Walking Speed of Pedestrian on Stairways at Intercity Railway Station in India

Jiten SHAH [a], Gaurang JOSHI [b], Purnima PARIDA [c]

[a] *Research Scholar, Department of Civil Engineering, S. V. National Institute of Technology, Surat, Gujarat, India; E-mail: jitenshah_civil@yahoo.co.in*
[b] *Associate Professor, Civil Engineering department, S. V. National Institute of Technology, Surat, Gujarat, India; E-mail: gj@ced.svnit.ac.in*
[c] *Principal Scientist & Head, Transportation planning division, CSIR-Central Road Research Institute, New Delhi, India; E-mail: punam31@gmail.com*

Abstract: Pedestrian walking speed on a stairway at transit station is affected by direction of movement, age, gender, luggage carried and group size for the prevailing physical condition and space availability. The speed of the pedestrian varies notably under various state of these factors and hence calls for study so as to assess the quality of service in terms of comfort and safety of pedestrian traffic at transit stations. This paper discusses the variability in pedestrian walking speed on the stairways before and after arrival of a train at an intercity transit station for different categories of pedestrians based on field videographic survey. The average horizontal walking speed of pedestrian is 0.442 m/s in ascending direction and 0.460 m/s in descending direction. Influence of direction of movement, gender, age and loading condition on the speed is also studied by statistical analysis.

Keywords: Pedestrian, Walking speed, Stairways, Railway station, Transport terminal.

1. INTRODUCTION

Improving socio-economic conditions in industrially vibrant environment in India has increased the mobility levels of its population. Indian railways carry nearly 21 million passengers daily through its rail network of more than 60,000 km. Rail corridor in western Indian state of Gujarat connecting Mumbai and Ahmedabad is one of the busiest routes on Indian railways. Due to high level of industrialisation along the corridor has generated huge amount of commuter traffic as well as casual travellers. Apart from efficient train services along the corridor, the facilities for pedestrian movements within the transit station facilities are vital for convenient access and egress from the train platforms. The travellers need to use foot over bridges to cross over railway lines from one platform to the other as there is no provision of escalators on intercity transit stations.

Primary function of passenger transport station is gathering and distributing passengers (Yang, 2010). Fluctuations in pedestrian flow depends on schedule of arrival and departure of the train, particularly during the peak hours as there are large passenger flow in short interval of time. Due to limited capacity of pedestrian facility, especially staircases, desired speed cannot be achieved by the pedestrian while walking in crowd with baggage.

Walking speed as the measure of effectiveness of pedestrian facility has been one of the major issues in pedestrian flow analysis. Fruin (1971), Tanaboriboon *et al.* (1991), Lam, W. H. K (1995), Liu *et al.* (2008) observed higher walking speed on downstairs than upstairs with

reduction in speed with increase in pedestrian density. Outdoor stairs are reported to offer more speed than the indoor stair (Kretz *et al*. 2006), Tanaboriboon *et al.* (1991) observed that small variation (0.01 m) in the riser height cab cause +7% variation in the speed at upstairs and +1% at downstairs. Templer (1992) gives the equation for the walking speed on stair considering tread and riser however the pedestrian characteristics is not taken in to consideration, where it play a major role in walking speed. Fujiyama & Tyler (2004) investigated relationship between the walking speed and physical characteristics to predict the walking speed of a variety of pedestrians by their characteristics and the stair-gradient. They concluded that the effect of pedestrian age, height and weight are not affecting the walking speed albeit the leg extensor power (Bassey, 1992) and stair gradient are the only influencing factors. Kretz *et al*. (2006) found mean upward walking speed on the short stairway was found roughly twice than the long stairway. Predtetschenski and Milinski (1971) found average walking speed of pedestrian is affected by surrounding conditions like: comfortable, normal, dangerous and also geographical slant (steep slope-20-30^{o}), access setting, weight of pedestrian also affect their behaviour and decision, most of them avoid to use stair due to they work against gravity (Eves, 2013) but in transit area they have limited choice of mode hence they must use stair. Knoblauch *et al*. (1997) found speed is depends on the start-up time of the pedestrian and it play a vital role in design. Lee and Lam (2006) the walking speed variation was smallest when pedestrian flow at approached capacity. Directional of flow and arrival time of train also affect on average horizontal speed, however effect of various activities (baggage, use of cell phone) on ascending and descending speed was not taken in to consideration. Jia *et al.* (2009), Yang *et al.* (2010), established maximum and minimum dynamic space and static space required for the pedestrian. Yang, Lizhong *et al.* (2012) studied student crowds in college campus at staircase under normal and emergency condition, and found that the average waking speed of pedestrian in emergency condition is 2.5 times higher than normal condition. Yao *et al.* (2012) showed that the weaving phenomena of pedestrian crowd tends to occur in transport terminals due to need to walk faster with minimum available space which forced weaving of pedestrians avoiding conflicts frequently during the transfer process. Zhang *et al.* (2009) reported that, average walking speed is lower in non-working day due to majority trip are non-working trip(recreation and leisure) and also affect on the percentage of the older pedestrian, and also reported that the male having higher speed than the female in each group rather than old age, having no speed variation. HCM (2000) recommended that the walking speed on stairways varies from 0.4 m/s for LOS F to 0.53 m/s for LOS A. The horizontal walking speeds of pedestrian on stairways reported by various researchers are shown in Table 1.

Table 1. Average horizontal walking speed on stairways in different countries

Sr. No.	Author	Year	Country	Stairways	
				Ascending	Descending
1	Fruin	1987	USA	0.54	0.72
2	Tanaboriboon	1991	Bangkok, Thailand	0.52	0.60
3	Lam et al.	1995	Hongkong	0.62	0.74
4	Liu W.	2008	China	0.82	
5	Zhang R.	2009	Beijing, China	0.71	0.90
6	Xiang Z.	2009	Singapore		0.45

As discuss above the ascending speed is lower than the descending speed of pedestrian. The lowest walking speed (0.453 m/s) is reported in Singapore by Xiang (2009) whereas highest descending speed is observed in China as reported by Zhang *et al.* (2009), Liu *et al.* (2008).

This study examines the effect of the pedestrian age and carrying baggage on the mean speed of the pedestrian flow. Most of the studies described above were conducted in USA, China, Thailand and Singapore, where pedestrian characteristics and behaviour is different compared to India. Study in China found that the size of pedestrian has influence on walking speed, Chinese person having small size which requires more steps to cover same distance than westerners. In India, the physical dimension is somewhat intermediate than the Chinese and American for which no literature is found for the effect of age and baggage on the average speed of pedestrian flow on stairways in transit stations. The present study was undertaken with objective to analysing flow characteristic and to compare the effect of the age and baggage on walking speed with the outcomes of research elsewhere for similar condition.

For this paper, walking speeds were monitored on a stairway at railway station of Vadodara, India. Vadodara is the third largest and most populated (over 1.6 million, Census India 2011) city in the state of Gujarat, India. Vadodara is situated on major rail and road corridors connecting Mumbai with Ahmedabad and New Delhi. Figure 1 shows the location of selected stair in station area. The time and location were chosen as the railway station handles more than 130 intercity trains in a day. The outline of the data collection method and analysis is first presented, followed by a discussion of significance of the parameters. Finally conclusion is drawn and recommendations given for further study.

2. DATA COLLECTION

Pedestrian movement data was collected by vidiographic survey on Vadodara railway station on 20 October, 2012, on the stairway connecting to platform and foot over bride leading towards outside of railway station. The survey duration was selected to capture pedestrian traffic 15 min before and after the arrival of train during peak period (3:40pm-4:10pm). The aim was to capture the pedestrian speed behaviour during the time of arrival and departure of trains.

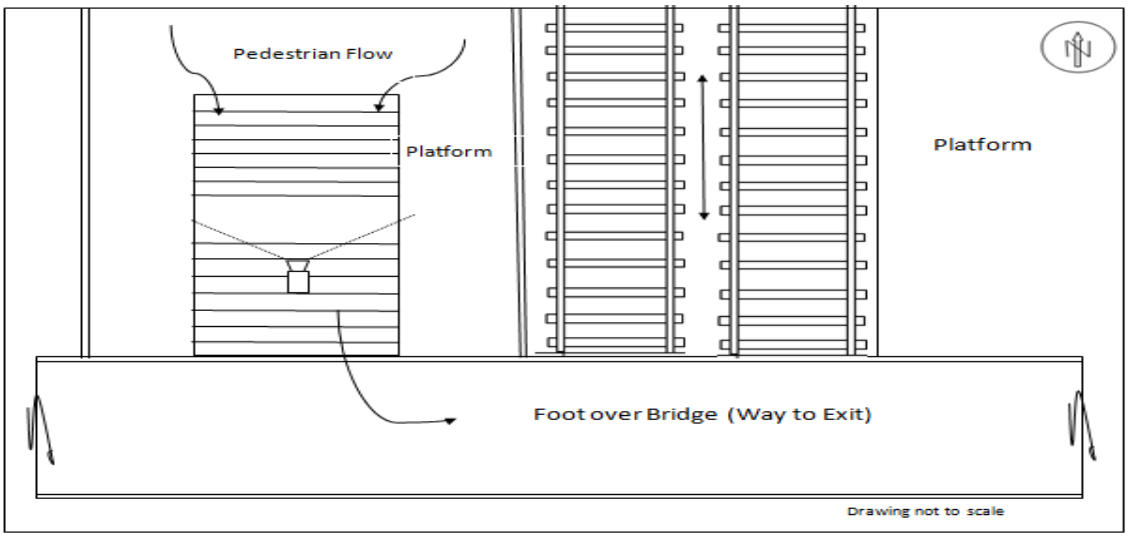

Figure 1. Location of study area

Pedestrian walking speed and flow data were collected at selected location by marking the longitudinal section on steps of 3.55 m horizontal trap length. Width of the stairway is 3.68m and total height of stair is 5.8 m having gradient 23.24^{o} with riser height 0.15 m and tread width 0.31m which is normal configuration of the staircase. The video camera was set at the centre of the staircase, since it was not possible to take the whole length of the staircase due to available vertical clearance of the ceiling preventing coverage of the whole length of staircase. The camera was set at 45^{0} with the horizontal to cover the maximum possible stretch and for perception of the pedestrian age by face. The walking speed of pedestrian and flow rate were manually extracted from the recorded video.

A pedestrian volume was count when they enter in to the selected trap length and it is categorized in gender, age and performance of activity like carrying baggage, talking on cell phone, talking to other fellow passengers etc. The pedestrian walking speed are calculated for randomly selected five samples of each category in one minute time interval by noting entry and exit time across the trap length. The personal characteristics of pedestrian such as gender, age and performance of activity were noted from video. The advantage of the technique is that the data can be analysed by replaying the same video for extraction of the flow and speed data which is quite difficult to obtain manually at site.

3. SURVEY RESULT

3.1 Composition of Pedestrian

Classified data of 1118 pedestrian is extracted from video film out of which 835 pedestrian are moving in up direction and 283 in down direction without segregation. 30% of the pedestrian are reported to be commuters whereas rest are occasional travellers. Pedestrian are grouped into three categories as children (age < 15 years), young (age between 15-60 years) and elder(age > 60 years). The ascending pedestrian flow constitutes 75% male and 25% female where as in downstream direction 77% male and 23% female pedestrians are observed. The proportion of children, younger and elder is 5%, 17% and 78% respectively in both the directions. 23% of pedestrian are found walking with luggage in both the directions in general.

3.2 Walking Speed under Different Influence

The walking speed is subjected to pedestrian characteristics, such as gender, age, walk in group, walking with luggage, stair gradient and physical disability. Walking speed is also influenced by time to reach their destination. From the analysis of speeds of all selected pedestrians, the average horizontal walking speed of pedestrian on stairway is 0.442 m/s on up stair and 0.460 on down stair with the overall mean speed of 0.451 m/s, which is the lowest speed compared to the speeds reported in literature. Table.2 provides mean walking speed of pedestrians with respect to the direction, age, gender as well as loading condition.

Table 2. Categorized mean walking speed of pedestrian

Category	Mean pedestrian Walking Speed (m/s)		
	Upstream stair	**Downstream stair**	**Overall**
Gender:			
Male	0.482	0.490	0.486
Female	0.413	0.439	0.426
Age:			
Children	0.402	0.545	0.474
Young	0.505	0.523	0.514
Elder	0.409	0.335	0.372
Loading Condition:			
With Baggage	0.388	0.384	0.386
Without Baggage	0.499	0.502	0.500
Overall	**0.442**	**0.460**	**0.451**

3.2.1 Gender

As discuss in literature, walking speed of male pedestrian is higher on down stairs which is corroborated by the present study. Compared to female, male pedestrian walk at 17% faster speed at 0.482 m/s on up stairs and 12% higher on down stairs. This shows that if the flow rate of the female pedestrian is higher the mean speed of walking will reduce and hence will affect the provision of space for comfortable walking.

3.2.2 Age

Walking speeds of the three age group are studied to understand the effect of the direction of movement on the stairway on walking speed while climbing (Table 2). Significant variation in horizontal walking speed is observed between three groups on both up stair and down stair. But higher variation in speed of 25% is observed between the younger and both (younger and children) age group. However, the walking speed of children and elder is observed to have very small difference of (1.7%) compared with younger on up stairs. The speed of pedestrian of different age groups on down stair gives completely different scenario where walking speed of the children is 63% higher than elder pedestrian and 4% higher than younger pedestrian. Moreover elder pedestrian walk 56% slower than the younger. In short, if the percentage of children and older pedestrian increases, that will reduce the average walking speed of pedestrian on stairways. As volume of pedestrian is high at the time of arrival and departure of the train with higher percentage of elder pedestrian, overall performance of the pedestrian facility is severely affected. In some observations, elder people with some physical disability and also person waiting for them is observed to reduce overall mean speed of pedestrian on stair.

3.2.3 Pedestrian in platoon

Platoon is described as the bunch of pedestrian walking in group speed will reduce with increase in size of group. In the present study, pedestrian group is observed 10 min before and after arrival of train. On arrival of train, pedestrian walk as individual with higher speed to enter the coach, and after arrival pedestrian move towards approach of the staircase and make

a crowd such that all pedestrian merge together and follow the speed of pedestrian ahead of them. Average speed of pedestrian stream is almost same as the average walking speed of individual.

3.2.4 Pedestrian with luggage

The speed of the pedestrian carrying luggage is shown in Table 2. The luggage of substantial size carried in hand is considered to classify a pedestrian with luggage. Pedestrian carrying college bag, plastic bags, ladies purse etc. is not taken in to consideration to categorise as pedestrian having baggage or luggage. It can be observed from the table that the speed of pedestrian carrying luggage reduces speed up to 28% on up stair and 31% on down stair. However, the variation in such speed is very less in both the directions.

Table 3. Distribution of the pedestrian walking speed (m/s) for various conditions

Direction	Gender	Loading Condition	Sample size	Mean	Median	Stand. Deviation	CV	Range of Confidence Interval (95% C. L)	Length of C.I
Up Stair	Male	Without Luggage	507	0.521	0.443	0.204	0.392	[0.441, 0.601]	0.160
		With Luggage	120	0.399	0.389	0.047	0.116	[0.381, 0.417]	0.036
	Female	Without Luggage	150	0.430	0.426	0.112	0.261	[0.386, 0.474]	0.088
		With Luggage	58	0.357	0.375	0.058	0.163	[0.334, 0.380]	0.046
Down Stair	Male	Without Luggage	172	0.523	0.490	0.145	0.278	[0.466, 0.580]	0.114
		With Luggage	46	0.420	0.447	0.092	0.219	[0.384, 0.456]	0.072
	Female	Without Luggage	47	0.478	0.474	0.107	0.223	[0.436, 0.520]	0.084
		With Luggage	18	0.332	0.361	0.109	0.330	[0.286, 0.378]	0.092
Both Stairs	**Age Group**								
	Children	---	54	0.426	0.427	0.111	0.260	[0.383, 0.470]	0.087
	Young	---	870	0.500	0.489	0.078	0.155	[0.470, 0.531]	0.061
	Elder	---	194	0.232	0.236	0.064	0.277	[0.207, 0.257]	0.050

Table 4. Test of Variance

	Comparison Groups	F_c	F_t	Hypothesis
	Children v/s Younger	2.036	1.98	Rejected
	Younger v/s Elder	1.468	1.98	Not rejected
	Children v/s Elder	2.989	1.98	Rejected
	Male v/s Female	1.492	1.98	Not rejected
Up Stream Direction	Male without baggage v/s Male with baggage	19.231	1.98	Rejected
	Female without baggage v/s Female with baggage	3.726	1.98	Rejected
Down Stream Direction	Male without baggage v/s Male with baggage	2.493	1.98	Rejected
	Female without baggage v/s Female with baggage	0.951	1.98	Not rejected

F_c: Calculated F value; F_t: Table value of F

The mean speed of pedestrian carrying luggage for all the categories: up stair – down stair and male-female is falling outside the confidence interval at 95% level and same, result obtained for the children and elder pedestrian compared with younger shown in Table 3. This proves that there is significant effect of luggage on the walking speed. Female pedestrian with luggage on down stair has sample value less than 30 and hence are analysed by t-score and rest of the pedestrian class are analysed by considering normal distribution (z-score). Variation in speed for different categories of pedestrian is shown through box-plot in figure 2. The disparity in variance of the speed of different categories of pedestrians was checked by conducting F-test at 5% level of significance. Table 4 contains results of hypothesis test on variance of two populations of pedestrians. It can be seen that null hypothesis is accepted in case of variance in speeds of younger and older pedestrian, male and female pedestrian and female with and without luggage on down stairs, thereby meaning, the variance in speeds of these category of pedestrian is not significantly different. However, for rest of the categories, the variance in speeds of two populations of pedestrian is significantly different.

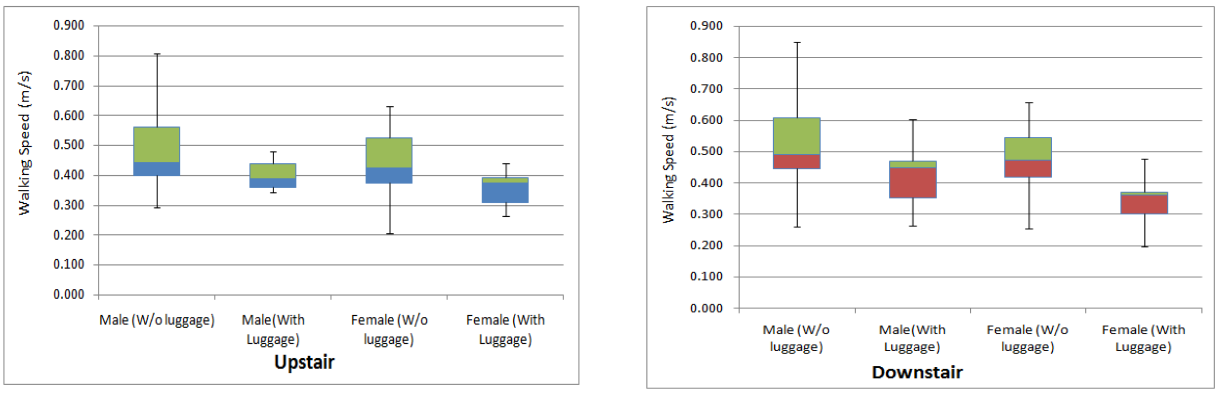

Figure 2. Boxplot of pedestrian average walking speed and loading condition on up stair and down stair.

The range of walking speed of male and female pedestrian without luggage varies over a wide range of 0.85m/s, maximum speed of males, and up to 0.20 m/s, minimum speed of females.

During the arrival of the train, pedestrian walk faster than their normal walking speed. Even elder pedestrian are also observed walking much faster than their normal walking speed higher than the younger carrying luggage. The walking speed of outgoing passengers is also affected by their arrival at the railways station with respect to the arrival of their train.

4. CONCLUSION

The present study reports profile of walking speed of the pedestrian during period of 15 min before and after the arrival of a train at an intercity railway station considering age, gender and loading condition of the pedestrian in ascending and descending directions on stairway. Result shows that male pedestrian walk faster than female and average walking speed is higher on down stair than up stair with same physical features of stairway. Compared with the literature, even though maximum speed obtained is about 0.8m/s, the average speed of the pedestrian on up stair and on down stair in present study is 0.442 m/s and 0.460 m/s respectively, which is very close to the speeds reported by Xiang et al.(2011). Age, gender

and loading condition act in combination with each other and have definite influence on the pedestrian speed. In general, walking speed of elder persons and pedestrians with luggage is less than the young pedestrians without luggage. This observation can lead to variation in pedestrian stairway facility design at transit stations based on the type of transit station and composition of pedestrian. Due to restricted permission for videography, the study carried out in short period during arrival of train and subsequent boarding of passengers move towards stair resulting in restriction in downstream movement in unsegregated stairway which cause reduction in downstream speed, hence further need in this study considering longer period of time and friction effect of bidirectional movement, for better insight. Extension of the study to relate space availability per passenger with the flow rate under the influence of age, gender and loading condition is necessary to evolve level of service regimes considering perception of pedestrian as well.

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