REPORT

The Christmas Day landslide at Nottingham Castle

Newspapers and television news programmes featured the landslide at Nottingham Castle on Christmas Day, 1996. Initial impressions of a demise of the sandstone crag on which it stands, or of any involvement by descendants of Robin Hood, were unfounded.

Nottingham's real castle was of Norman origin. Sadly for expectant latter-day tourists, it was almost completely destroyed in 1651 at the end of England's civil war. It had stood on a steep crag of Triassic Sherwood Sandstone which rises nearly 40m above the floodplain of the River Trent. The commanding site was subsequently occupied by the seventeenth century mansion, which survives in modified form today as the Castle Museum, and is often incorrectly referred to as the Castle. The mansion, splendid and spectacular in its own right, is firmly founded on solid sandstone, but is surrounded by a wide paved terrace.

At the outer edge of the terrace, a perimeter wall, built in about 1700, retains a soil fill which is capped by the terrace paving. To make space for the terrace, this wall had to be founded out beyond the flatter top of Castle Rock, and it probably rose from narrow ledges cut into the steeply sloping sandstone of the upper cliff. The height of this wall reached about 7m on the corner at its southernmost tip, where it projected farthest out from the museum building and where it crossed a shallow gully cut into the sloping top of the Castle Rock sandstone.

Prologue

A corroded iron water main within the terrace fill chose Christmas Eve to finally burst, just after everyone had packed up and gone home. At 9 o'clock that evening, water and soil was seen pouring down the cliff; a small fan of sand and silt had formed in the garden below, and the occasional rock came crashing down through the darkness.

On Christmas Day morning, Castle staff found the flagstones of the paved terrace had been disturbed due to the raised water pressure in the soil fill around the broken main; some flags had even lifted a little. Yet water was also pouring out from the bottom of the perimeter wall, taking the odd piece of masonry with it. The water main was closed off at the entrance to the Castle grounds, but back pressure on the ring main ensured that water continued to flow at a significant rate.

Leakage of the water through the base of the wall provided the outlet for yet more of the finer components being washed out of the fill. Piping cavities must have been developing; these characteristically expand in the upflow direction, so that some grew just beneath the paving and close to the break in the water main. At about 1pm, two of the paving flags collapsed into a small crater. A potential hazard was perceived, and the Castle grounds were closed. But the water was switched off, the Council engineers were off on holiday, and there did not seem to be much else that could be done.

Down below, the alluvial fan at the foot of the cliff continued to grow, in mute testimony to the amount of fill being washed out from behind the wall. By mid-morning, it had spread across the 7m of the Castle's lower gardens, so that silt and sand were being washed through the paling fence and across Peveril Drive. The water could be seen to be pouring from the foot of the wall, mainly where it sat on the rock on its western edge; it was also weeping out of the lower two thirds of the wall's height.

Collapse

Early in the afternoon, water, sand and masonry were still falling down the cliff. From his home on Castle Boulevard, a man had seen and heard the debris coming down at various times since first light. Some time between 2 and 3pm, an increase in the noise of the falling debris made him look up. He stood almost mesmerised as the whole wall slowly

The site of the failure seen from the foot of the cliff on 27th December, before the loose debris was removed, and with the fallen tree and lamp post still leaning across Peveril Drive (photos by Tony Waltham).

bulged out at mid-height; then its lower section failed and burst outwards, followed by total collapse of the whole structure. It was all over in a few minutes, and the observer only cursed that he had not had a camera to hand. There were no dramatic sound effects, and people inside nearby houses heard nothing. The museum duty attendant was in his office 50m away, when he heard a whooshing noise, and went outside to find that the terrace had gone.

The wall, the fill and the paving all fell to the foot of Castle Rock. Nearly 100 cubic metres of soil and masonry, weighing around 200 tons, lay piled on the strip of garden below. Most of it remained behind the iron fence, though the odd block of stone had bounced across Peveril Drive, where a sheet of sand and silt was also washed out. A plane tree was hit by the debris, so that it was laid across the road, where it bent a lamppost to a bizarre angle.

Up above, there was a yawning gap where about 10m of the wall had fallen away. With it had gone most of the soil and old masonry that had originally been held behind it. None of the bedrock sandstone had failed. The wall and artificial fill, and perhaps some remnants of natural soil, had merely slipped off the rock, with a slip surface at the rockhead. Fortunately the massive stone foundations of the Castle Museum had been built up from solid sandstone bedrock behind the rim of the steeper cliff, and the mansion stood unharmed. The museum foundations are bonded with only a weak lime-clay mortar, which is best not exposed to rainwash or frost for long. A good spread on the foundation masonry has ensured that there is no danger of further failure before the constraining terrace is replaced.

The Christmas Day collapse provided a classic example of the failure of a retained soil which had become saturated by a sudden input of water from a broken pipeline. Water has a devastating influence on a soil structure, and increased water has three separate effects. First, the raised water pressure within the ground acts laterally as an increased force pushing the retaining wall outwards. Second, the raised pressure of the interstitial water within the soil forces the soil particles apart; soil strength is largely due to its internal frictional resistance to shear, which depends on the force pressing the grains together, so the strength is reduced by increased water pressure, and yet more load is cast onto the retaining wall. Third, flowing water washes the finest particles out of the soil, in a process which increases until all the soil is washed out along the drainage route to create a piping cavity, which ultimately collapses. The sequence of events at the Castle clearly shows that all three processes were active through the 18 hours between first sight of the water leak and the final collapse.

Closer view of the slide scar, with the masonry of the Norman wall visible beneath the overhanging terrace paving; undisturbed sandstone is exposed at the foot of the picture.

The landslide site seen from almost vertically above, after the loose debris had been cleared off. The straight line of the Norman wall is clearly exposed, as very little of it had fallen away; the gap in it dates almost entirely from about 1680, when space was created for the mansion foundations.

It is likely that irreversible damage was done to the terrace structure during the night when the water was flowing unchecked for over 12 hours. Large piping cavities were formed in this early phase, as indicated by the amount of fines washed down the cliff by Christmas Day morning. The total collapse may have been prevented if the water had been completely stopped early in the day; but the terrace would have remained as a distressed structure demanding rather tricky remedial engineering.

Epilogue

A veneer of loose material remained on the sloping rock of the slide scar; this was soon cleared off, to add to the debris pile far below. The newly exposed sandstone appeared devoid of any joints or open bedding planes which could be regarded as contributory to the failure; one niche across the rock face looked as if it had been artificially cut as a footing for the wall structure. The rock's bare surface had been scoured by the passing debris, but otherwise appeared to have remained intact. The bedding is nearly horizontal, so could contribute little to slip surfaces. Almost vertical joints are aligned mainly to the northwest; one underlies the landslide scar, but was not involved in the failure. It appears that practically none of the water drained into the rock; the nearest part of Mortimer's Hole is almost beneath the slide scar, offset just a few metres to the east, and no water entered it. The intact weathered sandstone has very low permeability at the rockhead surface, there are no open joints or fissures at the site, and the steep slope encouraged rapid run-off.

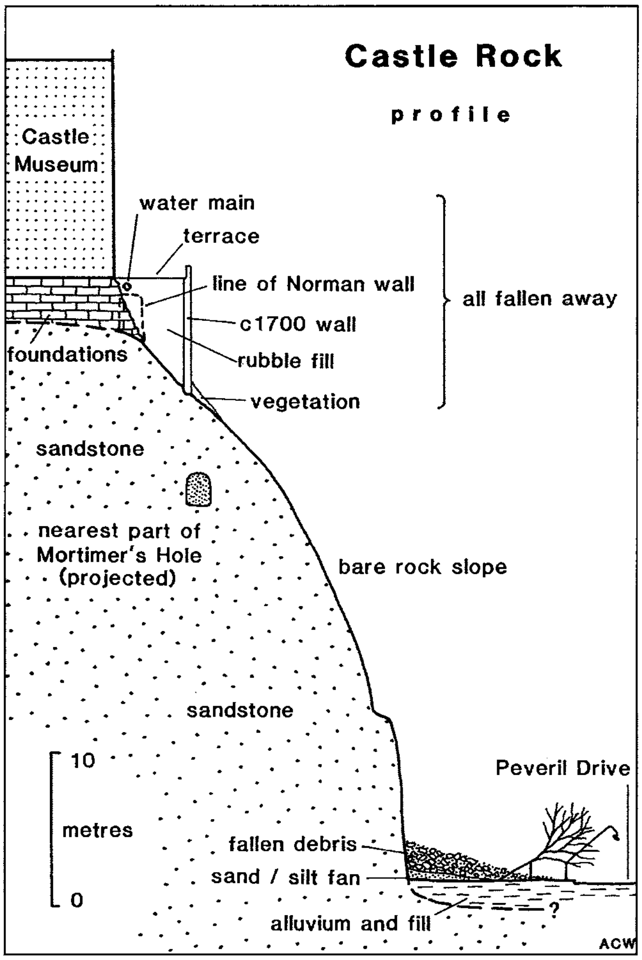
One incidental benefit of the landslide has been the exposure of a medieval wall, perhaps of Norman origin, which had lain buried under the paved terrace for over 250 years. A section of this was removed in about 1680, to make room for the foundations of the new mansion. A little more seems to have fallen away in the new landslide, but two cross sections through the rough sandstone stonework remain in either side of the slip scar. Repair work started in January. A temporary platform is supported on scaffolding columns which stand in vertical holes drilled a metre into the exposed sandstone. This working platform allows placement of rock anchors to tie the remaining walls and the museum foundations back to the sound sandstone. Designs for the renovated terrace have come down to two options. One has a new concrete wall, standing on and anchored to the exposed sandstone; behind it, a rubble or gravel fill re-buries the Norman wall, and carries the flagstone paving of a restored terrace. The concrete wall is faced with masonry blocks from the original wall, rescued from the debris below, so that the restored site will look as before. Alternatively, the hole in the terrace is left open to expose the different foundations and wall remnants, now stabilised, and a cantilevered viewing platform will complete the terrace walkway by spanning the gap. Aesthetics and costs are the two factors which must determine the choice, hopefully to be made in time to complete the main works before the 1998 summer visitor season.

The only map of the original castle is that by Smithson, drawn in 1617. An overlay of this on a modern plan of the site, correlated with features excavated at the north end of Castle Rock, aligns two medieval walls on the southern rim of the rock crag; the wall exposed by the landslide lies exactly midway between these. This indicates an error in the overlay. It remains uncertain that the exposed wall is the original outer wall, set back a little from the lip of the cliff; traces of rendering on its outer face may be relics from the time when it was known as the White Tower. In the unlikely event that it is the original inner wall, then the outer wall has completely gone, and the whole cliff face must have retreated by about 6m — with some interesting implications for geomorphology.

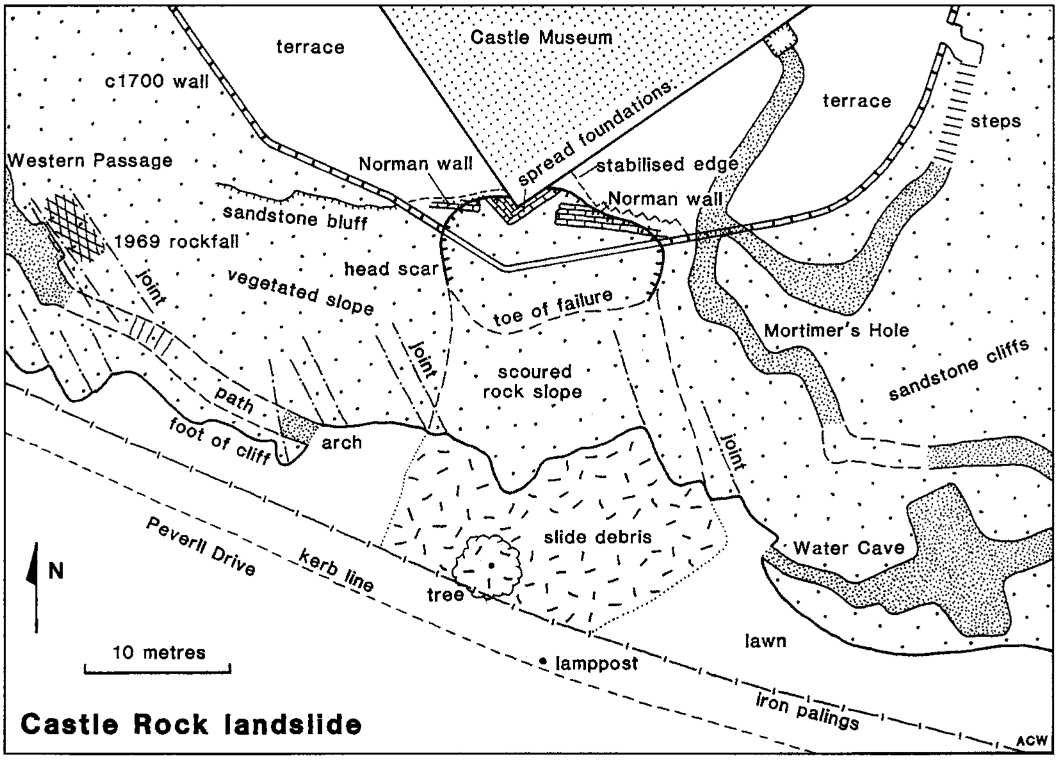
Peripherals

Castle Rock does have a history of rockfalls and failures, most of which were small and in styles not directly related to the latest event. The iron cross at the head of a masonry anchor was visible on the section of wall which fell on Christmas Day; but this was at least 100 years old, and was unrelated to the latest failure.

Beside one of the old cave entrances at pavement level on Castle Road, a slab of sandstone, measuring



Profile of the southern end of Castle Rock, on the line of the 1996 landslide. The wall and terrace fill around the edge of the museum building fell away to expose the foundation, while the rock slope remaind intact.



Plan view of the landslide site on the southwestern corner of Castle Rock.

about 3 tons, became unstable during 1996. Tree roots were growing in an inclined joint in the rock, forcing it open at a rate measured at over a millimetre per day in the summer growth season. This movement created new fractures in the adjacent rock, and a slab failure became a serious threat. The tree has since been removed, and concealed bolts now lie through the rock to restore its stability.

Trees and other vegetation do improve stability on soil slopes, by removing water, reducing erosion and providing tensile strength with their root mat; but those benefits are trivial on rock slopes, where roots are detrimental because they weaken sound rock by opening up the joints. Individual rockfalls are mostly small, but tree roots are a significant hazard on many of the sandstone cliffs. Clearance of the trees from the cliffs above Castle Road, in January 1997, is the best possible thing to have happened to them. Total removal of the trees, and killing of their root systems, would clearly lengthen the life of the rock faces around Castle Rock. There is a strong case for removing all the trees on the cliffs around the southern tip of the Rock, and this would also improve the visual appearance of this very distinctive geological feature.

The largest recent rock fall was in January 1969, on the southwestern face of Castle Rock. This is recognisably the least stable zone around the Castle, as the main cliff is parallel to the dominant set of joints, aligned northwest to southeast; there is little instability on the southern tip of Castle Rock, where the main joints are aligned straight into the cliff. Almost above the lower entrance to Western Passage, a pillar of rock rose 9m but had little support; more than 7m of it was separated from the main rock face by an open joint. The top of it appears to have fallen off in a separate failure 30 years previously. The main pillar failed by shearing through only about 1 metre of rock at its base, and about 20 tons of large sandstone blocks landed in Peveril Drive. This fall was of the type triggered by rising water pressure and frost action during the winter months, in contrast to the falls due to tree roots which occur in the summer months. With the outer slab gone, new support was necessary to prevent the next parallel slab of sandstone subsequently failing as the joint behind it opened due to stress relief; remedial works included concealed rock anchors, the large concrete buttresses which still stand against the rockface, and concrete grout seals in the exposed open joints.

Rockfalls are a component of the long-term erosion and denudation of Castle Rock. Records of earlier events are sparse, and it is difficult to make estimates of the overall rates of erosion and cliff face retreat. At the foot of the Rock, there are various caves which appear to be only the remnants of a more extensive group of artificially cut rooms and passages; their fragmentation is evidence of the cliff's retreat. Weathering and collapse of the caves accelerated the rates of face retreat on many of Nottingham's sandstone cliffs, notably when one generation of caves became unsafe and were therefore intentionally destroyed when the cliff was cut back to a new stable profile. This may have been a significant factor in creating steep cliffs in place of more gently graded natural buffs, and Castle Rock was probably no exception. Higher up the cliff, erosion rates would have been closer to natural levels, and could reasonably be expected to be in the order of 1 metre per 1000 years. Retreat of 6m since Norman times appears to be untenable, except that larger landslides could have created major anomalies in the retreat patterns. There is still much to learn of processes on Castle Rock.

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