A New Installation Mode of Elevators for Existing Residential Buildings

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Abstract. With the accelerating population aging in China, the demand for barrier-free vertical transportation in old residential communities is rising sharply. Retrofitting elevators for existing multi-story residential buildings has become a vital livelihood project. Nevertheless, conventional elevator retrofitting schemes suffer from prominent bottlenecks: difficulty in reaching consensus among property owners, large construction occupation, long construction periods, high reconstruction costs, damage to original building structures and complex pipeline coordination. By introducing computer finite-element simulation technology and quantitative analysis via engineering charts, this paper proposes an innovative integrated elevator installation system for existing residential buildings. Targeted optimizations are conducted for structural attachment patterns, prefabricated assembly procedures, classified load-bearing reinforcement and benefit distribution mechanisms. Computer-aided mechanical verification for connecting joints, together with quantitative comparison through construction-cost bar charts and seismic-load stress cloud diagrams, are adopted for engineering validation. The results show that this new mode can effectively mitigate construction disturbance, shorten construction cycles, cut comprehensive investment, reduce risks in structural renovation and ease neighborhood conflicts. The research findings provide technical references and implementation pathways for the nationwide promotion of elevator retrofitting in old residential communities and support the renewal of aging stock housing.

Keywords: existing residential building; elevator retrofitting; prefabricated assembly; finite-element simulation; structural reinforcement; old community renovation

1 Introduction

1.1 Research Background

A large number of 4- to 7-story walk-up apartments built before 2000 across China have no reserved elevator shafts. The proportion of elderly residents in these communities keeps growing, and many seniors face great difficulties in daily stair-climbing activities. Installing external elevators has become an inflexible livelihood demand. Local governments have rolled out supporting policies such as financial subsidies,

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streamlined approval procedures and technical guidelines. However, actual implementation progresses far below expectations.[1]

Traditional cast-in-place elevator shaft projects involve extensive on-site wet operations including foundation excavation and concrete pouring, which may impair original walls and foundations. Low-floor households suffer losses in lighting and ventilation while high-floor residents bear heavy sharing costs, resulting in imbalanced benefit distribution. Meanwhile, many old buildings have not passed seismic appraisal. Blind elevator retrofitting will bring potential structural safety hazards. Therefore, it is urgent to develop a new technical scheme featuring high safety, high efficiency and social compatibility.

1.2 Domestic and Foreign Research Status

Foreign research: Japan has developed mature prefabricated light-steel bolt-connected external elevators. European countries realize factory prefabrication of shaft modules and cut over 60 % of on-site working hours. North America mostly applies independent steel frames completely separated from main buildings, yet such schemes occupy considerable land area. Foreign design parameters and cost frameworks cannot be directly transplanted to Chinese old communities.[2]

Domestic research: Existing domestic studies mainly focus on structural reinforcement, shaft optimization and subsidy-compensation policies. Nevertheless, most literatures separate technical design from practical implementation. Complete integrated solutions combining computer-aided simulation, prefabricated construction and interest coordination are rarely reported, which forms the research motivation of this paper.

1.3 Research Content and Technical Route

This paper analyzes the drawbacks of conventional elevator retrofitting modes and establishes an integrated solution consisting of prefabricated light-steel shafts, flexible bolted connections, classified structural reinforcement, dry-type assembly and differentiated benefit distribution. Finite-element simulation software is applied for computer-aided mechanical verification of connecting joints. Charts are adopted to compare construction periods, costs and stress performance, followed by practical case analysis. Finally, promotion suggestions are put forward.[3]

Technical route: Literature review → field investigation on retrofitting projects → defect analysis of traditional modes → construction of innovative installation system → computer-aided finite-element mechanical verification → comparative analysis via charts and practical cases → conclusions and promotion proposals.[4]

2 Defects of Traditional Elevator Installation Modes for Existing Residential Buildings

2.1 Drawbacks in Structural Connection

Conventional cast-in-place shafts adopt post-anchored steel bar welding. Drilling operations damage the protective layer of steel bars in original beams and slabs and degrade seismic and bearing performance. Differential settlement between new elevator foundations and old building foundations induces additional shear force at joints, giving rise to wall cracking and shaft deformation. Though fully independent steel frames protect main structures, they occupy large public space in compact old neighborhoods.[5]

2.2 Low Efficiency of On-Site Cast-in-Place Construction

Conventional projects require 90-150 days of on-site work. Extensive wet operations generate noise and dust pollution, and rainy weather further delays construction. Construction quality heavily relies on on-site workers, making hidden defects hard to eliminate.

2.3 Rigid Cost-Benefit Distribution

Most projects allocate costs according to building floor area. Low-floor households obtain barely any convenience but share equal costs while suffering lighting losses, leading to high negotiation failure rates.[6]

2.4 Undifferentiated Reinforcement Design

Old residential buildings include brick-concrete, frame and mixed structures with diverse bearing capacities. Traditional “one-size-fits-all” reinforcement either fails to satisfy seismic requirements or causes unnecessary cost waste.

3 Construction of the Innovative Elevator Installation Mode for Existing Residential Buildings

This integrated system combines fully-prefabricated light-steel elevator shafts, flexible bolted joint systems, classified structural reinforcement, all-prefabricated dry-type construction and differentiated benefit allocation.

3.1 Main Structure: Fully Prefabricated Light-Steel Integrated Elevator Shaft

The unit weight of light-steel modules is only 1/5 of reinforced-concrete shafts (about 2.2 kN/m2 versus 11.0 kN/m2 for the representative project, from factory production-drawing statistics), which greatly reduces foundation loads.

3.2 Flexible Bolted Connection Node System

The core innovation is replacing post-anchored bar welding with low-damage high-strength flexible bolted connections. Reinforced connection steel plates are mounted on beam sides of each floor by chemical anchor bolts with small-aperture drilling. Ear plates reserved on light-steel shaft columns are fastened to connection steel plates with high-strength seismic bolts. Rubber damping cushions are laid on contact surfaces.

The drilling aperture is controlled within 12 mm to minimize damage to original beam steel bars. Flexible joints permit tiny displacements to absorb elevator-operation vibration and buffer micro-deformation induced by differential foundation settlement. Anti-seismic diagonal braces can be added for buildings with high seismic requirements.

3.3 Classified Structural Reinforcement Scheme

Targeted reinforcement strategies are formulated for three typical building types:

Brick-concrete structure: Adopt semi-independent foundations. Flexible bolt joints only transfer horizontal vibration loads rather than vertical dead loads of shafts. Carbon-fiber cloth is pasted on anchor beams to improve local shear resistance.

Frame structure: Partial vertical loads of light-steel shafts can be transmitted to frame beams through bolt joints. Only local beam-end reinforcement is required without large-scale foundation expansion.

Partial-frame / mixed self-built structure: Apply fully-independent light-steel foundations completely separated from main buildings, suitable for buildings failing seismic appraisal.

The excavation depth for light-steel-shaft foundations is merely 0.8-1.2 m, much shallower than the 2.0-3.0 m depth for concrete shafts, which mitigates disturbance to underground pipelines.

3.4 Fully Prefabricated Dry-Type Construction Process

The whole workflow contains six compact steps:

Pre-project appraisal: complete structural safety appraisal, underground pipeline detection, resident surveys and approval filing;

Factory prefabrication: manufacture all light-steel modules and connection components within 7-10 working days according to measured dimensions;

On-site shallow foundation pouring: small-area shallow foundation construction with a 3-5-day curing period;

Module hoisting and assembly: hoist shaft modules floor-by-floor, fasten bolted joints and install damping cushions and anti-seismic braces;

Embedding elevator equipment: connect pre-reserved brackets with traction machines, cars and control systems;

Exterior finishing and acceptance: install anti-collision strips, drainage fittings and decorative panels; complete fire-protection, electrical and structural inspection and acceptance.[7]

Chart 1 Comparison of construction cycle and comprehensive cost between traditional cast-in-place scheme and proposed prefabricated scheme (Figure 1).

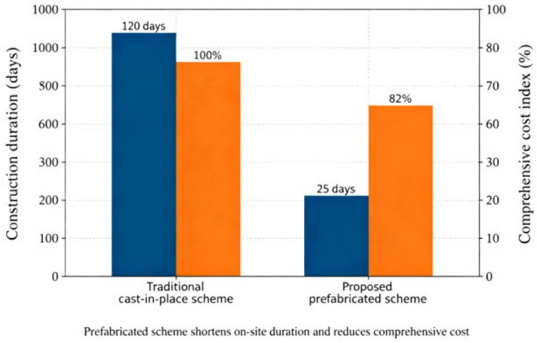


Fig. 1. Comparison of construction cycle and comprehensive cos

Figure 1 illustrates that the traditional cast-in-place scheme requires 120 days of on-site construction with a comprehensive-cost index of 100 %, while the proposed prefabricated scheme only takes 25 days with an 82 % comprehensive-cost index. The prefabricated mode shortens on-site construction duration by more than 70 % and reduces comprehensive costs by nearly 20 %. All quantitative data are obtained from a representative 7-story brick-concrete residential elevator-retrofit demonstration project in Dezhou, Shandong Province (28 households, completed in 1998, no pre-reserved shaft). Cast-in-place data are extracted from the bidding schedule and budget of the alternative scheme; prefabricated-scheme data come from the actual dry-assembly construction records and budget comparison of the implemented project.

3.5 Differentiated Cost-Sharing and Benefit-Compensation Mechanism

1. Tiered cost sharing: Calculate contribution ratios based on floor-level benefit coefficients. Households on higher floors bear higher shares. Residents on the first and second floors pay the lowest amount; some low-floor households can even be exempted by government subsidies.
2. Compensation for low-floor losses: Special subsidy funds are allocated to compensate low-floor residents for lighting, ventilation and landscape losses. Compensation values are assessed by professional housing-appraisal institutions.

3. Distribution of property-value increment: Part of the housing-value appreciation brought by elevator installation for high-floor households is fed back to low-floor residents through agreed transfer funds.
4. Unified post-operation managed by property companies: Elevator operation, maintenance and insurance fees are collected uniformly by property management with transparent special-account administration to avoid subsequent operational disputes.

This mechanism abandons rigid equal-cost-sharing rules and substantially raises the rate of owner consent. In the demonstration project of Dezhou, the owner-consent rate rose from 57 % under the conventional equal-sharing rule to 89 % after adopting tiered cost-sharing and low-floor-loss-compensation measures.

4 Mechanical-Performance Verification of Connection Nodes via Computer-Aided Finite-Element Simulation

Finite-element software is adopted to build a 1:1 numerical simulation model consisting of frame beams, connection steel plates and light-steel-shaft ear plates. Main parameters: C30 concrete for main-building beams, HRB400 longitudinal rebars, Q355 steel for connection plates, Grade-10.9 high-strength bolts and 10-mm-thick rubber damping cushions. Load cases cover elevator dead loads, passenger live loads, horizontal wind loads calculated per GB 50009-2012,[8] and seismic action effects according to GB 50011-2010 (2016 Edition). [9]Chemical-anchor performance and failure modes comply with JGJ 145-2013;[10] high-strength-bolted connection design follows GB 50017-2017.[11] Pre-project structural-safety and seismic appraisal of existing residential buildings shall satisfy GB 55021-2021.[12]

Simulation results:

The maximum tensile principal stress of the main frame beam concentrates around the chemical-anchor boreholes. The peak tensile stress obtained from finite-element calculation is 1.42 MPa, which is lower than the characteristic tensile strength of C30 concrete (ftk = 2.01 MPa); therefore, tensile crack initiation in the concrete substrate is avoided. According to JGJ 145-2013, the dominant failure modes around the chemical anchors are checked, namely steel-bolt fracture, concrete-cone breakout failure and adhesive-bond mixed failure. Under ultimate seismic load, the anchor-group load demand remains below the design capacity for each failure mode, and sufficient anchor edge distance and spacing prevent concrete cone breakout and edge spalling. The previous tensile-cracking judgement based on compressive strength is removed.

Under ultimate seismic loads, joints produce allowable micro-displacement no larger than 1.5 mm. Rubber cushions dissipate vibration energy effectively without bolt loosening or plate buckling.

Chart 2 Stress-cloud comparison under seismic loads for traditional welded joints and flexible bolted damping joints (Figure 2).

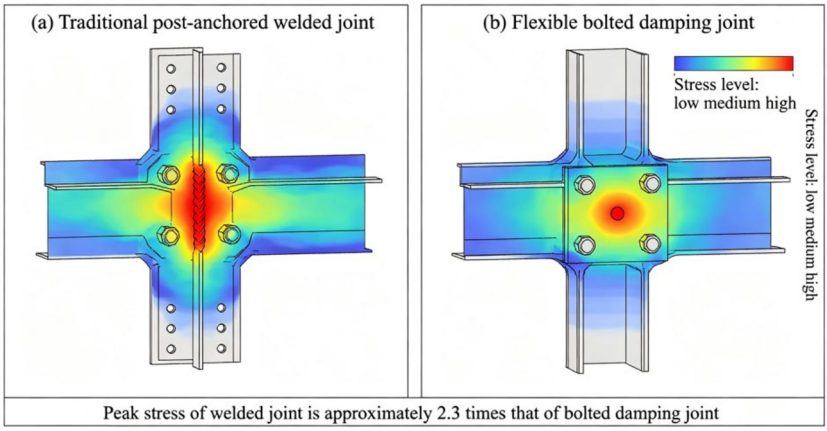


Fig. 2. Stress-cloud comparison under seismic load

Figure 2 presents stress cloud diagrams under seismic loads: (a) conventional post-anchored welded joint; (b) flexible bolted damping joint. Colors represent stress magnitudes (blue = low; green = medium; red = high). The peak stress of welded joints reaches approximately 2.3 times that of flexible bolted damping joints. Traditional welded joints suffer severe stress concentration prone to cracking under earthquakes. In contrast, flexible bolted-damping joints deliver more uniform stress distribution.

Computer-aided finite-element simulation confirms that flexible bolted joints satisfy national building-code requirements for bearing capacity, seismic performance and long-term durability.

5 Conclusions

Targeting multiple bottlenecks in conventional elevator retrofitting for existing residential buildings, this paper puts forward an integrated innovative installation mode centered on fully-prefabricated light-steel shafts and flexible bolted connections, supplemented by classified reinforcement, rapid dry-type construction and differentiated benefit-distribution mechanisms. Supported by computer-aided finite-element simulation and quantitative chart analysis, major conclusions are drawn as follows:

Prefabricated light-steel shafts greatly reduce foundation loads and on-site wet-work volume. Computer-aided finite-element simulation verifies that flexible bolted connections cause minimal damage to original buildings with reliable mechanical and seismic performance.

As reflected by statistical data in Figure 1, the new mode shortens on-site construction cycles by over 70 % and cuts comprehensive engineering costs by nearly 20 %. It reduces public-space occupation and disturbance to residents and achieves prominent economic and environmental benefits.

Tiered cost-sharing plus low-floor-compensation mechanisms ease conflicts between high- and low-floor households and significantly improve owner-agreement rates.

This scheme applies to brick-concrete, frame and mixed-structure old residential buildings and possesses high promotion value for national old-community renewal projects.

For follow-up research, intelligent monitoring sensors can be embedded in connection nodes to realize real-time online monitoring of joint stress, deformation and vibration with computer technologies. Combined with BIM whole-life-cycle management technologies, digital management covering design, fabrication, assembly and maintenance of prefabricated elevator shafts can be continuously improved to form a more intelligent elevator-installation system for existing buildings.

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