ORIGINAL ARTICLE

Ergonomics Aspects of the Architectural Design of the Staircase in Universitas Airlangga Public Health Faculty Building, Surabaya

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ABSTRACT

Introduction: Staircase is facilities functioned to connect floors. Stairs which are not ergonomic may cause fatigue and accident for the users. Universitas Airlangga Public Health Faculty Building is a three-story building. Each floor has 5 staircases on different sides. The aim of this study was to analyze the ergonomics aspects of the architectural design of the staircase. **Method:** This study used cross-sectional design with descriptive analysis. The measured dimensions of the staircase were riser's height, tread's depth, stairs width, stairs slope, landing, lighting level, handrail's height and diameter, and the presence of non-skid surface. The measurement tools were measuring tape, lux meter and cylinder bore gauge. **Results:** Measurement showed that all riser's height met the recommendation. Most tread's depth was below 30 cm. The width of Northwestern and Southwestern staircase was below the recommendation width, which was <125 cm. All slope of stairs was within the recommendation slope. The height and diameter of all handrails was 96 cm and 5.5 cm respectively and was above the recommendation. The lighting level during daytime on most staircase was above 100 lux but during nighttime was below 100 lux. There were landings that were wider than the stairs and non-skid surface at the edge of each tread. **Conclusion:** Most dimension of staircase (67.5%) in Universitas Airlangga Public Health Faculty Building met the design recommendation but the tread's depth, width of stairs, handrail's diameter and height, as well as the lighting on stairs need to be improved to make the stairs safer.

Keywords: Recommendation size, Ergonomic, Staircase

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INTRODUCTION

Ergonomics is a science that studies about relationship between humans, machines or tools, work environment, organization and work procedures, so that a work can be completed precisely, efficiently, comfortably, and safely (1). The domains of ergonomics are a) physical ergonomics, which concerns with human's physical characteristics, b) cognitive ergonomics, which focuses on mental processes, and c) organizational ergonomics, which addresses the design of technical social systems. One of the important issues in physical ergonomics' domain is the design of building facilities (2), as poor interface design can contribute to accidents such as slip, trip and fall (1).

The National Safety Council in the United States of America states that the third largest cause of unintentional injury related to death is falling. In 2014, there were 31,959 deaths due to falling, and 2,285 deaths were caused by falling on stairs (3). In 2016, 697 workers died and 48,060 workers were seriously injured as a result of falling to a lower place (4). More than 42,000 workers in Canada suffer injuries each year due to falling, and it caused the loss of 18% of productive work time in addition to compensation provided (5). Staircase is a component of a building that can cause injury to people regardless of ages (6). Staircase accounted for around 8.2% of all inpatient cases due to injuries because of falling in British Columbia which cost more than 17 million Canadian dollars on inpatient treatment in 2013-2014 (7). Analysis of National Electronic Injury Surveillance System data from 1990 until 2012 showed that every year there were 1,076,558 patients who were treated at United States Emergency Department because of injuries caused by using staircase. The most common types of injuries were sprained (32.3%), soft tissue injuries (23.8%) and fractures (19.3%) (6).

Some of the causes people to fall from staircase are difficult to see steps, poor lighting, high risers, short treads, slippery treads, missing handrails and loose or broken handrails (8). Oversteps when descending the stairs often happen as well because of undersized treads (9). Meanwhile, during ascending stairs, trips and falls often attributed to variation in risers (10). Therefore, the staircase needs to be designed to be as safe as possible to prevent accidents in the use of staircase.

Staircase is a part of the construction connecting two vertical floor which consists of several parts. A riser is the

vertical side facing the footsteps on the stairs. A tread is the horizontal surface of the footsteps on the stairs (11). A landing is a platform used as a temporary stop to avoid fatigue while climbing stairs (12). A handrail is a long piece of metal or wood that can be held by the user's hand while stepping along the stairs (11). Regulation Number 14, 2017 of the Ministry of Public Works and Public Housing of the Republic of Indonesia concerning Building Construction Requirements specified the dimensions of stairs components. The recommended depth for a tread is 30 cm and height for a riser is 15-18 cm. Handrail supposes to be 5 cm in diameter and 65-80 cm in height to be easy to hold. The slope of stairs should not exceed is 35° (13). In addition, lighting on the stairs is also important to maintain safety. Adequate lighting made staircase's users to be able to see each step on the staircase (14). The minimum lighting level standard for stairs in the buildings is 100 lux. The maximum width for stairs which only have a handrail on each side is 220 cm (13), the minimum width of stairs is not mentioned in this regulation but another reference state that the minimum width of stairs to create space for side by side passing movement is 125 cm (15). The width of landing should be as wide or wider than the stairs (16). It is also recommended to place a non-skid surface on the leading edge of each tread to minimize the opportunity of slipping and to distinguish between each tread (17). Figure 1 shows picture of the staircase along with the recommended dimension.

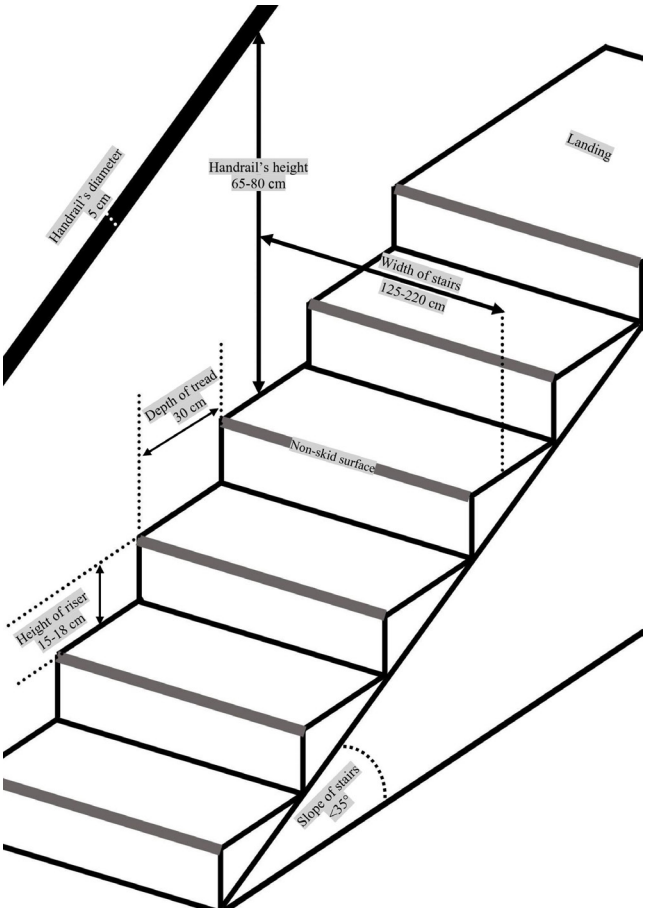

Figure 1: Recommended Stairs Size. The dimensions of stairs along with the recommendation size, such as the depth of tread is 26-37 cm, the height of riser is 14-19 cm, the width of stairs is 125-223.52 cm, handrails height is 3.81-5.08 cm, handrail's height is 76.2-96.6 cm and the slope of stairs is 30-35°, also the availability of non-skid surface and landing.

Universitas Airlangga Public Health Faculty building is one of the buildings that use staircase to connect floors. The developer constructed this building by referring to the standard that was set by the Ministry of Public Works and Public Housing of the Republic of Indonesia and the process of the construction had involved a civil engineer. The users of the staircase in Universitas Airlangga Public Health Faculty building are students, lecturers, and staffs with a total of 1000 people at the 17-65 age range. Based on the observations, when two people in different direction were met on the narrower stairs in the building, they cannot walk without tilting their bodies because there was no sufficient space. Furthermore, slips, trips and falls from stairs in this building were several times reported but the mechanism to report and record these incidents is not available yet, therefore, the exact number of the incidents is unknown. Thus, the aim of this study was to analyze the ergonomics aspect of the architectural design of the staircase in Universitas Airlangga Public Health Faculty building by determining the adherence to the ministerial regulation and design guidelines as provided in Figure 1.

MATERIALS AND METHODS

This research was an observational descriptive study with cross-sectional design. Data was collected on August 29, 2019 in the Universitas Airlangga Public Health Faculty Building. This building had 3 floors and each floor had 5 staircase in different sides as shown in Figure 2. All staircase in the building were the object of the research. The type of all stairs were u-shaped stairs with half landing. In addition, the staircase in the north and east are different (Figure 3 (a)), there are two narrower flight before the landing that is separated by a distance of approximately 2 meters, then it merges into one wider flight after the landing located in the middle. Meanwhile, the staircase in the northwest, west, and southwest only consists of one flight before and after the landing (Figure 3 (b)). The northern and northwestern staircase have 12 stairs in every section before and after the landing, while the western, southwestern and eastern staircase have 13 stairs.

The variables measured were the height of riser, depth of tread, the width of stairs, slope of stairs, lighting, width of landing, diameter and height of handrails, and the presence of non-skid surface (rubber pads). Measurements were done using a measuring tape, cylinder bore gauge and lux meter. The measurement was carried out by occupational safety and health laboratory assistant of Universitas Airlangga Public Health Faculty.

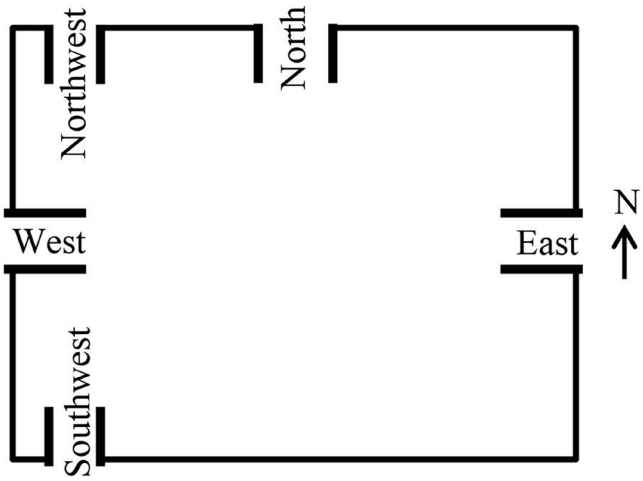

Figure 2: Simplified Sketch of the Location of Stairs in Universitas Airlangga Public Health Faculty Building. Universitas Airlangga Public Health Faculty Building has 5 stairs which located in the north, northwest, west, southwest, and east sides.

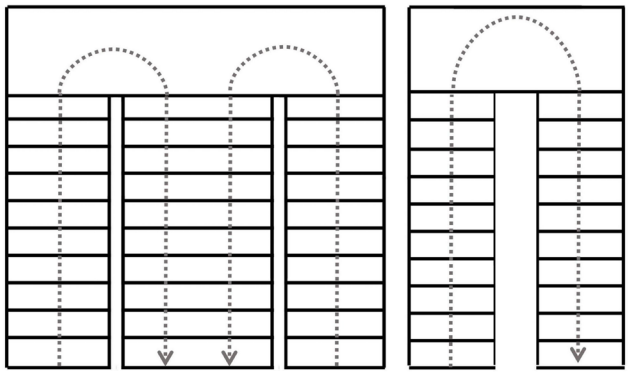

Figure 2: Simplified Sketch of Stairs in Universitas Airlangga Public Health Faculty Building. Two types of stairs in Universitas Airlangga Public Health Faculty Building, type one (a) has two flight before landing that was apart about 2 meters and one flight after landing located in the middle, type two (b) has only one flight before and after landing.

All tools were calibrated before doing the measurement. All steps in every staircase was measured regarding the height of riser and depth of tread, then the results of measurement in every staircase were averaged. The width of stairs was measured at the beginning of stairs. Lux meter was put on the surface of stair and the result was read in every 1-meter distance of stair. Then, the lighting levels were averaged for each staircase. The measurement of lighting was done during the day. The slope of stairs was found by calculated tangent inverse of the sum of depth of thread over the sum of height of riser in every staircase. The measurement data was presented in tabular form and analyzed by comparing the data and the recommendation size.

RESULTS

Height of Riser

Table I shows the measurement result of the riser's height and the recommended height. Based on Table I, the overall height of risers was in accordance with the recommended height. There were no risers that were less than 15 cm or more than 18 cm.

Depth of Tread

The measurement results of the depth of treads along with the recommendation depth are shown in Table I. Only the Eastern and Southwestern staircase's depth of treads that matched the recommended depth which were 30 cm. Meanwhile, the Northern, Northwestern, and Western staircase's depth of tread was less than 30 cm.

Width of Stairs

The width of stairs and its recommendation width are shown in Table I. The Northern, Western and Eastern staircase had width that was in accordance with the recommendation. Meanwhile, the width of the northwestern and southwestern staircase' stair was below the recommendation width of stairs for side by

Table I: Dimensions of Stairs in Universitas Airlangga Public Health Faculty Building

Stairs	Height of Riser (cm)				Depth of Tread (cm)				Width of Stairs (cm)		Slope of Stairs		Lighting Level (lux)			Landing's Size (cm)	
	Min	Max	Avg	Recommendation	Min	Max	Avg	Recommendation	Result	Recommendation	Result	Recommendation	Daytime	Night time	Minimum Standard	Width	Length
North (before landing)	14.8	15.2	15.0	15-18	27.4	27.7	27.5	30	198	125-220	28.6	<35			100		
North (after landing)	17.4	17.6	17.5		27.4	27.7	27.5		146		32.5		258.90	50.65		590	330
Northwest	17.3	17.6	17.5		28.7	28.8	28.75		114.5		31.3		101.30	47.85		260	260
West	14.9	15.1	15.0		28.3	28.6	28.5		198		27.6		159.75	58.50		500	245
Southwest	15.1	15.3	15.25		29.9	30.1	30		113		27		235.76	49.30		280	220
East (before landing)	14.9	15.1	15.0		29.9	30.2	30		202		26.6		66.70	56.20		580	210
East (after landing)	14.9	15.1	15.0		29.9	30.1	30		150		26.6						
Average		15.75				28.89			160.2		28.6		164.48	52.50		442	253

side passing movement.

Slope of Stairs
The calculation result of the slope of stairs is shown in Table I. The average slope of stairs was 28.6°. All slope of stairs was less than 35° and was within the recommendation slope of stairs.

Staircase's Lighting
The measurements result of the staircase lighting level and the minimum lighting level recommendations is shown in Table I. The average level of lighting during the day in all staircases was 164.48 lux and most staircase had lighting level which were above the minimum standard except the Eastern stairs. There were artificial lightings with LED type but they were only turned on at night. However, the lighting level in all staircases during nighttime was below the minimum standard with an average of 52.50 lux. The staircase's lighting was supported by brightly colored stairs with ceramic materials and white staircase walls, so it could reflect the light properly.

Landing
A half landing was available after every 12 or 13 steps on each staircase. The size of the landing on each staircase is shown in Table I. All of the width of landings was in accordance with the recommendation because the landing's width was wider than the width of stairs.

Handrail
All staircase had a round handrail on each side. The height of handrail was 96 cm on all staircase and was not in accordance with the recommendation, which was 65-80 cm. The diameter of the handrail on all staircase was 5.5 cm which exceeds the recommended diameter of handrail, which is 5 cm.

Non-skid Surface
There was a non-skid surface in the form of rubber pads on the leading edge of all treads and the edge of landing. The rubber pads were black and in contrast to the color of the stairs which was light brown that could distinguish each tread on stairs.

DISCUSSION

A study was conducted to evaluate the design of staircase constructed in the United States. The result showed that 355 of 578 (61%) staircases had minimum one design hazard and was classified as hazard-present and unsafe. Missing or inadequate handrails was the most design hazard found. Other design hazard found in this study were poor lighting on staircase (4.8%), handrails were too large or too thin (3.1%), short depth of stairs (2.9%) and narrow stairs width (2.8%) (18) which were also the problems in the staircase of Universitas Airlangga Public Health Faculty Building.

All of staircase has height of risers that were in accordance with the recommendation. Steps that were too high or too low were some of the main causes of accidents on staircase (19). Less than 10 cm of height of riser was almost unacceptable (20) and this shallow risers tend to make people trip (14). If riser is too high, it might decrease center-of-mass stability (21) and increase the reliance on the ankle joint while descending the stairs (22). Therefore, the height of risers in this building which was in accordance with the recommendations could reduce the possibility of trips and falls on the stairs.

Most stairs in Universitas Airlangga Public Health Faculty Building had the depth of tread that was not within the recommended depth. The 29-30 cm depth of tread was less difficult when descending the stairs (23) and it resulted least moment acting at the hip-joint, knee and ankle when ascending the stairs (24). Tread's depth of 30 cm was the optimum tread and was acceptable to both young and old, males and females, and taller or shorter people (20). The risk of slipping increases when the depth of tread is too narrow and cannot accommodate the length of the user's feet (18). Thus, the depth of tread of Northern, Northwestern, and Western stairs needs to be improved to accommodate the feet's length.

The Northwestern and Southwestern staircases' stairs in Universitas Airlangga Public Health Faculty Building were slightly below the recommended width. If the building had more than 49 occupants, a minimum of 112 cm stairs width was allowed (16) but it provided only a tight passage of two people, either in the same direction or in the opposing direction (25). Stairs width of 175 cm was recommended for people comfortably passing by in the different direction (26). The width of the stairs must be able to accommodate the traffic that occurs on the stairs and for the users to reach handrail. Sufficient space is needed to move safely and comfortably on the stairs (18) as well as to ensure safety in the case of fire in an appropriate level (27). Thus, the two stairs that did not fit the recommended width need to be improved by giving more spaces for people to move smoothly on the stairs.

All slope of stairs in Universitas Airlangga Public Health Faculty Building was within the recommended slope of stairs. Stairs that were too steep or too shallow both were tiring to walk on and dangerous (28). If the stairs was steep, it would be tiring and forbidding when ascending the stairs (29). If the stair was shallow, it would need more space for the stairs (30) but the tread had to be deep enough to fit the stride (29). Meanwhile, stairs with slope of 25°-30° are stairs which consume the lowest energy (31).

Most staircases in Universitas Airlangga Public Health Faculty Building had lighting levels during daytime that were above the minimum lighting level, which was above 100 lux. However, the lighting level during the

nighttime in all staircases did not meet the minimum standard. Sufficient lighting could prevent accidents to occur on the stairs because the users could see the steps area and determine their steps correctly (14). In addition, the visibility was the most important factor that could affect the speed of walking on the stairs, especially in conducting evacuations (32). A study conducted among elderly with visual impairment on stairs usage showed that the speed descending the stairs at 50 lux lighting intensity was slower compared descending at 300 lux lighting intensity because the fear of falling was increasing in the dimmer lighting condition (33). Fear of falling might lead to change in gait on stairs, such as decreased the length of stride and speed, but only little evidence showed the independent association between fear and falling (34). However, poor ambient lighting on stairs might have a role in stairs accident (35). Thus, the lighting on Eastern staircase during daytime and on all stairs during nighttime in the building need to be improved.

All stairs in the Faculty of Public Health Building had landing in every 12 or 13 steps which were wider than the width of the stairs. The height of stairs in the Faculty of Public Health Building was 3.90 m. A landing was required if staircase had height 3.66 m or more (16). Stairs should not have too many steps without landing because the risk of falling will increase if the duration of climbing the stairs is longer without resting. The more steps, the more energy is expended and it can lead to sudden loss of balance especially for those who need to stop periodically (18).

All stairs had handrails with a height that was not in accordance with the recommendations. Also, the diameter of the handrail was slightly larger than the recommendation's diameter. Response to grab handrails reduced the incidence of fall compared to the absence of handrail (36). The height of handrails influenced the ability to produce stabilizing forces and moments (37). The depth of fingers gripping the sides of handrail is an important factor affecting the handrail performance. The probability of a user losing grip was lower if the fingers grip the side of handrail deeper. Handrail with the diameter of 5.1 cm consistently showed good performance (38). Therefore, it is necessary to make improvements to the height and diameter of the handrail on the staircase in Universitas Airlangga Public Health Faculty Building, so that the user can grip the handrail firmly and help prevent them from falling on the staircase.

There were rubber pads at the edge of all treads and landing in all staircase in the building. Slippery stairs can increase the risk of falling on the stairs (7). A non-skid surface in the leading edge of tread could resist sliding of the foot and increase the stability of users, so, it could reduce the probability of falling (17). The rubber pad's color in the building was in contrast with the staircase's colors. The contrasting colors could help the user easier to distinguish each tread on the stairs (18) and could improve the safety on stairs (39).

The recommendation size used in this study might not be the best recommendation size for the occupants in the Universitas Airlangga Public Health Faculty building, since it was not the result of measurement of the occupant's body dimension. The stairs used natural lighting during the day, but the measurement was done only in the sunny day. Measurement of lighting level during the cloudy day was not carried out although it could affect the level of natural lighting, because there were various level of cloudiness and it happened in the uncertain period of time.

For future study, researcher should consider to measure the body dimensions of the occupants of the building to find the best recommended size. Also, future researcher should involve behavior to find out whether behavior of the users of stairs in the building might contribute to an incident, beside the design of stairs.

CONCLUSION

It can be concluded that most dimensions of the stairs (67.5%) in Universitas Airlangga Public Health Faculty building was in accordance with the recommended size. All height of riser, slope of stairs, and landing's width was within the recommended dimensions. Non-skid surface was also available in the edge of all tread. However, the depth of tread of Northern, Northwestern, and Western stairs was below the recommended depth, the width of Northwestern dan Southwestern stairs were narrower than the recommended width of stairs, the height of handrail was slightly higher and the diameter of handrail was slightly larger than the recommendation. Improvements to deepen the tread of Northern, Northwestern, and Western stairs, widen the Northwestern and Southwestern stairs, lowering the handrail, replacing the handrail with smaller diameter, and providing a better lighting during daytime on Eastern stairs and during nighttime on all stairs were needed to be considered to make the stairs safer.

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