Turkish Journal of Computer and Mathematics Education Vol.12 No.13 (2021), 5874-5882

Research Article

A Comparative Analysis of Evacuation Safety on Stairs and Ramp for High School Students

Chang-Jun Choi[a] , Ha-Sung Kong[b]

[a] Ph.D. Dept. of Fire and Disaster Prevention, Woosuk Univ. Korea
[b] Associate professor, Dept. of Fire and Disaster Prevention, Woosuk Univ. Korea, 119wsu@naver.com(Corrseponding Author[b])

Abstract: This study, assuming evacuation training in high school buildings, compared and analyzed the evacuation safety of two escape routes, stairs and ramps. In the gender-based evacuation experiment, male students' RSET(Required Safe Egress Time) was shorter in all scenarios of stairs and ramps, and both male and female students' RSET on ramps was shorter than stairs. In the grade-by-year experiment, third-grade students who are familiar with school facilities had shorter RSET on both stairs and ramps than first-year students. The students who participated in the experiment reported that it was difficult to evacuate due to the steep stairs and narrow field of view and that it was easy to evacuate the ramps because the field of view was wide and stable by contrast. In conclusion, students both by gender and grade were analyzed to have higher escape safety on ramps than stairs. Therefore, it was shown that there is the need to strengthen the installation of ramps in public buildings to minimize human damage and ensure evacuation safety in case of fire.

Keywords: Students by gender, students by grade, stairs, ramp, evacuation experiment

1. Introduction

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. The evacuation safety regulations in the event of a building fire have a wide range of targets ranging from initial firefighting facilities, fire detection, evacuation routes, firefighting facilities, internal materials, fire-fighting and fire-resistant structures, and in fact, safety against building fires can be secured by applying various measures against various buildings at the same time[1]. However, the scale or amount is very large or large, so the study limited the scope of the study to include stairs and ramps among the components of the escape route. For refugees familiar with building spaces, safe evacuation routes and efficient evacuation options are made. In addition, two examples show that repeated disaster safety education and constant training can curb human casualties and enhance evacuation safety in the event of an actual disaster. The fire, which broke out late on October 8 at a residential and commercial complex in Ulsan City, is said to have been extinguished without one person's death except for 93 patients with simple smoke inhalation and abrasion, even though the fire was large enough to soar to the 33rd floor[2]. It also said only 13 of the 2,700 employees at a financial company that worked on the 40th to 60th floors of the World Trade Center died and nearly survived, with 2,996 people killed during the September 11 attacks in 2001[3]. The common feature of minimizing casualties in the two cases is that they acted calmly and familiarly as in the fire escape manual as a result of repeated regular evacuation drills.

Lee Jung-chul (2012) analyzed that safety accidents in each place during school life were the fourth and insisted on protecting himself from accidents through continuous education and awareness[4]. According to **Park Chang-bae (2019)**, relative preferences can vary greatly depending on the slope and the type of stairs through comparative analysis of pedestrian preferences between stairs and ramps[5]. **Jeon Hyung-min** and two others (2020) analyzed the effect on knee joint moment depending on footstep differences while descending stairs and ramps[6].

E. N. Corlett et al. (1972) compared oxygen consumption, heart rate, and maximum knee joint angle when climbing stairs or ramps[7], and **Ali Tehrani Safa** et al. (2007) analyzed that they had more ability to walk stably by comparing the step movements and sloping steps when replacing the ramp with a girder using a simple walking model[8]. **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[9].

Up until now, prior studies on stairs and ramps have mainly focused on health, such as studies of the disabled or the elderly who are uncomfortable with walking and analysis of walking, and analysis of walking training data when climbing stairs or ramps, or comparing the angular changes of lower limb joints when walking on stairs or ramps. However, in the event of a disaster, studies of evacuation safety in the form of important escape routes, such as stairs and ramps, are extremely rare or no.

Therefore, the theoretical background of this study is to compare the structure of stairs and ramps with the 'Life Safety Code Handbook' of the American Fire Prevention Association(NFPA) and the Korean Fire Protection Act, and to analyze the safety of evacuation according to the actual evacuation time of stairs and ramps by grade and gender through three evacuation tests.

2. Standards for the Installation of High School Stairs and Ramps

2.1 Stairs

As shown in Table 1 , the effective width of staircases and staircases in Korean high schools is set at least 1.50 meters, not more than 0.18 meters high, and not more than 0.26 meters high. In addition, both stair and landing shall be made of non-combustible materials[10], and stairwell openings shall be equipped with stairwells, whereas the United States shall have a width of more than 1.12m, a height of less than 0.178m, and a short width of 0.279m[11].

Table. 1. High School Stairs Installation Criteria.

nation	Stairs and Landing Width	single height	Short Width	Application Criteria
Korea	1.50m min.	0.18m max.	0.26m min.	Rules on standards for evacuation, fire protection, etc. of buildings
USA	1.12m min.	0.178m max.	0.279m min.	NFPA 101(50 or more)

2.2 Ramps

If a ramp is planned instead without installing stairs in a building, the slope shall be within 1:12 and the effective width of the ramp shall be at least 1.2m, and the finishing material shall be finished using materials that do not slide easily. The standards for installation of handrails or trams according to the height of the ramp and for installation of intermediate rails according to the width of the ramp are stipulated to follow the installation standards of stairs[12]. In the case of Korea, the regulations are based on the standards for the general public, and regulations for the disabled, such as Table 2, are prescribed by special laws[13]. The U.S. sets regulations based on consideration for the disabled and with exceptions to conditions that do not require consideration for the disabled[14].

Table. 2. Standards for Ramps Installation in Korea and U.S.

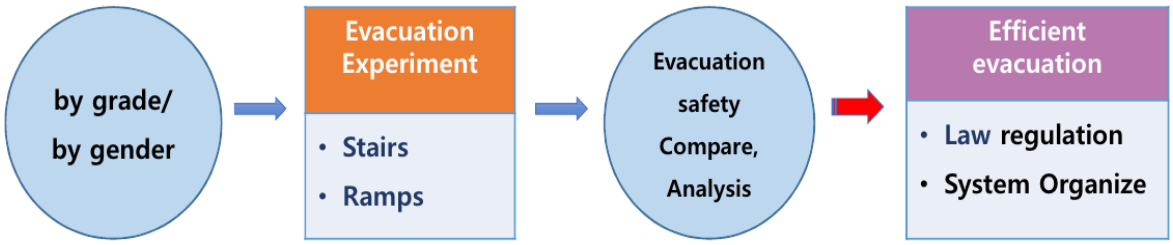
Sortation	Installation criteria	
	Korea	U.S.
Min. width clear of all obstruction	1.2m	1.12m (44 in.)
Max. Slope	1:12 (Max. cross slope 1:8)	1:12 (Max. cross slope 1:8)
Length of landing	1.8m or more	not less than 1.52m (60in.)
Material and finish	a flat finish with a material that doesn't slip well	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

3. Evacuation experiment

3.1 Research model

As shown in Figure 1, the study suggests that high school students can be classified by grade and gender and that the safety of evacuations on stairs and ramps can be compared and analyzed through evacuation experiments so that they can be applied systematically along with the performance aspects of the facilities for efficient evacuation.

Figure. 1. Research Model.



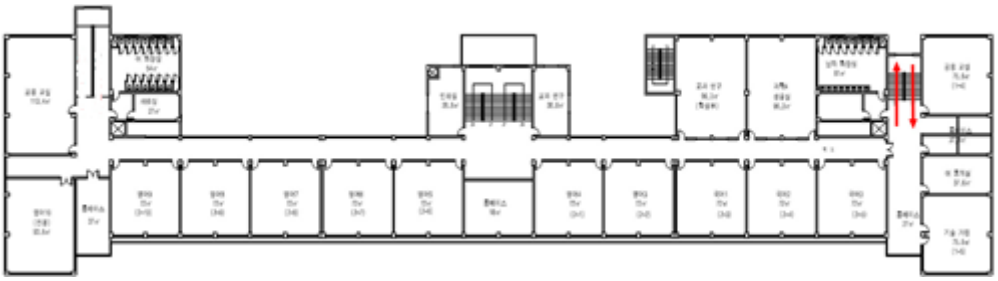
3.2 Target Building

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.

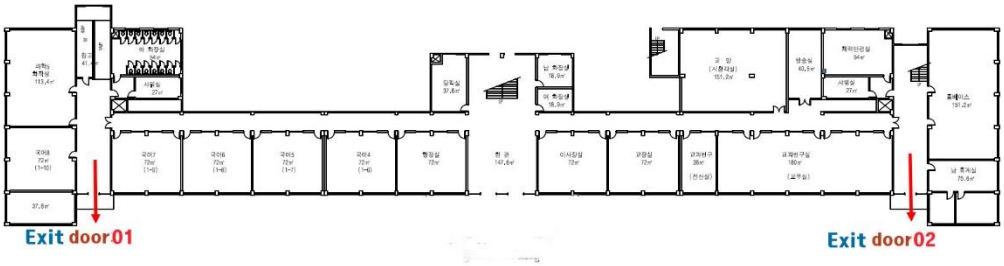
Figure. 2. Structural plan of the main building of OO High School on the 3rd floor.

(c) 3rd floor plan

(b) 2nd floor plan



(a) Floor plan on the first floor



The effective width of stairs and landing in this building is 2.02m, 0.175m high and 0.31m wide, meeting the installation standards of South Korea and the U.S. The slope is 9m long and has an angle of 8.3 (1:12 or less), an effective width of 1.91m, and a good finish to meet the installation standards of Korea and the U.S. Figure 3 is a photograph of the stairs and ramps of the target building.

Figure. 3. Stairs and ramps of the target building.

(a) Stairs

(b) Ramp

3.3 Composition of Evacuation Scenario

A total of 50 people were selected for each of the 25 healthy male and female students who had no inconvenience in walking, in order to evaluate the safety of evacuation by comparing and analyzing RSET on the stairs and ramps,

which are vertical evacuation routes in the event of a fire in the building. The evacuation scenario consisted of four different analyses comparing the time required for evacuation of two shelters by gender and the time required for final evacuation of two shelters by first and third graders, and conducted three evacuation experiments.

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)[15].

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

The maximum compartment area of A = 8.5, since the floor area of the classroom is 72m^2**.** 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 evacuation time is set at less than four minutes as shown in Table 3[16]. The minimum evacuation request time required for students to complete evacuation from a building is called Required Safe Egress Time (RSET), and the time when the fire reaches the hazard is called ASET (Available Safe Egress Time). 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.[17][18]

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 Setting the time of action before evacuation

In this study, the start time of evacuation was set at 30 seconds, including fire warnings and broadcast notices, because it was a simulated evacuation drill. Before evacuation, they were required to wear towels or masks soaked in water and not to use elevators. In order not to inhale fire smoke when evacuating, prior education was provided to avoid running low and not overtaking the person in front of them. Among the three evacuations of male and female students in the two grades, the first-year evacuation of stairs was shown in Figures 4 through 5.

Figures. 4. Test process for stairs escape of a high school 1st grade male.

(a) pre-escape (b) 60 seconds after evacuation (c) Evacuation complete

Figures. 5. Test process for stairs escape of a high school 1st grade female.

(a) pre-escape (b) 60 seconds after evacuation (c) Evacuation complete

In Figures 6 through Figure 7 the first grade male and female were tested on ramps. When going down the ramp, the ramp was smooth and slip-resistant, but it was guided to go down with caution so that it would not be tilted forward with regular steps.

Figures. 6. Test process for ramp escape of a high school 1st grade male.

(a) pre-escape (b) 60 seconds after evacuation (c) Evacuation complete

Figures. 7. Test process for ramp escape of a high school 1st grade female.

(a) pre-escape (b) 60 seconds after evacuation (c) Evacuation complete

4. Results and Considerations

4.1 Grade-by-year experimental results

According to the evacuation test results in Table 6, the average time required for final evacuation was 99.02 seconds for third-grade male on the stairs, 13.29 seconds faster than 112.31 seconds for first-grade male, and 115.20 seconds for third-grade female, 2.29 seconds faster than 117.49 seconds for first-year female. On the ramps, third-grade male were also analyzed 14.69 seconds faster than first-year male 104.89 seconds, and third-grade female were 106.69 seconds, 4.69 seconds faster than first-year female 111.38 seconds. The average time required for final evacuation of the evacuation route was analyzed to be 8.12 seconds for male students and 7.31 seconds for female students on the side of the ramps, making them evacuate faster than the stairs.

Table 6. Evacuation test results by evacuation route(*s*).

Sortation	Grade-Sex	1st time	2nd time	3rd time	Aver.
Stairs	1-M	112.67	112.58	111.67	112.31
	3-M	94.69	101.30	101.07	99.02
	1-F	117.89	117.75	116.84	117.49
	3-F	115.46	115.03	115.12	115.20
Ramp	1-M	105.94	104.76	103.97	104.89
	3-M	90.52	90.54	89.54	90.20
	1-F	114.15	109.79	110.21	111.38
	3-F	108.73	104.61	105.72	106.69

4.2 Gender experimental results

According to the results of the evacuation test in Table 6 above, the average of male students' final evacuation time was 105.67 seconds, down 10.68 seconds from 116.35 seconds for female students, and the average of male students' final evacuation time on the ramp side was 97.55 seconds, down 11.49 seconds from 109.04 seconds for female students. It was also analyzed that the final evacuation time on the ramps between the two escape routes was shortened by 8.12 seconds for male students and 7.31 seconds for female students, making them evacuate faster than the stairs.

4.3 Experimental review

As shown in Table 7, it was analyzed that the time after the evacuation was completed by gender and grade, all male students had shorter evacuation time than female students, third graders had shorter evacuation time than first graders, and all of them had shorter evacuation time on the slope than stairs. It was a common interview among students that the escape test on the stairs led them to think that the stairs were dangerous, but they were careful not to stare at the front and step down one by one, while the escape test on the ramps tended to speed down but felt safe.

Table. 7. Comparison of Average Evacuation Time of Evacuation Experimen(s).

Sortation		Stairs	Ramps	Ramps - Stairs
		Final RSET	Final RSET	
Evacuation Experiment	M. Aver.	105.67	97.55	-8.12
	F. Aver.	116.35	109.04	-7.31
Total Average	Male	119.89	112.18	-7.71
	Female	129.63	123.52	-6.11

5. Conclusion

In this study, 25 male and female in the first and third grades of high school conducted three escape tests on stairs and ramps to evaluate their safety by comparing and analyzing the time required for evacuation from stairs and ramps, which are vertical evacuation routes in case of fire in high school buildings.

The results of the study are as follows.

(1) Gender Evacuation Test:

Both stairways and ramps of male students were found to have shorter final evacuation time than female students.

(2) Evacuation experiments by grade:

Both the stairs of the third grade and the ramp were analyzed to have reduced the time required for final evacuation from the first grade.

(3) It has been analyzed that regular evacuation education can enhance evacuation safety with familiarity and calmness of evacuation routes as the number of evacuation experiments increases further.

While the limitations of the study are limited to failing to form evacuation scenarios in various situations, such as excessive strain or excitement of refugees, the size and temperature of heat, and the amount and spread of toxic gases, as the number of refugees increases, evacuation on the stair side is likely to require more time to evacuate due to bottlenecks. This is a future research project that plans to increase the number of refugees and increase the reliability of evacuation safety through simulation and experimentation. The results of the experiment also showed that repeated education and training could reduce evacuation time and increase evacuation safety.

In conclusion, the evacuation experiment showed that both male and female, had better escape safety than stairs. In particular, girls' great preference for safety on ramps needs institutional support for strengthening facilities on ramps where safety is legally secured in terms of public facilities' performance.

References

[1] Lee Yi-gil (2009), Comparative Study on Installation Regulations for Building Evacuation, Graduate School of Industrial Information, Graduate School of Master's Degree, pp. 1-3
[2] The Hankyoreh (2020.9. 9), Society, http://www.hani.co.kr/arti/area/yeongnam/
[3] The 11th page of the New Jeonbuk Newspaper (Thursday, June 2, 2016), Jeon Mi-hee, head of 119 General Situation Room 2 at Jeonbuk Fire Department
[4] Lee Jung-chul (2012), Analysis of Safety Accidents in School Life, 8(2), Korean Society for Social Safety, pp. 225-237
[5] Park Chang-bae (2019), Comparative Analysis of Preference for Slope and Stairway Recommended for Pedestrians, Journal of Korean Architectural Institute of Korea, 35(3), pp. 59-66.
[6] Jeon, Hyeong-Min, Choi Eui-Bum, Heo Jae-Hoon, Eom Gwang-Moon (2020), Influence of the initial foot contact strategy on knee joint moments during stair and ramp descent, National Library of Medicine. Scientific reports, 10(1), pp. 1-8
[7] E. N. Corlett, C. Hutcheson, M. A. DeLugan, J. Rogozenski (1972), Ramps or stairs: The choice using physiological and biomechanic criteria, Applied ergonomics, 3(4), pp. 195-201
[8] Ali Tehrani Safa, Mohammad Ghaffari Saadat, Mahyar Naraghi (2007), Passive dynamic of the simplest walking model: Replacing ramps with stairs, Mechanism and Machine Theory, 42(1), pp. 1314-1325
[9] Jinger S. Gottschall, Nori Okita, Riley C. Sheehan (2012), Muscle activity patterns of the tensor fascia latae and adductor longus for ramp and stair walking, Journal of Electromyography and Kinesiology, 22(1), pp. 67-73
[10] Korea Ministry of Government Legislation(www.law.go.kr), 「Article 15 of the Rules on the Standards for Evacuation, Fire Protection, etc. of Buildings」
[11] NFPA 101: Life Safety Code, 2003 Edition, NFPA, Conprehensive Consensus Codes(C3), pp. 1-1396, p. 49
[12] Korea Ministry of Government Legislation(www.law.go.kr), 「Article 15 of the Rules on the Standards for Evacuation, Fire Protection, etc. of Buildings」

[13] Korea Ministry of Government Legislation(www.law.go.kr), 「Enforcement Decree of the Act on the Promotion of Convenience of the Disabled, the Elderly, Pregnant Women, etc.」, [Appendix 1]
[14] NFPA 101: Life Safety Code, 2003 Edition, NFPA, Conprehensive Consensus Codes(C3), pp. 1-1396, p. 55
[15] Lim Wan-jae (2005), A Study on the Appropriateness of Evacuation in the Fire of School Buildings, Seoul National University of Industry's Master's Degree, pp. 1-88, p. 82
[16] Korea Ministry of Government Legislation(www.law.go.kr), 「Performance-oriented design methods and standards for fire-fighting systems」, [Appendix 1] subparagraph 3(b), revision 2019.12.31.
[17] Poon, S. L. (2014), A Dynamic Approach to ASET/RSET Assessment in Performance based Design, Procedia Engineering, 71(1), pp. 173-181
[18] Wang, S., Wang, W., Wang, K. & Shih, S. (2015), Applying building information modeling to support fire safety management, Automation in Construction, 59(1), pp. 158-167