ANALYSIS OF STAIRCASES STRUCTURE UNDER FOOTFALL LOADING

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Abstract: With increase in rise of assessments for structural components of buildings as a matter of safety, staircases play an important role for an emergency exit for the flow of people. It becomes important to check the structural vibrations induced by human movements' footfall loads on staircases, especially for crowd loading. The analytical results shows the comparisons of stairs vibrations for different models of staircases. The maximum acceleration for the different staircases is carried out showing parametric study, with parameters such as time intervals, dimensions and support condition. Use of the SCI code is done to verify the maximum vibration effect will fall within the permissible limit. SAP software is used for the calculations of accelerations

***Index Terms* – Staircases, Footfall loadings, time history analysis, SAP software.**

I. INTRODUCTION

1.1 DYNAMIC OF STAIRS

The forces induced on the staircases are much higher than that of footfalls on a horizontal surface. Stairs require an increase effort to raise the body with each stride, and this leads to higher compressive forces on joints. Every few codes describe about the serviceability criteria for stairs vibration.

Nothing about the Indian codes gives us idea on the vibration serviceability of staircases, and so the reference of the steel construction institute (SCI) UK, ISO etc. are referred. Pedestrian behaviour on stairs must be understood in order to make sure the level of service for the facilities being constructed for the traveller is to their maximum satisfaction.

1.2 DYNAMIC OF STAIRS

Dynamics is a part that considers the behaviour and effects of motion of the body. The field of dynamic excitation of structures induced by walking or running persons has become a significant research topic during the last recent years. Staircases have always been analysed for static load, while the dynamic loads on staircase have much more influence and should be studied for the vibration serviceability purpose. The human induced loading generally called as the footfall loading is to be analysed more on steel staircases to satisfy the serviceability and vibrational criteria to prevent a stair from collapse. Footfall for a single excitation and multiple footfall excitations are the need to be studied. The research on footfall loads induced by ascending or descending stairs is scarce, although in recent year's problems with vibrating stair constructions have occurred and needs to be analysed.

The applied human dynamic force on floors, stairs, etc., F (t), is defined in terms of Fourier series as: the human induced force on the floors, stairs, etc. is defined by f (t), in terms of Fourier series given as, The human footfalls are considered as periodical dynamic loads that are decomposed into a number of harmonic components according to Fourier series theory.

$$F(t) = G[1 + \sum_{i=1}^{n} \alpha_i \sin(2\pi i f_p t + \phi_i)]$$

Where,

G= Weight of the pedestrian normally considered as 746N

αi= Dynamic load factor

Φ= Phase lag

Fp= Frequency of the load

i= No. of the Fourier term

1.3) OBJECTIVE

- Parametric study of the behaviour of steel stairs and supporting structure, undergoing vibration due to footfall loads.

1.4) SCOPE OF WORK

- For different natural frequency, to evaluate stairs based on their structural configuration and parameters such as dimensions, supporting structure condition and time intervals for the footsteps for different staircase model.
- Acceleration corresponding to footfall loading depending on pace frequency within the range of 1.5 to 2.5 Hz (walking ascend) and 3 to 4 Hz (for fast descend).
- The results will be in the form of deflection and accelerations in vertical direction resulting from footfall.
- Performance of stairs under single and multiple induced footfall loading.
- Evaluation based on serviceability criteria for vibration will be verified.

II. STRUCTURAL PROPERTIES AND MODELLING

2.1) GEOMETRY

Staircase type: - Straight type
Location: - Char Rasta, Ahmedabad
Tread length:-1 m
Tread breadth: - 0.1 m
Riser: - 0.06 m
Railing: - 0.5 m hollow section, outside diameter: - 0.009m,
Wall thickness -0.004m
Railing holder: - circular steel diameter: - 0.005m
The height of the staircase: - 2m
Type of staircase: - steel Fe250
No of steps: - 19
Thickness and bending of shell element -0.014m

2.2) CALCULATIONS OF FOOTFALL DATA ON THE STAIRS

The following are the calculations carried out in the excel sheet for the frequency of 1.5 Hz (minimum walking frequency) and 2.5 Hz (maximum walking frequency) on stairs respectively using the above formulae and the graphs obtained are as bellows, these graphs represent the footfall data on staircase.
Force (kN/m^2) versus time (s) are then obtained from the calculations of footfalls:-

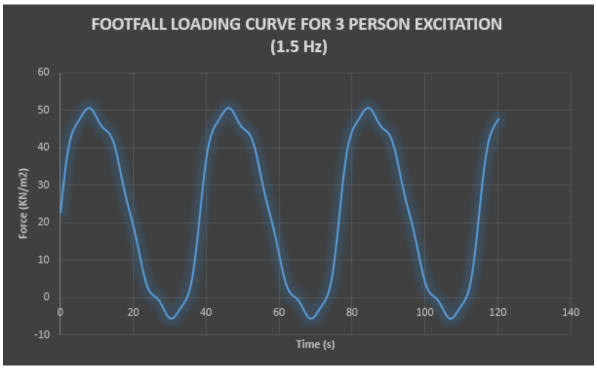

Figure 2.1:- Foofall curve for 1.5 Hz

Figure 2.2:-Footfall curve for 2.5 Hz

III. ANALYSIS

- The model is prepared in SAP ver19.As read from the above graphs footfall historys are implemented to run time history analysis.
- The model was evaluated for maximum and minimun ascend on the staircases. The mass source is then defined for the model, which includes the elemental self-mass.Since it's a framed structure the following available degree of freedom is applied are set to UZ,UY,UZ,RX,RY,RZ direction.
- The load is then applied to the stair to define the path of walking; taking unity value that is 1 Newton, it is then applied as an area load over each step, 0.001KN is divided by the area 0.1m and further divided by 24 parts. Progressive loadings applied accordingly for all the steps of the staircases to check the maximum value of the acceleration due to group loading (1+1+1) of the pedestrian on the stairs such that at a particular time (t) the entire staircase has at least three person on each step proceeding upwards on the staircase pathway.
- The values of the modal frequency , accelerations and displacements are obtained as output.

IV. RESULTS AND DICUSSIONS

The following are the results obtained:-

Original staircases

Model 1		
	min	max
Step Frequency (Hz)	1.5	2.5
Acceleration (m/s^2)	0.189	0.195
Displacement(m)	8.43E-09	8.76E-09
Natural Frequency (Hz)		
1st mode	9.82	9.82
2nd mode	12.27	12.27
3rd mode	12.98	12.98

Table 4.1) original stair output data

Time Intervals

For model-1				
ascending				
Step Frequency (Hz)	1.5			
Time interval (s)	0.25	1	1.5	2
Acceleration (m/s^2)	0.0109	0.0100	0.0080	0.00407
Displacement(m)	1.35E-07	3.05E-08	2.00E-08	1.15E-08
Natural Frequency (Hz)				
1st mode	9.811	9.811	9.811	9.811
2nd mode	12.262	12.262	12.262	12.262
3rd mode	12.976	12.976	12.976	12.976

For model-1				
ascending				
Step Frequency (Hz)	2.5			
Time interval (s)	0.25	1	1.5	2
Acceleration (m/s^2)	0.0115	0.0114	0.0114	0.00419
Displacement(m)	1.43E-07	3.32E-08	2.18E-08	1.22E-08
Natural Frequency (Hz)				
1st mode	9.811	9.811	9.811	9.811
2nd mode	12.262	12.262	12.262	12.262
3rd mode	12.976	12.976	12.976	12.976

Table 4.2) Time intervals 0.25 Hz, 1 Hz, 1.5 Hz, 2 Hz for ascending staircases.

Dimensions

For Model-1		
	min	max
Step Frequency (Hz)	1.5	2.5
Thickness (m)	0.005	
Acceleration (m/s^2)	0.4861	0.4900
Displacement(m)	2.15E-09	2.22E-09
Natural Frequency (Hz)		
1st mode	7.9818	7.9818
2nd mode	9.7375	9.7375
3rd mode	10.3564	10.3564

For Model-1		
	min	max
Step Frequency (Hz)	1.5	2.5
Breadth(m)	2	
Acceleration (m/s^2)	0.72611	0.7462
Displacement(m)	3.18E-09	2.89E-09
Natural Frequency (Hz)		
1st mode	6.7457	6.7457
2nd mode	9.7182	9.7182
3rd mode	9.8334	9.8334

Table 4.3) Dimensions of change in thickness and change in breadth for ascending staircases.

The graph for the maximum accelerations for the original modal are show below, where we see that the orange dot(first modal frequency) is on the verge of unsafe vibrational criteria compared to the other two frequency for model 1 type of staircase.

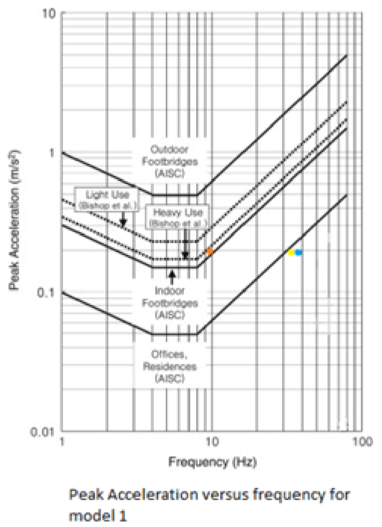

Figure 4.1) Maximum acceleration versus time

Comparing the time intervals values:-

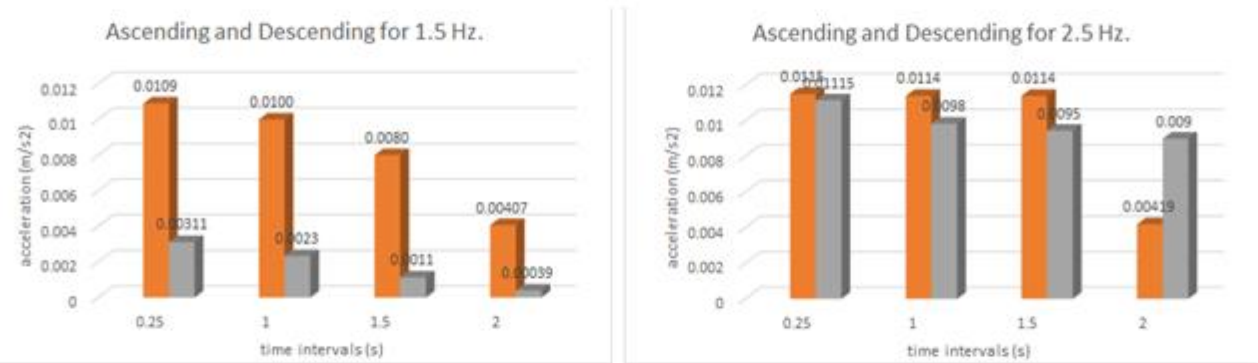

Figure 4.2:- Comparisons of time intervals graph of stair model 1

Comparing the dimensions criteria original thickness was 0.014 m and decreasing thickness is 0.005m , original breadth is 1m and increased breadth is 2m:-

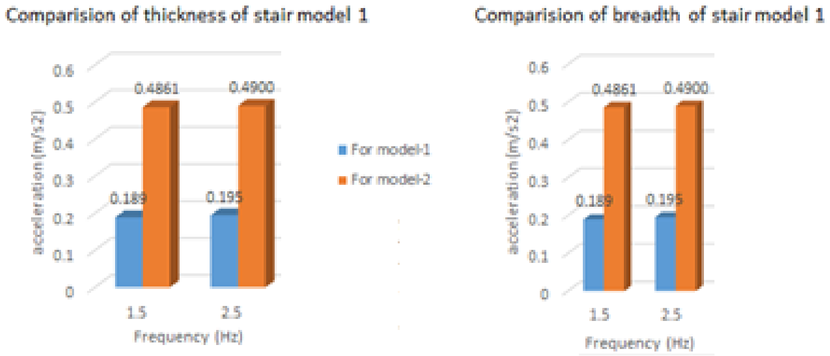

Figure 4.3:-Comparison of thickness and breadth graph of stair model 1

V. CONCLUSIONS

1) Staircases having natural frequency less then 10 Hz,for group pedestrain footfall loadings is said to be dynamically unsafe.

2) The analysis of footfall vibrations on staircases can be verified through the acceptable limits proposed by SCI (steel construction institute) and the ISO (international standard organisation) codes.

3) As time intervals value increases for a given pace frequency the acceleration decreases. As displacement is directly proportional to accelerations, increase in pace frequency the displacement also decreases for acending.

4) With decrease in thickness the acceleration increases and with increase in breadth the acceleration increases for staircases for group loading ascending.

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- Codes:- Steel Construction Institute (UK code)