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Evacuation Safety Evaluation According to Slope of the School Ramps

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Abstract

This study, in order to evaluate the safety of evacuation by comparing and analyzing the RSET according to the slope change of the ramp, which is a vertical evacuation route in case of fire in a high school building, Evacuation simulation was run the Pathfinder program changed the slope of the ramp to 10°, 15°, and 20° for each male students and female students. In the case of female students, it was analyzed that when the final RSET slope was 15°, 25.7 seconds were shorter than when 10°, and 4.2 seconds were shorter than when 20°. Male students also found that when the final RSET slope was 15°, 23.8 seconds were shorter than when 10°, and 5.4 seconds shorter than when 20°. It was analyzed that even if the number of participants was increased and the evacuation simulation was executed, the safety of evacuation could be improved when the slope of the slope is 15° as the RSET when the slope of the slope is 15° is shorter than that of 10° and 20°.

Keywords: *Ramp, Slope Change, Pathfinder Simulation, RSET, Evacuation Safety.*

1. Introduction

According to the analysis of major fires[1] in the 2019 Fire Statistical Yearbook by the National Fire Data System of the National Fire Service Agency of Korea, among important fires, in 2019, 45 cases (28.8%) occurred in schools, followed by public offices, 13 cases (8.3%), public buildings 7 cases (4.5%), and so on[2].

Stairs and ramps, which are structures that connect the spaces to be used, which are the main purpose of architecture, and expand these spaces horizontally or vertically, are important environmental elements of buildings related to movement. In addition, it has been an element that expresses the spirit of a new era with psychological values that are practically connected by movement to the upper and lower spaces[3]. These connecting passages should be used without inconvenience, considering the safety of occupants using the space of the building. When designing buildings in South Korea and the U.S., the design of the buildings is stipulated as part of the escape route along with the corridor. Korea's existing research on evacuation safety was to compare many evacuation regulations in the United States, Britain and Japan with domestic evacuation regulations, or to extensively study of evacuation safety centered on certain buildings, such as high-rise buildings and nursing hospitals, and facilities that are frequently used or inhabited by patients.

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The safety regulations for evacuation when a fire occurs in a building covers a very wide range from fire detection, firefighting facilities, initial fire extinguishing facilities, fire and fireproof structures, evacuation routes, and interior materials, and practically safety against building fires. The safety performance can be secured by simultaneously applying various measures for several buildings [4]. However, if this is summarized, the scale or quantity is very large or large. Also, when designing buildings under the Korean Fire Protection Act and the National Fire Agency (NFPA)'s "Life Safety Code Handbook", it stipulates the design of stairs and ramps as evacuation routes along with corridors among evacuation facilities. Therefore, this study limited the scope of the study to that of stairs and ramps among the components of escape routes.

Oh, Tae-young et al. (2010) analyzed the difference between the angle of flexion of the slant joint and the low-pressure of the pedigree while climbing the ramp according to different gradientslop (0°, 3°, 6°, 9°) [5]. According to Choi, Young-oh (2014), a population of 30 people was formed and the optimal gradient slope was analyzed to determine the degree of overcoming the slope of the ramp [6]. Yang, So-yeon and Lee, Tae-kyung (2016) analyzed the user's preference for changing the surface length of the ramp according to the slope as basic data for the design of the ramp [7]. According to Kim, Myung-kwon and Cha, Hyun-kyu (2016), comparing the kinematic effects of forward and backward walking on the ramps showed a positive effect on the 10° slope on the backwalk [8].

E. N. Corlett et al. (1972) compared the O2 consumption, heart rate and maximum knee joint angles when climbing stairs or ramps ranging in slope from 10° to 30° [9].

I. Canale et al. (1991) analyzed the muscle-ability enhancements of the slope or length of the ramp in public buildings of wheelchair users [10], Yu, Bing et al. (1996) analyzed the pressure of the lower extremities according to the moment of the joint during the climb, suggesting a new stair design [11].

A. Nagel et al. (2008) analyzed the pressure patterns on the soles of the feet during stair climbs to study whether there are specific stair uphill or downhill modes to be recommended for diabetics with foot problems [12]. Jinger S. Gotttschall et al. (2012) compared the pelvic stability according to the slope and slope on the stairs to evaluate and analyze muscle activity patterns [13].

Previous studies on stairs and ramps so far have mainly analyzed the moments of joints and soles of feet from the viewpoint of medical and kinematics, and are studies of walking training for patients, the elderly, and the disabled when climbing stairs or ramps, or the slope of the ramp is not affected by the structure and function of the feet. Because of its impact, the focus was on the health sector, such as recommended for diabetics. However, in the event of a disaster, there is very little or no study of evacuation safety in the form of important evacuation routes, such as the single height of stairs or the slope of ramps.

Therefore, this study compares the structure of ramps prescribed by the National Fire Protection Association (NFPA) of the U.S. and Korean Fire-related laws, and the laws related to firefighting in Korea, and sets a scenario in which the slope of the ramp are different for fire training. In this way, an evacuation simulation is executed to compare and analyze the safety of evacuation according to the required safe egress time (RSET).

2. Standards for the Installation of Ramps

According to the rules on the standards for evacuation and fire protection of buildings in Korea, in the case of planning to install a ramp instead of a staircase in a building, the slope must be installed within 1:12, and the ramp installed in the existing facility, not the new construction. In this case, the slope of the ramp can be reduced to 1:8. In addition, the effective width of the ramp must be installed in accordance with the standard of 1.2m or more. However, when it is difficult to secure an effective width of 1.2 meters or more, in the case of extension, renovation, reconstruction, relocation, major repair, or change of use of a building, it may be reduced to 0.9 meters. At the beginning and end of the ramp, the refraction part, and the resting area, an activity space of at least 1.5m × 1.5m must be secured. The criteria for finishing materials shall be finished flat with a rough surface or a material that does not slip easily, and the criteria for installation of rails or true rails according to the height of the ramp and installation of intermediate rails according to the width of the ramp are prescribed [14].

In the case of Korea, the regulations are based on the standards for the general public, and regulations for the disabled, such as Table 1, are prescribed by special laws [15]. The U.S. sets regulations based on consideration for the disabled and with exceptions to conditions that do not require consideration for the disabled [16].

Table 1. Standards for Ramps Installation in Korea and U.S.

Sortation	Installation criteria	
	Korea	U.S.
Min. width clear of all obstruction	1.2 m	1.12m (44 in.)
Max. Slope	1:12 (Max. cross slope 1:8)	1:12 (Max. cross slope 1:8)
Horizontal area	Install the horizontal resting area every 0.75 m from the floor	
Length of landing	1.8 m or more	not less than 1.52m (60in.)
Material and finish	a flat finish with a material that doesn't slip well	
Application standard	Rules on the Standards for Evacuation, Fire Protection, etc. of Buildings	NFPA 101(More than 50 people)

3. Evacuation Simulation

3.1 Research Model

This study attempts to compare and analyze the safety of evacuation by analyzing the results of the required safe egress time (RSET) through evacuation simulation by dividing high school students by gender and changing the slope of the slope as shown in Figure 1. This is to make suggestions for institutional application of facilities in buildings for efficient evacuation along with performance design.

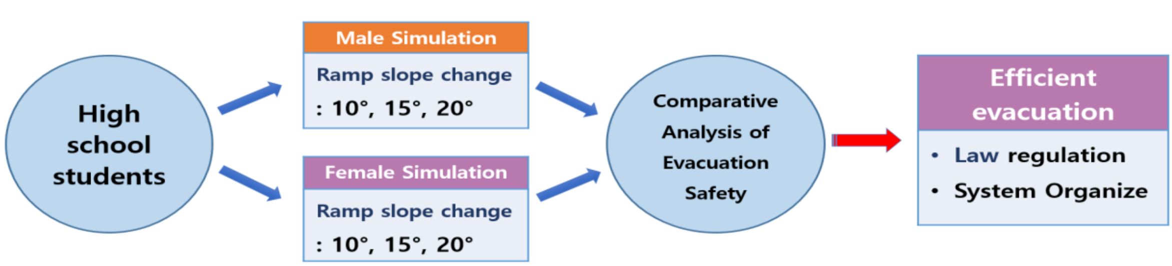
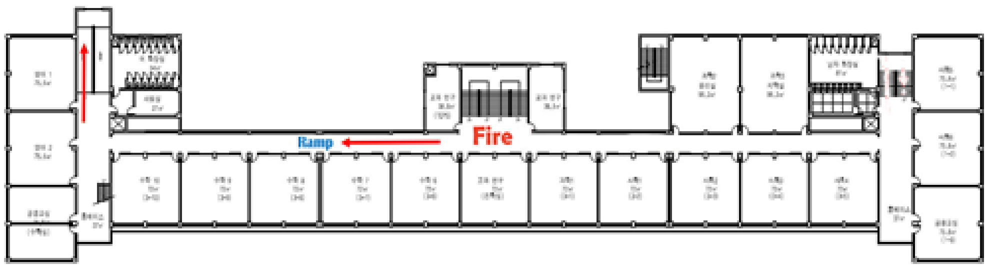


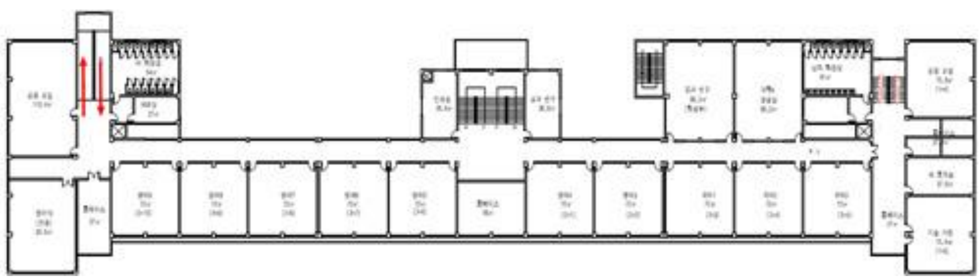
Figure 1. Research Model

3.2 Target Building

The building subject to the evacuation experiment is OO high school building located in OO city. It is a coeducational school with 10 classes per grade, with a total of 30 classrooms, four science rooms, and two creative convergence rooms on the first, second and third floors. Each floor has ramps at the left end of the corridor and stairs to the right. In (a) of Figure 2, the final exit of the ramp on the first floor of the building is marked as Exit Door 01. In Figure 2(b) and Figure 2(c), each floor has a ramp at the left end of the corridor with an arrow.



(c) Floor plan of the 3rd floor



(b) Floor plan of the 2nd floor

(a) Floor plan of the 1st floor

Figure 2. Structural plan of the main building of OO High School on the 3rd floor

Figure 3 is an actual photograph of the ramp of the target building, completed in 1983. design of the target building in Figure 3 is not violate the regulations because the building was completed in 1983 prior to the performance-oriented design methods and standard statutes of fire-fighting facilities. The slope of this building was installed at 15°.

Figure 3. Ramp of the target building

3.3 Composition of Evacuation Scenario

3.3.1 Scenario 1: 10° Slope for Female Students of the Ramp

In the training of a virtual situation where a fire broke out on the 4th floor and expanded to the 3rd floor for 25 female students, a simulation was performed on the evacuation in the direction of the ramp, which is the left evacuation route of the building through the corridor, which is a horizontal evacuation route. At this time, the slope of all ramps was set at 10°, and door01, an evacuation exit on the ramp side of the first floor, was set as the final evacuation exit of the evacuation simulation.

3.3.2 Scenario 2: 15° Slope for Female Students of the Ramp

In the training of a virtual situation where a fire broke out on the 4th floor and expanded to the 3rd floor for 25 female students, a simulation was performed on the evacuation in the direction of the ramp, which is the left evacuation route of the building through the corridor, which is a horizontal evacuation route. At this time, the slope of all ramps was set at 15°, and door01, an evacuation exit on the ramp side of the first floor, was set as the final evacuation exit of the evacuation simulation.

3.3.3 Scenario 3: 20° Slope for Female Students of the Ramp

In the training of a virtual situation where a fire broke out on the 4th floor and expanded to the 3rd floor for 25 female students, a simulation was performed on the evacuation in the direction of the ramp, which is the left evacuation route of the building through the corridor, which is a horizontal evacuation route. At this time, the slope of all ramps was set at 20°, and door01, an evacuation exit on the ramp side of the first floor, was set as the final evacuation exit of the evacuation simulation.

3.3.4 Scenario 4: 10°, 15°, 20° Slope for Male Students of the Ramp

In order to find out the difference in the time required for evacuation (RSET) when the slope of the ramp varies according to the gender of male and female students, an evacuation simulation was performed for male students as in scenarios 1, 2, and 3.

Table 2. Configuration of Scenarios

Sortation	Sex	Participants	Ramps slope(°)	Evacuation Final exit
Scenario 1	female	25	10	door01
Scenario 2	female	25	15	door01
Scenario 3	female	25	20	door01
Scenario 4	male	Each 25	10, 15, 20	door01

3.4 Evacuation Delay and Available Safe Egress Time (ASET)

Evacuation delay time was used by the test formula "Estimation of evacuation start time" as shown in Expression (1) [17].

$$\text{Evacuation initiation time (min)} = \sqrt{\sum A}/30 \quad \text{------------------- Expression (1)}$$

The maximum compartment area of A = 8.5, since the floor area of the classroom is 72m2. Therefore, evacuation initiation time (min) = 8.5/30 = 0.28 minutes, which translates into 17 seconds. However, since the evacuation training was notified in advance in this study, the detection time and recognition time of the fire detector should be considered in the event of a fire do not occur. Therefore, the evacuation start time was set at 30 seconds, including the time of evacuation after listening to the broadcast in 17 seconds of Form (1) because it was assumed that the person in charge was directly evacuated through the broadcast. The ASET is set at less than four minutes as shown in Table 2 based on the performance-oriented design method and standards for firefighting facilities, etc [18].

The minimum evacuation request time required for students to complete evacuation from a building is called RSET, and the time when the fire reaches the hazard is called ASET. According to Poon (2014), Wang, et al. (2015), achieving the goal of the disaster prevention design is judged to be the case where the RSET is below the ASET [19] [20].

Table 3. Escape Time Criteria

Building usage	ASET (available safe egress time)
office, commercial and industrial buildings, schools, universities(residents are familiar with the building's interior, alarms, escape routes, and always awake)	4 minutes, or less

3.5 Input Variables and Input Values

In this study, the input variables reflected in the Pathfinder evacuation simulation [21] were divided into walking speed, evacuation initiation time, height, and shoulder width and applied as shown in Table 3. Among the input variables, height was based on the 2019 student health examination sample statistics published by the Ministry of Education [22], the shoulder width reflects the body size of Korean people in their 20s based on their standard body type by gender and age [23]. Therefore, the height was calculated based on 173.4 cm for male students and 161.2 cm for female students, and the shoulder width was 39.8 cm for male students and

35.7 cm for female students. The walking speed was calculated by applying 1.19 m/s for male students and 1.10 m/s for female students to the average adult walking speed [24].

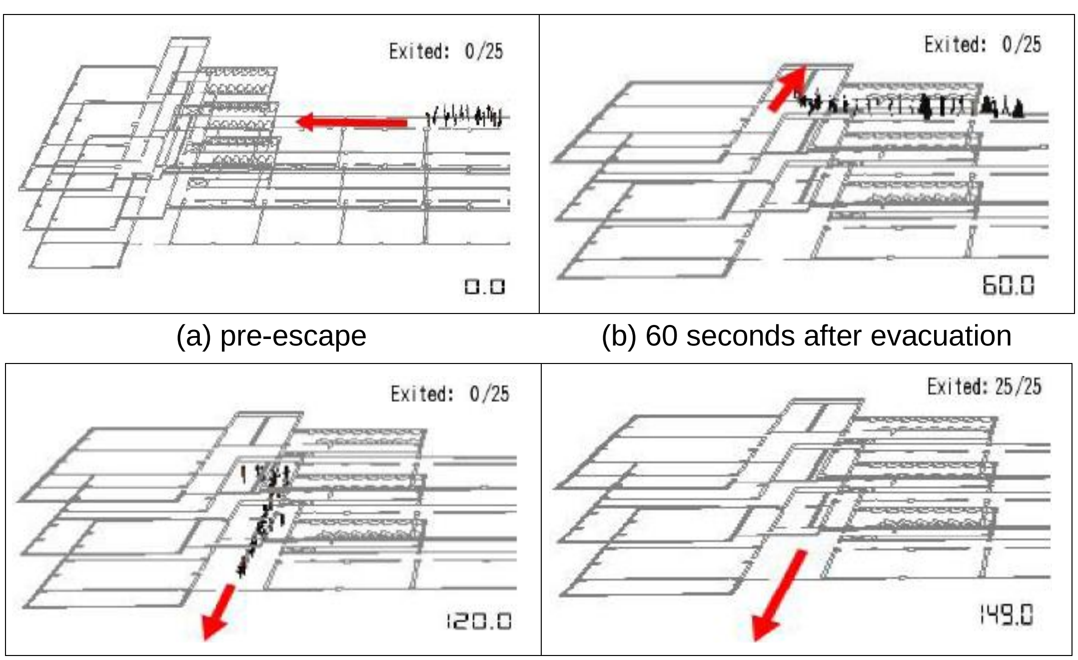
Table 4. Input variables and input values

Input variable	Input values	Sources
walking speed	man: 1.19 m/s woman: 1.10 m/s	The SFPE Handbook of Fire Protection Engineering 2
evacuation initiation time	30 seconds	Time for all occupants in the classroom to recognize training and begin evacuation
height	man: 173.4 cm woman: 161.2 cm	2019, Student Health Examination Sample Statistics
shoulder width	man: 39.8cm woman: 35.7cm	「Human Dimension Survey of Koreans(2015)」 Apply

4. Results and Considerations

4.1 Scenario 1: 10° Slope of the Ramp

Figure 4 shows the results of the evacuation simulation according to the time change of the evacuation route on the ramp side of the female student after the fire occurred. In the event of a fire, the female students start evacuating after 30 seconds, depending on the evacuation scenario. Various actions are performed according to the algorithm of the simulation, and the evacuation is completed 149.0 seconds after the start of evacuation.



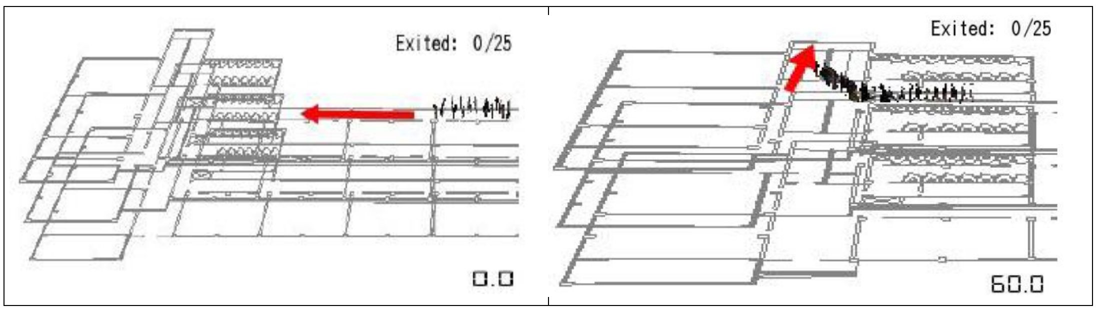
(a) pre-escape (b) 60 seconds after evacuation

(c) 120 seconds after evacuation (d) Evacuation complete

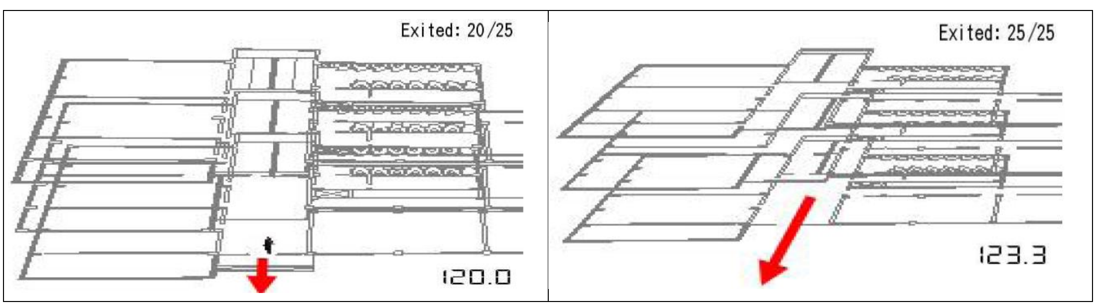
Figure 4. Evacuation situation over time with slope of 10°

4.2 Scenario 2: 15° Slope of the Ramp

In Scenario 1, the results of the simulation of the female students when the slope was changed to 15° are shown in Figure 5. Evacuation was completed in 123.3 seconds after the start of the evacuation, and 25.7 seconds were shortened compared to when the slope was 10°.



(a) pre-escape (b) 60 seconds after evacuation

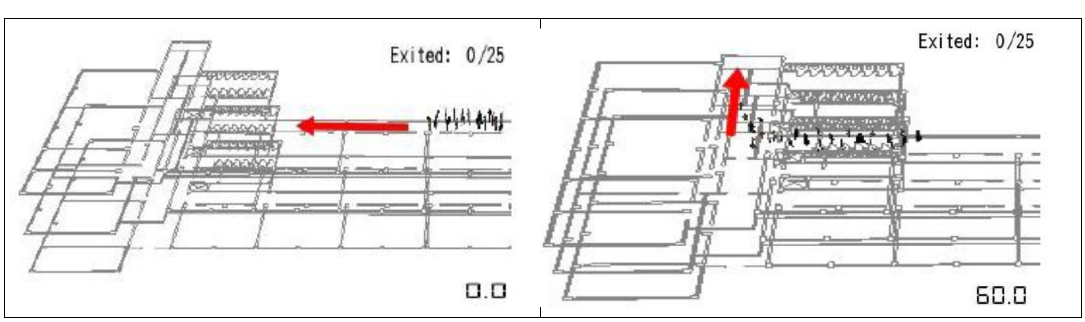


(c) 120 seconds after evacuation (d) Evacuation complete

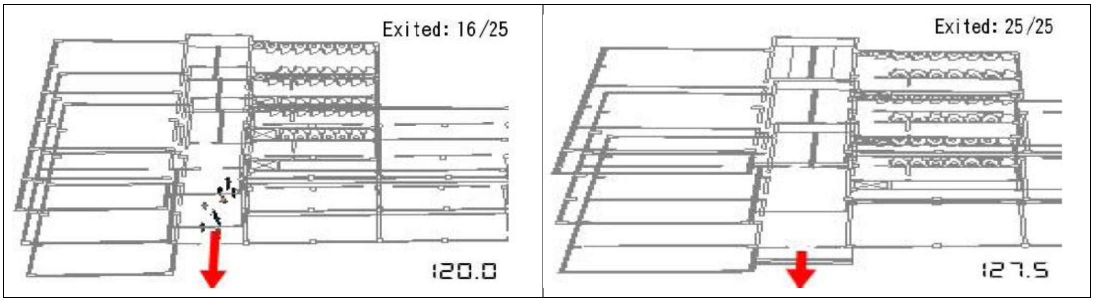
Figure 5. Evacuation situation over time with slope of 15°

4.3 Scenario 3: 20° Slope of the Ramp

In Scenario 1, the results of the simulation of the female students when the slope was changed to 15° are shown in Figure 6. Evacuation was completed in 127.5 seconds after the start of the evacuation, and 21.5 seconds were shortened compared to when the slope was 10°. However, it took 4.2 seconds longer than the slope of 15°.



(a) pre-escape (b) 60 seconds after evacuation

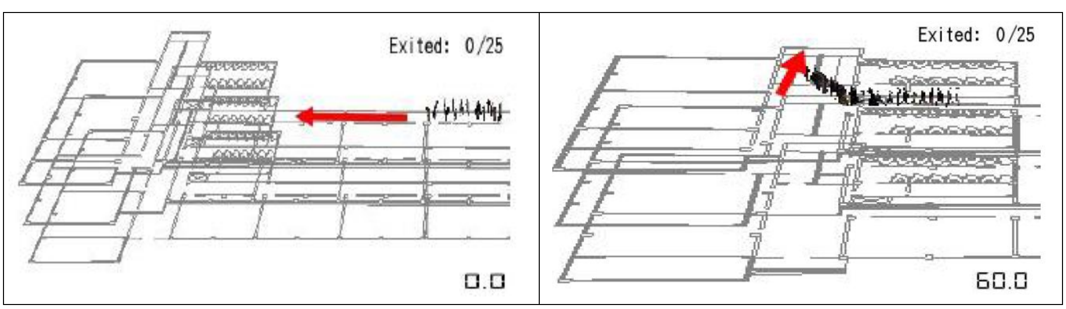


(c) 120 seconds after evacuation (d) Evacuation complete

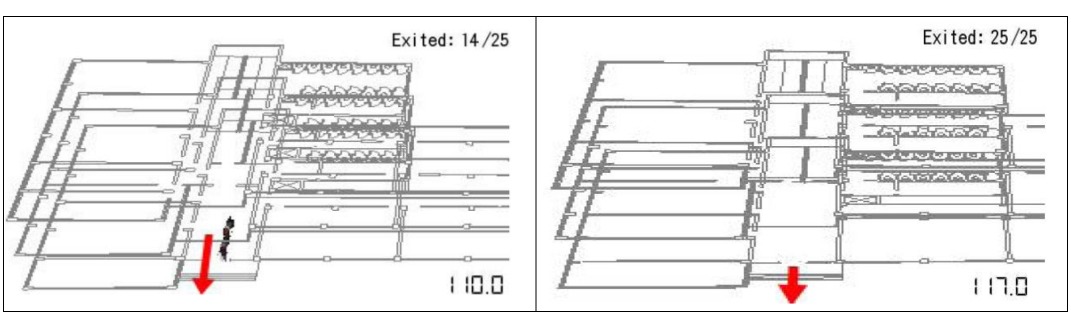
Figure 6. Evacuation situation over time with slope of 20°

4.4 Scenario 4

Scenario 4 ran the simulation by setting up male students with different physical conditions as in Scenario 1,2,3. Simulation results showed that in all scenarios, male students RSET was shorter than female students RSET, and male students evacuation was completed the fastest when the slope of ramp was 15°, just like female evacuation time. Figure 7 is a simulation result of a male student with a slope of 15°. At 15° with the same slope, male students evacuation was completed at 117.0, which was 6.3 seconds shorter than female students evacuation completed at 123.3 seconds. This result is analyzed because the walking speed of male students is faster than that of female students.



(a) pre-escape (b) 60 seconds after evacuation



(c) 110 seconds after evacuation (d) Evacuation complete

Figure 7. Evacuation situation over time with slope of 20° of male students

4.5 RSET Comparison Analysis by Slope

The RSET values of the simulation results according to the slope are shown in Table 5. In the case of female students, it was analyzed that when the final RSET slope was 15°, 25.7 seconds were shorter than when 10°, and 4.2 seconds were shorter than when 20°. Male students also found that when the final RSET slope was 15°, 23.8 seconds were shorter than when 10°, and 5.4 seconds shorter than when 20°. The maximum evacuation distance of female students is 90.2m when the slope is 15°, which is the shortest than 118m at 10° and 94.4m at 20°, so it seems that the movement distance affected RSET. The results of the male student's simulation also showed the same trend as that of the female student.

In the simulation results according to the slope change of the ramp for which 25 people were set in Table 5, both the final RSET and the average RSET were analyzed to be fast at the 15° slope. In addition, when the slope of the ramp was changed, the RSET according to gender was also analyzed to be fast in both the final RSET and the average RSET at 15° slope for both male students and female students.

Table 5. Simulation results according to slope change (25 people)

Sortation	Ramp Slope(°)	Min. RSET(s)	Final RSET(s)	Avg. RSET(s)	Travel Distances Max.(m)
female	10	122.2	149.0	138.3	118.0
	15	105.4	123.3	114.6	90.2
	20	101.6	127.5	116.7	94.4
male	10	115.7	140.8	131.0	119.6
	15	100.0	117.0	108.6	90.5
	20	96.6	122.4	110.9	97.9

In order to improve the reliability of the simulation results, the results of analysis by setting the number of participants in the simulation to 50 are shown in Table 6. Even though the number of male and female students increased, the final RSET and average RSET tended to decrease when the slope of the ramp is 15° compared to when the slope is 10° and 20°.

As a result of this data, both male students and female students were analyzed to be fast in both the final RSET and the average RSET at a 15° slope. In the case of female students, it was analyzed that when the final RSET slope was 15°, 28.4 seconds were shorter than when 10°, and 8.7 seconds shorter than when 20°.

Male students also found that when the final RSET slope was 15°, 25.3 seconds were shorter than when 10°, and 5.5 seconds shorter than when 20°. The maximum evacuation distance of female students is 92.8m when the slope is 15°, which is the shortest than 124.5m at 10° and 106.6m at 20°. As with the results of 25 participants, the movement distance seems to have affected RSET. The results of the male student's simulation also showed the same trend as that of the female student.

Table 6. Simulation results according to slope change (50 people)

Sortation	Ramp Slope(°)	Min. RSET(s)	Final RSET(s)	Avg. RSET(s)	Travel Distances Max.(m)
female	10	122.4	168.1	147.5	124.5

	15	105.7	139.7	122.8	92.8
	20	101.7	148.4	128.2	106.6
male	10	115.6	159.1	139.8	125.3
	15	100.3	133.8	117.0	93.1
	20	96.5	139.3	120.5	101.1

5. Conclusion

In this study, in order to evaluate the safety of evacuation by comparing and analyzing the RSET according to the slope change of the ramp, which is a vertical evacuation route in case of fire in a high school building, Evacuation simulation was run the Pathfinder program changed the slope of the ramp to 10°, 15°, and 20° for each male students and female students.

The results of the experiment are as follows.

1) In the case of female students, it was analyzed that when the final RSET slope was 15°, 25.7 seconds were shorter than when 10°, and 4.2 seconds were shorter than when 20°. Male students also found that when the final RSET slope was 15°, 23.8 seconds were shorter than when 10°, and 5.4 seconds shorter than when 20°.
2) The maximum evacuation distance of female students is 90.2m when the slope is 15°, which is the shortest than 118m at 10° and 94.4m at 20°, so it seems that the movement distance affected RSET. The maximum evacuation distance of male students is 90.5m when the slope is 15°, which is the shortest than 119.6m at 10° and 97.9m at 20°
3) As a result of the evacuation simulation, the RSET was shortened at 15° slope for both male students and female students, and the average moving distance was 90.2m for female students and 90.5m for male students, almost no difference. It was analyzed that the RSET of male students with fast walking speed was shortened.
4) It was analyzed that even if the number of participants was increased and the evacuation simulation was executed, the safety of evacuation could be improved when the slope of the slope is 15° as the RSET when the slope of the slope is 15° is shorter than that of 10° and 20°.

The limitation of this study was that when the slope was 5°, the ramp was lengthened and it protruded to the outside of the final evacuation exit due to the characteristics of the current building, so it could not be evaluated by simulation.

In conclusion, in the evacuation simulation according to the change of the slope of the ramp, it was found that evacuation safety was secured when the slope was 15° for both gender and number of people.

Therefore, the implications of this study are that the construction method, which is applied uniformly regardless of the purpose of a particular fire-fighting object, needs to be determined by evaluating the safety of evacuation by specific fire-fighting object.

As a future research project, it is necessary to increase the reliability of evacuation safety through simulations and experiments according to the slope of the ramp and the height of the stairs.

References

[1] Major fire: Fires in government offices, schools, government-owned factories, cultural assets, subways, underground streets, underground wards, public buildings, public facilities, more than 100 victims, and similar places

[2] National Fire Data System of the National Fire Agency, Fire Statistics Yearbook, p.144, 2019

[3] K. S. Lee and W. G. Shim, "A Study on the Expression Method and Meaning Expansion of Stair Lam ps in Modern Architecture", *Journal of the Architectural Institute of Korea*, Vol. 21, No. 2, pp. 701-704, 2001. 10.

[4] Y. G. Lee, Comparative Study on Installation Regulations for Building Evacuation, Graduate School of Industrial Information, *Graduate School of Master's Degree*, pp. 1-3, 2009.

[5] T. Y. Oh, "Characteristics of Knee Joint Flexion Angle and Foot Pressure according Slope Climbing", *Th e Korea Contents Society*, Vol. 10, No. 2, pp. 268-276, 2010.

[6] Y. O. Choi, "A Simulation for Physical an Psychological Load Measurement of the Healthy Adults using Wheelchairs on the each Specific Ramp Gradients of Building Entrance", *Journal of the Regional Associa tion of Architectural Institute of Korea*, Vol. 34, Issue 2, pp. 109-110, 2015.

[7] S. Y. Yang and T. K. Lee, "A Study on User Preferences of the Surface Length on the Each Specific Ramp Gradients", *The Korean Housing Association*, p 357, 2016.

[8] M. K. Kim and H. G. Cha, "Therapeutic efficacy of walk backward and forward on a slope in normal adults", *Korea Contents Association*, Vol. 2016, No. 5, pp. 267-268, 2016.

[9] E. N. Corlett, C. Hutcheson, M. A. DeLugan, J. Rogozenski, "Ramps or stairs: The choice using physiological and biomechanic criteria", *Applied ergonomics*, 3(4), pp. 195-201, 1972.
DOI: http://dx.doi.org/10.1016/0003-6870(72)90100-7

[10] I. Canale et al., "Ramp Length/grade Prescriptions for Wheelchair Dependent Individuals", *Paraplegia*, Vol. 29, No. 7, pp.479-485, 1996.
DOI: http://dx.doi.org/10.1038/sc.1991.65

[11] Bing et al., "Calibration of measured center of pressure of a new stairway design for kinetic analysis of stair climbing", *Journal of Biomechanics*, Vol. 29, Issue 12, pp. 1625-1628, 1996.
DOI: http://dx.doi.org/10.1016/S0021-9290(96)80015-7

[12] A. Nagel et al., "Plantar pressure pattern in stairs climbing", *Clinical biomechanics*, Vol. 23, No. 5, pp. 662-720, 2008.
DOI: http://dx.doi.org/10.1016/j.clinbiomech.2008.03.026

[13] Jinger S. Gottschall, Nori Okita, Riley C. Sheehan, "Muscle activity patterns of the tensor fascia latae an d adductor longus for ramp and stair walking", *Journal of Electromyography and Kinesiology*, 22(1), pp. 67-73, 2012.
DOI: http://dx.doi.org/10.1016/j.jelekin.2011.10.003

[14] Korea Ministry of Government Legislation(*www.law.go.kr*), 「Article 15 of the Rules on the Standards for Evacuation, Fire Protection, etc. of Buildings

[15] Korea Ministry of Government Legislation(*www.law.go.kr*), 「Enforcement Decree of the Act on the Prom otion of Convenience of the Disabled, the Elderly, Pregnant Women, etc.」, [Appendix 1]

[16] NFPA 101: *Life Safety Code*, 2003 Edition, NFPA, *Conprehensive Consensus Codes(C3)*, pp. 1-1396, p55

[17] W. J. Lim, "A Study on the Appropriateness of Evacuation in the Fire of School Buildings", *Seoul Natio nal University of Industry's Master's Degree*, pp. 1-88, p. 82, 2005.

[18] Korea Ministry of Government Legislation(www.law.go.kr), 「Performance-oriented design methods and sta ndards for fire-fighting systems」, [Appendix 1] subparagraph 3(b), revision 2019.12.31.

[19] Poon, S. L., "A Dynamic Approach to ASET/RSET Assessment in Performance based Design", *Procedia Engineering*, 71(1), pp. 173-181, 2014.
DOI: http://dx.doi.org/10.1016/j.proeng.2014.04.025

[20] Wang, S., Wang, W., Wang, K. & Shih, S., "Applying building information modeling to support fire safe

ty management”, *Automation in Construction*, 59(1), pp. 158-167, 2015. DOI: http://dx.doi.org/10.1016/j.autcon.2015.02.001

[21] Pathfinder, Thunderhead (USA), User Manual (*www.thunderheadeng.com*)

[22] Ministry of Education, “2019 Student Health Examination Sample Statistics”, p 3, 2020.

[23] National Statistical Office, “Human Dimension Survey of Koreans: statistics of 120 parts”, pp. 133-139, 2006.

[24] Morgan J. Hurley, The SFPE Handbook of Fire Protection Engineering 2, 5th edition, *United States: Springer*, p2-216, 2016.