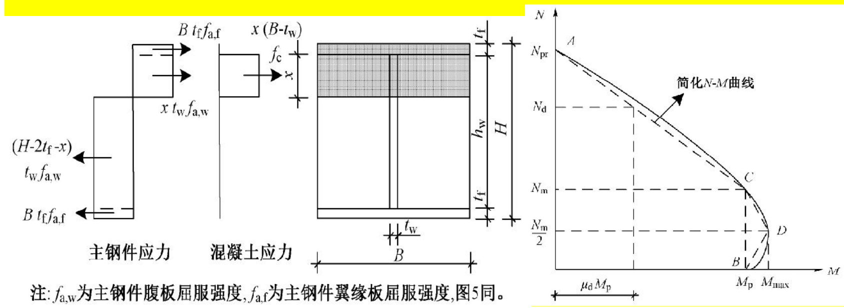

Figure3 Calculation diagram

1.2 Current status of domestic research

In 2004, Hao Jiping and Zhao Qirong [11] studied the mechanical properties of partially wrapped steel section concrete, such as cracks, bearing capacity and stiffness, and carried out finite element simulation analysis. The experimental results show that the stability and seismic performance of the partially wrapped profiled concrete structure are high, and the relevant calculation formula is summarized.

In 2006, Chen Yiyi [12] conducted seismic tests on welded H-beam compression bent members under monotonic static and repeated loads with different loading methods as test parameters. The results show that all the specimens have similar damage characteristics before reaching the ultimate load capacity, and the formula for calculating the area reduction of the column cross-section after exceeding the limit value of the width-to-thickness ratio is summarized.

In 2018, D. H. Lin and Y. I. Chen [13] established a finite element simulation analysis of PEC specimens using transverse bollard spacing and cross-sectional aspect ratio as test parameters. The results yielded that the formula about the overall stability of PEC column.

In 2019, Zhao Gentian and Guo Yaru [14] conducted axial compression tests on 12 PEC medium-length columns using steel content and concrete strength as parameters. The results showed that the low strength concrete can only play the role of filler in the work, and the strength is limited.

In 2023, Zhang Yifan, Chen Yiyi et al[15] designed three nodal substructure specimens of PEC columns connected with beams in the weak-axis direction, numbered JM, JH, and BH, respectively, and carried out

UNDER PEER REVIEW

static monotonic loading and hysteresis loading to investigate the stress performance of the nodes and the damage modes of the specimens. The test results show that the tested PEC weak-axis node connection form can meet the requirements of rigid connection.

2 Current status of domestic and international research on PEC beam-column nodes

The current national and international studies on PEC beam-column nodes are as follows:

In 2006-2008, Bursi O.S. and Braconi A. et al [16] carried out a structural seismic test study of beam-column frames with different frame beam-column nodal domains and different footing treatments as test parameters. The results showed that yielding occurred at the beam ends and column flanges and plastic hinges were formed at the column footings.

Plumier et al [17] conducted tests on 12 foot-size PEC column beam-column edge nodes to investigate the force properties in the node region, with the following results: the connection method and web thickness have a small effect on the performance of the PEC column nodes; all the yields in the tests occurred in the beams, and the flanges of the beams were always bending outwards due to the concrete action.

Jingfeng Wang [18] studied the outer reinforcing link points of steel beams of steel-tube concrete columns at high temperatures through finite element simulation, and analyzed the effects of the parameters such as the width of the ring plate, the thickness of the steel tube, the width and thickness of the flange of the steel beam, and the height of the beam, on the nodal bending capacity and initial stiffness at different constant high temperatures. On this basis, a simplified calculation method of node flexural load capacity and initial stiffness at high temperature was established, and the connection classification method of Eurocode EC3 was used to analyze the node stiffness at high temperature.

Fang Youzhen et al [19] carried out a low-cycle load test on the steel-beam node of a new type of rolled edge steel plate concrete combined PEC column, and the results showed that: the new type of rolled edge steel plate concrete

UNDER PEER REVIEW

combined PEC column meets the requirements of "bidirectional equal stiffness"; the setting of pre-tensioned bolts enables the node domain to fully realize the concrete diagonal compression zone force transfer, and the shear requirements on the web of the steel column are reduced. Requirements are reduced, and all the specimens show different degrees of self-resetting function and good energy dissipation capacity, realizing the seismic defense goal of strong nodes.

3 Research progress of PEC shear wall at home and abroad

In 2016, Yin Zhanzhong et al [20,21] modeled PEC-column steel plate shear wall structures with different axial compression ratios, height-to-thickness ratios, concrete strength grades and other parameters using ABAQUS. The results of monotonic and cyclic loading studies on specimens showed that the lateral stiffness and ultimate strength of PEC column steel plate shear wall were improved and the energy dissipation capacity was more stable than that of ordinary H-beam steel plate shear wall structure.

In 2022, Yin Zhanzhong [22] et al. designed a finite element model considering eight different plate thicknesses aimed at solving the stiffness matching between the edge framing and the steel plate shear wall of PEC column steel plate shear wall, and fabricated a one-third bays scaled down specimen of steel plate shear wall with partially encased concrete columns, and finite element and experimental values verified the accuracy of the lateral stiffness calculation formulas.

In 2022, Chen Yiyi[23] and others conducted low-circumference static loading tests on three foot-size PEC shear wall specimens with practical engineering applications as a starting point, observed the test phenomena and damage process of PEC shear walls, and examined the damage modes and deformation characteristics of the PEC shear walls under reciprocating loads by analyzing the stresses and strains of key parts; analyzed the mechanical properties of PEC shear walls under low-circumference reciprocating loads, such as hysteresis curve, skeleton curve, energy dissipation capacity, ductility, bearing capacity, and stiffness, and evaluated their lateral resistance performance; compared the effects of crimping construction measures on their damage characteristics, deformation and lateral resistance performance; and compared the mechanical properties of crimping construction measures on

UNDER PEER REVIEW

their lateral resistance performance. The mechanical properties of PEC shear wall under low-week reciprocating load, such as hysteresis curve, skeleton curve, energy dissipation capacity, ductility, bearing capacity, and stiffness, were evaluated; the effects of crimped construction measures on the damage characteristics, deformation, and lateral resistance were compared and examined; the effects of different axial compression ratios on the lateral resistance of crimped construction of PEC shear wall were comparatively analyzed.

In 2023, Zhu Jie [24] and others in order to study the partially clad steel-concrete combination wall used finite element software ABAQUS to establish a finite element analysis model, based on the existing test data for comparison, to verify the accuracy of the model. After that, the numerical parametric analysis of the axial compressive stability performance of the PEC wall was carried out based on the stability theory of the combined structure, according to the composition of the concrete and the main steel members in the combined section, the equivalent strength f_{EQ} , the equivalent modulus of elasticity E_{EQ} of the combined section were comprehensively determined, and the regularized length-to-slength ratio λ_n of the PEC wall members were deduced.

In 2024, Hao Josi [25] and others designed and fabricated five pieces of short limb shear walls in order to study the bending capacity and seismic performance of assembled partially clad steel-concrete combination short limb shear walls. The effects of axial compression ratio, flange thickness, concrete strength and steel section strength on the damage pattern, hysteretic performance, bending capacity, deformation capacity, stiffness degradation and energy dissipation capacity of the specimens were analyzed by the proposed static tests. The test results show that: the short limb shear wall exhibits typical compression bending damage; the axial compression ratio increases from 0.4 to 0.6, and the bearing capacity and ductility of the specimen are reduced; the change of the thickness of the flange plate has a small effect on the bearing capacity and ductility of the specimen; the bearing capacity of the specimen is increased with the increase of the strength of the concrete and the steel section; and the specimen exhibits a good performance of seismic performance under the effect of rare earthquakes.

UNDER PEER REVIEW

4 Conclusions and outlook

(1) PEC structures have stronger seismic performance and better toughness than pure steel structures, which is in line with the current concepts of "resilient cities" and "post-earthquake restoration".

(2) More experimental studies need to be carried out. Concrete with too low a strength may only serve as a filler and not have a good load-bearing capacity, especially for PEC structures with foam concrete or ECC, in order to have a more comprehensive understanding of their performance.

(3) Since PEC members are mainly used in assembled structures, the study of their stress performance needs to be further extended to the connection between vertical and horizontal members, and the connection between vertical members (including vertical and horizontal parallel connections), which need to be explored experimentally and theoretically.

UNDER PEER REVIEW

Disclaimer (Artificial intelligence)

Option 1:

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of manuscripts.

Option 2:

Author(s) hereby declare that generative AI technologies such as Large Language Models, etc have been used during writing or editing of manuscripts. This explanation will include the name, version, model, and source of the generative AI technology and as well as all input prompts provided to the generative AI technology

Details of the AI usage are given below:

1.

2.

3.

5 References

[1]. Engineering Project Management Committee of China Construction Industry Association. Research on new construction mode and project management innovation in the context of modernization of construction industrialization [M]. Beijing: China Construction Industry Press, 2018
[2]. National Engineering Technology Research Center for Prefabrication and Assembly of Civil Structures, Tongji University. China Construction Industrialization Development Report 2016[M]. Beijing: China Construction Industry Press, 2016.
[3]. National Standard of the People's Republic of China. Code for seismic design of buildings: . [S], 2010.
[4]. Technical Regulations on Seismic Reinforcement of Buildings: JGJ 116-2009
[5]. Code for Seismic Design of Buildings: GB 50011-2010 [S]. Beijing: China Construction Industry Press, 2010.
[6]. Design Code for Reinforcement of Concrete Structures: GB 50367-2013 [S]. Beijing: China Construction Industry Press, 2014.
[7]. Technical specification for partially clad steel-concrete composite structures:T/CECS 719-2020 [M]. Beijing: China Construction Industry Press, 2020
[8]. Chicoine T, Massicotte B, Tremblay R. Long-term behavior and strength of partially encased composite columns with built up shapes[J]. Journal of Structural Engineering, ASCE,2003, 129(2): 141-150
[9]. Begum M, Driver R G, Elwi, A E. Behaviour of partially encased composite columns with high strength concrete[J]. Eng. Struct. 2013, 56: 1718-1727.
[10]. Patrick A, Marinho M, Krahl P A, et al. Parametrical analysis of partially encased composite columns with fiber reinforced concrete subjected to uniaxial and biaxial non-constant bending moments[J]. Structures, 2021, 34(1): 1872-1889.
[11]. Zhao Qiaorong. Research on Performance of Outsourced Section Steel Concrete Beams [D]. Xi'an: Xi'an University of Architecture and Technology, 2004.
[12]. Chen Yiyi, Ma Chao et al. Experimental and seismic bearing capacity assessment of thin flexible high-frequency welded H-steel columns[J]. Journal of Tongji University, 2006, 34(11):1421-1426.
[13]. LIN Dehui, CHEN Yiyi. Integral stability analysis of partially infilled steel-concrete composite columns [A] In:Proceedings of the 27th National Structural Engineering Symposium (Volume I) [C], Xi'an, Shaanxi, China, 2018:459-464.
[14]. ZHAO Gentian, GUO Yaru. Experimental study on axial compressive
UNDER PEER REVIEW

bearing capacity of H-shaped steel partially wrapped concrete medium-length column[J]. Construction Steel Structure Progress 2019, 21(04):19-27.
[15]. Zhang Yifan, Chen Yiyi. Force performance analysis of PEC columns rigidly connected with beams in the weak axis direction - tests and calculations[J]. Steel Structures (in Chinese and English) 2023, 38(06): 32-41
[16]. Bursi Oreste S. and Zandonini et al. Seismic behavior of a 3D full-scale steel-concrete composite moment resisting frame structure [C]. Proceeding of the 5th International Conference on Composition in Steel and Concrete Ⅴ, 2006, 641-652.
[17]. Plumier A,AbedA,TiliouneB.Increase of Buckling Resistance and Ducilty of HosectionsbyEncasedConcrete.Behaviour of stel Structures in Seismic Areas
[18]. [J].1995:211.
[19]. Fang Youzhen, Gu Qiang, Yao Jiangfeng, et al. Experimental study on seismic performance of nodes in new rolled edge steel plate combination PEC column-steel beam [. Journal of Civil Engineering, 2014,47(7):53-62.
[20]. Wang JF, Han LH. Simplified calculation method of steel pipe concrete structural nodes under high temperature []. Advances in Architectural Steel Structures, 2009,11(2):28-34.
[21]. YIN Zhanzhong, REN Yage, FANG Shunzhong, et al. Energy consumption performance analysis of steel plate shear wall structure with PEC column[J]. Lanzhou
Journal of Lanzhou University of Science and Technology, 2017, 43(06): 126-132.
[22]. SU Minghao. Research on seismic performance of steel plate shear wall structure with PEC column [D]. Lanzhou University of Science and Technology, 2016.
[23]. Yin Zhanzhong, Liu Jun, Yang Bo, et al. Analysis of lateral stiffness of steel plate shear wall with PEC column[J]. Harbin Engineering University
Journal of Harbin Engineering University, 2022, 43(03): 392-398.
[24]. SUN R, CHEN Yi Y. Experimental study on lateral resistance of PEC shear wall[J]. Steel Structure (in Chinese and English), 2023, 38(06):1-11
[25]. Zhu J. Study on stability performance of partially clad steel-concrete combined shear wall [D]. Zhejiang University. 2023
[26]. Hao Yosi, Yang Yukun et al. Calculation of bending capacity of assembled partially clad steel-concrete combination shear walls[J]. Building Structure, 2024, 54(08).
UNDER PEER REVIEW

[27]. Li Junhua, Xue Jianyang, Zhao Hongtie Experimental study on seismic performance of high-strength steel reinforced concrete columns World Earthquake Engineering, 2004 (4): 94-99
[28]. Jia Jinqing, Jiang Rui, Xu Shiqian, Sun Genqin, Houtong Experimental Study on Seismic Performance of Ultra High Strength Concrete Short Columns Earthquake Engineering and Engineering Vibration, 2006 (6): 120-126
[29]. Chuanguang Hong, Chen Yiyi Static test and shear bearing capacity calculation of partially filled composite structural frame assembly nodes [J]. Journal of Building Structures, 2017, 38 (8): 83-92
[30]. Shi Qingxuan, Wang Bin, Wang Peng, Tian Jianbo Comparative analysis of bidirectional seismic performance of T-shaped RC shear walls Journal of Xi'an University of Architecture and Technology (Natural Science Edition), 2014, 46 (2): 159-165
[31]. Chen Xiaogang, Mou Zaigen, Zhang Jubing, Wang Cuikun, Chen Caicai, Sun Huizhong Experimental study on seismic performance of steel reinforced concrete columns Journal of Beijing University of Science and Technology, 2009, 31 (12): 1516-1524
[32]. Huang Liang, Sun Qiang, Deng Peng, etc Research on Seismic Performance of Fast Recoverable Seismic Damage Frame Structures [J]. Building Structures, 2021, 51 (15)
UNDER PEER REVIEW