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Analysis of Soundproof Technology of Assembled Steel Structure Houses

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Abstract: The problem of noise has always been highlighted in assembled steel structure houses. Therefore, it is necessary to use effective soundproof measures where steel beams intersect with the reserved line pipe openings, doors, windows, elevator shafts, and other locations. In this paper, we will investigate the areas with subpar soundproof performance in an assembled steel structure residential project and propose suitable noise control measures to address this issue.

Keywords: Assembled steel structure; Residential engineering; Sound insulation; Construction technology

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1. Introduction

The acoustic environment is one of the necessary factors for healthy housing. In the process of continuous development and promotion of assembled steel structure housing, its physical properties have been optimized in many aspects. However, soundproof performance has not received adequate attention, and the high assembly rate and lightweight properties of steel structures pose challenges to improving soundproofing. This limitation somewhat hinders the broader application of assembled steel structure housing. Human activities produce noise, and air conditioning, ventilation, heating, and other equipment can also produce continuous low-frequency noise. This affects the daily lives of people, and even causes chronic damage to the body. In fact, steel structures can further amplify low-frequency noise and increase the propagation distance and penetration of vibrations [1]. Therefore, in order to improve the living standard of the people in the assembled steel structure housing, it is necessary to carry out an in-depth discussion on the soundproofing of these types of houses.

2. Overview of the project

In an assembled steel structure residential district covering a construction area of 142,666 square meters, consisting of 10 high-rise buildings and 4 associated podiums, the entire system is based on steel structures. The interior infill wall material is a lightweight autoclaved aerated slat wall, and the elevator shaft occupies the core cylinder position, featuring anti-flexing steel plate walls. This residential district holds a green three-star building certification and is recognized as a healthy building. In terms of construction, the acoustic control for this assembled steel structure residential district primarily revolves around managing the sound at reserved line pipe openings on steel beams, doors, windows, elevators, shafts, subdivided walls, and pipelines, among other locations.

3. Causes of poor soundproofing of assembled steel structure houses

(i) Partition walls

The walls of traditional houses are mainly made of heavy materials, resulting in adequate soundproofing. However, in assembled steel structure houses, almost all the walls are lightweight, including the partition walls between two households, resulting in the soundproofing between different households being less than 40dB, which is less than the required standards.

(ii) Intercomponent porosity

There may be pores between assembly components, because air is the main medium for sound propagation, so there is a close correlation between room airtightness and acoustic performance. If there are errors in the design due to improper selection of materials or unskilled workers, it may lead to excessive pores between assembly components, which affects the soundproofing of the building.

(iii) Steel beams and columns

Compared to traditional concrete houses, steel frame structures require additional cladding due to their unique materials and processing methods. Soundproof treatment often gets overlooked or may not even be considered. Steel structures inherently have limited soundproofing and strong sound transmission characteristics. Combined with the growing use of modern equipment like air conditioning and heating systems that generate low-frequency noise, the utilization of steel beams and columns can lead to suboptimal soundproofing in assembled steel structure houses [2].

4. Noise control measures

(i) Sound insulation measures for holes reserved for wires and pipes on steel beams

In assembled steel structure buildings, there are more integrated functional systems, resulting in complex equipment pipelines. Additionally, the building demands a considerable net height, resulting in limited space at the top. Consequently, most pipelines need to cross over beams. After the pipeline installation, there tends to be a gap between the pipelines and the steel structure. This gap allows the noise generated by equipment operation to quickly propagate through it, potentially leading to noise pollution. Therefore, it is necessary to use appropriate blocking measures to improve the soundproof effect. Current blocking measures mainly include using fire-resistant mastic or rock wool. Before applying fire-resistant mastic, it is imperative to verify the completion of all pipeline projects. Then, the fire-resistant mastic is used to fill the gaps. It is essential to consider that fire-resistant mastic may undergo changes in hardness due to variations in ambient temperature. To prevent any detachment of the fire-resistant cement from the gap, it is imperative to weld steel plates on both sides of the gap. The recommended thickness for the fire-resistant mastic filling is generally more than 50 mm, and the steel plate should have a thickness exceeding 1.2 mm. For the application of the rock wool insulation method, it is also necessary to await the completion of pipeline installation. Typically, the gap between the pipeline and the steel structure falls within the range of 30 to 50mm. It is essential to cut the rock wool into appropriately sized pieces and proceed with the filling process. Subsequently, a plate is installed as a second layer of insulation. This precaution is taken to prevent rock wool from falling through the gap and causing environmental contamination. In summary, fire-resistant mastic tends to offer superior results compared to rock wool insulation. It is easier to apply, effective, and does not cause secondary pollution [3].

(ii) Sound control measures for windows and doors

Doors and windows are usually thinner and have more gaps, so they are less soundproof than the walls. Therefore, they have become a typical weak link in the soundproofing of houses. In order to improve the soundproof effect of windows and doors, their quality should be improved. The soundproof performance should be regarded as one of the main assessment indexes when choosing the doors and windows from a manufacturer, so that the quality of the doors and windows are in line with the relevant standards. In addition, the installation precision should also be improved to reduce the installation gap to enhance the soundproof effect.

In contemporary assembly steel structure housing projects, sectional doors are often designed as comprehensive doors that combine functions like burglary and fire protection. For doors with heightened soundproofing requirements beyond typical standards, two specialized approaches are commonly employed. The first approach is rooted in the principle of mass law, which posits that the greater the weight per unit area of the door, the better the soundproofing effect. This involves enhancing the door's thickness and weight. The second approach involves the use of a multi-layer composite structure. Multiple materials with distinct properties, such as steel plates, wooden panels, sound-absorbing materials, and damping materials, are layered to create the door. Since there is a significant impedance contrast between these diverse materials, they effectively enhance the soundproofing effect.

As for the windows, because they play a role in the ventilation and lighting of the house, they have to be made of glass. In order to improve the soundproof effect of windows, double glass, multi-layered glass, or thicker glass should be used. The separation between adjacent layers of glass should be maintained at a distance of 10–15 cm. When using double or multi-layer glass, it is advisable to avoid placing the glass layers in a completely parallel configuration to prevent resonance or the coincidence effect caused by identical thicknesses between layers, which can result in sound leakage. Furthermore, installing sound-absorbing materials within the window seals between the different glass layers can further enhance the soundproofing effect [4].

(iii) Measures to improve the soundproof effect of elevator shafts

The primary source of noise within the elevator shaft during operation is the mechanical sound resulting from the friction between the elevator car, counterweight guide shoe, and the guide rail. This noise becomes particularly significant when there are issues with the guide rail's installation. Common problems include a substantial deviation from perpendicularity between the guide rail's side and the working surface, excessive steps on the guide rail connecting surface, improper adjustment of the guide shoe gap, damage to the guide boot, twisted wire ropes, and uneven tension in the wire rope. Furthermore, the elevator operates within an enclosed shaft, and its high-speed, vertical movement can generate wind noise within the shaft. Additionally, it is worth noting that the elevator's traction motor relies on air cooling, which can contribute to the overall noise in the system. When the rotor's circumferential speed exceeds 60 m/s or the rotational speed surpasses 2,000 revolutions per minute, it becomes the primary source of ventilation noise within the shaft [5]. The wall around the elevator shaft is also the partition wall between the public area and the household, so it is necessary to apply appropriate soundproof measures. Typically, in a standard elevator shaft, glass wool is used with mineral powder particles sprayed on it for soundproofing. However, when the rock wool boards are in place, the wind pressure generated during elevator operation can blow the sound-absorbing panels within the glass wool out, causing secondary pollution and a decrease in sound insulation effectiveness. To address this, an alternative method is to combine rock wool with the application of sprayed silica sand. When doing so, it's advisable to select fire-rated (A grade) silica sand material with NRC ≥ 0.5, VOC ≤ 120 g/L, and formaldehyde content ≤ 100 mg/kg. This approach helps to maintain soundproofing while minimizing potential pollution issues. The situation of the slatwall in the shaft is first observed, and cement mortar is then used to smoothen out the gaps or any leakage. Next, a binding agent should be applied, the glass wool is secured in place, and rock wool nails are then used along with thermal insulation nails. It is important to ensure that at least 6 rock wool nails are used to secure each rock wool board. Afterward, the seams between each rock wool board should undergo a secondary grouting treatment. Finally, spray silica pore sand should be applied, ensuring complete coverage of the insulation nails, with the thickness of the silica pore sand being controlled at 3 mm. This approach helps ensure effective soundproofing in the elevator shaft [6].

(iv) Control measures for soundproofing in house walls

Partition walls are traditionally made of clay brick, with a thickness of 24 cm, and their weighted soundproofing is about 53 dB, which is satisfactory. However the walls in assembly steel structure houses are lightweight, so their soundproof performance is far worse than the ordinary clay brick walls. Therefore, it is important to look into the materials used to make the walls [7]. There are currently three types of new wall materials: block-type, light steel keel type, and hollow plate strip type. In high-rise residential buildings, achieving both "lightweight walls" and "excellent acoustic performance" can be realized using two approaches. The first method involves employing a double-wall system, using lightweight blocks and lightweight slats as wall materials, with a cavity of 50 to 100 mm established between the two layers of materials. This cavity is then filled with rock wool or other sound-absorbing materials. Care should be taken during construction to avoid creating acoustic bridges between the two layers of the wall. In the second approach, two layers of wall panels are installed at each end of the light steel keel, with the thickness of wall panels being 8–12 mm. The cavities of the two layers of wall panels are filled with rockwool or other sound-absorbing materials, so as to achieve satisfactory soundproof effect, i.e., 49–52 dB. Several other measures can be taken to improve the soundproof effect of the lightweight walls: (a) Adding elastic strips between the keel and the plate, such as elastic pads or elastic metal strips, etc., which can improve the soundproof effect by about 3 dB compared to directly fixing the plate onto the keel [8]. (b) The keel width determines the width of the cavity between the two sides of the wall panel; a keel with a width of 75 mm provides the best soundproofing effect, and a double-row keel configuration can be employed to enhance the soundproofing performance compared to a single-row keel. (c)

The more layers of boards on both sides of a lightweight partition wall, the greater the soundproofing of the wall. Typically, each additional layer of board increases the weighted soundproofing of the partition wall by about 3 dB. To avoid the occurrence of sound frequency valleys in the main frequency range of 100–2500 Hz, it is advisable to minimize the board thickness. The wall panel thickness should be controlled at 12 mm, and the ceiling can be 9.5 mm. Using boards with different thicknesses on different sides or staggering the thicknesses on the same side can further enhance the soundproofing effect. (d) It is necessary to fill up cavities or gaps on the wall, a gap on the wall that is one ten-thousandth of the wall area, can reduce the soundproof effect of the wall by about 10 dB [9].

(v) Control measures for soundproofing of piping and equipment

Indoor sources of noise, such as bathroom downpipes and the vibrations from operating indoor equipment, stem primarily from pipes and equipment. The main sources of sound include downpipes, air filters, and air conditioning systems. To meet building standards and improve the indoor living environment, it is essential to apply soundproofing and vibration-damping measures to the installation of pipes and equipment [10]. In general, equipment can be equipped with spring hangers for support. For sewage pipes, elastic hanging rods or hangers can be installed on the horizontal pipe segments, and rubber mats can be wrapped around the exterior of the pipes. In the vertical riser sections, it's advisable to use thick sound insulation felts along with 1.2 mm-thick melamine sponges for soundproofing. When pipes pass through walls, it's important to use fire-resistant mastic or rock wool for sealing, with preference given to fire-resistant mastic where feasible due to its superior soundproofing properties [11].

5. Conclusion

At present, assembled steel structure has become the trend of the construction industry, and measures should be taken to improve the soundproof effect of these buildings while also achieving energy efficiency and environmental sustainability. Therefore, the dynamic and static areas inside the building should be reasonably laid out during the design stage. Moreover, it is crucial to choose suitable materials for important areas and opt for modern construction materials. This method helps control noise during construction, ensures smooth coordination among all stages, and improves the soundproofing of assembled steel structure residential buildings. This enhances the quality of life for the building's occupants and promotes the use of assembled steel structures, benefiting the local community.

Disclosure statement

The author declares no conflict of interest.

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