AD 406:
Transient response factors in vibration analysis of staircases

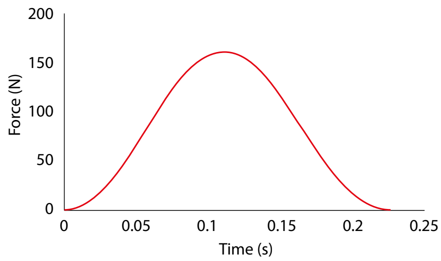
SCI recommends that for most orthodox designs the **transient** response of a staircase should not be considered in design, as first implied by AD330[1]. The purpose of this advisory desk note is to clarify the reasoning behind this advice.

The SCI's key publication on design for vibration is P354[2]. This publication describes an acceleration-based checking methodology (response factor), suitable for both floors and staircases, that supersedes traditional checking of the natural frequency of the structure. The publication describes two checks that must be performed; steady-state and transient analysis. While both checks must be carried out, steady-state response tends to be critical for lower natural frequency structures, while the transient response tends to be critical for structures with higher natural frequency.

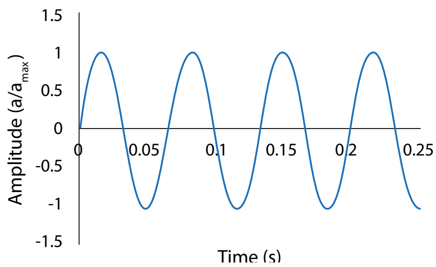
Several differences exist between design of staircases and floors for vibration. Staircases tend to have low mass and a low damping ratio. Staircases are also subject to a different force profile, since users tend to travel faster and step harder when ascending or descending a staircase than they would on a flat surface. The force functions provided by Bishop et al.[3] are recommend for use in steady-state analysis.

Conversely, the acceptable response factor for a staircase is higher (less onerous) than for a floor, as the audio and visual stimuli that accompany vibration of a floor, such as monitors and shelves shaking, are not present on a staircase. SCI currently recommends limiting response factors of 32 for light use (such as stairs in offices) or 24 for heavy use (such as stairs in public buildings and stadia)[1,2].

Even with the less onerous acceptance criteria, it is very difficult to design a staircase with a



Force of a footstep (Input)



Response of structure (Output)

low frequency that would pass the steady state criteria. In SCI's experience, staircases with natural frequencies, *f*, less than 15 Hz will struggle to pass. Designers may increase either the mass or stiffness to decrease the response factor, which is usually achieved by increasing member sizes.

The calculation of the transient response assumes instantaneous impulsive loading. For most structures, the response time of the structure is much larger than the contact time of a footstep so this assumption is valid. However, for structures with frequencies over about 15 Hz, this assumption begins to break down.

In reality, a footstep delivers most of its energy to the structure over a contact time of about 0.2 seconds[3]. A typical staircase might have a natural frequency of 15 Hz or greater, which gives a natural period of about 0.066 seconds. The response time of the structure is therefore less than the contact time of a footstep.

The figure shows the force function from Bishop et al. for a fast ascent (4.5 Hz) compared to the normalised response of a 15 Hz mode (left and right respectively). The x-axis, showing time, is consistent in both plots. This figure highlights the higher natural frequency of the structure compared to the frequency of the forcing function.

The assumption of instantaneous impulsive loading is therefore invalid in this case. The increased contact time between the person and the structure will result in destructive interference in the oscillation, which the analysis method does not take into account.

For the reasons presented, SCI considers that the transient response prediction is not applicable to typical staircases, and therefore should not be used in design.

References

1. AD 330: Vibration of steel staircases, Steel Construction Institute
2. SCI P354 Design of Floors for Vibration: A New Approach, Revised Edition 2009
3. N.W.M. Bishop, M. Willford, R. Pumphrey, Human induced loading of flexible staircases, Safety Science, Volume 18, Issue 4, February 1995, Pages 261-276, ISSN 0925-7535, http://dx.doi.org/10.1016/0925-7535(94)00035-2.

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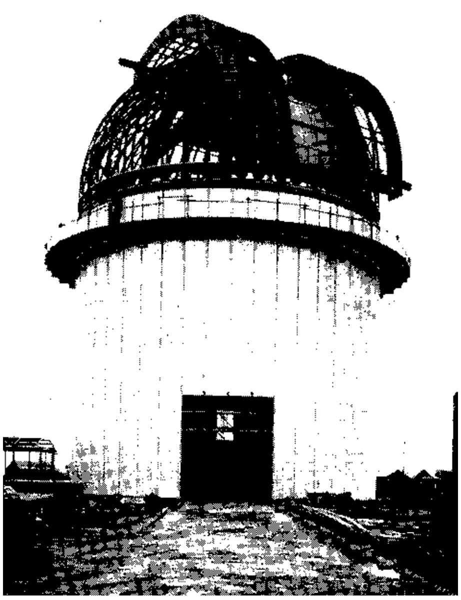

BUILDINGWITHSTEEL

The largest telescope in Europe

The Isaac Newton astronomical telescope at the Royal Greenwich Observatory, Herstmonceaux Castle, Sussex, is the largest in Europe. The main mirror is 98 in (2.5 m) in diameter and 16 in (41 cm) thick. Designed by Grubb Parsons, the telescope - weighing 100 tons - is housed within a dome which is accurately balanced and levelled on a track 56 ft above ground level.

The building housing the telescope is of steel-framed construction, circular in plan of 60 ft diameter and 60 ft high. Steelwork comprises sixteen 18 in by 7½ in by 66lb universal beam stanchions 55 ft high. Steelwork is grit blasted, zinc sprayed and painted with one coat of calcium plumbate.

Floor beams are at 36 ft 6 in and 48 ft levels with a cantilever balcony at 48 ft. This balcony is for the use of