Study of Pedestrian Flow Characteristics In Hilly Area

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Abstract

Walking is also considered to be a clear example of a sustainable mode of transport, especially suited for urban use or relatively shorter distances. Efforts are under way by various local authorities to restore pedestrian access to new developments. The present paper summarizes the results of studies conducted at two hill station in India, i.e., Dharamshala and Shimla in Himachal Pradesh where longitudinal gradient varies from 3 to 7.5 %. Various pedestrian characteristics like speed and flow were collected from the field, and their correlation was modeled using conservation of mass equation. The speed-density follows a linear relationship whereas the flow-density and flow-speed found out to be following quadratic relationships. Free flow speed varies about 37 % with respect to another flat gradient locations in India and 23, 36 and 31 % with respect to flat gradients locations in Asian, North American and European continents.

Keywords: Pedestrian, Speed, Flow, Gradient

1. Introduction

Walking is an indispensable part of day to day life, and all journeys start or end with walking and it is the best way to enjoy the beauty of nature (Jain et al., 2014). During walking, pedestrians face different conditions like different geographical and topographical conditions. Especially, in a hilly area, the gradient of the carriageway affects the pedestrian flow characteristics. Pedestrians from flat gradient areas face difficulty in going uphill and downhill because of the unfamiliar walking conditions (Mohanty and Gupta, 2016). In the present study, two hill stations, i.e., Dharamshala and Shimla in Himachal Pradesh, North India were studied to analyze the flow

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characteristics. Various pedestrian characteristics like speed, flow and density were analyzed through the data collected from the videography. Speed was separately analyzed for different pedestrian characteristics like age and gender. A suitable relation between these parameters was modeled using conservation of mass equation.

The literature review was carried out on all aspects of pedestrian flow characteristics. Pedestrian's speed, flow, and density were the main parameters studied. The walking speeds of pedestrians in Asian, European and American countries are listed in Table 1. In almost all of the countries, pedestrians walking speed is identified for the plain terrain. Pedestrians in Tokyo are the fastest in the world with walking speed of 93.6 m/min., whereas the pedestrians in Yogyakarta, Indonesia were the slowest with the average walking speed of 52 m/min. In India, the average walking speed is 76 m/min considering the average of three locations, i.e. Delhi, Madras (Chennai) and Roorkee pedestrians whose walking speed is 72, 72 and 84 m/min respectively.

The pedestrian's flow characteristics is affected by a numerous factors like gradient or surface roughness (Older, 1968), available space (Fruin, 1970), indoor or outdoor walkway (Lam et al., 1995), riser height of stairways (Tanaboriboon and Guyano, 1991), pedestrians intention, intelligence and physical fitness, and topography (Robertson et al., 1994). Also, it was observed that males walk faster than females, and walking speed declines with age of the pedestrian (Tarawneh, 2001, Montufar et al., 2007, Finnis and Walton, 2008, Gupta and Pundir, 2015). For sidewalks in a dense city, important factors identified include age and gender of pedestrians, and type of walking facility (Morrall et al., 1991; Smith, 1995), width of the walking facility (Mitchell and MacGregor, 2001 and Rastogi et al., 2011), time of day (Hoel, 1968), and density (Smith, 1995). In case of baggage handling conditions, it was observed that pedestrian walking speed is not affected by pedestrian baggage carrying capacity (Fruin, 1971 and Young, 1999), on the other hand it was also found that the walking speed of pedestrians was reduced by about 85% when pedestrians move with their baggage or luggage (Kotkar et al., 2010). Also, it was found that people carrying baggage tend to walk slower than the non-baggage-carrying pedestrians irrespective of the size and weight of the baggage (Morrall et al., 1991). This shows that the pedestrians walking speed vary with region.

Table 1: Comparison of Pedestrian Walking Speeds with Different Studies

City, Country	Mean Speed (m/min)	Author(s)
	(a) American and European Countries	
Pittsburgh, United States	88.0	Hoel, 1968 *(14)*
London, England	79.0	Older, 1968 *(2)*
Columbia, United States	79.0	Navin and Wheeler, 1969 *(18)*
New York, United States	81.0	Fruin, 1971 *(15)*
Paris, France	87.6	Kamino, 1980 *(19)*
	(b) Asian Countries	
Fukuoka, Japan	81.0	Kamino, 1980 *(19)*
Koori-cho, Fukushima, Japan	69.6	Kamino, 1980 *(19)*
Osaka, Japan	90.0	Kamino, 1980 *(19)*
Tokyo, Japan	93.6	Kamino, 1980 *(19)*
Haifa, Israel	79.0	Polus et al., 1983

Delhi, India	72.0	Gupta, 1986 *(20)*
Roorkee, India	84.0	Kotkar et al., 2010 *(17)*
Madras, India	72.0	Victor, 1989 *(21)*
Singapore	74.0	Tanaboriboon et al., 1986 *(22)*
Riyadh, Saudi Arabia	65.0	Koushki, 1988 *(23)*
Yogyakarta, Indonesia	52.0	Poei et al., 1995 *(24)*
Bangkok, Thailand	73.0	Tanaboriboon and Guyano, 1991 *(5)*
Kuwait City, Kuwait	71.0	Koushki and Ali, 1993 *(25)*
Shanghai, China	72.0	Yu, 1993 *(26)*
Tiruchirapalli, India	74.0	Arasan et al., 1994 *(27)*
Metro Manila, Philippines	70.6	Gerilla, 1995 *(28)*

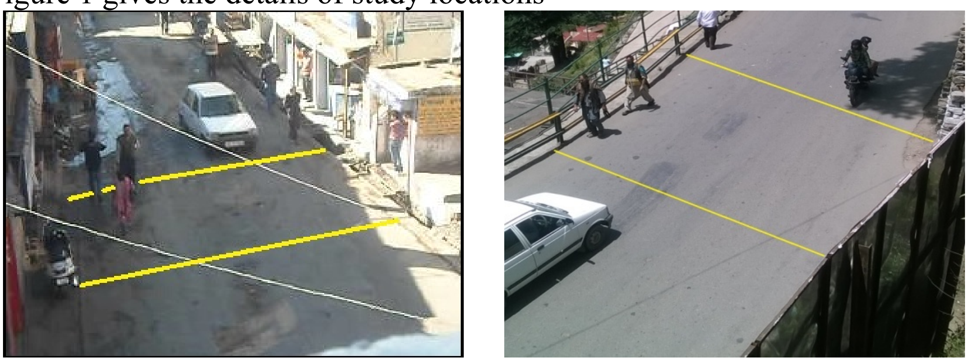
2. Data Collection Methodology

Data was collected from two hill stations of North India, i.e., Dharamshala and Shimla in Himachal Pradesh, to analyze the flow characteristics. Dharamshala has an average elevation of 1457 meters (4780 feet), covering an area of almost 8.51 km² Dharamsala is located in the Kangra Valley, in the shadow of the Dhauladhar mountains at 32.218°N 76.320°E. Shimla lies in the south-western ranges of the Himalayas at 31.61°N 77.10°E. It has an average altitude of 2,206 meters (7,238 ft) above mean sea level and extends along a ridge with seven Spurs. The city stretches nearly 9.2 kilometers (5.7 mi) from east to west. As per provisional data of 2011 census Shimla urban agglomeration had a population of 171,817, out of which males were 94,797 and females were 77,020.

Pedestrians were video graphed for one hour over the measured test length of 4 meters which was marked on the carriageway by two visual lines across the carriageway. From the recordings, the walking speeds of pedestrians were manually extracted. The accuracy of time for the speed measurement was about 0.1 sec. The time taken by a pedestrian to traverse the test length was measured from the recording and by dividing the length of a marked stretch by time taken by a pedestrian gave us the walking speed of that particular pedestrian.

To extensively analyze the effect of gradient on pedestrian flow characteristics the pedestrians were categorized by their age and gender based on the visual inspection of the videos. Based on these categorization pedestrians walking speed of one type were compared with the pedestrians of the same type traveling in the other direction of travel.

Figure 1 gives the details of study locations



a) Bus Stand Road, Dharamsala **b)** Bus Stand Road, Shimla

c) Meera Restaurant, Dharmasala

d) Vidhan Sabha Road, Shimla

e) Asian Hotel, Dharmasala

f) Mall Road, Shimla

Figure 1: Photos of Study location

Similarly, the effect of the gradient was checked on pedestrians who were carrying baggage (luggage). Pedestrians' categorization was done based on several factors like 1) Age -Young (0 to 15 years), Elder adults (16 to 25 years), Middle Aged (26 to 50 years) and Older (51 years & above) 2) Gender - Male and Female 3) Baggage – With and Without Baggage. The locations were grouped into three categories as, low gradient, mild gradient and high gradient where Low gradient is ≤ 3 %, the mild gradient is between 3 to 8 % and the High gradient is ≥8 %.

Table 2: Details of Selected Study Locations

Location ID	Location	Carriageway Width (m)	Gradient (%)	Exclusive facilities
BSD	Bus Stand Road, Dharamsala	7	3	No
BSS	Bus Stand, Shimla	7.5	3	No
MRD	Meera Restaurant, Dharamsala	7.5	4	No
VSS	Vidhan Sabha Road, Shimla	7.5	5	No
AHD	Asian Hotel, Dharamsala	3	9	No
MRS	Mall Road, Shimla	3.5	8	No

3.Data Analysis

Various findings from the data collected at two different tourist destinations are discussed in the following sections.

3.1 Mean Walking Speeds for Different Pedestrians at Low, Mild, and High Gradient categories

The uphill and downhill walking speed were grouped together and analyzed. The mean walking speed of pedestrian in selected tourist destinations for different gradient categories is presented in following Tables. The mean walking speed of different pedestrian categories for Low gradient category are given in Table 3, for Mild gradient given in Table 4 and for High gradient category at AHD and MRS locations are given in Table 5.

In gender category, female pedestrians were the slowest in both the directions at all locations and also showed maximum percentage difference in uphill and downhill walking speeds. Whereas, in age category, young adult pedestrians (16-25 years) were the fastest in an uphill and downhill direction at all locations except in uphill directions at the low gradient category. On the other hand, in baggage category, pedestrians showed varying behavior at different gradient categories. Maximum and minimum percentage difference in walking speed in uphill and downhill directions were observed at High gradient category for pedestrians with baggage. Compared to Low gradient pedestrian walking speed was found to increase by 2.82 % due to mild gradient and decrease by 2.65 % for high gradient for Uphill whereas for downhill movement this decreases by 2.98 % mild gradient and increases by 0.23 % for the high gradient. Compared to Low gradient pedestrian walking speed was found to increase by 2.82 % due to the extra effort exerted by the pedestrians to cover the gradient in mild gradient and decrease by 2.65 % for high gradient for Uphill whereas for downhill movement this decreases by 2.98 % mild gradient and increases by 0.23 % for the high gradient. The reason for the decrease in the downhill walking speed for the mild gradient is attributed towards the resistance or extra-cautiousness offered by the pedestrians while moving downwards but the same downward speed increases in the case of high gradient. The possible reason for this would be that even after exerting resistance by the pedestrian the high gradient forces them to move fast downwards.

Table 3: Mean Walking Speed of Different Categories of Pedestrians for Low Gradient Category (m/min)

Movement	Gender		Age				Baggage		Average
	Male	Female	Young	Elder Adults	Middle Aged	Old	With Baggage	Without Baggage	
Uphill	60.38	55.09	47.01	55.41	60.45	51.14	55.17	60.67	57.73
Downhill	71.89	68.52	65.65	71.42	72.98	55.22	67.49	74.12	70.21
Difference (%)	19.07	24.39	39.64	28.91	20.72	7.97	22.33	22.16	

Table 4: Mean Walking Speed of Different Categories of Pedestrians for Mild Gradient Category (m/min)

Movement	Gender		Age				Baggage		Average
	Male	Female	Young	Elder Adults	Middle Aged	Old	With Baggage	Without Baggage	
Uphill	61.74	56.99	59.60	66.56	60.63	51.77	58.48	61.22	59.37
Downhill	70.91	65.31	64.93	77.61	69.86	58.32	66.83	70.72	68.11
Difference (%)	14.85	14.61	8.95	16.60	15.21	12.66	14.28	15.51	

Table 5: Mean Walking Speed of Different Categories of Pedestrians for High Gradient Category

Movement	Gender		Age				Baggage		Average
	Male	Female	Young	Elder Adults	Middle Aged	Old	With Baggage	Without Baggage	
Uphill	58.27	54.14	50.01	69.06	57.85	46.66	53.16	59.58	56.21
Downhill	72.74	68.00	63.17	76.23	72.83	60.75	68.16	73.53	70.37
Difference (%)	24.84	25.58	26.31	10.39	25.90	30.20	28.23	23.43	

The mean uphill and downhill walking speed for Low, Mild and High gradient locations and all locations all together are compared in Table 6. The mean pedestrian walking speed of these two tourist destinations cities was found to be 64.35 m/min irrespective of walking direction. While at different gradient categories, the maximum uphill speed was 60 m/min at Mild gradient locations and maximum downhill speed was 71.12 m/min at High gradient locations. Irrespective of the gradient categories and taking locations altogether the uphill walking speed was found to be 58.58 m/min and downhill walking speed was found to be 70.25 m/min.

Table 6: Comparison of Mean Uphill and Downhill Walking Speeds at Different Gradient Categories

Gradient Category		Low	Mild	High	All locations
Gradient (%)		3	4-5	8-9	-
Mean speed (m/min)	Uphill	58.60	60.00	56.86	58.58
	Downhill	70.80	68.88	71.12	70.25
Difference in speeds (%)		20.82	14.80	25.08	19.93

As the gradient increased, the mean uphill walking speed of pedestrians decreased and the mean downhill walking speed of pedestrians increased as expected at Mild and High gradient locations. At low gradient locations, the behavior was not the same. This might be because of the proximity of low gradient locations to the Inter State Bus Terminal of their respective cities which was situated in the downhill direction of the locations. On the other side, mild and high gradients locations were situated in the CBD area of the respective cities far from ISBT. The low gradient locations had faster uphill and downhill speeds than mild and high gradient locations. Through this finding, it can be assumed that the pedestrians going to and coming from ISBT were time bound and in a hurry to reach their respective destinations. These type of human intentions might force them to move faster, and that is why the uphill and downhill speeds of low gradient locations were faster than uphill and downhill speeds of mild and high gradient locations.

3.2 Pedestrian Flow Characteristics Diagrams

The pedestrian data were analyzed with the help of Microsoft Excel software. At each study location, the values of pedestrian flow, pedestrian speed, and pedestrian density were computed. Speed-density, speed-flow, and flow-density curves were plotted using the analyzed data. These curves are presented in the Figs. 2-4 for uphill direction. The scattered data points on speed-density graph suggested a linear relationship, and for speed-flow and flow-density quadratic relationship was best suited. The general relationships used for the analysis are developed based on single-regime approach and are described as follows:

Pedestrian speed (*u*) and density (*k*): $u = a - bk$ (1)

Pedestrian flow (*q*) and density (*k*): $q = ak - bk^2$ (2)

Pedestrian speed (*u*) and flow (*q*): $q = u(a-u)/b$ (3)

The other important flow characteristics obtained from the developed relationships are given in Table 7. The correlation coefficient (R^2) value presented in Table 9 and 10 varies between 0.64 and 0.67. From each gradient category, one best fit speed-density relation for uphill direction is selected and compared with best fit speed-density relations of a research done in plain areas (Kotkar et al., 2010) and researches done on sidewalks in Singapore (Tanaboriboon et al., 1986), United States (Fruin, 1971) and Britain (Older, 1968). The developed pedestrian flow characteristics are compared in Table 8.

The compared speed-density relations in Table 7 for uphill direction are presented graphically in Fig. 2. When we calculate speed from speed-density relations shown in Table 7 for density, say 1 ped/m^2, the speed in the uphill direction for low, mild and high gradient categories and flat gradient comes out to be 43.55, 41.9, 43.44 and 50.67 m/min respectively and for Singapore, USA, and Britain 58.6, 61 and 58.4 m/min respectively. Walking speed of pedestrians on carriageways at studied tourist destinations for low, mild, high and flat gradients is less than walking speed of pedestrians on sideways on flat gradients.

Table 7: Comparison of Different Speed-Density Relations

Place of research	Gradient category	Traffic condition	Direction	Speed-Density Relation	R^2 Value
Himachal, India	Low (2-3%)	Mixed Traffic	Uphill	$u = 59.93 - 16.38k$	0.66

	Mild (4-5%)	Mixed Traffic	Uphill	$u = 61.3 - 19.4k$	0.67
	High (8-9%)	Mixed Traffic	Uphill	$u = 58.84 - 15.4k$	0.64
Roorkee, India	Flat gradient	Mixed Traffic	Uphill	$u = 82.52 - 31.85k$	0.74
Singapore	Flat gradient	No traffic	Both	$u = 73.9 - 15.3k$	-
United States	Flat gradient	No traffic	Both	$u = 81.4 - 20.4k$	-
Britain	Flat gradient	No traffic	Both	$u = 78.6 - 20.2k$	-

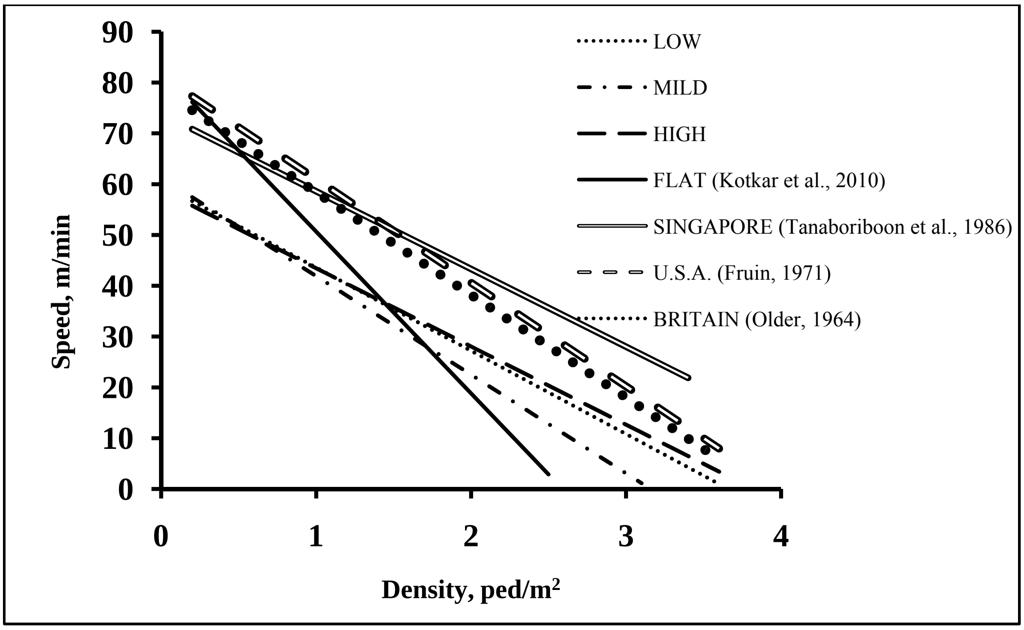


Fig. 2: Comparison of Speed-Density Relations

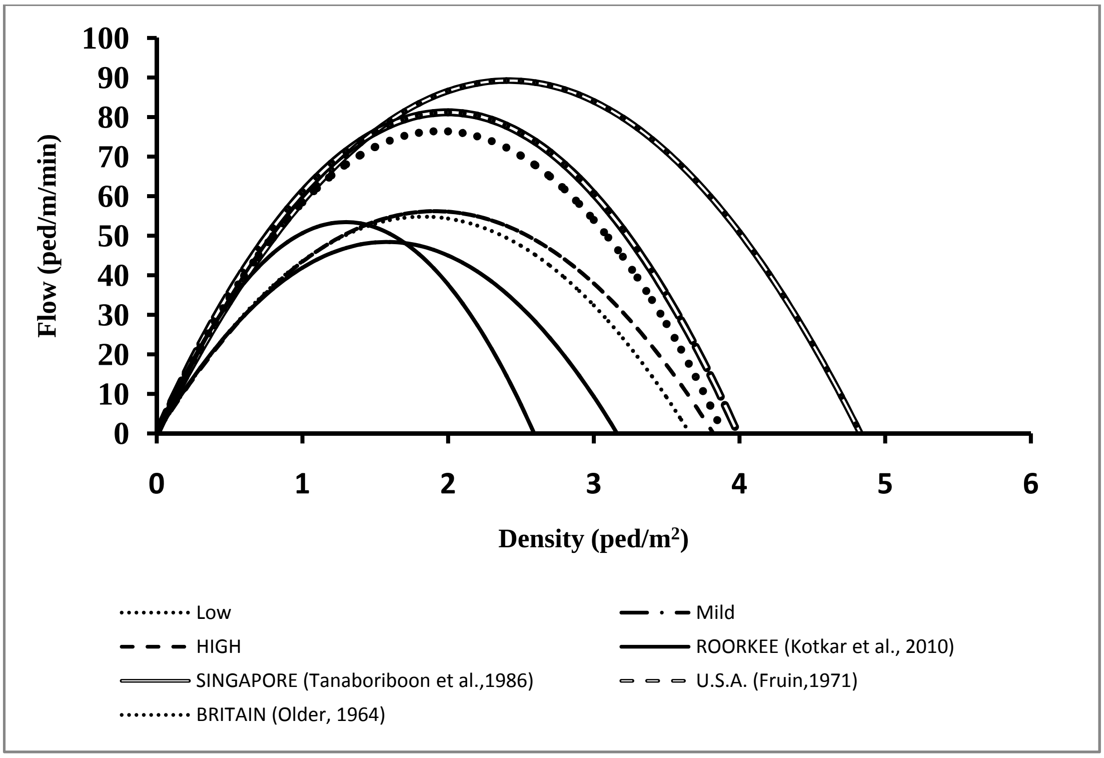


Fig. 3: Comparison of Flow-Density Relations

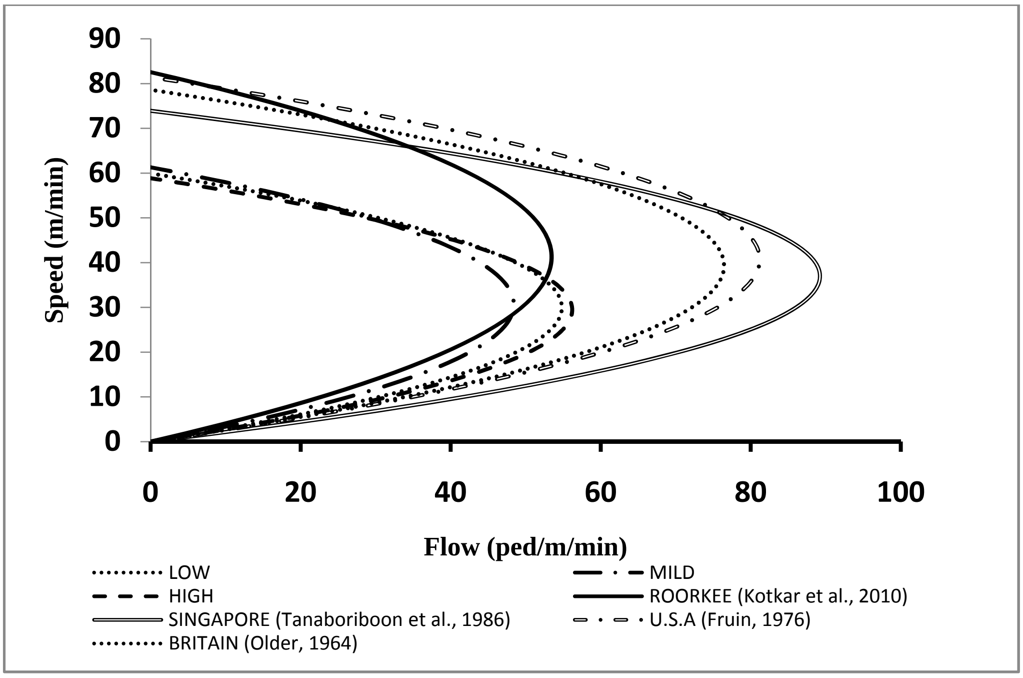


Fig. 4: Comparison of Flow-Density Relations

The pedestrian flow characteristics diagrams of different locations in Dharamshala and Shimla cities are presented in Fig 2-4. The speed-density follows a linear relationship whereas the flow-density and flow-speed found out to be following quadratic relationships.

Analyzed pedestrian flow characteristics at different study locations are presented in Table 8. The free flow speed was found to vary from 59.94 to 61.3 m/min, and jam density was found to vary from 3.16 to 3.82 ped/m^2. Free flow speed varies about 37 % with respect to another flat gradient in Indian (Roorkee, Kotkar et al..2010) and 23, 36 and 31 % with respect to flat gradients in Asian (Singapore, Tanaboriboon et al. 1986), North American (U.S.A, Fruin, 1976) and European (Britain, Older, 1964) continents.

Table 8: Pedestrian Flow Characteristics at Different Study Locations (Uphill)

Location ID	Free-Flow Speed (u_f), m/min	Jam Density (k_j), ped/m^2	Maximum Flow Rate (q_{max}), ped/m/min
LOW	59.93	3.66	54.84
MILD	61.30	3.16	48.43
HIGH	58.84	3.82	56.19
Roorkee (Kotkar et al.2010)	82.52	2.59	53.43
SINGAPORE (Tanaboriboon et al. 1986)	73.90	4.83	89.23
U.S.A (Fruin, 1976)	81.40	3.99	81.20
Britain (Older, 1964)	78.60	3.89	76.44

4. Conclusions

The average walking speed of pedestrians i.e. 64 m/min (irrespective of the direction of movement) at studied tourist destinations is slower than most of the American, European and Asian countries. The results show that the pedestrians of all the three cities are affected by changing topography of the walkways. Also, the walking speed of pedestrians is affected by human intentions as in the case of locations near the bus stand.

The behavior shown by pedestrians on uphill and downhill directions by age, gender and baggage conditions are observed to be satisfactory. However, the difference in uphill and downhill walking speed of pedestrians is different for different categories like age, gender, and baggage handling conditions of pedestrians.

The mean pedestrian walking speed of these two tourist destinations cities was found to be 64.35 m/min irrespective of walking direction. While at different gradient categories, the maximum uphill speed was 60 m/min at Mild gradient locations and maximum downhill speed was 71.12 m/min at High gradient locations. Irrespective of the gradient categories and taking locations altogether the uphill walking speed was found to be 58.58 m/min and downhill walking speed was found to be 70.25 m/min.

The speed-density follows a linear relationship whereas the flow-density and flow-speed found out to be following quadratic relationships. Free flow speed varies about 37 % with respect to another flat gradient locations in India (Roorkee, Kotkar et al..2010) and 23, 36 and 31 % with respect to flat gradients locations in Asian (Singapore, Tanaboriboon et al. 1986), North American (U.S.A, Fruin, 1976) and European (Britain, Older, 1964) continents.

The findings of this paper stress on the need of exclusive pedestrian facilities for the local pedestrians and tourists in the studied tourist cities to improve the flow characteristics, i.e., speed, flow and density at these tourist destinations. Improved flow characteristics will help in decongesting the roads and reduce pedestrian-vehicle friction and accidents. All this will help in making walking safe and attract more tourism at tourist destinations.

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