CROSS Safety Report

Failure of cantilevered stone staircase

This month we present a report concerning the partial collapse of a cantilevered stone staircase without warning during a renovation at a stately home built around 1830.

Abridged report

A reporter has provided details of a partial collapse, without warning, of a 'cantilevered' stone staircase. The collapse occurred during the renovation and change-of-use conversion of a former minor stately home while the staircase was subjected to pedestrian loading.

The property was constructed in the 1830s as a private residence, comprising traditional stone masonry, typical of the era. Before the refurbishment, the building remained empty and unmaintained for a period in excess of 15 years during which time the building fabric deteriorated largely due to the effects of weather and the absence of maintenance. Rainwater had penetrated the fabric of the building. Structural timber in the building had suffered from wet rot and the naturally porous limestone masonry in the walls had become damp, possibly to the point of saturation. Significant drying out of the damp fabric was required.

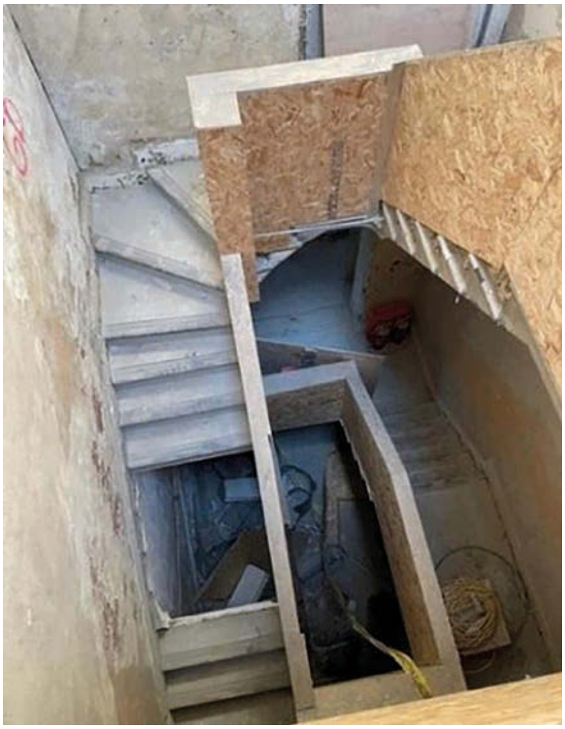
The staircase consisted of stone steps projecting out from the masonry walls. The reporter says this type of staircase is commonly referred to as a 'cantilevered' staircase, appearing to cantilever out from the wall, but in practice, it is not a true cantilever. The stability of each individual step relies on the presence of the step below for its principal vertical support while the shallow embedment into the wall resists the torsion induced in each step from the pedestrians traversing the stair. The reporter goes on to say that the presence or absence of a rebate to the lower front edge of each step also determines how and to what extent forces are transferred from one step to the next through a stair flight.

During the collapse incident, four steps of a flight of a staircase sheared off at the face of the wall **(Figure 1)**. The trigger for the collapse appears to have been the load of one pedestrian, two people having traversed the same steps moments before without incident. The four dislodged masonry steps and the person on the staircase at the time fell onto the flight directly below. This appears to have caused the immediate failure of six further steps of this lower flight.

The staircase was being used for the movement of personnel and lightweight materials during the refurbishment works. No excessive loading of the stairs had been reported. Dry rot filaments were, however, visible on the fracture surface of the lowest of these four steps. **Figure 2** shows the fracture of a step where it failed. The tread area and leading edge of each step was inset with a round-nosed slate wearing surface. The 40–50mm thick slate nosing was set on a bed of what appeared to be an epoxy-type mortar.

The reporter says the slate may have been an original construction detail but, equally, it may have been a later addition, introduced sometime after the original construction perhaps to address wear to the softer limestone treads. There were no records to confirm when the slate was introduced. The reporter goes on to say that epoxy mortar may suggest that some work was undertaken on the structure during the mid-to-late 20th century but it was not possible to be more precise.

The presence of the dry rot filament growth across the fracture surface



↑ FIGURE 1: A hole in the staircase where four steps collapsed onto the flight below

Key learning outcomes

For architects, designers, structural engineers and contractors dealing with stone staircases:

- →| Surfaces and the bearings of stone stairs should be closely examined
- →| 'Nosings' or other repairs should not be cut into existing stone treads without careful consideration of all effects
- →| Avoid heavy impact loadings to stone staircase treads
- →| Anything 'old' should be treated with care and records thoroughly researched
- →| Proceed with caution when considering buildings that have been poorly maintained

indicated that this fracture existed for some time prior to the collapse. This fracture surface and the 'clean' fractures of all the other failed steps, were close to the face of the wall into which the steps were built and are all broadly coincident with the ends of the cut-in slate. The rebate cut into each limestone step to receive the wearing slate, narrows the stone section and creates a point of stress concentration at the face of the wall in each step.

The reporter noted that prior to the collapse, the existing fracture would have been obscured by floor coverings on two of the three faces of the triangular step and therefore difficult to identify. Only the underside of the sloping soffit would have been visible; however, this would have been the 'closing' side of any crack at the fracture surface. It was possible that there was little visible evidence to indicate the pre-existing fracture.

Combination of events

The reporter concluded that it appears likely that the staircase was weakened by the fracture of one individual step. It was clear that the group of four steps in the upper flight collapsed under the load of one person. The collapse was perhaps due to a combination of the reduced torsional capacity resulting from the single fracture, the historical introduction of the slate nosings, and the impaired tensile strength due to more recent wetting or saturation of the masonry. Four steps fell onto the flight immediately below. Here, the sudden impact load resulted in the fracture of a further group of six steps which then also fell to the floor. The partial collapse of the staircase did result in injuries requiring hospital treatment, furthermore, the reporter considered that the potential for life-changing or fatal injuries was high.

FIGURE 2: Section through failed step at fracture position

Expert Panel comments

The reporter is to be congratulated for presenting a very good assessment of the likely cause of failure. As demonstrated by the reporter, working with existing buildings requires significant experience. Both designers and contractors must understand what potential faults and problems may be encountered. As in this case, defects are very often hidden and experience is required to understand how these will impact the building not only on completion of any works but also during the process of refurbishment. Where deterioration has taken place additional care is required. Understanding the type of construction and the issues that may be experienced is essential.

These stone staircases are a marvel of building work which has puzzled many as to how they stand up. However, this report does illustrate the risk of sudden and catastrophic failure even to structures that appear very stable and long-lived. Despite a thorough survey, the circumstances suggest the failure could not have been foreseen. It serves as a reminder to designers and contractors to remain vigilant and to always treat older structures with a degree of circumspection.

The report highlights the need for very detailed appraisals of such staircases and indeed buildings generally. The circumstances of the building should be carefully considered in planning inspections and assessments. Clearly, buildings that have been poorly maintained allowing water and rot to enter the structure are very likely to have hidden and potentially very significant degradation. The default assumption should be that deterioration has taken place over time. Unoccupied buildings may have had less observation and intervention. Anything 'old' should be treated with care and records searched to see if previous problems, existing problems or indeed future problems can be identified. Guidance on many types of potential failures and issues can be found if research at the investigation stage is thorough. Not all parts of a structure are, of course, capable of being visually inspected; intrusive investigations may be required in many areas. Other inspections and testing will likely also be required. Specialists experienced in the assessment of existing structures can add valuable insight.

As highlighted by the reporter, it is clear that very close inspections of stone stairways, particularly at their supports, should be carried out. The Conservation Compendium series in *The Structural Engineer* includes *Part 5: Inspection and repair of cantilever stone staircases* which includes information on how stone 'cantilever' stairs work, their inspection and repair. Where stone staircase treads are subject to a heavy impact loading, inspection of the structure would be prudent.

When old buildings move, there is sometimes hard-to-predict redistribution of loads. If walls and stairs have moved or deteriorated, such a structure may be subject to redistribution of forces with forces locked-in and hidden critical elements created. Alterations may release locked-in forces in unpredictable ways leading to collapse. In some cases, it may be prudent to provide temporary works which will provide support but not stress enough to unlock locked-in forces. Alterations in buildings generally (in this case possibly the cutting in of nosings) need to be approached with caution such that the effect of alterations on structural capacity is understood.

This example reminds us that the weak point in any structure will generally be the connections – here the wall junction and the tread rebates; assessments of buildings should ensure that connections between structural elements are carefully considered. Finally, and as amply demonstrated in this example, masonry fractures are brittle and any brittle failure is likely always far more hazardous than a ductile failure.

A further paper in *The Structural Engineer – Stone cantilevered staircases*, authored by Sam Prince and Helen Rogers, provides more in-depth background, history and explanation of the mechanics of the 'cantilevered' staircase.

The full report, including links to guidance mentioned, is available on the CROSS website (report ID: 1147) at **www.cross-safety.org/uk/safety-information/cross-safety-report/failure-cantilevered-stone-staircase-1147**.