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RESEARCH ARTICLE

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Investigating a university library building evacuation in Pakistan during a semi-announced fire drill

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Abstract

Evacuation models represent one of the main tools used to assess building fire safety. Existing evacuation models are based on data from evacuation drills in western and developed countries, while there is a need for data from South Asian and developing countries (in general). This paper presents the results of an evacuation drill carried out in a library of a developing country in South Asia (Pakistan). The data of 85 student evacuees were recorded and analysed. Pre-evacuation and walking speed data have been reported in this paper which are compared with the available data for library evacuations in other countries. The average pre-evacuation time of 24.3 s (± standard deviation [SD] = 19.83 s) obtained in this study was shorter than previously published data for similar building types in other parts of the world. Furthermore, unimpeded horizontal speeds (mean = 0.74 m/s, SD = 0.28 m/s) were also smaller than the values reported in the available literature. Stair descending speeds (mean = 0.97 m/s, SD = 0.36 m/s) were within the ranges of stair movement data listed in previous studies. These findings represent a pioneering dataset for future building designs and evacuation simulations in developing countries.

KEYWORDS

developing country, evacuation, fire drill, pre-evacuation, university library, walking speed

1 | INTRODUCTION

Different types of natural and manmade hazards could endanger the lives of the occupants of buildings. These hazards include earthquakes, fires, floods and terrorist attacks. It is critical to ensure the safety of building occupants during any such disaster. In addition to the structural safety of the building, the evacuation performance of the building should also be considered in this context.[1,2] The available building regulations or codes could be classified as prescriptive-based, performance-based or hybrid codes.[3,4] To assist engineers with performance-based codes, building evacuation models serve as useful tools to estimate and assess the evacuation performances of buildings.[5–8] Such simulation tools allow engineers and designers to test the safety of a building in an efficient manner before its construction.[9]

The data on different aspects of occupants' behaviours (such as pre-evacuation time and movement speed) is a prerequisite for evacuation simulation models, which can be used as input parameters to validate the outputs of those models.[10] Such evacuation data could generally be collected through case studies on actual fire evacuations[11] and evacuation drills.[12–14] Data collected from actual past incidents can be considered the most reliable data as they represent realistic behaviours (ecological validity). However, there is a serious lack of such data[10] owing to the difficulties in acquiring these types of data. Ethical considerations in the use of these data add further complications. To address such issues, data from evacuation drills can be used as a reasonable substitute for data from real-world incidents.[15–17] It is assumed that the responses and behaviours of evacuees can be approximated to an actual evacuation during a fire, particularly when the drills are unannounced.[17,18]

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Several previous studies have proposed evacuation data, such as pre-evacuation times, movement speeds on horizontal planes and walking speeds on stairs, which can be used to explore evacuation performances of buildings during fires.[10,14,17] Such studies have considered different types of buildings or occupancies, such as office buildings,[17] commercial buildings,[19] laboratory buildings,[20] high-rise apartments,[21] factories,[22] kindergartens and schools,[23–25] library buildings,[15,26] hospitals or healthcare facilities,[27–29] and university lecture halls.[30] As highlighted in several past studies,[31–37] cultural differences could largely influence occupants' behaviours and responses during an emergency. However, most of the studies on behaviours during fire evacuation have been conducted in western and developed countries,[38] and comprehensive studies from other regions of the world (such as South Asian and developing countries) have not been reported in the literature besides some exceptions. This indicates an outstanding need for fire evacuation data collection from different regions of the world for use in performance-based designs and evacuation models based on variations in evacuation behaviours.

This paper is a step toward expanding the existing evacuation databases by including data from developing countries. This is achieved by investigating the evacuation behaviours of students in a library building in Pakistan during a semi-unannounced fire drill. Although a few previous studies explored the evacuation behaviours associated with library buildings,[15,39] no such data are available in developing countries, such as Pakistan. Gleaning insights from these past studies, the current study collects and analyses the pre-evacuation times, and walking speeds on the floor and the stair of a library building.

This paper is organised as follows: the next section (Section 2) presents the methodology used for conducting the fire drill, including the method employed for extracting the data from the videos. This is followed by the results and discussion in Section 3 and a comparison of the proposed data with existing data in Section 4. Section 5 describes the limitations of the drill conducted in the presented study, while conclusions from this study are presented in Section 6.

2 | METHODOLOGY

This section provides an overview of the methodology used in this paper by describing the building and occupancy involved in the drill (see Section 2.1) and of the drill settings and data collection procedure (see Section 2.2). Finally, Section 2.3 provides details on the video analysis steps used to investigate the evacuation drill.

2.1 | Building geometry and occupancy

Engr Abul Kalam Library building at NED University of Engineering and Technology, Pakistan, was used to conduct the semi-unannounced fire drill. The building is a 3-storey reinforced concrete structure that comprises administrative offices, study halls, a shop and a digital library. The total area of the library is approximately 950 m^2. About 21 000 books and a large number of research journals have been placed on wooden shelves. The floor plans of all three storeys of the library building are shown in Figure 1. It is seen in Figure 1 that the plans for the first and second storeys are the same.

Figure 1 shows that the ground storey has only one entrance/exit in the front. Both the storeys above are connected with the ground storey through the central staircase (Staircase 1 in Figure 1). In addition, these storeys have a staircase for emergency exits (Staircase 2 in Figure 1) for the occupants directly outside the building. A summary of the staircase features and other elements of the exit routes is provided in Table 1. All the occupants at the first storey used Staircase 1 for their evacuation, as they would use it during their visit to the library under normal conditions. The geometry of Staircase 1 is shown in Figure 2.

The occupants of the library building include students (age group 20–24 years) and staff members (between 35–60 years). Approximately 300–400 persons (including students and staff members) may be present in the library during its hours of operation. Despite the presence of a large amount of fuel for a fire in the form of wood and paper, no fire suppression or fire alarm system is available in this building. The building fire safety only relies upon manual fire extinguishers and verbal communications to provide an evacuation alert. Furthermore, evacuation drills were never carried out in this building, as this is not a mandatory requirement in Pakistan.

2.2 | Drill settings and data collection

Given the absence of a fire alarm, signalling horn strobes (with sound pressure level > 110 dB) were installed at different locations in the building for the drill (Figure 1). Battery-operated cameras were employed for video recording the drill. These cameras provide 90 min continuous recording. Both the alarms and cameras were fixed in the evening when the student population in the building was very low. The drill was conducted in the morning hours (11 am) of the following day to avoid (as much as possible) the presence of students and staff who were aware of the earlier preparatory work for the drill the day before. The staff members present at the time of the drill were also from the early morning shift and were different people who witnessed the preparatory work the previous evening. Nevertheless, it is possible that the activities of installing fire alarm buzzers and cameras created some level of awareness of the planned activity among the students and the staff members, although the drill was intended to be unannounced. Additionally, a few staff members were made aware of the drill to make sure they could intervene and stop the drill in case of an accident. Furthermore, the necessary permissions were obtained by the relevant NED University authorities to record the drill and use the drill data for academic purposes. The collected data were handled according to the ethical guidelines set by the NED University for research involving human subjects. According to these guidelines, the recorded

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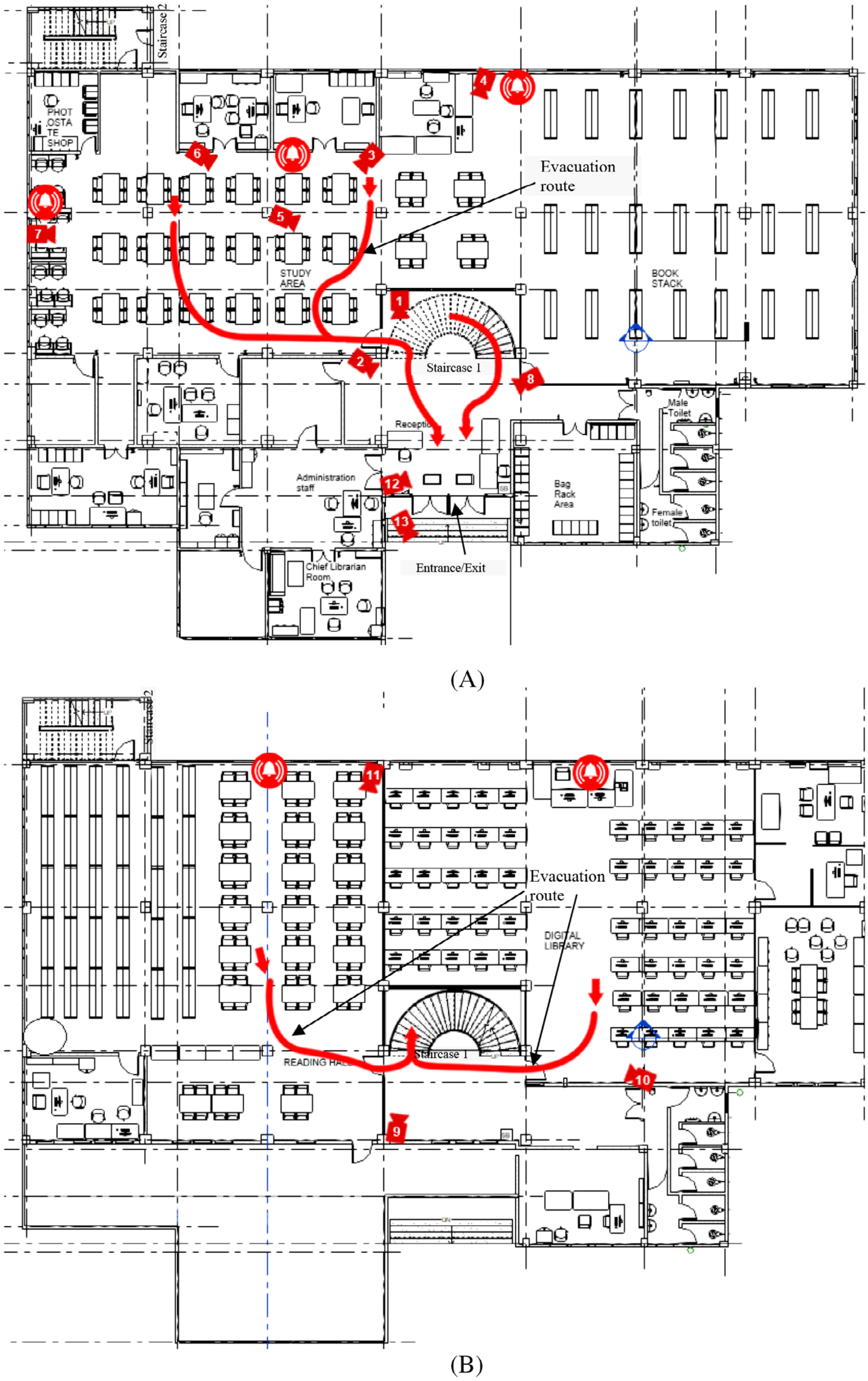
FIGURE 1 Plans of the library building: (A) ground storey; (B) first and second storey. In red the locations of the cameras used to record the evacuation drill



videos were securely stored on password-protected computers. Furthermore, the data were aggregated so that the individuals could not be identified. Finally, any screenshots used for academic purposes were processed to pixelate faces which avoided any possibility of individual recognition.

Since the second storey was scantily populated in the days other than the examination period in the university, only the ground and first storeys were included for conducting the fire drill. A total of 13 HD mini battery-operated cameras were used to record the data of evacuation. The positions of these cameras are illustrated in Figure 1.

2.3 | Video analysis

The recorded videos were of 15 min duration, including the actual drill record. All 13 individual video frames were time synchronised to have the same starting time of the fire alarm and were arranged side by

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TABLE 1 Miscellaneous details of exit route of Engr Abul Kalam Library

Description	Staircase 1	Staircase 2
Location	Centre of building	Upper right corner (emergency exit)
Clear width	1.83 m wide with handrails placed 75 mm inside from the edge.	1.22 m wide with no handrails
Riser	150 mm high	150 mm high
Tread	280–460 mm wide	300 mm wide
Landing	No landing	Two 1.2 × 2.7 m landings per floor of staircase travel
Door	One 1400 mm wide door at the staircase entrance and exit	One 900 mm wide door at the staircase entrance and exit
Miscellaneous	Each floor has a single 4.4 m wide corridor extending 13.7 m. Corridor terminates at staircase 1 from one side and dead end from the other side. Staircase 2 is located at upper right corner of 18.3 × 20 m room whereas the room is connected to the end of the corridor. Height of each floor is 3.5 m.	

side in a single video frame with a single clock for all (Figure 3). This was carried out using a video editing computer programme entitled Sony Vegas. This avoided the need for checking times in individual video frames and greatly facilitated the identification of the evacuee movement from the first to the last video frame. All videos are played concurrently in this single frame to measure different times for the evacuees.

The initial time (time = 0 s) is the time of the start of the drill at the beginning of the fire alarm. The evacuees in all the cameras were identified in their initial position before the start of the evacuation, and each of them was given a unique identity (ID) which was used to track the movement of each individual throughout their path of movement. An example of this step is shown in Figure 4. The gender and physical appearance (such as the colour of the shirt, jacket, head cover, scarf, etc.) of the individuals were noted at the time of assigning IDs. The details of the belongings (such as bags, books, laptops, etc.) of each individual were also noted as they started collecting these at their first movement. The movement of each evacuee through the building was analysed by using the previously noted gender and physical appearance and the single frame strategy illustrated in Figure 3. In fact, evacuees entered the successive camera view field after exiting the previous camera view field until they finally exited the building.

The pre-evacuation time and the total evacuation time of each evacuee were measured. In line with the existing literature,[38,40,41] the time between the fire alarm's activation and the evacuee's first movement towards the exit was defined as pre-evacuation time. The total evacuation time refers to the time from the initiation of the alarm until they exit the building via the front door.

The horizontal walking speed and density for determining the fundamental relationships for the observed evacuees were measured by using the area of the foyer in front of the main exit (Figure 5). This area was chosen based on the fact that it was a common area for the evacuees at both storeys of the building. Travelling time taken by an evacuee to walk between the Start and Finish lines (Figure 5) was recorded through the video analysis. Travel speed was calculated by dividing the distance between the lines (3.65 m) by the aforementioned time. The density of the population in the designated area was measured at both the entry and exit times of each evacuee, and an average value of it was used as density in persons/m^2.

The projected distance travelled (1.38 m) on the last four steps of Staircase 1 (Figure 2) was used to calculate speed on the stair, neglecting the effects of curvature being small over the considered length of travel. The mean straight length (l) (Figure 2) of the considered segment of the staircase was calculated at the centre of the tread to take an average width for calculating the projected length. The data of evacuees on these steps were collected with the help of video frame 12 (Figure 3). The density and flow on the stair were determined over the area defined by the projected length times the width of the stair (1.7 m.).

3 | RESULTS AND DISCUSSION

A total of 85 evacuees participated in this fire drill; all of them were students. Of these, 29 were females. It is worth highlighting that staff members were not made part of the drill, and three of them were taken into confidence beforehand and were asked to assist the students during the evacuation to avoid any incident as they were experiencing a fire drill first time in their life. There were 22 staff members present in their offices in the library at the time of the drill.

The following Section 3.1 describes the behaviour observed during the evacuation, while Section 3.2 presents the results of the pre-evacuation and total evacuation times. Finally, the evacuation speeds and their relationships with the density are reported in Sections 3.3 and 3.4, respectively.

3.1 | Observed behaviour

The video analysis indicated that most of the students in the Study Area at ground storey

appeared confused with the sound of the alarm and they did not know what to do. This may be attributed to the shyness, lack of knowledge and training on the required actions, and realisation of the importance of timely decisions under such circumstances. A few of them even felt amused and were seen laughing with each other under peer pressure to ignore the alarm. Although some of the students walked out of the room after listening to the alarm, others were directed by the staff members (within the first few seconds of the

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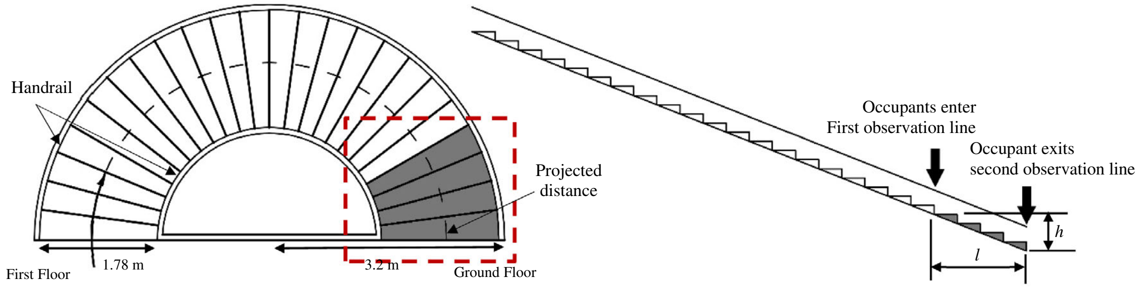

FIGURE 2 Circular Staircase 1 and method of measurement of travel distance

FIGURE 3 View of single video frame comprising all 13 individual frames

FIGURE 4 Example of tracking IDs of participants

ringing of the alarm) to stay in their seats and ignore the alarm. As a result, these students sat back in their seats and waited for the next thing to happen. On the contrary, the students in both the halls at the first storey (Digital Library and Reading Hall) appeared indifferent to the sound of the alarm and remained unmoved. They were also instructed by the staff members in these halls to remain seated, similar to the staff in the Study Area at the ground storey. Very few students left the halls during this time at both storeys. Eventually, one of the

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FIGURE 5 Demarcation of the area to determine the horizontal walking speed and density

members of the drill team interfered (after waiting nearly 1 min) and ordered the students to evacuate. The staff members in other rooms stayed in their offices throughout the drill. However, it is possible that they became aware that this was a drill and staff participation was not mandatory.

It was observed that 89% of the occupants collected their belongings before starting the evacuation. These included bags, books, stationery, and laptops and their chargers. Several previous studies also reported that people stop to collect their belongings, including keys, electronic items, bags, jackets and wallets.[17,37,42–46] These behaviours could be expected during general fire drills in places where fire cues (smoke and heat detectors) are not visible. The degree of attachment to belongings is positively correlated with pre-movement times.[45] However, stopping to collect personal items during real-life evacuations may considerably delay the evacuation and increase the evacuation times.[46] Galea et al.[32] reported that the students did not show the urgency of evacuation in a fire evacuation drill in a library in Izmir, Turkey.

Finally, a large majority of the evacuees (70%) started their evacuation in groups. These groups were formed by the students sitting in the library with friends. The groups comprised 2–4 members, and their response time (generally) was less as compared to those moving individually. Such behaviours can be expected in a university library building, as students (generally) visit the library in groups, and they sit and study together. Rahouti et al.[17] also observed group behaviours during an unannounced evacuation drill conducted in Switzerland and attributed this to the familiarisation with each other. Ma et al.[47] noted that when evacuees know each other and cooperate, group behaviours could positively influence evacuation dynamics.[47] Contrary to this, Bode et al.[48] observed that group behaviours could negatively affect evacuation performances as both the pre-movement and movement times could be increased due to the presence of social groups. Nevertheless, the group behaviour was not observed during the movement of evacuees in this study and the evacuees moved as individuals with or without their group members.

3.2 | Pre-evacuation and total evacuation time

The pre-evacuation data were analysed separately for all three halls of the building (Digital Library, Reading Hall and Study Area) included in this study. The statistics of the pre-evacuation times for these halls are given in Table 2. Figure 6 shows the boxplots of the pre-evacuation times of these halls individually and the combined data for the full building. The lowest pre-evacuation times were observed for the Reading Hall and Study Area, while the highest pre-evacuation times were observed in the Digital Library and Study Area. Table 2 and Figure 6 show that the mean pre-evacuation time for the Digital Library is nearly 320% and 130% higher than the mean pre-evacuation times for the Reading Hall and Study Area, respectively. This may be attributed to the student response and behaviour, which was different in the halls at the first storey, as described earlier.

The combined pre-evacuation data have been compared with the Lognormal distribution in Figure 7. This distribution was estimated using Equation (1).

$$F(x|a,b) = \frac{1}{b\sqrt{2\pi}} \int_0^x \frac{\exp\left(\frac{-(\ln(t)-a)^2}{2b^2}\right)}{t} dt \tag{1}$$

where a and b are the distribution parameters. Figure 7 shows that the distribution has a good fitting of the observed data as is also indicated by the R^2 value of 0.98. The values of a and b came out to be 2.87 and 0.85, respectively. The Kolmogorov–Smirnov (K-S) test was additionally conducted to compare the empirical data which also confirmed that the data can be fitted to the Lognormal distribution. Galea et al.[32] also reported a good correlation of the observed data of pre-evacuation time with Lognormal distribution.

Figure 8 shows the distribution of the number of evacuees versus the total evacuation time for three halls of the building (Digital Library, Reading Hall and Study Area). It is seen in Figure 8 that the first person exiting the Study Area reached the exit at 22 s. The evacuation times of the initial evacuees in both the halls at the first storey are

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TABLE 2 Statistics of pre-evacuation times

Hall	Sample size	Minimum time (s)	Maximum time (s)	Mean	S.D.	25th Percentile	Median	75th Percentile
Digital Library	19	27	82	45	13	38	42	49
Reading Hall	22	3	41	15	11	5	12	16
Study Area	44	0	82	20	19	14	13	7
All	85	0	82	24	20	11	15	39

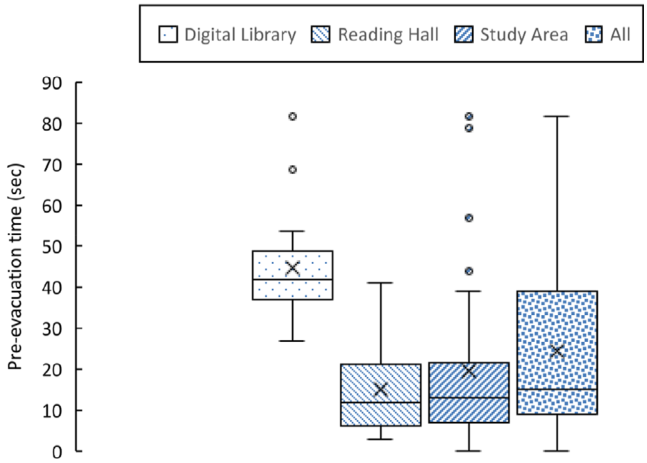

FIGURE 6 Pre-evacuation time distributions

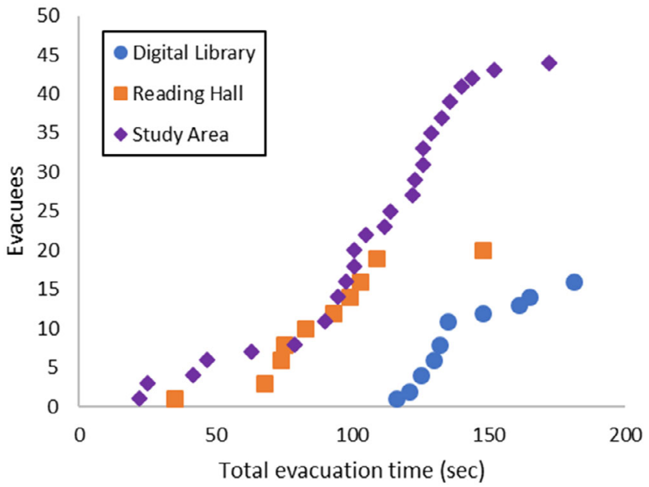

FIGURE 8 Exit time of evacuees

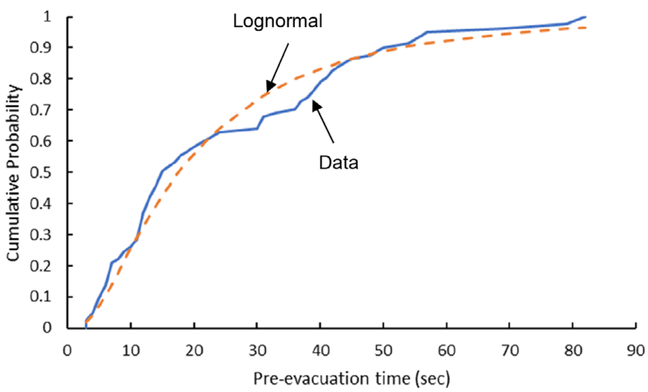

FIGURE 7 Cumulative distributions of pre-evacuation times

longer, which could be attributed to their longer response time, as mentioned earlier. All evacuees vacated the premises in 181 s (3 min), which is the time for the last evacuee exiting from Digital Library. The statistical summary of the total evacuation time (plotted in Figure 8) is provided in Table 3.

3.3 | Evacuation speed

Figure 9 shows a boxplot of the unimpeded horizontal speed of the evacuees. The mean speed is 0.74 ± 0.28 m/s (with only one outlier) at an average density of 0.42 ± 0.20 persons/m^2. This mean speed value was lower than the value provided in the SFPE handbook for the same density range. Furthermore, the minimum and maximum speeds were observed as 0.26 m/s and 1.83 m/s, respectively. Lower observed mean walking speeds and higher variation observed in the presented study could be a result of shyness due to the presence in social groups and unawareness of fire evacuation or evacuation drills. Gorrini et al.[49] reported that people walking in groups tend to walk much slower compared to solo walkers. In addition, a lack of understanding of the importance of such drills among the evacuees could also be an element affecting walking behaviours. The higher variation in evacuation speeds could also be due to the composition of evacuees with different characteristics (male and female) and group compositions. Wong and Cheung[50] reported average unimpeded walking speeds of 1.6 m/s and 3.6 m/s (at a crowd density of nearly 0.3 persons/m^2) for students at the Hong Kong Polytechnic University, Hong Kong, under normal and emergency conditions, respectively, while Galea et al.[32] noted an average speed of 1.0 m/s. These speeds were substantially higher (35%–385%) when they are compared to the mean speed observed in this study for similar crowd densities.

The boxplot in Figure 9 also illustrates the 25th and 75th percentile of evacuees' speeds. It is seen that there was only one evacuee with a speed above 1.8 m/s, which is highlighted as an outlier. In line with previous studies,[17,29,51] a normal distribution was used to fit the horizontal speed data. The results are given in Table 4, showing a good fit with the data (R^2 > 0.90).

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TABLE 3 Statistics of total evacuation times

Hall	Sample size	Minimum time (s)	Maximum time (s)	Mean (s)	SD (s)	25th Percentile	Median	75th Percentile
Digital Library	19	116	181	140	21	122	132	132
Reading Hall	22	35	148	86	25	93	88	75
Study Area	44	22	172	103	35	102	109	126
All	85	22	181	106	35	86	108	130

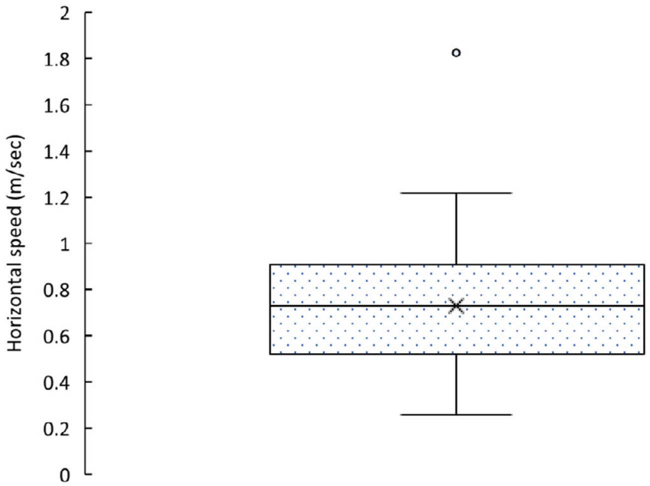

FIGURE 9 Boxplot of horizontal travel speed ("+" represents the mean speed)

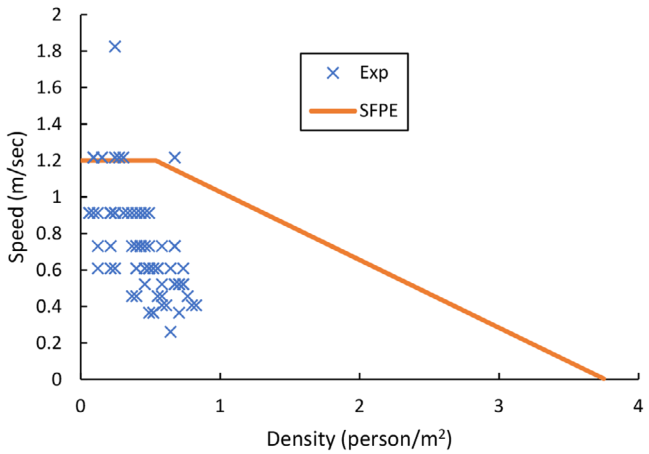

FIGURE 11 Fundamental diagram of horizontal speed versus local density

TABLE 4 Parameters of the normal distribution for the horizontal and stairs speed distributions

	Parameters (s)		
Distribution	a	b	R^2
Horizontal	0.89	0.34	0.95
Stairs	0.97	0.36	0.68

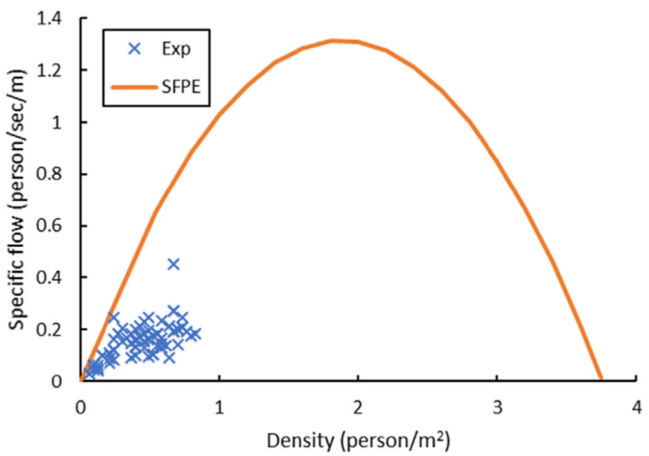

FIGURE 12 Fundamental diagram of horizontal specific flow versus local density

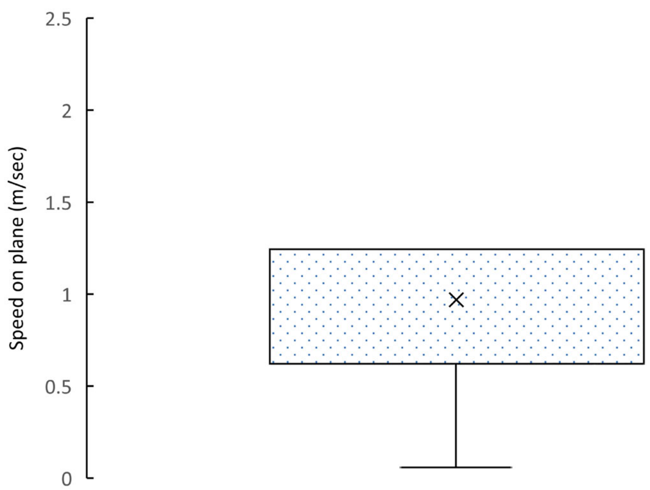

FIGURE 10 Boxplot of travel speed on stairs ("+" represents the mean speed)

Figure 10 illustrates the boxplots of observed speed on the stair. The unimpeded average stair walking speed was 0.97 ± 0.36 m/s, whereas the minimum and maximum speeds were 0.059 m/s and 1.24 m/s, respectively. These minimum and maximum speeds are also two common speeds of the majority of evacuees, which can be attributed (in part) to the short distance used to measure the speed. Table 4 summarises the estimated parameters of the normal distribution fit for these speeds. In this case, the distribution shows an acceptable fitting rate (R^2 > 0.65).

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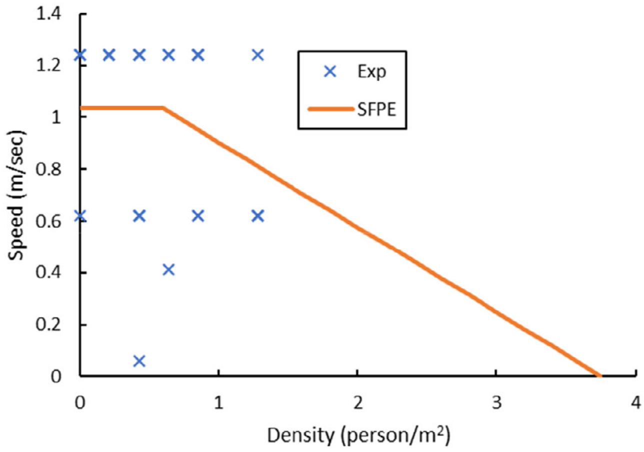

FIGURE 13 Fundamental diagram of stairs speed versus local density

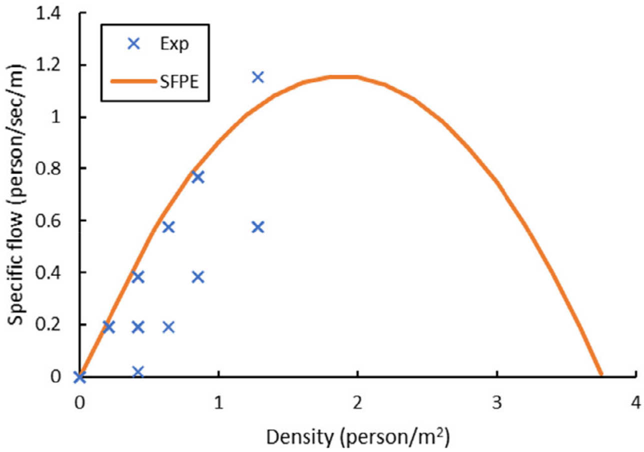

FIGURE 14 Fundamental diagram of stairs specific flow versus local density

3.4 | Fundamental relationship

Estimated relationships between horizontal speed and local density, and specific flow and local density in uncongested scenarios were studied in this paper by comparing the observed data with the design curves provided in the SFPE handbook by Gwynne and Rosenbaum.[52] For the horizontal speed data, the standard SFPE curve was used, while the stair curve for a 6 in. (150 mm) riser and a 13 in. (325 mm) tread was selected, as these parameters were close to the configuration of the stair shown in Figure 2.

Figures 11 and 12 show the comparison of the observed data with the SFPE curves. It is seen that the local density varies between 0.061 and 0.83 persons/m^2 and that there was no congestion. Furthermore, although the observed data points in Figure 12 fall below the SFPE relationships nearly 13% of walking speed data is above the SFPE curve in Figure 11. Note that SFPE curves are design curves and a comparison of these with the observed data assists in understanding

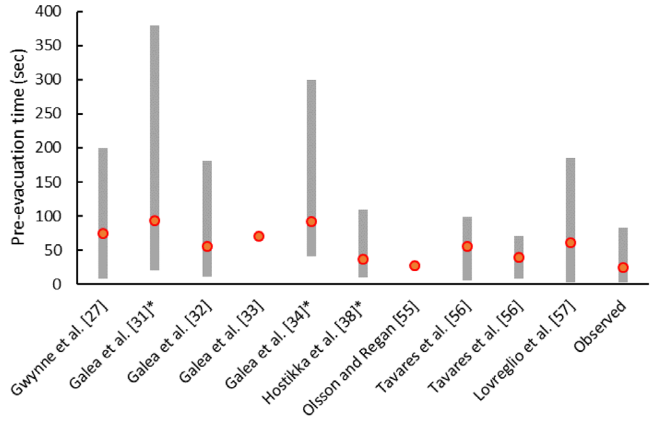

FIGURE 15 Comparison of pre-evacuation time with that reported in the literature. The dots represent the mean values while the bar the range of the data (i.e., min-max values). Note the data marked with * symbol gave min and max values retrieved from a figure

the differences and need of any revision in these design curves in future for a particular context.

Figures 13 and 14 show a comparison of observed stair data with the SFPE curves. It is seen that the local density varies between 0 and 1.28 persons/m^2 and that there was no congestion. Furthermore, the majority of experimental data points in Figure 14 fall below the SFPE relationships. On the other hand, the experimental data in Figure 13 are evenly distributed above and below the SFPE curve.

4 | COMPARISONS WITH PREVIOUS STUDIES

Although fire drills have been conducted in Pakistan in the past,[53,54] the outcomes and the data of such drills have not been published. Thus, the evacuation data presented in this study can be used to update building codes and can be compared with the traditional fire drill data from western and developed countries available in the literature. In addition, the evacuation drill presented in this study represents an attempt to raise awareness within the university population regarding the measures that should be taken during a fire evacuation.

Figure 15 compares the pre-evacuation times from this study and those extracted from previous studies conducted in different western countries. The red mark in Figure 15 represents the average value, while the grey bar shows the range of the pre-evacuation data. It is seen in Figure 15 that the pre-evacuation times observed in this study are (in general) shorter as compared to previous studies of similar facilities (library buildings). This may be because the staff assisted in alerting people. In addition, the main areas are open spaces which make it easy to communicate with multiple students at the same time. The only study comparable in terms of average is the library data from New Zealand reported by Olsson and Regan.[55] This similarity can be explained by the fact that the drill conducted by Olsson and Regan[55]

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was also semi-announced, and the staff was informed that the evacuation would take place on the given day. Note that the actual level of staff awareness was not reported by Olsson and Regan.[55] In terms of pre-evacuation ranges, it is possible to observe that the presented data are comparable with the data collected for a public library building in Brazil by Tavares et al.[56] This similarity could be due to several conditions that were comparable in both studies. Firstly, this was the first ever drill for the occupants of the library in both places (Brazil and Pakistan). Furthermore, no fire alarm system or evacuation procedures were available in both of these library buildings. Finally, designated staff interference to start the evacuation of occupants was necessary at both places.

Available studies in the literature on library evacuations do not provide speed data to compare with the observed data presented in this paper. As such, the observed horizontal and stair evacuation speeds reported in this paper are compared with the existing databases on pedestrian and evacuation dynamics[58,59] and previous work carried out in Saudi Arabia by Almejmaj et al.[60] In terms of horizontal speed, the observed data (mean = 0.74 m/s and standard deviation [SD] = 0.28 m/s) is smaller than the aggregate data proposed by Bosina et al.[58] for educational buildings, showing an average of 1.25 m/s. On the other hand, the observed average speed (0.74 ± 0.28 m/s) seems comparable with the data collected in Saudi Arabia, which shows an average horizontal speed of 0.90 m/s and 1.05 m/s for female and male participants, respectively.[60]

Regarding the descending walking speed on stairs, a mean speed (± SD) of 0.97 (± 0.36) m/s was recorded. This value is larger than the values reported in previous studies. A higher stair speed could be due to the curiosity of finding out the reason for the alarm after reaching the ground storey. In addition, the familiarity of the facility could also influence the walking speeds on stairs.[61] However, the stair speed values were not considerably deviated from the values provided in the SFPE handbook for the same density range (<1.5 people/m^2).

The observed stair speed data also seem to be within the ranges of previous stair movement data listed by Peacock et al.[59] (0.07–1.7 m/s). However, the observed stair speed seems relatively larger than the mean stair speed observed for high-rise buildings in the US by Peacock et al.[59] which was found to be 0.44 ± 0.19 m/s. The observed stair speed in this paper is also higher compared to the stair speed reported by Almejmaj et al.[60] in Saudi Arabia as 0.62 m/s for men and 0.57 m/s for women descending the stairways while lifting a closed "*abaya*" (a cloak worn by Muslim women); this study did not provide stair speed for male participants. Similarly, stair density observed in this study (0 persons/m^2 to 1.28 persons/m^2) lies within the range of stair density reported by Peacock et al.,[59] although the observed mean density (0.57 ± 0.40 persons/m^2) appears smaller compared to the mean density of 1.87 ± 0.16 persons/m^2 reported by Peacock et al.[59]

5 | LIMITATIONS OF DRILL

Although this study provides evacuation data (pre-evacuation times, horizontal and stair speeds) from a university library evacuation that can be used in performance-based design and evacuation simulation models, it has some limitations. The evacuation drill reported in this study was semi-unannounced, as the drill was unannounced to students while a few staff members were aware of the drill. Such arrangements reduced the ecological validity of the study. On the other hand, this choice was due to ethical reasons as students and staff were not familiar with the evacuation drills being this the first ones ever they participated in. Unannounced drills could be performed in future when the staff becomes more familiar with the procedures. Another limitation is that the data were obtained from a single drill. To better understand evacuation data (such as seasonal variations), multiple drills are preferred. Not only this, but the data collected through multiple drills also help in better explaining behavioural uncertainties.[62] Nevertheless, the samples collected in this study were adequate to investigate heterogeneities among the evacuees. Furthermore, it should be noted that (as congestions were not observed during the drill) the complete range of the fundamental relationships could not be obtained for both horizontal and stair scenarios. Therefore, the comparisons could be made for the unimpeded region of the fundamental diagram and this is also a limitation of this study. Further studies should consider such aspects to observe evacuees' behaviours under different conditions. Finally, any future study may consider measuring the interpersonal distance between the evacuees for more accurate density measurement.

6 | CONCLUSIONS

This study presented the data collected during a semi-unannounced evacuation drill that took place in a university library in Pakistan. The evacuation data, including pre-evacuation and total evacuation times, walking speeds, flows, and occupant densities in horizontal and stair configurations, were extracted from the observations made using video analysis. The pre-evacuation times obtained in this study could be well-fitted to Lognormal distribution. It was noted that the average pre-evacuation time obtained in this study was shorter than the previously published data for similar building types. Unimpeded horizontal speeds obtained in this study were compared with the design values in the SFPE handbook and the values published in previous studies. The average unimpeded horizontal speed was found to be smaller than the values published in those previously published sources. The average speed of descending the stair was comparable with the values in the SFPE speed-density relationship in the unimpeded region. Although the speed values on descending stairs in this study were within the ranges of previously published studies, the average value was noted to be larger as compared to the previously published values.

Being the first study conducted in an educational institution in Pakistan, this study provides new insight into the behaviour of library building occupants in a South Asian country during a fire evacuation. The data distributions presented in this study could be used in future building designs in the South Asian region. Furthermore, the data and findings could be useful in calibrating and validating evacuation simulation models, particularly for developing countries.

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CONFLICT OF INTEREST

The Authors declare that there is no conflict of interest.

DATA AVAILABILITY STATEMENT

Author elects to not share data.

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