Asian Agricultural Research 2026, 18 (8): 19 -23 DOI: 10.19601/j.cnki.issn1943 -9903.2026.08.003

Design and Application of Repairability-Oriented Prefabricated Steel Plate Walls for Post-Earthquake Scenarios

Liang CHEN[1*], Xiaohong ZHANG[1], Baibin SUN[1], Fan ZHANG[1], Yuan DING[1], Zuohua LI[2]

1. CSCEC4 Civil Engineering Co., Ltd., Shenzhen 510000, China; 2. School of Civil and Environmental Engineering, Harbin Institute of Technology (Shenzhen), Shenzhen 518055, China

Abstract Aiming at facilitating rapid post-earthquake repair, this study presents an optimized assembly design for a novel prefabricated steel plate wall, focusing on refining the connections among its components. On the basis of the wall's energy-dissipation mechanism, the components are clearly categorized into sacrificial energy-dissipating elements and permanent elements. The permanent parts are embedded into and integrated with the main structure, transferring loads during earthquakes while remaining undamaged. In contrast, all dissipative components are connected using detachable bolts to enable convenient removal and replacement. A lightweight design philosophy is adopted for individual members to prevent oversized or overweight units that would hinder onsite handling. Furthermore, a two-stage assembly procedure is developed, clearly defining the erection sequences for both dissipative and permanent components. The proposed approach is verified through a real engineering application, confirming its technical viability for achieving rapid post-earthquake repairability. This research advances the design, fabrication, and installation methods of such prefabricated energy-dissipating walls, offering practical guidance for analogous projects.

Key words Prefabrication, Repairability, Steel plate wall, Damage, Energy-dissipating components

0 Introduction

With the continuous advancement and proliferation of prefabricated construction, the height of prefabricated buildings has been steadily exceeding the limits specified by current codes, posing new challenges to the seismic performance of high-rise prefabricated structural systems. Incorporating novel energy-dissipating components equipped with buckling-restrained steel plates is considered a rational solution to enhance their seismic resistance[1-2]. At present, there are two primary approaches for integrating energy-dissipating steel plates into the main structure: embedded construction and prefabricated assembly. The embedded method, however, requires wet works on site, which makes construction quality difficult to control and extends the on-site construction period[3-5]. Moreover, in the event of earthquake-induced damage, the subsequent repair of affected components is extremely inconvenient. This not only contradicts the original green-building philosophy of prefabricated construction but also hinders the effective promotion of such energy-dissipating measures in prefabricated building practices. The prefabricated approach enables the assembly of buckling-restrained steel plates into the structural system, which aligns with the fundamental characteristics of industrialized construction. Considerable research has already been conducted on energy-dissipating components based on this novel prefabricated buckling-restrained steel plate[6-9], for instance, replacing the original coupling beams with prefabricated energy-dissipating coupling beams, or substituting a portion of the shear walls or infill walls with prefabricated energy-dissipating steel plate walls to improve the overall seismic performance of the structure. In response to these new components, tailored assembly procedures and construction methods have also been developed[10].

Focusing primarily on installation convenience, existing studies on the assembly methods of new prefabricated energy-dissipating components give relatively scant consideration to post-earthquake repairability. Welded connections and embedded joints, which are unavoidable during erection, can be implemented smoothly on site, yet they turn out to be unfavorable for future maintenance and repair after an earthquake. This unfriendliness leads to significant difficulties in replacing the seismically damaged energy-dissipating modules, and such difficulties have long remained a technical gap confronting these novel prefabricated components.

In summary, focusing on a novel type of prefabricated energy-dissipating steel plate wall component[11], and integrating the industrial green-building attributes of prefabricated construction, this study proposes the key technologies for repairability-oriented assembly design. These technologies not only enable rapid installation during the construction phase, but more importantly, they address the critical need for quick disassembly and component replacement in the later operation and maintenance stages.

1 Novel prefabricated energy-dissipating steel plate wall component

According to the design configuration of this novel prefabricated energy-dissipating steel plate wall component[11], the steel plate wall consists of an external steel frame, steel connecting members, energy-dissipating steel plates, concrete cover plates,

Received: May 3, 2026 Accepted: July 15, 2026
Supported by Shenzhen Collaborative Innovation Project (CJGJZD202205-17142401002).

* Corresponding author. Liang CHEN, doctoral degree, senior engineer, research fields: construction technologies in the fields of prefabricated construction, urban renewal, and green building.

and embedded steel plates. Among these, the energy-dissipating steel plates, the concrete cover plates, and the embedded steel plates function as the energy-dissipating components, all housed within the external steel frame (Fig. 1). In the design, the energy-dissipating steel plates are embedded into the concrete cover plates to form an integral unit, namely, the concrete-cover-plate assembly, while the embedded steel plates are sandwiched between the cover plates. Together, these subassemblies constitute the energy-dissipating structure of the novel prefabricated steel plate wall. During earthquakes, the energy-dissipating steel plates, the embedded steel plates, and the concrete cover plates undergo energy-dissipating damage in sequence. After an earthquake, the energy-dissipation structure of the steel plate wall becomes deformed and damaged (as shown in Fig. 2 and Fig. 3), causing the entire wall component to lose its energy-dissipating capacity. To ensure the normal post-earthquake serviceability of the structure, the damaged subassemblies must be replaced so that the steel plate wall component can fully recover its energy-dissipation capacity and functionality. The prefabricated design of this novel energy-dissipating steel plate wall should therefore take into account the repairability issues associated with later operation and maintenance.

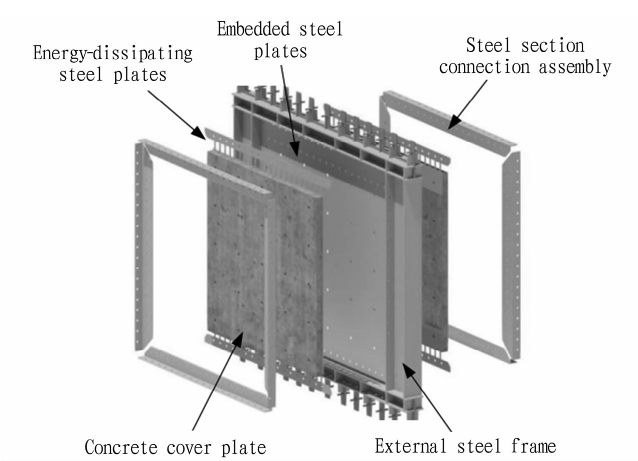


Fig. 1 New prefabricated energy-dissipating steel plate wall component

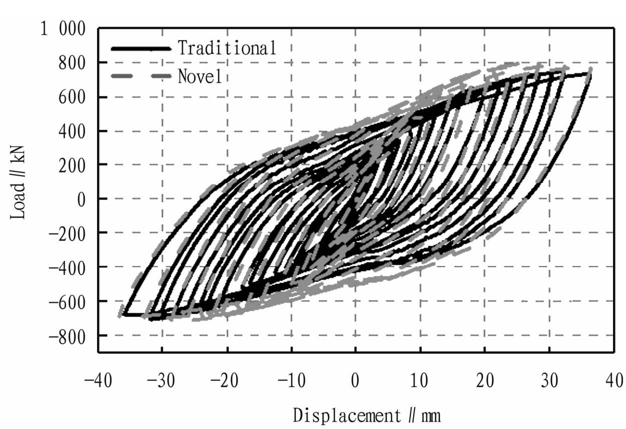


Fig. 2 Energy dissipation hysteresis curves under earthquake load

2 Repairability-oriented assembly design and construction for the novel prefabricated energy-dissipating steel plate wall component

2.1 Optimization of repairability-oriented assembly design

Based on the functional requirements of the energy-dissipating steel plate wall[11], when this novel prefabricated component is used to replace a portion of the original building wall as the energy-dissipating zone, a reliable connection with the main structure at the original wall location must be ensured. Serving as the primary link between the main structure and the internal energy-dissipating system is the external steel frame, whose purpose is to enable effective force transfer between the main structure and the internal energy-dissipating components of the steel plate wall. According to the energy-dissipation mechanism of the prefabricated steel plate wall[11], the external steel frame does not participate in energy dissipation under seismic actions and sustains no damage after an earthquake. Thus, it can be permanently connected to the main structure by being embedded into the frame beams of the main structure, without repair or replacement after an earthquake (Fig. 4).

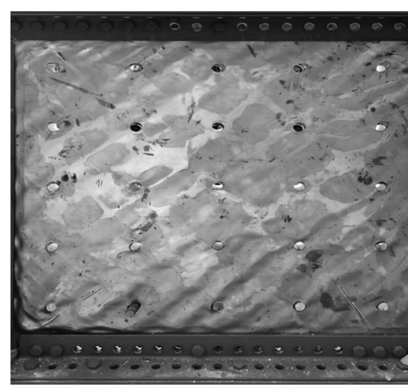


Fig. 3 Deformation and damage of energy-dissipating components

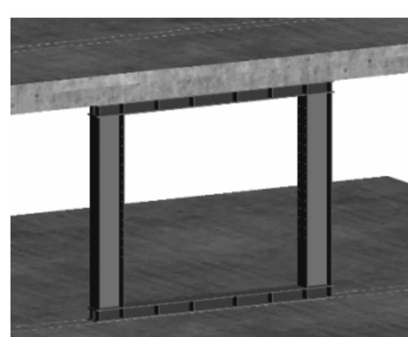


Fig. 4 Embedment of the external steel frame

For the energy-dissipating components housed within the external steel frame, namely, the concrete cover plates, the energy-dissipating steel plates, and the embedded steel plates, irreversible damage and deformation occur under seismic actions, necessitating post-earthquake disassembly and replacement. To facilitate rapid disassembly and repair after an earthquake, all dissipative components are designed with easily detachable bolted connections, as shown in Fig. 5, through which they are linked to the external steel frame via steel section connection assemblies. The concrete cover plates on both sides of the steel plate wall are closely fitted against the embedded steel plates and are also secured by bolted connections. In the repairability-oriented design of the energy-dissipating steel plate wall, the limited working space for post-earthquake repair operations must also be taken into account—a constraint not present in new construction, where adequate lifting and erection space is typically available. The volume and weight of each individual dissipative component should therefore be determined from the very beginning with full consideration of the internal spatial dimensions and environmental conditions of the existing building, so as to meet the lightweight prefabrication requirements that facilitate transportation and subsequent maintenance. Overly large or heavy components, which would hinder disassembly and reinstallation within confined spaces, must be avoided. Through the above structural optimization of the dissipative components (Fig. 6), not only is easy installation of the novel prefabricated partition wall achieved, but also, during the service life, particularly in post-earthquake repair, rapid replacement of the damaged energy-dissipating components can be realized by simply disassembling the bolted connections.

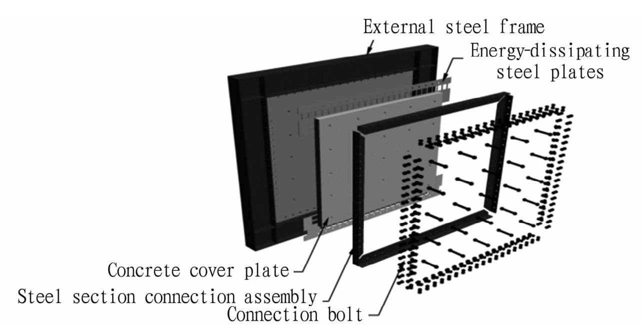
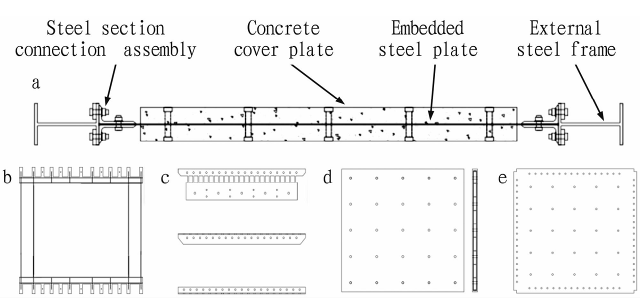


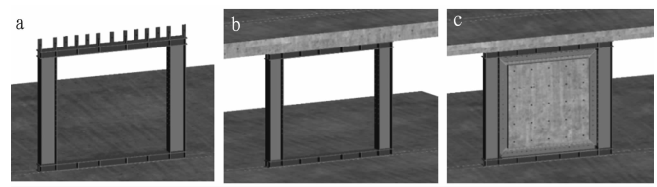
Fig. 5 Bolted connections of the energy-dissipating components



NOTE a. Assembly profile; b. External steel frame; c. Energy-dissipating steel plate and steel section connection assembly; d. Concrete cover plate; e. Embedded steel plate.

Fig. 6 Structure of energy-dissipating steel plate wall

2.2 Two-stage assembly construction Based on the repairability-oriented design optimization and the damage-location characteristics of the novel prefabricated energy-dissipating steel plate wall, we further propose a two-stage on-site assembly technique for the wall component. The energy-dissipation mechanism of the prefabricated wall component enables a rational classification of its subassemblies into damage-prone components and permanent components. The external steel frame of the wall, serving as the permanent component, is embedded and installed first, integrated with the main structure as a whole, and participates only in force transfer without sustaining damage under seismic actions. After the permanent component has been fully embedded and installed, the energy-dissipating subassemblies (acting as the damage-prone components) are then assembled and installed using fully bolted connections, as shown in Fig. 7.



NOTE a. Stage I of permanent component embedment; b. Stage II of permanent component embedment; c. Assembly stage of damage-prone components.

Fig. 7 Stage of permanent component embedment and assembly stage of damage-prone components

The specific assembly construction procedure is as follows:

(i) Embedment construction of the bottom components of the external steel frame. A clash detection simulation and verification is first performed between the bottom embedded components of the external steel frame and the reinforcement bars of the existing main frame beams, so as to optimize the spacing of the frame beam rebars at the embedment location. After the placement and tying of the slab reinforcement bars are completed, the external steel frame is positioned. Once the positioning is finished, short reinforcing bars are used to weld the embedded energy-dissipating frame to the slab rebars, thereby preventing misalignment during concrete pouring.

(ii) Concrete pouring of the embedment floor for the bottom assembly of the external steel frame. After the external steel frame is positioned and fixed for embedment, the concrete pouring of the embedment floor commences and is completed.

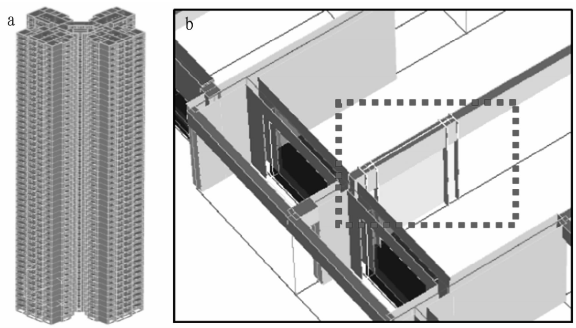
(iii) Embedment construction of the top assembly of the external steel frame. The reinforcement bars of the main structural frame beams at the embedment location of the top assembly are tied only when the concrete strength of the embedment floor reaches above 70%. Following the same procedure as step (i), clash detection simulation and verification between the rebars and the embedded components are carried out, the rebar spacing is optimized, and the tying is finalized.

(iv) Concrete pouring for the embedment floor of the top assembly of the external steel frame. Once the reinforcement tying is completed, the formwork erection and closing procedures are initiated. During the closing process, the aluminum formwork at the embedment location of the upper assembly requires careful sealing to ensure tightness and avoid slurry leakage. The concrete pouring can commence immediately after the formwork sealing is finished.

(v) Assembly of the energy-dissipating components. With the embedment of the external steel frame completed, the energy-dissipating components of the novel prefabricated partition wall are ready for assembly and installation.

2.2 Engineering application

2.2.1 Project overview. The project is a prefabricated super high-rise residential structure, with a main structural height of 149.50 m, 49 stories above ground, and 3 stories underground, adopting a reinforced concrete shear wall system. The main structural model is presented in Fig. 8a. Due to the need for enhanced overall seismic performance, the structural design is optimized, and novel prefabricated energy-dissipating steel plate wall components are employed to replace the original ALC partition walls so as to strengthen the energy-dissipation capacity of the structure, as shown in Fig. 8b. The number and locations of these novel components are determined according to the floor-wise distribution of structural damage.



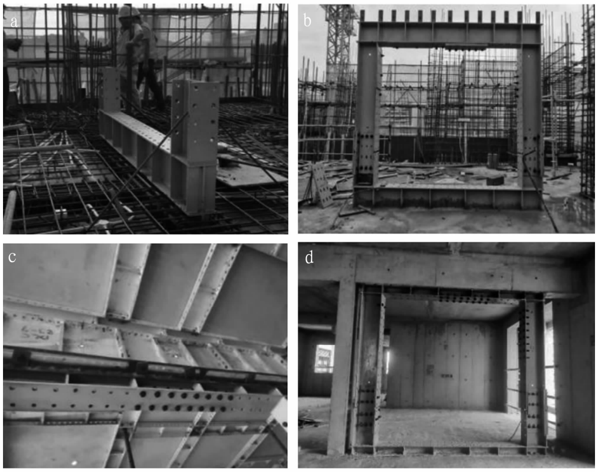
NOTE a. Structural model; b. Schematic drawing for replacing steel plate wall components.

Fig. 8 Structural model and Schematic drawing for replacing steel plate wall components

2.2.2 Assembly implementation effect. The permanent component of the novel prefabricated steel plate wall component is the external steel frame during on-site assembly, and its embedment construction procedures are detailed in Fig. 9.

The damage-prone components of the novel prefabricated energy-dissipating steel plate wall component are the concrete cover plates, the energy-dissipating steel plates, and the embedded steel plates. For these components, the assembly and installation construction procedures are detailed in Fig. 10.

2.2.3 Structural performance optimization effect. Simulation analysis under rare earthquake actions indicates that the installation of the novel prefabricated energy-dissipating steel plate wall components can effectively reduce the damage degree of primary structural members and lower the maximum inter-story drift ratio of the structure. Under very rare earthquake actions, the damage reduction becomes more pronounced and the maximum drift ratio is further decreased. This optimization also prevents full-section crushing of critical components in the main structure, thereby enhancing the overall seismic performance and safety reserve. The optimization effects are detailed in Table 1 below.



NOTE a – b: show bottom embedment; c – d: present top embedment.

Fig. 9 Embedment of the bottom and top of the external steel frame

NOTE a. Installation of embedded and energy-dissipating steel plates; b. Assembly of concrete cover plate; c. Steel plate wall decoration sealing.

Fig. 10 Assembly and installation procedures of the novel prefabricated energy-dissipating steel plate wall components

Table 1 Comparison of effect before and after optimization

Seismic magnitude	Scheme	Maximum inter-story drift ratio	Damage energy//kJ	Damage degree optimization
Rare earthquake	Original	1/209	5 296 920	Reduced damage to bottom wall piers
	Optimized	1/213	5 067 160	
Very rare earthquake	Original	1/131	11 347 400	Reduced damage to wall piers at the installation locations
	Optimized	1/141	10 365 200	

3 Conclusions

Based on the structural features of the novel prefabricated energy-dissipating steel plate wall component, this study proposes a repairability-oriented design optimization and a two-stage on-site assembly construction technique. The optimization design improves the connection methods and introduces a lightweight design concept for the energy-dissipating components. With the two-stage assembly technique, the component types are scientifically classified and the assembly procedures for both damage-prone and permanent components are specified. Through an engineering application, the technical feasibility is further verified, which enriches and promotes the design, assembly, and installation technologies of such novel prefabricated energy-dissipating components and provides a reference for similar projects.

References

[1] LI ZH, GE L, QI YH, *et al.* Seismic performance optimization design for modular structure with energy dissipation component[J]. Journal of Building Structures, 2023(S2): 272–281. (in Chinese).

[2] ZHU CP, WANG JY. Theoretical model and shaking table test verification of the new energy dissipation structure with damping concentration system[J]. World Earthquake Engineering, 2024, 40(1): 135–145. (in Chinese).

[3] HAO GQ, ZHANG PF, ZHAO YY, *et al.* Research on seismic performance of new steel plate bolted assembled concrete shear wall[J]. Hebei Journal of Industrial Science and Technology, 2022, 39(6): 480–486. (in Chinese).

[4] DENG ZH, LIN Q, HU Q, *et al.* Experimental study on seismic performance of new steel truss coupling beams[J]. Journal of Vibration and Shock, 2012, 31(1): 76–81. (in Chinese).

[5] LI JW, LIU YL, ZHANG X, *et al.* Structural design and analysis of Kunming China Resources Center T1 super high-rise tower[J]. Building Structure, 2023, 53(9): 25–31. (in Chinese).

[6] LIU ZZ, XU TN, HUANG FW. Design and simulation study of new buckling-restrained steel plate wall[J]. Journal of Wuhan University of Technology (Transportation Science and Engineering Edition), 2020, 44(1): 177–185. (in Chinese).

[7] TIAN WF. Incomplete tension field of steel plate shear wall[J]. Journal of Building Structures, 2023, 44(3): 279–293. (in Chinese).

[8] BU Y, ZHANG P. Finite element analysis of seismic performance of buckling-restrained butterfly-shaped steel plate wall[J]. Industrial Construction, 2022, 52(4): 62–70. (in Chinese).

[9] LIU J, XU LH. Study on mechanical behavior of steel plate shear wall with self-centering energy dissipation brace[J]. Engineering Mechanics, 2019, 36(7): 156–164. (in Chinese).

[10] CHEN L, LUO ZM, ZHANG F, *et al.* Key technology research and application of easy-assembly and disassembly design and construction for new energy-dissipating partition wall components[J]. Guangdong Civil Engineering and Architecture, 2025, 32(5): 97–102. (in Chinese).

[11] GENG Y. Seismic performance and experimental study of prefabricated two-stage energy-dissipating buckling-restrained steel plate shear wall [D]. Shenzhen: Harbin Institute of Technology, 2024. (in Chinese).

(From page 18)

harness the technological expertise and human resources of these entities. Such cooperation should focus on research and development targeting key technical challenges in the transformation of small-scale peasants, thereby accelerating the application of scientific and technological advancements. By leveraging universities and research institutions, the cultivation of new professional farmers can be promoted to provide specialized talent necessary for the successful transformation of small-scale peasant production.

4.4 Cultivate small-scale peasants as the main body to stimulate their internal motivation and enthusiasm for transformation As the central focus of collaborative governance, the intrinsic motivation of small-scale peasants is crucial for advancing continuous and profound transformation. Therefore, it is imperative to fully activate the enthusiasm and creativity of small-scale peasants by strengthening their subject consciousness, enhancing their capacity, and protecting their legitimate rights and interests. Specifically, it is essential to cultivate the subject consciousness of small-scale peasants. Through publicity, education, and exemplary demonstrations, small-scale peasants should be guided to abandon traditional production concepts and adopt modern business practices, market awareness, and green development perspectives. It is important to fully respect the will and demands of small-scale peasants, positioning them as active participants, decision-makers, and beneficiaries of the transformation process, thereby enhancing their sense of belonging and identity. Concurrently, channels for small-scale peasants to express their demands must be improved, and interest coordination mechanisms should be established and refined to promptly address the difficulties and challenges they encounter during the transformation. These measures will enhance their sense of gain and well-being, thereby stimulating their intrinsic motivation for transformation.

References

[1] LYU JY, WANG YB. Critique and development: Lenin's exposition of the laws of agricultural capitalism development and its multiple significances[J]. Contemporary Economic Research, 2026(4): 43–50. (in Chinese).

[2] SUN Y, RUAN JH. Exploring approaches to building the agricultural socialized service system in the digital era: Based on the national conditions of "small-scale peasant economy of the large country"[J]. China Rural Survey, 2026(2): 45–68. (in Chinese).

[3] XU ZG, LU BZ. Centennial transformation of China's smallholder economy: A comparative analysis between Buck's farm household survey data and contemporary rural household survey data[J]. World Economic Papers, 2026(1), 23–43. (in Chinese).

[4] DUAN YB, DENG HT, ZHAO Y. Farmland institutions, transaction costs, and the "optimal interval" of agricultural operation scale: With a discussion on transcending the logic of small-scale peasant economy[J]. Journal of Shaanxi Normal University (Philosophy and Social Sciences Edition), 2025, 54(5): 98–113. (in Chinese).

[5] LI H, GUO YM. Endogenous-led reorganizational governance of smallholder farmers: Mechanism construction and implementation pathways [J]. Contemporary Economic Research, 2025(8): 37–48. (in Chinese).

[6] LI JZ. Signs of rural modernization and the resilience of the small peasant economy in modern China[J]. Modern Chinese History Studies, 2025(3): 15–25. (in Chinese).

[7] WANG YQ, HE Y. Inner logic and practical direction of returning farmers to promote rural revitalization from the perspective of farmers' re-peasantization[J]. Journal of South China Agricultural University (Social Science Edition), 2024, 23(5): 1–10. (in Chinese).

[8] YUAN YY. Connotation characterization, practice ways and dynamic mechanism of digital transformation of "big country and small farmers" [J]. Economist, 2024(5): 108–117. (in Chinese).