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A General Survey on Lift Ride Quality at Public Buildings of the Hong Kong Special Adminstrative Region

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Abstract

In recent years, the subject of lift ride quality or lift ride comfort has increasingly received attention from lift users. Lift ride quality in terms of lateral and vertical vibrations, acceleration and deceleration, and jerk has become important criteria for judging a lift's performance. Noise produced during lift operation is also a salient factor for consideration. Doors are expected to be operated at their highest speed yet still need to commensurate with safety, smoothness and noise requirements. The issue of lift ride quality would likely become a basic requirement in the specifications for new and modern lift systems and a symbol of quality lift service.

This paper summarizes the measurement results and analyses of a quantitative research undertaken by the Architectural Services Department (ArchSD) of the Hong Kong Special Administrative Region (HKSAR) on the ride quality of existing lifts in public buildings of the HKSAR and proposes a prototype performance standard on lift ride quality. Measurement methodology used in this research was based on the draft Australian Standard[1], DR99446 – Measurement of Lift Ride Quality, which defines, measures and interprets objectively and analytically the ride quality of lifts instead of relying on non-repetitive qualitative methods based on personal evaluations of vibration and noise felt and heard by the passengers inside a lift car.

Keywords: Lift, Vibration, Jerk, Noise, Ride Quality

1. Introduction

Along with the development of new lift technologies, specifications for lift installation have become more and more detailed. Floor to floor traveling time received greater attention and high speed cars become more common than before. Since the provision of lift(s) has become an indispensable requirement for multi-storey buildings, the performance of lift installation has received increasing attention and passengers expect better and better lift service and ride comfort.

At present, a lift's performance is usually evaluated on the basis of the time it takes to perform the function of vertical transportation. This includes the time required to close the doors, start the car, move to another floor, stop the car and open the doors, etc. To accomplish these actions, some levels of noise and vibration would be generated. These are then perceived as the lift ride quality by the passengers. However, the most important aspect of lift ride quality is how to quantify it by defining exactly what lift ride quality is, how it is measured, and how it is interpreted.

2. Parameters of Lift Ride Quality

As mentioned above, physical motion is one of the main factors that determines lift ride quality. Lateral and vertical accelerations of a lift car are the two main motion elements and the perceptible levels of which will affect the ride quality perceived by the passengers.

Lateral Movements

Lateral accelerations are the horizontal accelerations or vibrations caused by contributing factors[1] such as:

a) Guide rail misalignment
b) Guide roller configuration
c) Static balance of car frame
d) Lift well configuration and air displacement
e) Car speed

a) Guide Rail Alignment

Guide rail alignment is probably the most significant contributor to a good or bad lift ride quality. A properly aligned guide rail can significantly reduce the lateral vibrations of a lift car.

b) Guide Roller Configuration

For quality lift system, guide rollers rather than guide shoes should be used to render higher level of comfort. Configuration of guide rollers can add

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quality to or detract quality from a lift ride. A guide roller out of round (eccentric) or with a flat spot will have different effects on ride quality and the effects also depend on the size of the roller and speed of the lift car.

c) Static Balance of Car Frame

Static balance of car frame with respect to its geometry is very important to good ride quality. Deflection of a guide rail may occur if a lateral force of 450N is exerted by a lift car on the guide rail[2]. This deflection varies as the car moves through the lift well, depending on whether the car is traveling across the guide rail bracket fixing positions or traveling between guide rail brackets. When compensating ropes or traveling cables are mounted off centre of a lift car, varying unbalances will also be created.

d) Lift Well Configuration and Air Displacement

The higher the speed of a lift car, the relief of the air pressure created by it inside a lift well becomes more difficult.

When a lift car moves in a lift well, it will create a wind velocity which exerts a pressure on the sides of the car. This pressure fluctuates each time when the car passes a divider beam, sill plate or counterweight frame. It also causes landing doors to be pushed as far as possible towards the lobby side. When the car passes a floor, pressure on the well side of the entrance is immediately reduced, causing the landing doors to be pulled back towards the lift well. These pulsations create a combination of discomfort noise and motions.

Therefore, a lift well should have a clear area at least 150% of the car platform area for lift speeds up to 5 m/s and this figure should be increased by 5% for each additional 0.5 m/s increase in car speed[3].

e) Car Speed Effects

Speed effects on ride quality are numerous and the effects of guide roller, guide rail alignment and air displacement are all amplified as car speed increases.

Vertical Movements

Acceleration is the rate of change of velocity. Velocity profile of a lift travel includes the change from rest to full speed and back to rest position again. Acceleration only occurs during a change in velocity.

The effects of vertical acceleration on passengers are both physical and psychological, and vary in degree from one individual to another.

Jerk is the rate of change of vertical acceleration and is the motion felt by the passengers. It is always necessary to compromise between high speed performance and passenger comfort. A lift should not have too severe jerk that becomes objectionable, but yet be fast enough to give good traffic performance.

3. Measurement Methodology for Lift Ride Quality

It is generally adopted that vibration, jerk, and noise level are the quantities that need to be measured if lift ride quality is to be quantified in any meaningful way. To minimize individual's subjective interpretation of lift ride quality, detailed definitions of terminology and field measurement methodology are therefore required to be devised and adopted.

Two fundamental issues of lift ride quality are instrumentation characteristics and measurement methodology. The instrumentation used would likely be utilized for measurement of both lift ride quality and performance.

The evaluation of vibrations and noise inside a lift car relies on the measurement of vibration and noise level by instruments which should be as close as possible and consistent with the perception of a passenger inside the lift car.

Although there are numerous national and international standards on the aspects of technology, performance and safety of lifts being developed and adopted worldwide, standards and methodologies for determining lift ride quality remain as areas for further exploration. Without an internationally adopted measurement standard on lift ride quality, there will be no objective tools to gauge the ride quality even though there is an increasing demand for quality performance on lift riding.

At present, no international standards established so far clearly specify the acceptance standard applicable to lift ride quality. One of the reasons why the development of lift ride standard lags behind its technical and safety counterparts may be due to the fact that such a standard is of "dynamic" nature which depends on the progressive demand on ride comfort from lift users.

Upon the increasing demand for continuous improvement in lift service quality, many lift manufacturers and associations have developed their own in-house standards on lift ride quality for their products. However, there is no consensus amongst the stakeholders in the trade at the moment. Nevertheless an attempt has been made in Australia that a standard on measurement of lift ride quality was being developed as the first step towards this issue.

In 1995 a committee was formed by the Lift Manufacturers Association of Australia to address the lack of standards in the measurement of lift ride quality. As a result of the consensus amongst the representatives, a draft Australian Standard for Measurement of Lift Ride Quality, DR 99446 (the

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[2, 2 & 4] Abraham E, *Performance Criteria: Car Ride Quality*

Draft Standard) was issued on 15 August 1999 for a consultation period of two and a half months.

The objective of the Draft Standard is to encourage industry-wide uniformity in the definitions, measurement, processing and interpretations of the vibration and noise data which contribute to lift ride quality.

The Draft Standard is intended to establish lift ride quality measurements which:-

a) are simple to understand without specialized knowledge on vibration and noise analysis;
b) correlate well with actual human response; and
c) can be verified via calibration procedures that are traceable to National Standards.

The following are definitions of some of the specific terms used:-

Acceleration : Rate of change of z-axis velocity, attributed to lift motion control.
Jerk : Rate of change of z-axis acceleration, attributed to lift motion control.
Velocity : Rate of change of z-axis displacement, attributed to lift motion control.
Sound : Sound pressure level in ‘A’ weighted decibels, resulting from lift motion and door operation.
A95 : The statistical estimate for which 95% of the values are less than or equal to, and which is evaluated between defined boundaries. It is used to represent “typical” levels.

<u>Notes:</u>
Axes of measurement for lifts of conventional configuration:

x = perpendicular to the plane of the guide rails (i.e. front to back)
y = horizontally in the plane of the guide rails (i.e. side to side)
z = perpendicular to the car floor (i.e. vertical)

The following units are used:
Displacement : metre (m)
Velocity : metre per second (m/s)
Acceleration : metre per second squared (m/s^2)
Jerk : metre per second cubed (m/s^3)
Vibration : metre per second squared (m/s^2)
Sound Level : ‘A’ weighted decibel (dB(A))

For vibration, other commonly used units are ‘Gal’ and ‘mill-g’. The conversions are as follows:-
1 Gal = 0.01 m/s^2
1 mill-g= 0.980665 Gal
(where 1 g = the acceleration of gravity
= 1000 mill-g
= 9.80665 m/s^2)

<u>Measurement Boundaries</u>

As suggested by the Draft Standard, there are four boundaries to be used to define the regions over which lift ride performance signals should be measured and analysed. These four boundaries are named as 1, 2, 3 and 4 as follows:

Boundary 1	Minimum 0.5 second before starting of door closing at the departure floor.
Boundary 2	500 mm from the departure floor after starting of lift motion.
Boundary 3	500 mm from the arrival destination floor before ending of lift motion.
Boundary 4	Minimum 0.5 second after completion of door opening at the arrival destination floor.

Boundaries 1 and 4 include all of the noises of door operation which cover all the data required to be measured for practical evaluation. Boundaries 2 and 3 allow the measurement of lift motion to be evaluated separately from the effect of door operation.

The assessment of ride quality during the jerk phase of motion shall be determined by calculation of the vertical vibration i.e. jerk is evaluated from the weighted z-axis time domain signal between boundaries 1 and 4.

Vibration signals shall be weighted in accordance with ISO 8041 to simulate the human body’s response to vibration. The vibration signals shall be frequency weighted with the whole body x, y and z weighting factors and shall include band limiting as defined in ISO 8041. The maximum and A95 Peak to Peak vibration levels of the weighted x and y axes time domain signals are evaluated between boundaries 2 and 3.

Velocity attributed to motion control shall be measured with the highest absolute value evaluated by integration of the 10 Hz low pass filtered data.

The sound pressure levels (SPL) are evaluated and expressed in ‘A’ weighted decibels with respect to a reference SPL of 20 μPa in measuring maximum and Leq SPL.

4. Scope of Site Measurements in the Research

To cope with the metropolitan development in Hong Kong, the HKSAR Government has been building a great variety of public buildings for different purposes and usages. To achieve a broad coverage and wide representation for this research undertaken by the Architectural Services Department (ArchSD) of the HKSAR, 12 typical government premises including office buildings, institutional buildings, quarters and market complex had been chosen for conducting the measurements of lift ride quality and a total number of 55 lift installations were measured. The site measurements were conducted in February and March 2004.

The selected lift installations were supplied and installed by 6 different lift manufacturers comprising two Japanese companies, one American company, two European companies and one Korean company.

During the site measurements, the following characteristics of the lifts were recorded in the Data Recording Sheet:

a) Date and time of the measurement.
b) Date of last calibration of the measuring instruments.
c) Name(s) of the responsible staff conducting the measurement.
d) Site location and building name.
e) Measurement identification number.
f) Name of lift manufacturer.
g) The lift number.
h) Type of lift installation.
i) Carrying capacity of the lift in kg.
j) Departure and arrival terminal floor designations.
k) Number of floors served by the lift.
l) Direction of travel.
m) On/Off status of lift ventilation fan.

The following data were measured, recorded and processed by the measuring instrument:-

a) Travel distance of the lift.
b) The maximum and A95 velocity in m/s.
c) The maximum peak to peak and the A95 peak to peak x, y and z axis vibrations in m/s^2.
d) The maximum and A95 acceleration and deceleration in m/s^2.
e) The maximum jerk in m/s^3.
f) The maximum and Leq sound levels.

The measurements at each building venue were taken on a day at a time during normal office hours. The preparation for the lift ride quality measurements were generally in accordance with the Draft Standard except that the announcement features and chimes in the lift cars and at the landings remained in normal services during the measurement process in order to take account of the actual situations of the lift installations under normal operation conditions. Therefore, all building plants and equipment including adjacent lift(s) remained in normal service.

For the acquisition of lift ride quality data, the measurements included 0.5 second prior to commencement of the door-close operation at the departure terminal floor, the full travel of the lift from terminal to terminal, and the entire door-open operation plus an extra 0.5 seconds after completion of the door-close operation. Two round trips i.e. one UP run and one DOWN run were measured of which one round trip measurement was taken under normal car fan operation and another set of measurement was taken when the car fan was inoperative. Any runs appeared to be non-typical due to unusual or unforeseen events were permitted to be re-measured.

In each venue, one lift installation in each lift bank in the building was chosen for taking measurements. For the purpose of measuring realistic data on ride quality of the lift installations, the lifts were selected by random without giving advance notice to the lift maintenance companies and no pre-adjustments of the lift installations were allowed.

In order to investigate the potential biological effect of natural electromagnetic flux generated on human body traveling in a lift car, measurement of electromagnetic field strength has also been conducted during the lift ride quality measurement. The field strength is measured by means of monitoring the induced current on human body directly.

5. Instruments and Procedures for Site Measurements

To measure lift ride quality, the EVA-625 Elevator Vibration Analysis system from PMT was used to take the measurements. HI-3702 Clamp-on Induced Current Meter from Holaday was used to measure directly the current induced on the body of the measuring personnel.

The EVA-625 was placed on the lift car floor and within a 100 mm radius of the centre of the floor. The sound transducer of EVA-625 was located between 1 m and 1.5 m above the same region of the floor, and aimed directly at the doors. All transducers were aligned within 3 degrees of the axis of measurement.

The base of the instrument remained in stable contact with the lift car floor throughout the measurement process. No more than two persons were allowed inside the lift car and they stood in locations that would not significantly unbalance the lift. The measuring personnel remained still and quiet during the entire measurement process. They placed their feet 150 mm and 300 mm away from the vibration and sound measuring transducer respectively, in order to avoid any localized deflections of the car platform and disturbance to the measured sound levels.

The HI-3702 meter was mounted on the leg of the measuring personnel in the lift car and induced current were recorded and stored vide a personal computer.

6. Results of Site Measurements

As the measurement of each lift installation requires at least one UP run and one DOWN run, measurement of 3 lift installations was incomplete due to site constraints. Therefore a total number of 52 lift installations were successfully measured and put into further analyses.

The age (i.e. years of service) of the measured lift installations ranged from 2 years to 18 years old (Diagrams 1 & 2). The speed range of the measured lift installations was from the lowest 0.5 m/s to the highest 7 m/s (Diagram 3). The measured distance of lift travel comprised of the shortest 6 m to the longest 180 m (Diagram 4).

Distribution profiles of the measured lifts were as follows:-

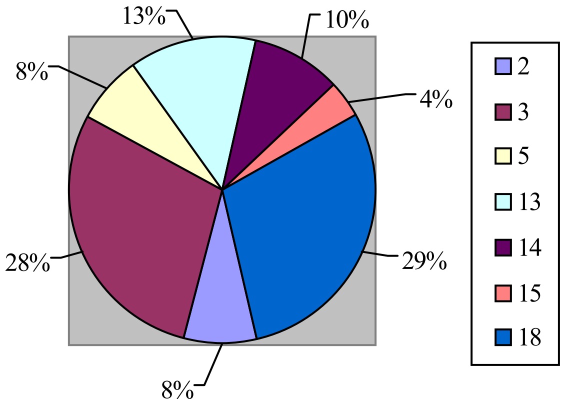

Diagram 1 - Age of Lifts

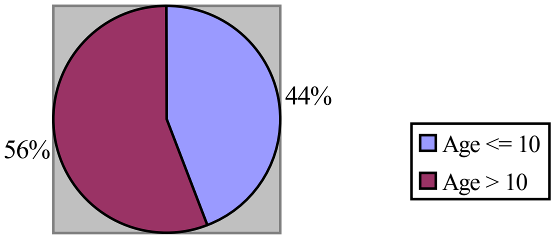

Diagram 2 - Age Groups

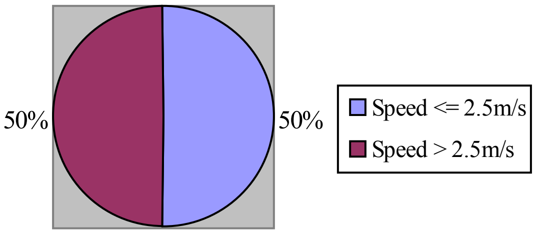

Diagram 3 - Speed Groups

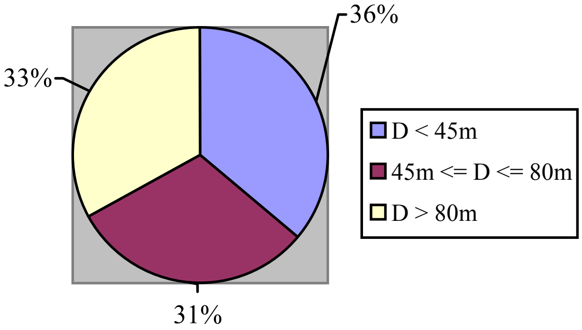

Diagram 4 - Distance of Travel

In the Draft Standard, it only aims at objective perspective that provides a uniformity platform of measurement of lift ride quality by reducing variability in the results of measurement caused by differences in data acquisition and quantification processes.

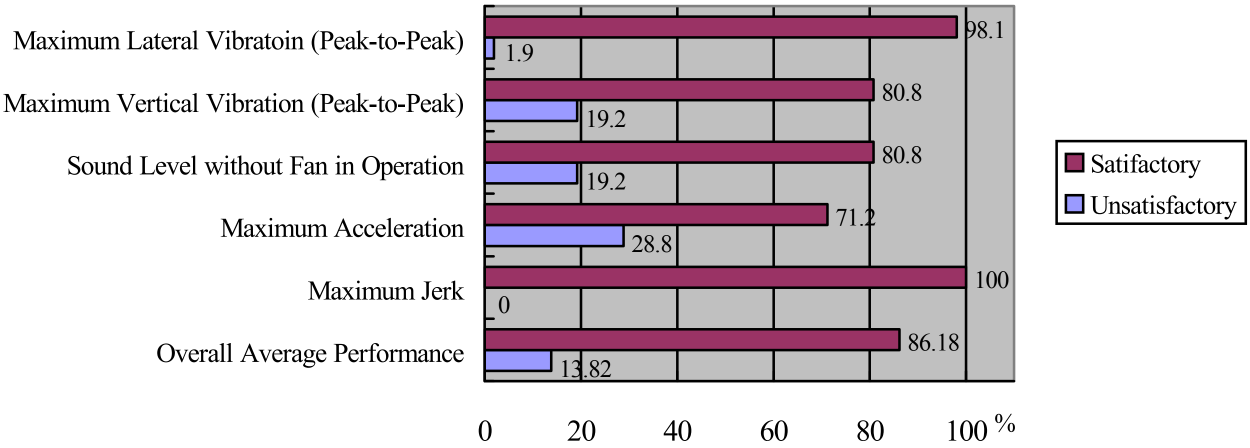

Diagram 5 - Lift Ride Quality Parameters

Table 1 - Prototype Performance Standard of Lift Ride Quality

Lift Ride Quality Parameters	Acceptance Criteria
Maximum Lateral Vibration (Peak-to-Peak):	**0.25 m/s^2**
Maximum Vertical Vibration (Peak-to-Peak):	**0.25 m/s^2**
Equivalent Sound Level without Fan in Operation (Full Run):	**55 dB(A)**
Maximum Acceleration:	**1 m/s^2**
Maximum Jerk:	**4 m/s^3**

However, there are no prescriptive requirements on quality performance. Consultation with the trade associations of the lift industry in HKSAR and reference to the General Specifications for Lift, Escalator and Passenger Conveyor Installation in Government Buildings of the HKSAR has been made. Furthermore, research has been conducted in respect of published papers and standards. The ArchSD research team then devised the lift ride quality parameters and quality performance requirements as shown in **Table 1** as the prototype acceptance criteria for comparison and evaluation purposes in this research.

Overall performance

The overall results of the successful lift measurements with respect to the standards as laid down in Table 1 are summarized in Diagram 5.

Amongst those lift installations that cannot meet the lift ride quality as stated in **Table 1**, further analyses under different characteristics were carried out to investigate their riding quality performance.

Owing to the full satisfaction of lift performance in jerk measurement, this parameter was excluded and only lateral and vertical vibrations, sound level, and acceleration of lift were taken into further analyses.

For the results of electromagnetic field strength measurement, it was indicated that the electromagnetic current induced on a passenger in a lift travel was not more than 50 μA. Therefore, there should be no potential adverse effect on human being.

7. Observations and Discussions

For the purpose of interpretation of the measured results, any one single lift travel measurement of each lift installation failed to meet the prescribed criteria as shown in **Table 1** would be regarded as unsatisfactory performance in that aspect of lift ride quality.

Table 2. Performance of Lifts at Different Ages

Lift Ride Quality Parameters	Failure Rate	
	Age□10	Age>10
Max. Lateral Vibration (P-P):	0%	100%
Max. Vertical Vibration (P-P):	20%	80%
Sound Level w/o Fan in Operation:	30%	70%
Max. Acceleration:	13%	87%
Average Failure Rate:	**15.75%**	**84.25%**

Age of Lift

Due to the advancement of lift technologies including the improvement of lift control system in the past 10 years, lifts installed in recent years show a salient leap in lift ride quality.

From Table 2 above, it is noted that among all the failed results, most of them were due to their ages. The rate of unsuccessful performance ranged from 70% up to 100% and in average around 85% for lifts over ten years old.

In respect of the parameter on sound level, 30% of the lift installations exceeding the performance limits were installed during the past 10 years. As the site measurements were conducted in existing buildings during weekdays, taking into account of the practical difficulties in eliminating the surrounding background noise, relatively high failure rate of the young lifts could be by reason of the site constraints in this respect.

Speed of Lifts

The rated speed of the selected lift installations covers a wide range from the lowest 0.5 m/s to the highest 7 m/s. Evaluation was made on the respective performance between low speed and high speed lifts.

Table 3. Performance of Lifts at Different Speeds

Lift Ride Quality Parameters	Failure Rate	
	Speed□ 2.5m/s	Speed>2.5m/s
Max. Lateral Vibration (P-P):	0%	100%
Max. Vertical Vibration (P-P):	50%	50%
Sound Level w/o Fan in Operation:	20%	80%
Max. Acceleration:	53%	47%
Average Failure Rate:	**30.75%**	**69.25%**

From Table 3 above, in average almost 70% of the failed lifts are high-speed lifts which means that the overall ride quality of low speed lifts is relatively better. Nevertheless, from the measured results the vertical vibration and acceleration performance for the two lift groups do not have significant difference. Apparently, the motion controls of high-speed lift systems seem to have remarkable performance as there is no significant deterioration in vertical vibration due to increased lift speed.

However, the control of lateral vibration for high speed lifts in reliance of a refined guide and rail system seems to be still a challenge to lift designers and engineers. Sophisticated vibration damping control of lift guides and stringent checking of guide rail alignment would be required to combat the lateral vibrations of lift car in motion. Periodic inspection and adjustment of guides and rails during preventive maintenance of a lift installation would help deferring the deterioration of ride quality of existing lifts. For ultra-high speed lifts of 8 m/s or above, specially designed car top and bottom covers that shaped to take account of the aerodynamic effect inside lift shaft could further reduce the car vibrations during travel.

Noise level inside a lift well is proportional to the increase in traveling speed of a lift car. In addition to the specially designed car top and bottom covers provided to reduce the noise level inside a lift car for ultra-high speed lifts, double wall car cabinet and double sealed car doors could also be adopted to improve the performance in this aspect.

Distance of Travel

As the site measurements were conducted in different types of buildings, the heights of these buildings vary considerably from several floor high market complex to high-rise multi-storey offices blocks. Distances of lift travel from 6 m to 180 m were recorded and they were divided into three groups for analyses. The first group is for travel distance below 45 m (around 15 typical storeys). The second group is for distance between 45 m and 80 m and the last group is for travel distance above 80 m (around 27 typical storeys).

Table 4. Performance of Lifts at Different Travel Distance

Lift Ride Quality Parameters	**Failure Rate**		
	Distance < 45m	**Distance 45 - 80m**	**Distance > 80m**
Max. Lateral Vibration (P-P):	0%	0%	100%
Max. Vertical Vibration (P-P):	50%	0%	50%
Sound Level w/o Fan in Operation:	20%	20%	60%
Max. Acceleration:	47%	13%	33%
Average Failure Rate:	**29.25%**	**8.25%**	**60.50%**

Table 4 above shows that the results of the measurements are quite similar to the performance of the lifts with respect to speed. High-rise lifts had the overall highest failure rate and amongst all the parameters the sound performance is an area that requires attention. This high failure rate is probably due to the fact that the longer the lift well, the higher the speed of the lift driving machinery would often be required in order to provide prompt vertical transportation service and the noise level thus become much higher.

With regard to middle-rise lifts, they have the best overall performance especially in the aspect of vertical vibration. This is probably due to the reason that roller guide system was used instead of guide shoes which are normally employed at low-rise lift installations. However, the effect of this damping control device gradually diminished as the lift speed increased.

8. Conclusion

With the increasing demand from lift users for quality performance of lift installations, lift ride quality would likely become a basic requirement in the specifications for new and modern lift installations to symbolize quality lift service in the near future. The need to develop an internationally recognized performance standard on lift ride quality that could provide strict definitions of terminology, establishment of methodology, explanation of data analysis techniques, and clearly detailed instrumentation requirements is therefore vital.

The draft Australian Standard for Measurement of Lift Ride Quality provided a good starting platform for discussion amongst the stakeholders in the lift industry but apparently, it would still need some time for the industry to come up with a consensus.

From the site measurement results, the prototype parameters and standards for lift ride quality devised and used in this research proved to be practical and reasonable utilizing the present commercially available lift technologies. They could therefore be used by developers, consultants, designers or authorities for including into their specifications for the procurement and acceptance of new lift installations that require lift ride quality performance.

Reference

1. Abraham, Earl (1984) Performance Criteria: Car Ride Quality. Elevator World, I-19-23
2. Asian Institute of Intelligent Buildings (2001) The Draft Manual of the Intelligent Building Index (IBI).
3. Building Services Branch, Architectural Services Department, General Specification for Lift, Escalator and Passenger Conveyor Installation in Government Buildings of the Hong Kong Special Administrative Region, 2002 Edition.
4. Lorsbach, Gregory P. Measurement of Lift Ride Quality. Physical Measurement Technologies, Inc.
5. National Elevator Industry, Inc. (1994) Vertical Transportation Standards – Standards for Elevators, Escalators and Dumbwaiters, 7th Edition.
6. Standards Australia (1999) Measurement of Lift Ride Quality, DR99446 - Draft Australian Standard for Comment.