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Technical Note

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Vibration Design of Steel Staircases

Traditional methods of determining the acceptability of structures for human induced vibration relied on using estimating a natural frequency for the structure and comparing with a baseline frequency. This was generally done by estimating the natural frequency based on the deflection.

More modern methods for vibration design have been developed which look at either the accelerations of velocity of the structure under human induced vibrations. For concrete structures, the Concrete Centre have produced publication CCIP-016 “A Design Guide for Footfall Induced Vibration of Structures”, while the Steel Construction Institute have produced SCI P354 “Design of floors for vibration: A new approach”.

The Concrete Centre publication CCIP-016 provides no specific guidance regard to the design of staircases. The SCI publication however does provide specific analysis guidance and acceptance criteria for the vibration design of steel staircases.

Vibration design: Steady State versus Transient response

The response of a structure to a dynamic force is made up from two components, the steady state and the transient response. The steady state response represents a sinusoidal response where the displacements match the frequency of the forcing function. The transient response dissipates rapidly, with the forcing function acting like a series of short duration impulse forces being applied to the structure. For structures which have a low natural frequency, the transient response is less significant and the steady state response will be critical, whereas for a structure with a high natural frequency, the transient response will dominate.

In section 6.3 of SCI P354, it notes that where a structure is considered to be low-frequency, the response analysis should be carried out for both the steady state and transient conditions. Where the structure is high frequency, only a transient response needs to be considered. Table 6.1 of the publication gives guidance on the low to high frequency cut off. For staircases, this cut off is defined to be 12 Hz.

Design considerations for vibration analysis of steel stairs

Stairs differ from floorplates in some key design aspects which can have a significant effect on their design for vibration. Steel stairs tend to be low mass structures, when compared with floor structures, with low levels of damping. SCI P354 gives a damping ratio ζ of 0.5% for fully welded steel staircases. The low mass and low damping tend to be compounded by the fact that the dynamic load applied to stairs is higher in frequency and magnitude.

Conversely, however, the acceptance criteria for stairs are less onerous than for floor plates. While floors will tend to have factors that will act to accentuate the effects of the vibration such as desks, computer monitors, lights and shelving, these are absent from stairs. These environmental considerations are reflected in the larger acceptable response factors given in SCI P354 for stairs given Table 5.3. The current response factors are given as 32 for light use stairs, for example stairs in offices, and 24 for heavy use stairs, such as stairs in public buildings or stadia.

While SCI P354 provides methods of vibration design that look at single person footfall excitation, SCI Advice Note AD330 notes that for multi person footfall excitation a maximum response factor of 64 can be achieved by designing to the applicable limits given in Table 5.3 for a single person footfall excitation.

Steady State versus Transient response in stairs: SCI AD 406

While SCI P354 requires that a transient analysis is used for both low and high frequency structures, with both the steady state and transient analysis required only for low frequency structures, it does not differentiate between floor and stair structures. However, as the SCI notes in AD406, achieving the required response factors for low frequency stairs is problematic and often the stiffness or mass of the stair needs to be increased to the point where the stair is no longer classed as low frequency, potentially requiring a natural frequency above 15 Hz.

With a natural frequency of 15 Hz, the period of the vibration is given by $T = 1/f$ which gives a period of less than 0.067 seconds. However, the defined impulse force used in the transient analysis is applied over a time of around 0.2 seconds. As noted in SCI AD406, the assumption that the force applied in the transient analysis acts as an impulsive force is no longer valid.

Since the assumption of an impulsive force is no longer valid, the conclusion drawn in AD406 is that, for steel staircases structures, the use of the transient analysis is not valid.

Conclusion

While the design methods for vibration design as given in CCIP-0166 and SCI P354 are valid for the assessment of human induced vibration of stairs, the nature of steel stairs means that the transient analysis method as given in SCI P354 is not valid for steel staircases and should not be used.

Regards

MasterSeries Team ☺