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Review of elevator noise and vibration criteria, sources and control for multifamily residential buildings

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ABSTRACT

Elevators in residential buildings present the potential for intrusive noise and vibration to the dwelling units. The adverse noise and vibration can result from the elevator equipment located in the machine rooms or the shafts. The impacts can be significant issues related to the sound quality, sleeping conditions, and enjoyment within residences. There are often challenges to identifying the transmission path (airborne vs. structureborne) and how the transmission paths can be mitigated to reduce the noise and vibration. Issues relating to the reliability and safety of the elevator operation can introduce difficulties and conflicts with implementing mitigation. This presentation will discuss various criteria to consider for quantitatively assessing the effects of noise and vibration from elevators. In addition, two different case studies describe the conditions and mitigation for a mid-rise traction elevator machine room and from a hydraulic elevator machine room.

1 INTRODUCTION

In today's buildings, elevators are a necessary building component providing vertical circulation and access for residents in buildings with numerous floors. When used in residential facilities, the noise and vibration of the elevator operation can be a potential intrusion for residences that are adjacent to the equipment. The impact is often compounded by the modern trend toward using lightweight building materials and toward increased density in residential buildings. The most significant effect can result in lower sound quality, disturbed sleeping conditions, and reduced enjoyment of the residences.

Criteria for assessing elevator noise and vibration vary in the industry. Elevator industry criteria typically apply to the sound and vibration levels in the cab or the machine room, rather than the adjacent spaces. Typical mechanical system criteria do not seem to apply to the transient nature of elevators. Criteria from Canada offer more specific and detailed goals, though it is unclear whether they are feasible to apply. These issues will be reviewed in the following sections.

Attempts made during the design of facilities to minimize and avoid adverse impacts from the elevator systems to the adjacent residences encounter several challenges. There are often no sound level data for the equipment. Furthermore, many of the impacts can result from structureborne transmission issues that are not easily predicted or estimated for each specific project. Therefore demonstrating design compliance with the noise or vibration criteria for a project is impossible. Ultimately, many designers, consultants and owners rely on reasonable over-design of the noise control, substantial constructions, or reliance on manufacturer supplied noise and vibration control elements to attempt to achieve suitably quiet noise and vibration levels from the equipment.

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Another complication of mitigating these conditions is that residents do not experience these adverse impacts until after the final installation of the equipment, the completion of the construction and the initial occupation by the residents. Two such examples and the associated challenges with these conditions are presented in this paper.

2 GUIDELINES AND CRITERIA

There are several guidelines and criteria that could be considered when assessing the impact from elevator systems to residences within the facility. They are as follows:

2.1 National Elevator Industry, Inc.

This organization represents the companies that are involved with the manufacturing, installation, and maintenance of elevators, escalators, and other building occupant transportation systems. The organization provides standards and guidelines for building transportation systems that include sound and vibration levels [1]. The sound guidelines provide levels for within the elevator car, of the door opening, in the machine room and at the landing. The sound guidelines do not provide suggestions for sound levels within adjacent spaces. Likewise, the vibration guidelines are concerned with the levels for the occupant of the elevator car, as opposed to the building occupants. These guidelines are concluded with approaches to mitigating issues related to ambient sound and vibration; however, they are merely conceptual in nature with no quantitative goals for an installation to achieve.

2.2 American Society of Heating, Refrigeration and Air-conditioning Engineers

Engineers, designers and consultants commonly refer to ASHRAE for sound level criteria of mechanical systems within buildings, chiefly with HVAC systems. Their Applications Handbook provides a list of Room Criteria for a variety of occupancy uses, which includes residences, apartments, condominiums, and hotels; these sound levels are provided in Table 34 of the 2003 ASHRAE Applications Handbook [2]. The guidelines state that sound levels within these spaces should achieve RC(N) 25 to RC(N) 35. However, the guidelines are very clear in stating that these levels apply to HVAC-related background sounds. In fact, the guidelines even state that non-HVAC sources may require lower sound levels for the design of occupied spaces. Recent experience suggests that the stated sound level goals are thought to be suitable for systems that operate without producing significant transient sounds, a condition that is often associated with elevators.

ASHRAE also provides guidelines for short-duration or transient sounds under the heading Noise From Plumbing Systems. In this section, the guidelines define the sound level criteria for these transient sounds by the maximum A-weighted sound pressure levels specifically associated with plumbing systems. For residential bedrooms, living rooms and dining rooms, the maximum sound levels are 35 dBA, while in a hospital or classroom the suggested maximum sound level is 40 dBA. The guidelines also note that for high-end luxury residences the sound level goals should be 5 to 10 dBA lower than the previously stated goals. The guidelines state that these sound levels should be measured using a slow response on the sound level meter. These criteria seem to be more applicable to elevator systems, since they address the transient quality to the sound levels. However, it is clear that these guidelines are not intended to apply to elevator systems.

2.3 Canadian Mortgage and Housing Corporation

Numerous acoustical comfort studies over many years by the CMHC were summarized in a document produced several years ago [3]. The results of these field assessments and studies were that maximum sounds from elevator systems should be less than NC 20 when measured with a 35 ms time constant with a sound level meter. The research also applies this sound level to plumbing, the operation of garage doors, condensers, transformers, and trash chutes.

2.4 Criteria Summary

The Canadian criterion is the most applicable and appropriate for avoiding elevator noise and vibration issues to residences. The suggested sound level and its method of assessment (Max, with 35 ms time constant) are well defined. However, there may be several practical challenges with this criterion. First, achieving such a low level of noise is impossible to confirm in the design. Second, this low noise goal may be significantly difficult to validate for an installed condition, except under the quietest of ambient conditions, which may not be possible in an urban housing environment. Finally, when elevator systems exceed this sound level, it may be unfeasible to achieve such criteria once the equipment is installed, depending on the magnitude of the exceedance and whether the installed conditions allow for the necessary upgrades.

3 SOURCES, TRANSMISSION PATHS AND CONTROL OF ELEVATOR SOUND AND VIBRATION

The sound and vibration from elevator systems can result from a variety of sources and transmission paths. Several of the more significant sound sources are presented here.

3.1 Traction Elevator Hoist Machinery

3.1.1 Sources and Transmission Paths

Traction elevators operate by using a motor located at the top of an elevator shaft that raises and lowers the elevator car and counterbalance. Traditionally, the motor assembly includes the electric motor that uses gears to transfer the motor's energy to a cable, which raises and lowers the elevator car. For general operation and safety, this assembly also includes a brake, which restricts the motor from moving when the elevator car is at rest. Traction elevators are traditionally used in buildings that are more than 5 to 6 stories tall.

Each of these components introduces its own sound and vibration to the system. The motor generates a tonal sound related to the speed at which it rotates. Likewise the gears also produce a tonal signal that is related to the meshing frequency of the geared system at the speed it operates. Interactions between the pulley and the cables that suspend the elevator cab also present the potential of a tonal sound. These sounds vary in loudness and frequency with the speed of the system, generally with the loudest airborne sounds resulting from the fastest speed of operation.

The brakes are activated prior to the system starting in motion, and shortly after the system comes to a stop. As the brakes disengage or engage with the motor axle, there is typically an impulsive sound. This sound is often more perceptible than the other sources, since the other components of the elevator are not operating when the brakes engage.

Impacts from traction elevator machinery may require a combination of airborne and structureborne noise and vibration control.

3.1.2 Airborne Sound Isolation

When there are acoustically sensitive spaces, such as residences, around the machine room (in the case of a mid-rise elevator that serves lower floors), then it is important that the partitions consist of a sufficiently effective sound isolating construction. A concrete masonry unit (CMU) wall with a single layer of gypsum wall board (GWB) on a single row of studs that is separate from the CMU is often a very effective construction, which provides significant mass and separation between the two spaces. Alternatively, when CMU is not possible (perhaps due to structural limitations), a double stud construction with multiples layers of GWB and batt insulation can be a reasonable option. It is important that studs of different rows not be rigidly braced to one another, so that the two rows of studs are structurally separated to minimize transmission. It is also critical that these constructions are well sealed to the floor and ceiling structures, and that any penetrations of the walls by ductwork, electrical conduit, or electrical boxes be well sealed to limit any degradation to the partition's performance. Single stud constructions with resilient elements and multiple layers of GWB and insulation can be sufficient in some cases, though this approach may be a risk if the machine room is adjacent to a bedroom.

Another factor may be the build up of noise within the machinery room. In a machine room without sound absorption, the build up of noise may contribute to the sound that is transmitted to the adjacent spaces. The use of effective sound absorbing materials (NRC 0.80 or higher) can provide a reduction of the reverberant acoustic energy in the machine room, thereby reducing the sound that could potentially transmit to the adjacent space. The application of this material could be considered for the ceiling and walls. Prior to installation of such materials, installers should check to determine that sufficient clearance between the elevator equipment and the walls is achieved, if such clearance is required by code.

3.1.3 Vibration Isolation

Vibration is another consideration for an adjacency of a traction elevator machine room and a residence. In many cases, the equipment manufacturers often provide a standard option for vibration isolation pads underneath the supports of the machinery. These isolators are typically suitable and sufficient for penthouse installations or with adjacencies to commercial office spaces or other less acoustically sensitive spaces. For a condition where a mid-rise elevator machine room is surrounded by residences, the vibration isolation may require more attention.

In the design, it is important that the building structure under the elevator be designed to provide a sufficiently stiff foundation with little deflection for the equipment. This typically means incorporating additional structural steel underneath the hoist equipment and carrying the supporting structure directly to columns where possible. Thicker slabs can also help, though they typically provide a smaller margin of benefit.

Beyond the stiffening of the structure, discontinuous slabs can significantly improve the isolation through the common floor of the adjacent space. Effective discontinuities require either expansion joints or slab cuts to introduce sufficient attenuation and separation of the adjacent slabs. These should be discussed and engineered by the structural engineer on the project.

The application of vibration isolation for the hoist equipment requires significant attention to ensure that the operation of the equipment is not adversely impacted. Modern elevators include sensors that are extremely sensitive to where the elevator car is located, particularly when arriving at a landing. The use of vibration isolation under the hoist machinery inherently introduces additional deflection of the equipment to achieve the improved isolation, but this may compromise the ability of the elevator car to assess its location. Accurately locating the car is a safety requirement, since misalignments between the elevator car floor and the landing can introduce tripping hazards for the users of the elevator system. As a result, isolation deflection should be minimized to avoid improper operation and safety issues with the elevator system. To accomplish this, it is critical that the isolation deflection be discussed in close cooperation with the elevator manufacturer and installer.

There are a variety of ways to isolate the vibration of hoist equipment. Neoprene, rubber or synthetic foam pads can be used to support the hoist equipment. They should be selected to achieve the most isolation possible within the accepted operating limits of the elevator equipment. For existing systems, these types of pads may be the least challenging to implement, since such pads are generally about 19 to 25mm (¾ to 1 inch) tall and should not require substantial increases to the elevation of the hoist equipment.

An alternate means of isolating hoist equipment could be to install the equipment on a concrete inertia base that is supported on springs [4]. This approach attempts to achieve increased static deflection, when compared to the previously discussed pad isolation. The use of the concrete inertia base is intended to minimize the additional dynamic deflection of the isolation when the elevator is loaded or unloaded. The isolation is achieved using spring isolators with a static deflection of about 19 to 38mm (¾ to 1½ inch). This approach requires substantial height (about 150 to 200mm (6 to 8 inches) and is therefore more appropriate to consider during the design of a project, when sensitive adjacencies are initially identified. This type of isolation should be closely engineered with the elevator manufacturer.

3.2 Switchgear for Traction Elevators

Many hoist elevators use electrical contact switches to control the operation of the elevator and its electrical components. These switches are generally housed in a rack that is located within elevator machine room. These contact switches generate significant impulsive noise as they engage and disengage. This noise often stands out from general ambient noise due to its impulsive character.

3.2.1 Airborne Sound Isolation

Noise control of this airborne sound is generally achieved with the application of sound absorption within the elevator machine room and the noise reduction provided by the machine room constructions. Incorporating sound absorption on the available wall and ceiling surfaces can reduce the build up of noise within the machine room, which in turn reduces the sound energy that could transmit through the machine room constructions. Selecting constructions that have mass (such as CMU or multiple layers of GWB) and separation (double studs or resilient framing elements) can further improve the noise reduction of the enclosure.

3.2.2 Vibration Isolation

The switchgear cabinet should be mounted on neoprene pads to effectively isolate it from the machine room floor slab. For most applications on concrete floor slabs, the pads should be selected to support the weight of the cabinet while achieving a static deflection of about 2.5mm (0.1 inch). The pads should have a steel shim overtop to uniformly distribute the weight of the switchgear cabinet to the entire area of the pad.

For mid-rise machine rooms, with acoustically sensitive spaces above, vibration isolation of the electrical conduit or any other connections may be necessary to isolate the cabinet vibrations from the building structure. These isolators should consist of neoprene elements to effectively isolate the switchgear vibrations.

3.3 Hydraulic Elevator Machinery

Hydraulic elevators are raised and lowered by what is referred to as a power unit. This power unit includes a pump that uses fluid to activate a hydraulic ram (piston) to lift the elevator car. This equipment is typically located adjacent to the bottom of the elevator shaft in a separate machine room with hydraulic piping routed between the power unit and the elevator piston. Hydraulic elevators are generally used for buildings that are less than 5 or 6 stories tall.

The power unit produces sound and vibration as the rotary motion of the pump pressurizes the fluid to raise the elevator car. The power unit transmits the noise through the air and vibration through the piping and the fluid.

The system also generates sounds when the elevator descends. The descending elevator car compresses the piston and forces the hydraulic fluid back through a controller valve, where the sound is generated. The sound is caused by the fluid turbulence, as the fluid passes through orifices that restrict the flow.

Hydraulic elevators require airborne sound and vibration isolation when this equipment is located adjacent to acoustically sensitive spaces.

3.3.1 Airborne Sound Isolation

The specification of the power unit (the pump assembly) is the first opportunity for airborne noise control of this equipment. It is useful to select a power unit that has the pump and its components submerged within the hydraulic oil to minimize the airborne sound from the pump. The equipment should also include a hydraulic line silencer to minimize the transmission of sound and vibration through the fluid and piping.

Further airborne sound isolation of hydraulic elevator machinery is primarily dependent on the placement and the enclosure of the room. Whenever possible, this equipment should be located away from any acoustically sensitive spaces. Utilizing buffer spaces, such as storage rooms or closets, can be effective for improving the airborne isolation of this equipment.

The constructions that make up the machine room should be as massive as possible. CMU constructions should be implemented if possible; the mass of this construction is very effective for isolating the lower frequency noise, typical of this equipment. Alternatively, double stud constructions with multiple layers of GWB and batt insulation can be effective for isolating the low frequency sound of this equipment. In situations where very low noise goals are necessary, CMU walls may be upgraded with an additional stud construction with multiple layers of GWB for high levels of sound isolation.

3.3.2 Vibration Isolation

Effective isolation of this vibratory energy requires several components. It is important to isolate the power unit from the building structure. This can be achieved with neoprene isolators or pads with the appropriate seismic restraints to constrain the equipment. Such isolators should achieve static deflections between 3mm to 7mm (0.1 to 0.25 inches).

In addition to the equipment isolation, it is important to isolate the hydraulic piping from the building structure. This should be accomplished using neoprene isolators and hangers where there are connections to the building structure. Flexible pipe connections are also beneficial, where feasible, to provide additional isolation of the piping and fluid vibrations.

3.4 Interaction of Rails and Elevator Car Guide

To ensure that the elevators travel vertically with little side-to-side movement, the elevator is guided by rails within the shaft. These rails are fastened to the building structure. The elevator car uses rollers to guide the car along the rails. Often, these rollers have nylon or rubber coatings to minimize noise with the rail.

3.4.1 Airborne Sound Isolation

Generally, there is little airborne noise generated by the interaction of these components. Significant noise from these components may indicate a need for maintenance.

3.4.2 Vibration Isolation

For elevator shafts, the rails should be fastened to the building at the edges of the floor slab. The floor slab edges are inherently stiffer than the shaft walls and will limit the transmission of the rail/guide interactions from generating structureborne noise in adjacent spaces.

3.5 Elevator Doors

The operation of elevator doors can generate significant sound levels. This can be the result of typical door operation or may be caused by misalignments or improper installation. The elevator installer should repair any door noise issues.

3.6 Door Enunciators

Many elevators use audible signals to announce their arrival at a floor. These signals vary between older mechanical bells to modern electronically generated chimes. Modern systems occasionally allow for volume adjustments of this signal. The elevator installer should adjust and modify the door enunciators to ensure reasonable sound levels at nearby locations.

3.7 Other sources

Some installations can have their own unique sound or vibration issues. In one example, a transient noise was generated within the shaft when the elevator was initially energized, but not in motion. It was eventually determined that the source of this noise was the electrical cable that was routed through a conduit within the shaft. The assessment found that the abrupt transmission of the significant initial electrical current through cable produced sufficient electrical field to induce movement of the electrical cable resulting in contact with the conduit through which the cable was routed. The noise of the contact with the conduit was extremely subtle, but distinct enough to intrude on a residence that was served by the elevator.

Noise and vibration control for this and other unique elevator noise and vibration issues are beyond the scope of this paper.

4 CASE STUDIES

Two recent case studies presented the opportunity to apply the previous guidelines and noise and vibration control options.

4.1 Traction Elevator Machine Room surrounded by Residences

A tall residential facility included rental apartments on lower floors with condominiums on the floors above. The elevators systems were split to separate the rental occupants from the condominium residents. As a result, the elevators serving the apartments stopped at the highest apartment floor, with the elevator machine room surrounded by condominiums on the floor above. Shortly after occupying the condominiums, the residents noted the noise of the elevator machine room adjacent to their residences. In one residence, there was a bedroom adjacent to the elevator machine room.

A study of the conditions indicated that sound levels exceeded any reasonable sound and vibration criteria. There were both airborne and structureborne isolation issues, though initially it was unclear which was most prominent. The hoist was supported on the manufacturer's standard neoprene isolators; however, vibrations were clearly feelable in the floor of the adjacent residence and structureborne noise from the elevators was perceptible in many of the partitions. The machine room wall consisted of a single stud construction with double layers of GWB and insulation. Gaps were evident around the perimeter of the machine room walls.

Sound and vibration isolation upgrades were pursued. Airborne isolation was improved by upgrading the partition to the adjacent bedroom with a resilient GWB layer inside the machine room. Also, the top and bottom of the walls were well sealed with caulk to eliminate leaks in the constructions. The recommendations also included vibration isolation of the switchgear cabinet and its associated conduits, along with new isolation for the hoist machinery. The only feasible hoist isolation to implement on this installed system consisted of new neoprene pads with increased deflection, designed in cooperation with the elevator manufacturer. The results indicated substantial improvements of both sound and vibration isolation for the residents.

4.2 Hydraulic Elevator Adjacent to Residences

A hydraulic elevator machine room located next to a residence introduced significant noise and vibration to the residence, exceeding any reasonable sound or vibration criteria. The most significant impact resulted from airborne and structureborne noise from the power unit into the adjacent residence. There was little space available to upgrade the machine room partition. There were also many practical challenges to introducing vibration isolation under the equipment. Furthermore, the elevator installer indicated that due to the local building code, the power unit could not be isolated from the structure. It is not clear whether it is possible to resolve this condition to the satisfaction of the resident.

5 SUMMARY

Elevators generate significant sound and vibration that should be considered for the potential impact on adjacent residences. Guidelines and criteria should be reviewed to determine how to assess the impact from these systems so that suitable levels can be set for goals on projects. When elevators systems are adversely impacting residences, the sources of the offending sounds and vibrations should be determined; these may vary depending on the type of elevator, the operation of the system and installed conditions of the equipment. Recommended sound and vibration isolation should be discussed with the elevator manufacturer and installer to determine how it can be implemented without adversely affecting the operation and safety of the elevator systems.

6 REFERENCES

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