A Fundamental Study Concerning the Proper Performance of Lift Buffers in Revised JIS A 4306

Osamu Furuya[1], Naoki Fujiwara[2] and Satoshi Fujita[3]

[1]Associate Professor, 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] Professor, Vice President, 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

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Abstract. Various safety devices are provided to ensure the safety of the 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 to satisfy a new safe condition in the revised JIS A 4306. The relation between a natural frequency, a damping ratio and a maximum displacement for satisfying the safety requirements was confirmed by using one degree of freedom model with linear damping characteristic.

1 INTRODUCTION

In recent years, lifts installed in many high-rise buildings have high stratification, resulting in improvements to theresidential environment. On the other hand, further safety improvements have been expected because various accidents have occurred. Various safety devices such as an emergency stop device, a deceleration switch and an emergency stop switch are installed to ensure the safety of the user in the case of a trouble with a lift. Especially, as for the probability of a falling down accident, a buffer in the bottom of lift hoistway will be a key element to prevent the progress to a serious accident.

A buffer plays a role to minimize the damage of a passenger by absorbing the shock of the falling down accident of the lift car. However, little research has been carried out from an engineering viewpoint[1]-[3]. In the research, it is considered that the following viewpoints are important factors in the way of thinking about the safety design for severe accidents, "Defense in Depth", "Safety Margin and Fail safe system" and "Redundancy, Diversity and Independence". The first one is an important fundamental safety way of thinking for the design of the lift to prevent the progress of a serious accident in each safety function. The others are also important key points to maintain the safety of the passengers in the lift.

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, a performance requirement of buffer and so on in Japan. Therefore, as for the performance of the buffer, the standard has been revised as necessary with a governor. In Japan, the performance regulation for an emergency stop device was revised in JIS A 4306 in 2016[4].

In this study, the way a buffer design satisfies the safety requirement of the revised Japanese Industrial Standards is analytically examined. Especially, analytical conditions are examined in the case of using an oil buffer for a lift.

2 PERFORMANCE REQUIREMENTS FOR OIL BUFFER IN JIS A 4306

In the performance regulation in JIS A 4306, the stroke of the oil buffer must be bigger than the smallest stroke calculated from the next expression. 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.

$$L_{min} = \frac{(1.15 \times V_R / 60)^2}{2 \times g_n} \times 10^3 = \frac{V_R^2}{53.4} \tag{1}$$

in here,

L_{min} : stroke of buffer [mm]

V_R : rating speed [m/min]

In addition, duration of deceleration more than $2.5g_n$ must not be over 0.04 seconds. Figure 1 shows the example of the 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 the 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 by the velocity at the start point of slowing down for the oil buffer by the time from the start point to end point of slowing down.

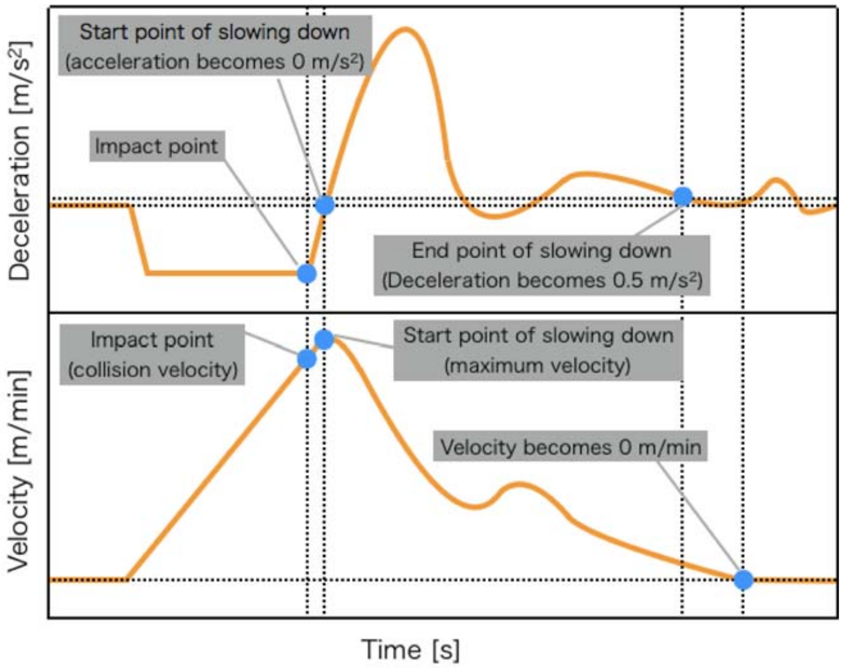

Figure 1 Example of deceleration characteristic of oil buffer

One example of a buffer characteristic from the design assumption is shown in Fig.2. A shock is absorbed instantaneously by huge deceleration in a short time. Then, an average deceleration is reduced in a small range from a long slowdown section by low vibration reduction. Although such buffer characteristics might be able to satisfy the performance requirements, the performance characteristic does not play a role as a buffer. The situation will occurwith the combination of a high capacity buffer and a lightweight lift car.

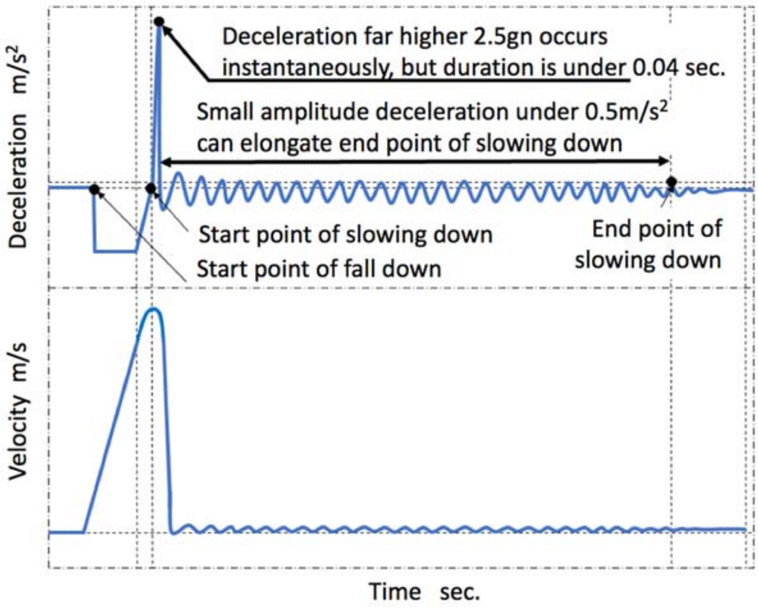

Figure 2 Example of buffer characteristic from the design assumption

3 ANALYTICAL METHOD

In the situation that a lift 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 coefficient c [Ns/m] is considered to evaluate the response in downwards direction after impact between the lift car and buffer by time response analysis. Figure 3 shows the analytical model for time response analysis, and also the equation of motion as follows;

$$\ddot{x} + 2\zeta\omega_n\dot{x} + \omega_n^2 x = 0 \tag{2}$$

in here, natural circular frequency ω_n [rad/s] and damping ratio ζ are obtained from the following,

$$\omega_n = \sqrt{k/m}$$

$$\zeta = c/2\sqrt{mk}$$

In the case of initial condition,

$$\left.\begin{array}{l} \dot{x} = v_0 \\ x = 0 \end{array}\right\} \tag{3}$$

the response displacement x, velocity $\dot{x}$ and acceleration $\ddot{x}$ are obtained respectively as follows;

$$x = \frac{v_0}{\sqrt{1-\zeta^2}\cdot\omega_n} e^{-\zeta\omega_n t}\cos\left(\sqrt{1-\zeta^2}\cdot\omega_n t\right) \tag{4}$$

$$\frac{dx}{dt} = \dot{x} = -\frac{v_0}{\sqrt{1-\zeta^2}} e^{-\zeta\omega_n t}\cos\left(\sqrt{1-\zeta^2}\cdot\omega_n t - \phi\right),\ \phi = \tan^{-1}\left(\frac{\sqrt{1-\zeta^2}}{\zeta}\right) \tag{5}$$

$$\frac{d}{dt}\left(\frac{dx}{dt}\right) = \ddot{x} = \frac{v_0}{\sqrt{1-\zeta^2}}\omega_n e^{-\zeta\omega_n t}\cos\left(\sqrt{1-\zeta^2}\cdot\omega_n t - \phi - \psi\right),\ \psi = \phi = \tan^{-1}\left(\frac{\sqrt{1-\zeta^2}}{\zeta}\right) \tag{6}$$

Therefore, the average deceleration is calculated from the response velocities as following,

$$\frac{v_1 - v_2}{t_2 - t_1} = -\frac{v_0}{(t_2 - t_1)\sqrt{1-\zeta^2}}\left\{e^{-\zeta\omega_n t_1}\cos\left(\sqrt{1-\zeta^2}\cdot\omega_n t_1 - \phi\right) - e^{-\zeta\omega_n t_2}\cos\left(\sqrt{1-\zeta^2}\cdot\omega_n t_2 - \phi\right)\right\} \tag{7}$$

Specifically, the combination of the spring element and damping element becomes very important to design the actual oil buffer. Therefore, in this analysis, the natural frequency and damping ratio of the buffer are assumed 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 parameter is obtained to satisfy the performance specification requirements.

The initial conditions of analytical parameters are as follows:

Mass of lift 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 lift of standardized speed 90 [m/min]

The total combination of all input parameters becomes 2,500 ways in this time. Besides, the mass of the lift car with a passenger changes in an operation, but supposes that the mass is constant to examine the basic performance specifications of the buffer here.

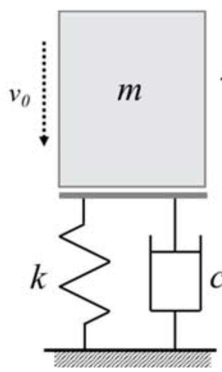

Figure 3 Analytical model for time response analysis of design way for lift buffer

4 ANALYTICAL RESULT

Figure 4 shows the relation between the natural frequency and average deceleration for each damping ratio.The diagram in Fig. 4 shows the case of ζ=0.01, 0.25, 0.5 as an example. From the result, it was confirmed that the relation between natural frequency and average deceleration is almost linear in 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. 5 shows the range of analytical parameters which 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] basically satisfies 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. The smallest stroke of the buffer is obtained as follows, when the rating speed of the lift car is set to be 90 [m/min] as an initial condition.

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

Figure 6 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. Besides, the stroke limit of the buffer was selected for the reason that a lot of buffer stroke is shorter than 1.0 [m] generally. As a result, white color area satisfies the safety requirement in the analytical parameters. It is confirmed that the maximum displacement becomes larger when each parameter becomes smaller. Especially, maximum displacement tends to become higher as a quadratic function when a natural frequency is smaller than 0.5 [Hz]. Therefore, Fig.7 shows the specification condition of a buffer in the case of satisfying the safety requirement and the practical design possibility such as showing the white color area. As a result, it was confirmed that the following region of analytical parameters satisfies the safety requirement.

$$0.2 \le f_n \le 1.8\ \text{[Hz]}$$

$$0.01 \le \zeta \le 0.5$$

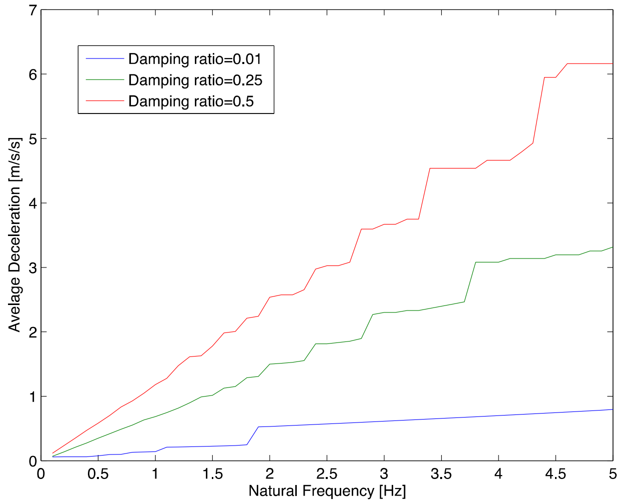

Figure 4 Relation between average deceleration and natural frequency

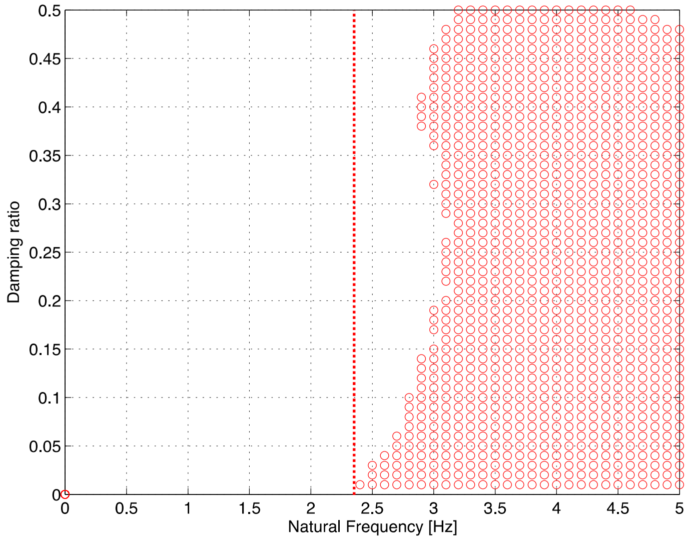

Figure 5 Relation between natural frequency and damping ratio for maximum deceleration for satisfying the safety requirements

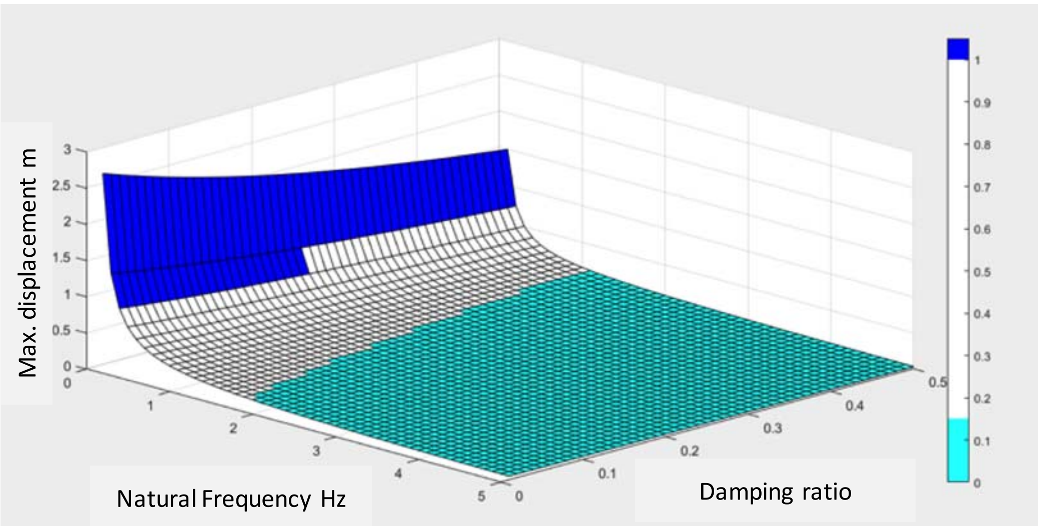

Figure 6 Relation between natural frequency and damping ratio for maximum displacement

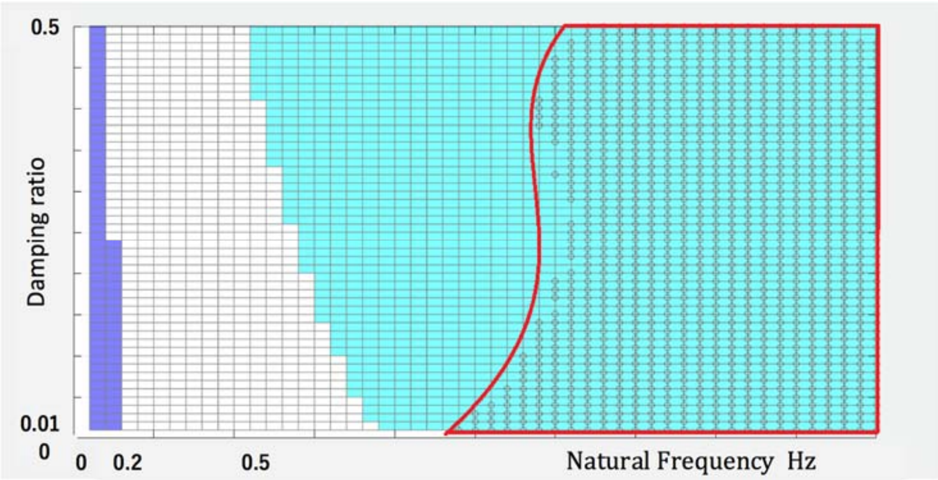

Figure 7 Design specification for satisfying the safety requirements in JIS A 4306

5 CONCLUSION

This study examined the way a buffer is designed to satisfy the revised standard JIS A 4306 from the relation between a natural frequency and damping ratio in 1DOF analytical model under typical analytical parameters. In the time response analysis, the fundamental performance of an oil buffer for satisfying the performance demands was examined as the first step of research. As the result, it was confirmed that the combinations of design parameters are obtained and shown visually in the figures to satisfy the safety requirements. Specifically, the following parameters are satisfied for the performance demands in the revised standard JIS A 4306.

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

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

However, the research in the paper was the analytical results using 1DOF model with a damper of linear characteristic. In the next step, nonlinear time response analysis will be conducted by using an analytical model of an actual oil buffer with a nonlinear characteristic and several car load conditions.

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