Summary of Research on Supporting Facilities and Structure Vibration and Noise Reduction of High-Rise Buildings

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Abstract. At this stage, mid-to-high-rise buildings are flooding every corner of my country's urban construction, and large-scale buildings have also become an inevitable result of urban planning and development. The comfort and safety issues associated with mid-to-high-rise buildings as well as the comfort and safety caused by structural vibration have also come into our sight. This article will explain the research on the vibration control of building power systems, air conditioning systems, network systems, pipeline systems and other building supporting facilities, as well as the research on the vibration control of building structures. These details reflect the improvement of vibration and noise reduction research in the comfort and safety of middle and high-rise buildings.

1. Introduction

With the further acceleration of my country’s urbanization process and the development of the real estate industry and construction technology, mid- and high-rise buildings have emerged in various cities in my country, starting with landmark buildings from all over the country, such as the 528m-high CITIC Tower in Beijing's central business core area, to the Shanghai Tower with a total height of 632m in Lujiazui, Shanghai, to Ping An International Financial Center (592.5m) in Shenzhen, Chow Tai Fook Center (530m) in Guangzhou and other high-rise buildings. We can observe from it that China's urban planning development will inevitably result in the city center dominated by medium and high-rise buildings radiating to the surrounding areas.

However, there are also many problems in middle and high-rise buildings. With the continuous increase of floors and heights, the power equipment, plumbing equipment, and network systems required by the building will become more and more complicated. Offices bring a lot of trouble; on the other hand, higher floors and floors, rooms and rooms will also vibrate due to wind loads and earthquake loads. This brings about two problems of comfort and safety, and also requires excellent design and technical solutions to solve the impact of vibration and noise caused by supporting facilities of middle and high-rise buildings and the impact of vibration caused by external loads on the structure itself [1].

2. Research on vibration and noise reduction of supporting facilities in high-rise buildings

There are many ways to produce vibration and noise in the supporting facilities of middle and high-rise buildings. There are also many ways to reduce vibration and noise in each supporting system.
Below we will start from the air conditioning system, elevator system, building water supply and drainage, and vibration reduction of equipment in the machine room. These aspects of noise reduction will be introduced one by one.

2.1. Research on vibration and noise reduction of air conditioning system
For the air-conditioning system of high-rise buildings, the source of vibration and noise itself mainly comes from the following aspects: water pumps, fans, air-conditioning pipes, etc. [2]. Below we conduct research based on the sources of these vibration and noise.

2.1.1. Water pump vibration isolation
Reinforced concrete counterweight block is added under the pump base to increase the overall weight of the pump and make the center of gravity of the pump shift to the middle part. At the same time, the high frequency shock absorber is installed under the original base, and the original vibration of the pump body with high frequency, low amplitude and high vibration is transformed into the vibration of low frequency, high amplitude and low vibration energy after the first stage vibration damping, and the low frequency shock absorber is added under the counterweight block to carry out the second stage vibration damping.

2.1.2. Fan vibration isolation
Check and adjust the original spring shock absorber on the upper part of the boom, and replace the shock absorber that does not need to be replaced. Add a rubber ring to the hole where the boom passes through the shock absorber to avoid the hanger collided with the shock absorber shell. A high-frequency shock absorber is installed at the bottom of the equipment; the fan unit can also be suspended to reduce vibration transmission [3].

![Image of suspended installation of air-conditioning units and vibration damping measures of the wind box](image)

Figure 1. Suspended installation of air-conditioning units and vibration damping measures of the wind box

2.1.3. Pipe vibration isolation
For the support fixed on the floor, through the method of adding I-steel between the beams, it is fixed on the I-steel, reduce the disturbance of the support directly on the floor; If the rubber shock absorber bracket is used, it should be changed into a flexible silica gel shock absorber bracket and two high frequency shock absorbers are added below; The two sides of the original channel steel support will be suspended and cut off and equipped with spring shock absorber. For the floor bracket, the steel plate connected with the ground is cut off, and a high and low shock absorber is added. Water pump inlet and outlet is generally stainless steel soft connection to double ball rubber soft connection, which can effectively separate the vibration transmission of water pump and pipeline. A soft rubber connection is added at the connection with the water collector for secondary vibration isolation.

In general, the research on vibration and noise reduction of air-conditioning systems focuses on secondary vibration isolation, replacement of original rod and pipe materials, and the installation of high-frequency vibration dampers.

2.2. Research on vibration and noise reduction of elevator system
Regarding the vibration and noise reduction of the elevator system, it is mainly in the construction aspect. At present, measures such as setting a rubber vibration damping device or adding a sound insulation wall between the traction machine and the load-bearing beam are usually adopted [4]. Two
main methods for reducing vibration and noise in elevator systems will be introduced below.

2.2.1. *Replace the cushion directly*

The first method to reduce vibration and noise in elevator construction is to sink the main load-bearing beam, reinforce the concealed project, replace the cushion, and increase the thickness of the rubber cushion after the replacement.

2.2.2. *Installation of damping device*

The second construction scheme is to lift the main engine, add a vibration damping device under the main engine, and add a rubber cushion between the vibration damping device and the main engine. In the engine room, in addition to the above changes to the relative positions of the host, the control cabinet, wire rope, the governor will install damping means.

![Installation of damping device](image)

Figure 2. Installation of damping device
(a.lower part of speed limiter; b.damping device)

2.3. *Research on Vibration and Noise Reduction of Building Water Supply and Drainage*

Because the main components of the water supply and drainage of high-rise buildings are water tanks and pipes, we will introduce these two aspects.

2.3.1. *Sources of building water supply and drainage noise*

The main sources of professional noise in water supply and drainage are as follows: (1) Noise generated by the vibration of pumps and other equipment during operation. (2) Water pump and other equipment and the foundation are rigid bodies. When they are connected with each other nearly rigidly, there is little deformation during vibration. The interference force borne by the equipment acts on the surrounding stratum or the structural floor through the foundation almost all, and the stratum or the structural floor will vibrate accordingly. The interaction causes vibrational energy to be transmitted along the continuous solid structure.(3) The vibration of pumps and other equipment stimulates the vibration of the pipe wall and produces radiated noise.(4) Noise generated by the impact and friction of high-speed water flow on the pipe wall in the pipeline system.(5) When the pipeline is rigidly connected to the building structure, the vibration of the pipeline will stimulate the noise generated by the vibration of the building structure.

2.3.2. *Vibration and noise reduction methods for building water supply and drainage*

Vibration and noise reduction methods for building water supply and drainage are mainly divided into two categories: vibration isolation treatment of water tanks and other water supply and drainage equipment, and changing the connection method of pipes (rigid to flexible) [5].
Figure 3. Pipe flexible joint connection  
(The capital letters in the picture are the flexible connector model)

2.4. Research on Vibration and Noise Reduction of Equipment in the Computer Room

Machine room equipment is introduced in the above high-rise buildings with each system, so the research on vibration and noise reduction of machine room equipment has a very wide range of applications, but also more easy to attract our attention. Here introduces a mature technology widely used in our country: Floating floor construction technology[6]. The method is to build a new layer of ground on the ground of the original structure and connect it with the equipment foundation as a whole. The newly poured ground is separated from the ground of the original structure, so that the vibration of the equipment during operation can be digested in the flooring rather than transmitted to the structure, thus reducing vibration and noise.

Figure 4. Floating floor layer structure
(1. the concrete equipment base is connected to the flooring  
2. flooring with concrete and self-leveling with thick cement base  
3. waterproof non-asbestos calcium silicate board  
4. SBS  
5. glass wool board  
6. the ground)

2.4.1. Floating floor construction process and construction difficulties

The construction process of flooring flooring is as follows: clean up the ground base → lay glass wool board → lay waterproof layer → roll up the facade and close the wall → lay calcium silicate board → bind the reinforcing bar of flooring and equipment foundation → pour concrete.

The construction difficulty that builds a floor to float has the following a few respects: (1) structural ground should clear clean, must not have sedimentation or sundry, the ground should level off dry, must not have outstanding thing. The glass wool board must be laid and pasted tightly. (2) The waterproof layer shall be constructed by empty paving method. The lap length of the coil shall meet the design requirements. The coil and the water retaining platform shall be closely pasted and strictly pasted according to the design height, without omission. After the acceptance of the waterproof layer,
the construction of calcium silicate board should be carried out immediately to avoid damage to the waterproof layer. Calcium silicate board should also be pasted along the waterproof layer in the facade, so as not to omit, so as not to affect the shock absorption function by connecting the flooring with the structural wall on the facade. (3) the thickness of the protective layer should be controlled when binding the steel bar, and the steel bar should not be placed directly on the calcium silicate board. Concrete for flooring and equipment foundations shall be poured continuously, and individual rooms shall be poured at once, with no construction joints and no cold joints as far as possible. If the room is too large to be cast at one time, the construction joint shall be left in the gap between the equipment foundation and shall not cross the equipment foundation. (4) after the concrete pouring surface should be timely surface pressure, concrete surface smoothness deviation control within ±3mm. Equipment foundation forming should be square, straight corners, pay attention to the protection of finished products to avoid missing edges and corners.

3. Research on structural vibration control of high-rise buildings

The vibration and noise of mid- and high-rise buildings are mainly caused by the vibration of their supporting facilities, and we cannot ignore the vibration of the structure itself due to wind loads, ground loads and dynamic loads inside the building. There are many researches on various aspects of structural vibration control, but relatively few are related to vibration and noise reduction. The research of dampers is the main direction. Next, we will introduce two damping structural vibration control methods: the engineering application of building vibration damping viscous dampers and the research application of tuned liquid dampers.

3.1. Viscous Damper

The research on the use of viscous damper for structural vibration control began in the late 1980s, and the research in this field started earlier in the United States and Japan. At present, it has formed a series of studies and been applied to a large number of practical projects. At the same time, design specifications, procedures and construction manuals for the application of viscous dampers have been formulated. Domestic study of viscous dampers started relatively late, since the early 1990s, some domestic universities and research institutes to fluid damper has explored, and some articles in concept, the principle of fluid damper, at present our country has been in the damper test research and development and engineering application and so on have made significant achievements. At the same time, the Code for Building Seismic Design (GB50011-2001) also specifies the relevant aspects of the application of dampers. Developed with independent intellectual property rights of southeast university double from the viscous flow of damper is mainly composed of the following parts: cylinder, piston, damping hole and damping materials, guide bar (on both sides of the piston symmetric set), sealing materials and the connection device, operates as a damping hole on piston, the cylinder was full of high viscosity fluid damping materials as damping medium. The experimental results show that the viscous fluid damper is a kind of velocity-dependent damper without stiffness, which has the characteristics of high energy consumption, insensitivity to temperature and stable dynamic performance[7].

Figure 5. Double rod type fluid damper
(1.main tank 2.auxiliary cylinder 3.guide rod 4.piston 5.damping material 6.orifice)

3.2. Tuned Liquid Damper

The tuned liquid damper (abbreviated as TLD) has been widely used and a lot of research in recent years because of its convenient installation and multi-purpose advantages. Li Hongnan et al.[8] studied
the TLD-structural system through shaking table test, and the test results showed that the vibration control of the structure by TLD was satisfactory. When the oscillation frequency of the liquid in the TLD was close to the frequency of the corresponding vibration mode of the structure, the vibration reduction effect was the best. Controlling the first and second mode responses at the same time is better than controlling the first mode response only. Qu Chengzhong et al.[9] used a three-story frame model test to explore the application of TLD-structure system, and found that the damping effect of TLD is related to the size, quantity and placement of water tanks. Zhang Minzheng et al.[10] discussed the optimal parameters when TLD achieves the strongest damping effect through experimental methods. Generally, the oscillating water quality must reach more than 1% of the total mass of the structure to have a better damping effect. These studies on tuned liquid dampers have shown their ability to reduce vibration in building structures.

Figure 6. Tuned liquid damper

4. Discussion & Conclusions
Based on the above, the following conclusions and prospects can be drawn:

This paper expounds the major high-level architecture supporting system, including air conditioning system, elevator system, water supply and drainage system and computer system of the vibration noise reduction research (objectives and methods), and combining the construction of their vibration control (damper) research, comprehensive illustrates the current high-level construction facilities, as well as the content of the building structure vibration noise reduction technology research;

Through the research description of the vibration and noise control of middle and high-rise buildings, and the enumeration of typical studies, this article illustrates the universality of the current vibration and noise and the lack of research on vibration and noise reduction in various studies (many quotes in the text are derived from building renovation), we must pay attention to it in the future;

At present, the limits for noise emissions in buildings are becoming more and more stringent, and noise reduction projects have also become a problem that plagues design and construction parties. It is hoped that the summary of vibration and noise reduction can provide a reference for the improvement of building vibration and noise reduction in the future.

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