Study on the Proper Performance of Lift Buffers in Revised JIS A 4306 Using Non-linear Damping Characteristic

Osamu Furuya[1], Ryoto Matsuzaki[2] and Satoshi Fujita[3]

[1]Division of Mechanical Engineering, School of Science and Engineering, Tokyo Denki University, Ishizaka, Hatoyama-cho, Hiki-gun, Saitama 350-0394 Japan
[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

Keywords: lift buffer, performance requirement, non-linear damping, time response analysis

Abstract. Japanese regulatory requirement was revised in 2016. Some important safety requirements were upgraded to ensure the safety of the lift passengers. The car and counterweight buffers play an important role in a safety system. This study has been conducted for an appropriate performance of the car and counterweight buffers to satisfy the revised JIS 4306. In this paper, the analytical results using a time response analysis is shown based on the non-linear damping effect.

1 INTRODUCTION

Further safe improvement has been expected in a lift because a lot of various accidents have been occurred. Various safety devices such as an emergency stop device, a deceleration switch and an emergency stop switch have already been installed to ensure the safety of the user even in the case of a trouble into 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, few researches have been investigated in an engineering viewpoints. In the research, it is considered that following viewpoints are important factors for the way of thinking of the safety design to the severe accidents, “Defense in Depth”, “Safety Margin and Fail safe system” and “Redundancy, Diversity and Independence”. First one is an important fundamental safety way of thinking for the design of lift to prevent the progress of a serious accident in each safety function. The other is also an important key points to keep the safety for the passengers in the lift. Although the performance requirements of a buffer has 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 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 [1].

In this study, the way of a buffer design satisfying a safety requirement of revised Japanese Industrial Standards is analytically examined. In a former paper [2], the fundamental parameters to satisfy the revised performance regulation as JIS. As the next step of the study, the way of design parameters for buffer of lift is examined in non-linear response analysis from a practical viewpoint.

2 REVISED PERFORMANCE REQUIREMENTS FOR OIL BUFFER IN JIS A 4306

2.1 Stroke

The stroke of the oil buffer is a stroke slowing down on a condition to collide at a speed of 1.15 times of the rating speed in deceleration $1g_n$, and also should be bigger than the smallest stroke calculated from the next expression.

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

in here,

L_{min} : stroke of buffer [mm]

V_R : rating speed [m/min]

g_n (= 9.8 m/s^2) : gravity acceleration [m/s^2]

2.2 Braking performance

The oil buffer satisfy the next regulation in the performance test by 4306 JIS A 8.2.2.

- In maximum impact speed of 1.15 times of the rating speed, a weight for performance test equivalent to a maximum and minimum mass is in a free-fall, and then an average deceleration should not be exceed 1g_n when it collided with a buffer at most impact speed.
- Duration of deceleration more than 2.5g_n should not be over 0.04 seconds.

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

$$\dot{V}_{average} = (v_1 - v_2)/(t_2 - t_1) \tag{2}$$

in here,

$\dot{V}_{average}$: average deceleration [m/s^2]

v_1 : velocity at start point of slowing down [m/min]

v_2 : velocity at end point of slowing down (Deceleration becomes 0.5m/s^2) [m/min]

t_1 : time at start point of slowing down [s]

t_2 : time at end point of slowing down (Deceleration becomes 0.5m/s^2) [s]

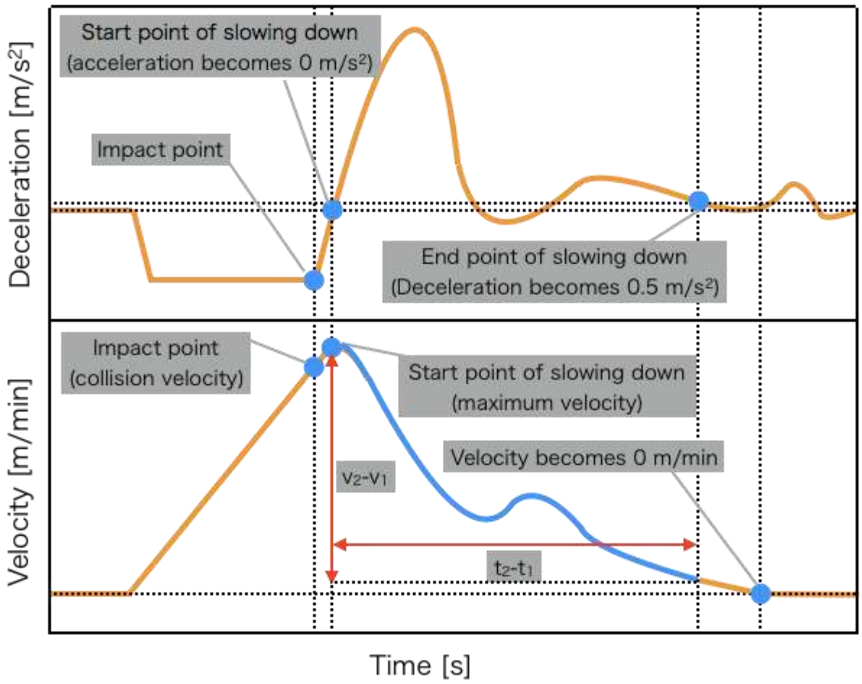


Figure 1 Example of deceleration characteristic of oil buffer

2.3 Restoring time to original position

Plunger head should be returned to an original position from the maximum sinking condition of plunger after external force was released, and also it should be less than 90 seconds.

Figure 2 shows an example of inside mechanism of oil buffer.

1) Oil buffer has a cylinder enclosing oil as an actuating fluid, and buffer action is given by fluid resistance when oil passes an orifice with the drop of the plunger.

2) Materials of a cylinder and a plunger are made by a steel.

3) Surface of the hydraulic fluid should be able to confirm.

4) The main compose of buffer material becomes an elastic materials such as a synthetic rubber.

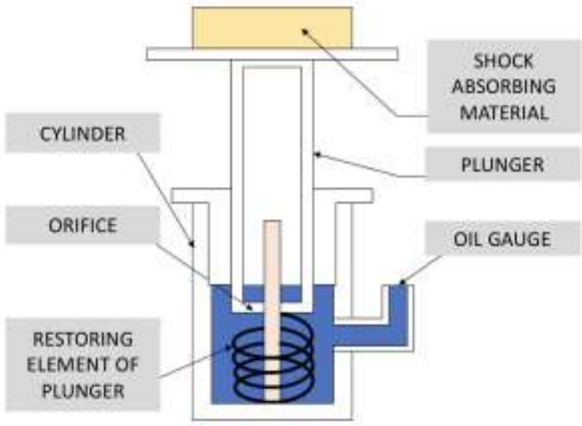


Figure 2 Example of inside mechanism of oil buffer

As for the mentioned above, although the revised JIS A 4306 has several regulations such as average deceleration, duration time of deceleration and so on, there is some example of buffer characteristic out of the design assumption.

Figure 3 shows one of example for out of design assumption. In here, a shock is absorbed instantaneously by huge deceleration in a short time, and also average deceleration is reduced in small range from a long slowdown section with low vibration reduction. Such response will occur in a combination with high capacity buffer and lightweight elevator car. Although such buffer characteristic might be able to satisfy the performance requirements, the characteristic does not play a role as a buffer.

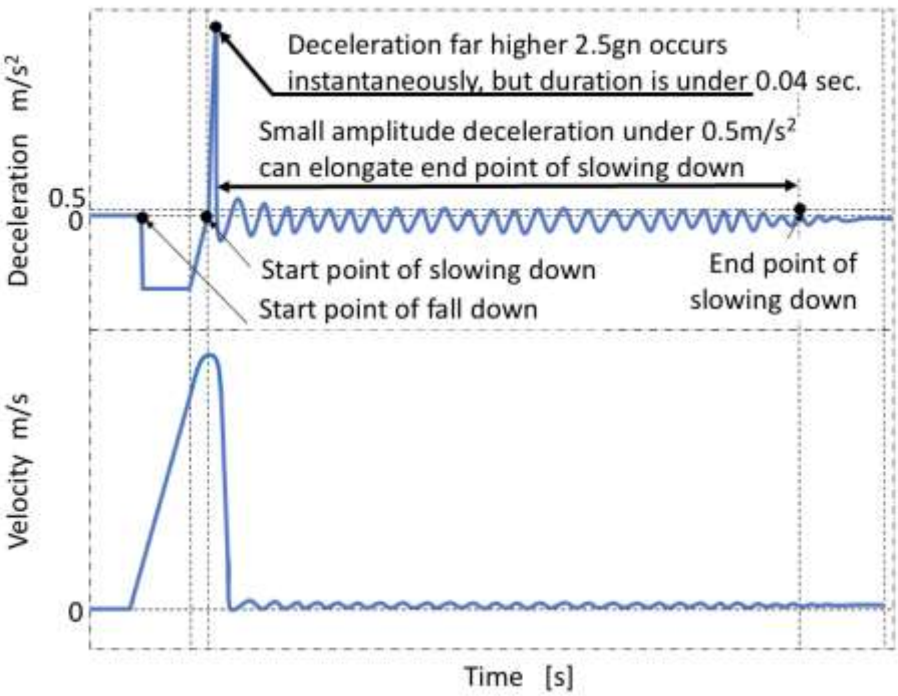


Figure 3 One of Example of Buffer Characteristic out of the Design Assumption

3 ANALYTICAL METHOD

In the previous study, the design way of oil buffer was examined to satisfy the revised standard JIS A 4306 from the relation between a natural frequency and damping ratio in 1DOF analytical model in case of linear damping characteristic. 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.

In the next research step, the nonlinear time response analysis is conducted by using analytical model of assumed actual buffer with a nonlinear damping characteristic.

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 constant k [Hz] and damping coefficient c is considered to evaluate the response in sinking direction after impact between elevator car and buffer by time response analysis. Figure 2 shows a simplified diagram of nonlinear time response analysis, and also the equation of motion is as follows;

$$m\ddot{x} + c(x)\dot{x}^n + kx = 0 \tag{3}$$

here,

m : mass of car

x : relative displacement from basement of oil buffer

k : spring constant of restoring force to return a plunger head to an original position

$c(x)$: non-linear damping coefficient

Besides, the time response analysis in this time is used as non-linear damping characteristic as next expression. Besides, superscript character p means a parameter for displacement dependency on damping coefficient.

$$c(x) = \alpha x^p + \beta \tag{4}$$

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)

Initial velocity 103.5 m/min (=1.725 m/s): 1.15 times of the elevator of standardized speed 90 m/min

The spring constant is set to k = 300 N/m, because the plunger head returns to initial position by spring element.

In this paper, the analytical results is summarized about a non-linear damping characteristic to satisfy the revised JIS A 4306 from the evaluation factor such as average deceleration, maximum displacement and duration time in constant deceleration.

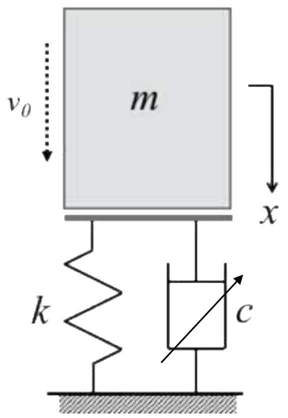


Figure 4 Analytical model for time response analysis of design way for elevator buffer

4 ANALYTICAL RESULT

Before the non-linear time response analysis, the analytical parameters of non-linear damping characteristics are examined in condition with $\alpha = 0$ or $\beta = 0$. Besides, the analytical parameter p is 0 in here because the fundamental qualitative tendency is examined at first. Equation of motion (4) is solved by using Runge-Kutta Gill method for a non-linear time response.

Figure 5 shows the relation between sinking displacement of buffer and maximum damping force in the case of $\beta = 0$ and $1.0\times10^5 \leq \alpha \leq 9.0\times10^5$. It is confirmed that the maximum displacement decreases and the maximum force increases by increasing α. Next, Fig.6 shows the relation between maximum displacement and maximum damping force in the case of β is the parameters. It is confirmed that the displacement decreases and the maximum force increases by increasing β as the same tendency in case of α. As the results, the time response analysis is carried out using α as a parameter for a non-linear damping effect, because an initial damping coefficient makes to increase a response acceleration and also to be undesirable as an actual buffer.

Figure 7 shows the time response in displacement, velocity and acceleration after a car impact to a buffer as the analytical parameter α. It is confirmed that the response displacement and duration time of slowdown decreases in increasing α as shown in the figure. On the other hand, increasing α leads a large maximum acceleration and a reduction of response duration.

Finally, it is examined that the range of parameter α satisfy the regulatory requirement. Figure 8 shows the relation between the responses and analytical parameter α. In the condition that the analytical parameter α is over 7.2×10^5, the average deceleration exceeds $1g_n$ which is a regulatory requirement in the revised JIS 4306. Moreover, in the case of range of α over about 3.0×10^5, the maximum stroke does not satisfy the safety requirement. Therefore, next range of the parameter α shows the specification condition of buffer in the case of satisfying the safety requirement and the non-linear damping characteristic possibility.

$$2.0\times10^4 \leq \alpha \leq 3.0\times10^5$$

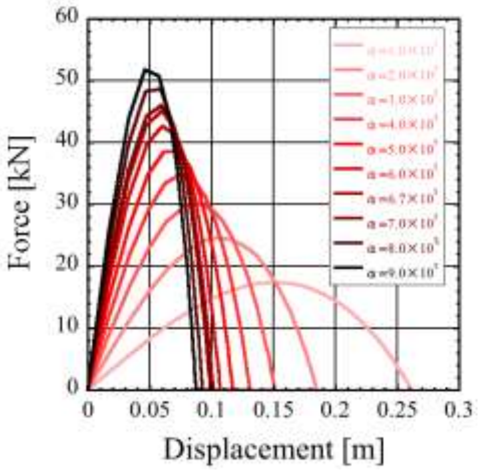
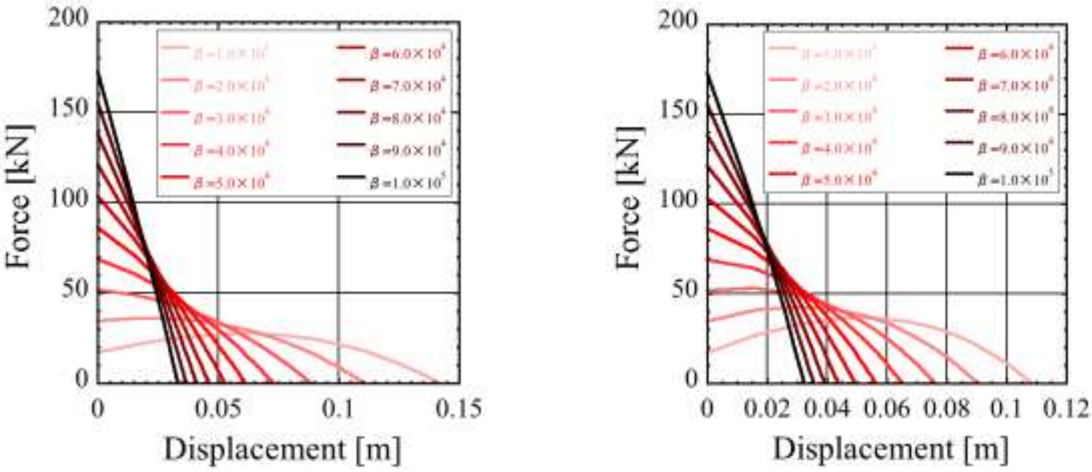
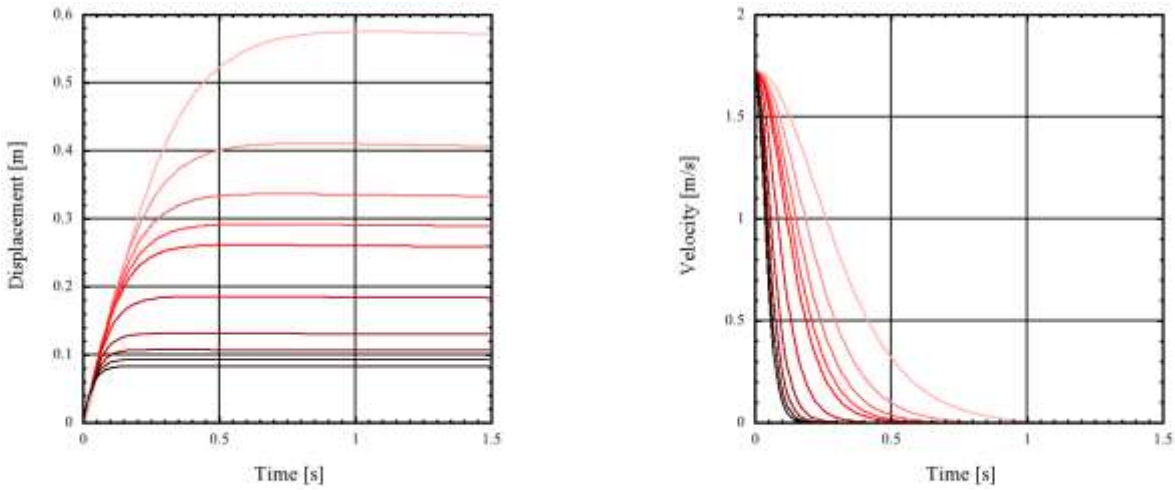


Figure 5 Relation between displacement and force in $\beta = 0$ and $1.0\times10^5 \leq \alpha \leq 9.0\times10^5$

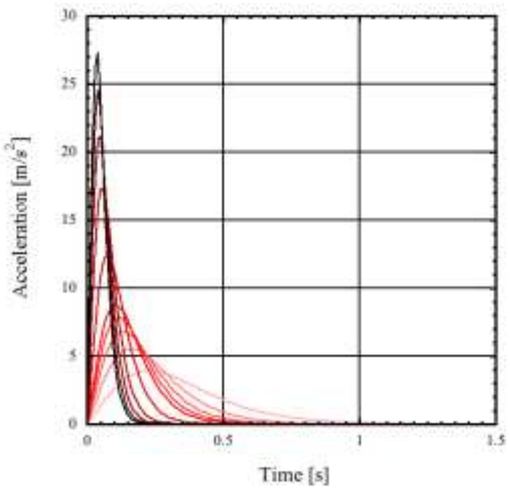


(a) $\alpha = 2.0\times10^5$ **(b) $\alpha = 4.0\times10^5$**

Figure 6 Relation between displacement and force in $1.0\times10^4 \leq \beta \leq 1.0\times10^5$

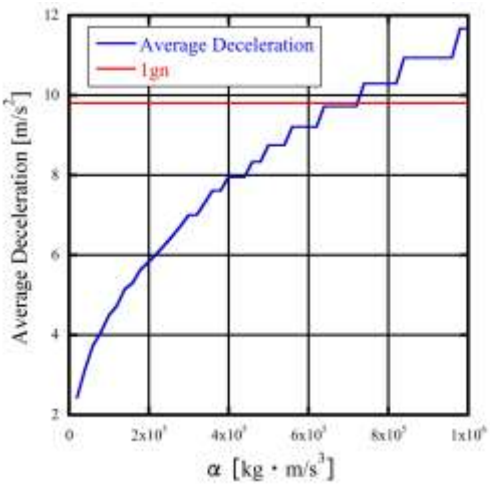


(a) Response displacement **(b) Response velocity**

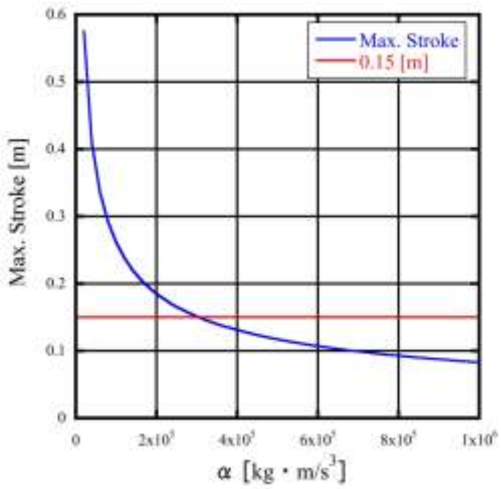


(c) Response acceleration

Figure 7 Response displacement, velocity and acceleration as the analytical parameter α



(a) Average deceleration



(b) Maximum stroke

Figure 8 Relation with responses to satisfy the regulations as the analytical parameter α

5 CONCLUSION

This study have carried out about the suitable design way of elevator buffer to satisfy the revised industrial standard JIS A 4306 from the time response analysis using an analytical model of non-linear damping characteristic in 1degree freedom (1DOF) model. In this paper, as the result, it was confirmed that the analytical parameters α was obtained to satisfy the performance requirements from the non-linear time response analysis using analytical model of a nonlinear characteristic. In the next step, the analysis will be conducted to investigate an actual condition by considering an effect of gravity in a car and a buffer, and also the car load will be changed to satisfy several load conditions. Because the response analysis carried out since the starting point in the condition that the weight of mass balanced to restoring force in spring element of dynamic analytical model.

REFERENCES

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

[2] Osamu Furuya, Naoki Fujiwara and Satoshi Fujita, "A Fundamental Study Concerning the Correct Performance of Elevator Buffers", P*roceedings of The Lift & Escalator Symposium*, (2017).

BIOGRAPHICAL DETAILS

Prof. Osamu Furuya has a PhD in Mechanical System Engineering, Graduate School of Tokyo Denki University, 1996. He has been a 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. Recently main research object is research and development of vibration reduction for various structures and seismic safety for important facilities.

Mr.Ryoto Matsuzaki is a Master Course Student, Department of Mechanical Engineering, School of Science and Engineering, Tokyo Denki University,2017

Prof. Satoshi Fujita is a JSME (Japan Society of Mechanical Engineers) Fellow, has ten years of management experience as a director, a dean of school of engineering and a vice-president of Tokyo Denki University. He has been engaged in engineering research and development of seismic isolation systems and vibration control systems for buildings or key industrial facilities for over 35 years at both University of Tokyo and Tokyo Denki University. In recent ten years, he has been a committee member of the Panel on Infrastructure Development of Japanese ministry of land, infrastructure and transport (MLIT), and a chair of the Special Committee on Analysis and Evaluation of Lifts, Escalators and Amusement Facilities Accidents and Failures held in MLIT. In addition, he has been a chair of the ISO TC178 Japanese committee.