A Fundamental Study Concerning the Correct Performance of Elevator Buffers

Osamu FURUYA[1], Naoki FUJIWARA[2] and Satoshi FUJITA[3]

[1]Division of Electronics and Mechanical Engineering, School of Science and Engineering, Tokyo Denki University, Ishizaka, Hatoyama-cho, Hiki-gun, Saitama 350-0394 Japan
osamu.furuya@mail.dendai.ac.jp
[2]Department of Mechanical Engineering, School of Science and Engineering, Tokyo Denki University, 5, Senju-Asahi-cho, Adachi-ku, Tokyo 120-8551, Japan
[3]Department of Mechanical Engineering, School of Science and Engineering, Tokyo Denki University, 5, Senju-Asahi-cho, Adachi-ku, Tokyo 120-8551, Japan
sfujita@cck.dendai.ac.jp

Keywords: Elevator buffer, Shock absorber, Time response analysis, Performance evaluation.

Abstract. Various safety devices are provided to ensure the safety of lift passengers. A number of safety systems are employed to prevent injury in case of uncontrolled movement. The car and counterweight buffers (shock absorber) play an important role. This paper considers appropriate performance of the car and counterweight buffers. Buffer performance is examined to satisfy a safe condition in the revised JIS A 4306.

1 INTRODUCTION

In late years an elevator is installed in many high-rises buildings with the high stratification, and convenience largely improves. On the other hand, further safety improvements of elevators have been expected because of various accidents including the enclosure accidents. Various safety devices are installed to ensure the security of the user, even if there is trouble in the elevator itself. Plural safe systems are considered for fall accident of elevators. However, in general, as for the probability of a fall accident, a buffer is installed in the bottom of elevator hoistway.

A buffer plays a role to minimize the damage of a passenger and the building by absorbing the shock of the fall accident of an elevator car. Although the performance requirements of a buffer have been determined in the Ministry of construction notification No.1423, an issue has occurred in an examination item, a standard for judgment, the performance requirement of buffer and so on in Japan. Therefore, as for the performance of buffer, the standard was revised with a governor, an emergency stop device in JIS A 4306 in 2016[(1),] and then a review and a change were planned. In addition, the review of standard is shown in when the specialized knowledge about acceptable deceleration or acceleration applied time against a human body is obtained in the future, because the buffer must satisfy enough security.

In this study, the way of a buffer satisfying the safety requirements of revised Japanese Industrial Standards is analytically examined for an oil buffer for elevators.

2 PERFORMANCE REQUIREMENTS FOR OIL BUFFER IN JIS A 4306

The stroke of the oil buffer must be bigger than the smallest stroke calculated from the next expression.

$$L_{min} = {V_R}^2/53.4$$

in here,

L_{min} : stroke of buffer [mm]

V_R : rating speed [m/min]

The average deceleration at the time of collision in case of rating speed of 1.15 times must not be beyond $1g_n$. g_n means 9.8 m/s^2. In addition, duration of deceleration more than $2.5g_n$ must not be over 0.04 seconds.

Figure 1 shows the example of slowing down characteristic of an oil buffer. The average deceleration is calculated from following methods.

1) The average deceleration is defined as the time average value of deceleration obtained from the start time of slowing down to the end time for oil buffer. The slowing down origin of the oil buffer is set in the time when acceleration becomes 0 m/s^2. The slowing down endpoint is set with the point when the deceleration becomes 0.5 m/s^2 right before the velocity 0 m/min.

2) The average deceleration defines the value that is divided the velocity at start point of slowing down for oil buffer by the time from the start point to end point of slowing down.

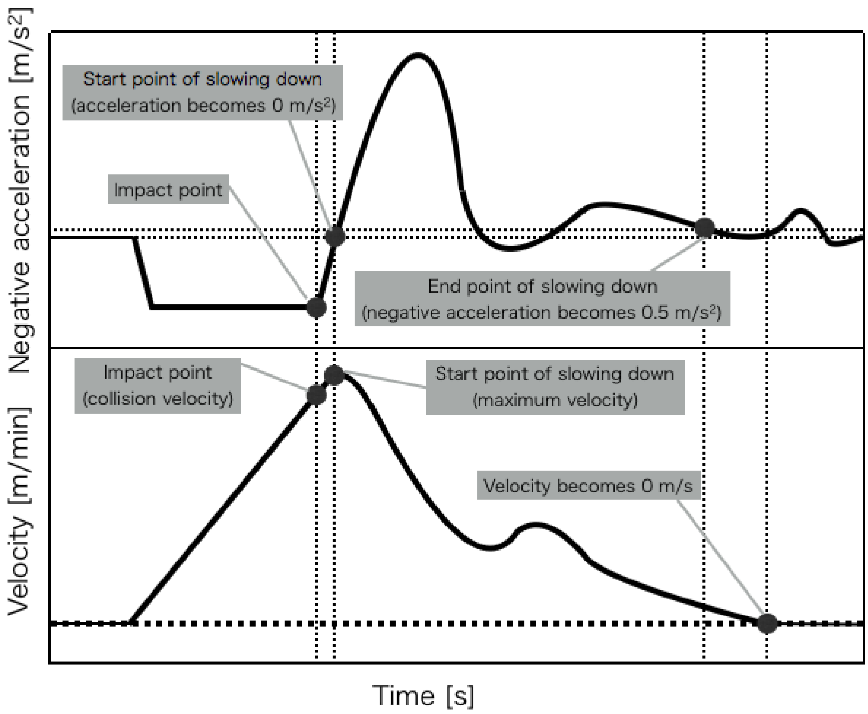

Figure 1 Example of deceleration characteristic of oil buffer

3 ANALYTICAL METHOD

In the situation that an elevator collides with an oil buffer, one degree of freedom model that is constructed from a mass m [kg], a spring of natural frequency k [Hz] and damping ratio ζ is considered to evaluate the response in sinking direction after impact between elevator car and buffer by time response analysis. Figure 2 shows the analytical model for time response analysis, and also the equation of motion is as follows:

$$m\ddot{x} + c\dot{x} + kx = 0$$

In the case of initial condition:

$$\left.\begin{aligned} \dot{x} &= v_0 \\ x &= x_0 \end{aligned}\right\}$$

The responses are obtained as follows:

$$x = e^{-zw_n t}\left\{ x_0 \cos w_d t + \frac{zw_n x_0 + v_0}{w_d} \sin w_d t \right\}$$

$$\dot{x} = -\zeta\omega_n e^{-\zeta\omega_n t}\left\{ x_0 \cos\omega_d t + \frac{\zeta\omega_n x_0 + v_0}{\omega_d}\sin\omega_d t \right\} + \omega_d e^{-\zeta\omega_n t}\left\{ -x_0 \sin\omega_d t + \frac{\zeta\omega_n x_0 + v_0}{\omega_d}\cos\omega_d t \right\}$$

$$\ddot{x} = \omega_n e^{-\zeta\omega_n t}\left[x_0 \left\{ \left(\zeta^2\omega_n^2 - \omega_d^2\right)\cos\omega_d t + 2\zeta\omega_n\omega_d \sin\omega_d t \right\} + \frac{\zeta\omega_n x_0 + v_0}{\omega_d}\left\{ \left(\zeta^2\omega_n^2 - \omega_d^2\right)\sin\omega_d t + 2\zeta\omega_n\omega_d \cos\omega_d t \right\} \right]$$

Besides, the deceleration is calculated from the following expression:

$$\frac{v_1 - v_2}{t_2 - t_1} = \frac{\left(w_d - zw_n\right)\left\{ e^{-zw_n t_1}\left(x_0 \cos w_d t_1 + \frac{zw_n x_0 + v_0}{w_d}\sin w_d t_1 \right) - e^{-zw_n t_2}\left(x_0 \cos w_d t_2 + \frac{zw_n x_0 + v_0}{w_d}\sin w_d t_2 \right) \right\}}{t_2 - t_1}$$

$$- \frac{2 w_d x_0 e^{-zw_n t_1}\sin w_d t_1 + e^{-zw_n t_2}\sin w_d t_2}{t_2 - t_1}$$

Specifically, combination of spring element and damping element becomes very important to design the actual oil buffer. Therefore, in this analysis, natural frequency and damping ratio of the buffer is assumed analytical parameters. Response acceleration, deceleration, velocity and displacement of 1DOF model with the buffer are analyzed from the combination of each parameter. Based on the responses analyzed by time response analysis, the combination of each analytical parameters are obtained to satisfy the performance specification requirements.

The initial conditions of analytical parameters are as follows:

Mass of elevator car 2,000 kg: mass of car 1,000 kg + loading mass 1,000 kg (15 person * 65 kg/person)

Natural frequency: $0.1 \leqq f_n \leqq 5.0$ Hz

Damping ratio: $0.01 \leqq \zeta \leqq 0.5$

Initial velocity 103.5 m/min: 1.15 times of the elevator of standardized speed 90 m/min.

Total combination of analytical parameters becomes 2,500 ways in this time.

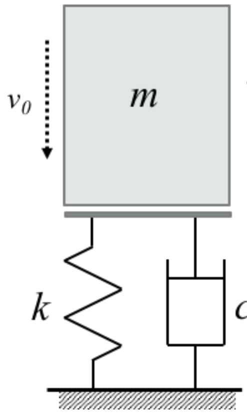

Figure 2 Analytical model for time response analysis of design way for elevator buffer

4 ANALYTICAL RESULT

Figure 3 shows the relation between natural frequency and average deceleration with each damping ratio. Besides, the figure indicates in the case of ζ=0.01, 0.25, 0.5 as a typical example. From the result, it was confirmed that the relation between natural frequency and average deceleration is almost linear characteristic. Moreover, it was confirmed that the safety requirement of average deceleration was satisfied in the range of the analytical parameter in this time, because of that the average deceleration does not exceed $1g_n$.

Next, Fig.4 shows the range of analytical parameters satisfied the safety requirement. The red plot means the plot that the deceleration over 2.5 g_n is continued more than 0.04 seconds based on the evaluation criteria. From the result, it was confirmed that the area of parameters less than 2.4 Hz satisfies basically the safety requirement. Besides, there are the parameter combinations for satisfying the safety requirement in over 2.4 Hz such as examples of near natural frequency 5 Hz and damping ratio 0.5.

Based on an evaluation standard, the combination of parameters when the maximum displacement of the buffer is less than the smallest stroke does not satisfy a safety requirement. Smallest stroke of buffer is obtained as follows in when the rating speed of the elevator car is set to be 90m/min as an initial condition.

$$\mathrm{L} = {V_R}^2/53.4 = 90^2/53.4 = 151\ [mm]$$

Figure 5 shows the relation between natural frequency, damping ratio and maximum displacement. The combination of analytical parameters in the case of maximum displacement under 0.15 [m] and also in the case of maximum displacement over 1.0 [m] does not satisfy the safety requirement. As the result, white color area satisfies the safety requirement in the analytical parameters. It is confirmed that the maximum displacement becomes a large when each parameter becomes a small. Especially, maximum displacement tends to become higher as a quadratic function when a natural frequency is smaller than 0.5 [Hz]. Therefore, Fig.6 shows the specification condition of buffer in the case of satisfying the safety requirements and the practically design possibility such as showing the white color area. As the results, it was confirmed that the following region of analytical parameters satisfies the safety requirement.

$$0.2 \leq f_n \leq 1.8\ [\mathrm{Hz}]$$

$$0.01 \leq \zeta \leq 0.5$$

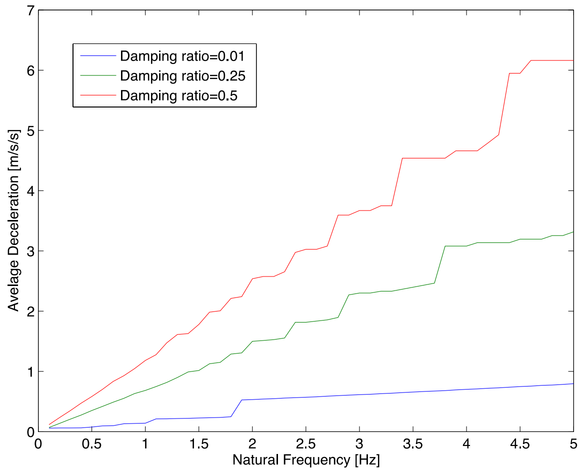

Figure 3 Relation between average deceleration and natural frequency

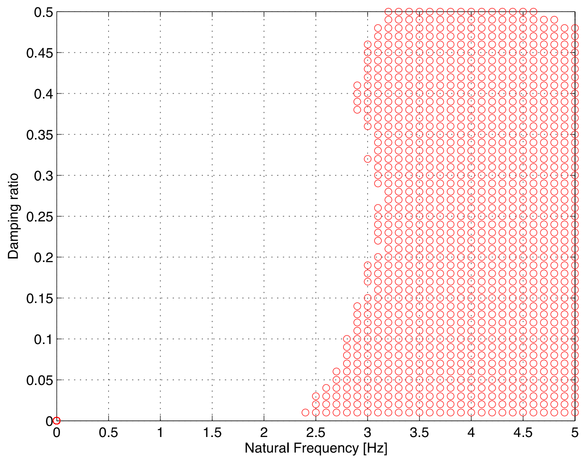

Figure 4 Relation between natural frequency and damping ratio for maximum deceleration for satisfying the safety requirements

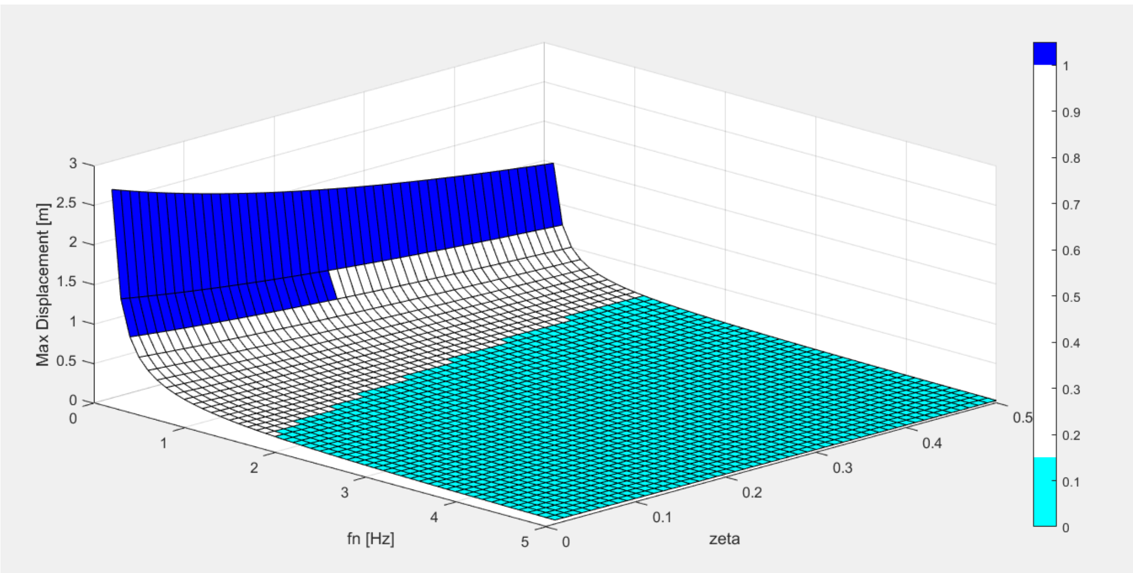

Figure 5 Relation between natural frequency and damping ratio for maximum displacement

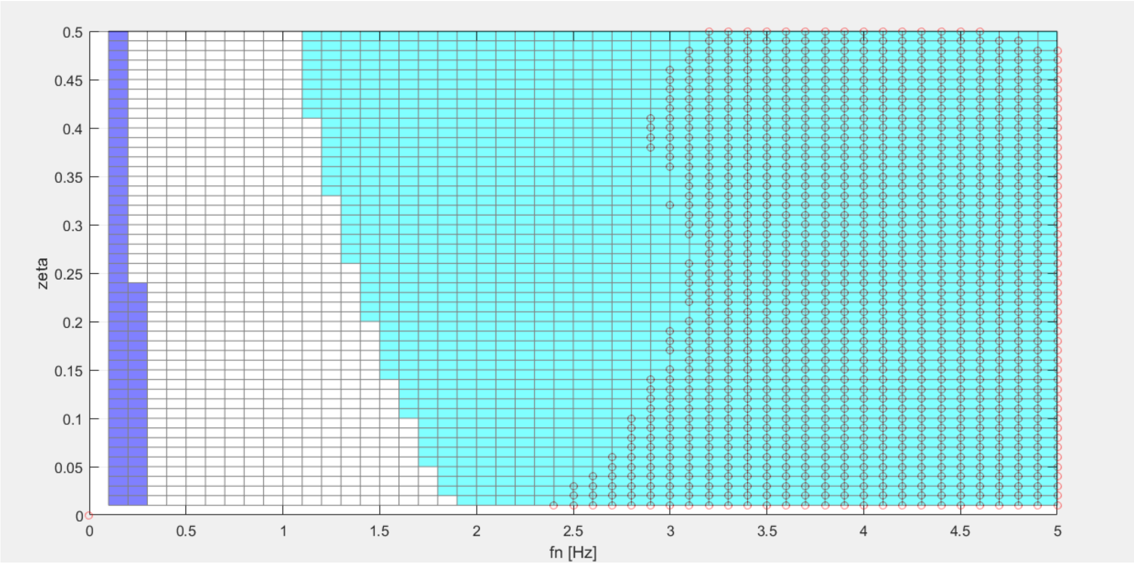

Figure 6 Design specification for satisfying the safety requirements in JIS A 4306

5 CONCLUSION

This study examined about the design way of elevator to satisfy the revised standard JIS A 4306 from the relation between a natural frequency and damping ratio in 1DOF analytical model in case under typical analytical parameters. As the result, it was confirmed that the combination of design parameters are obtained and shown visually in the figures to satisfy the safety requirements. The nonlinear time response analysis will be conducted by using analytical model of actual buffer with a nonlinear characteristic in future. Moreover, the car load will be changed to satisfy several load conditions.

References

(1) Buffer for elevators, Japanese Industrial Standard (JIS) A 4306, 2016 (in Japanese).

BIOGRAPHICAL DETAILS

PhD, Mechanical System Engineering, Graduate School of Tokyo Denki University, 1996
Research Associate, Tokyo Metropolitan College of Technology,1996
Lecturer, Tokyo Metropolitan College of Technology,1998
Associate Professor, Tokyo Metropolitan College of Technology:2001
Associate Professor, Tokyo City University:2010
Associate Professor, Tokyo Denki University:2016

Recent main research object is research and development of vibration control and base isolation technique and its upgrading.