REPORT

Microgravity in Nottingham

Expansion of the ice stadium is creating various engineering works on the eastern edge of Nottingham's city centre. A main sewer draining from the Lace Market underlies Barker Gate, and is unwelcome where it lies beneath the site of the expanded stadium. It was therefore proposed to divert it northwards under Belward Street to join the existing sewer under Hockley.

Belward Street was only created in 1970 by cutting through old houses and factories between Barker Gate and Hockley (Fig. 1) to create the last link in the northbound inner ring road. A conventional trench to install the sewer beneath the road would require excavation through a complex of old building foundations, floor slabs, ditches and backfilled cellars; the natural 1-2 metres of sand formed by weathering probably survives nowhere along this stretch of road. The trench would then need to be sunk through another 3-5 metres of Sherwood Sandstone. With night working and severe access restrictions on the busy road with no scope for traffic diversion, the proposed sewer diversion was becoming an expensive item.

A straight, small diameter, bored tunnel was therefore considered as an alternative to the sewer. This would require a small boring machine to cut through the sandstone for the 130 metres between shafts sunk in Barker Gate and Hockley; a tunnel lining of concrete rings would then be jacked into place behind the advance of the boring machine. In sound intact rock beneath the old foundations, this operation would be very simple, but there was a serious prospect of encountering caves in the sandstone. Recovering a boring machine that had dropped into a cave would have been prohibitively difficult and costly.

In this part of Nottingham there was a strong likelihood that caves would be encountered along the tunnel line. Unfortunately, there were no records of caves beneath the buildings that were demolished in 1970, except for the cistern cave under the old mill west of the tunnel line, and the position of this was known only roughly (Fig. 1). It was therefore decided that a geophysical survey was the best means of exploring the possible existence of caves beneath the street; a microgravity survey was the most appropriate, and was completed in April 1998.

A LaCoste and Romberg Model D gravimeter was used to measure the Earth's gravitational field strength. This small, portable and very expensive instrument contains a weight on a spring, whose length is therefore proportional to gravitational pull. It is read to 1 microgal (one millionth of normal gravity), and was operated by one technician over five nights to complete the survey. He had to work at night because lane closures on the busy road were not acceptable during the day; this did have the benefit of reducing artificial vibrations which interfere with reading the very sensitive instrument. A passing car was no problem, and he had to wait less than a minute for the ground to settle down after any heavy truck passed.

The geophysicist took three readings every five minutes at each of 401 stations, spaced 2 metres apart on lines 3 metres apart to produce a grid of data. He also took 117 readings at a base station to detect temporal changes, and levelled each station to ±5mm. The data was then computer processed to produce a contoured map of the local gravitational field strength. Effects of altitude, latitude and Earth tides were removed to produce a Bouguer gravity map that indicated geological anomalies. Small shallow caves produce negative anomalies with a

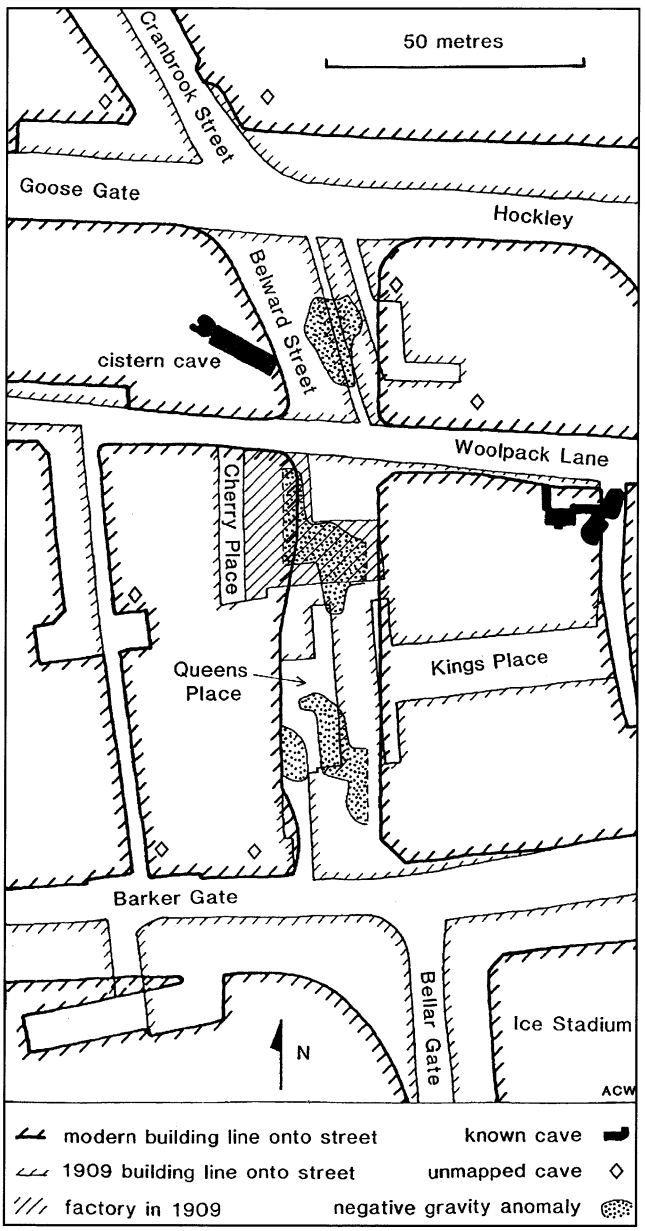

Fig. 1. Simplified map of the area around Belward Street, Nottingham, showing the relationships between the modern streets, the old streets (as on a map of 1909), the known caves, and the negative gravity anomalies (shaded where more than 40 microgals below background values).

total width (wavelengths) of about 20 metres, so the data was filtered to remove all anomalies with wavelengths >50 metres (which could have been due to deeper geological structures). The resulting map revealed a series of significant, small negative anomalies (Fig. 1). A typical cave 3 metres in diameter beneath 4 metres of cover produced a negative anomaly about 50 microgals deep and about 8 metres across; the anomaly decreases and widens as the depth of cover increases, and also decreases if the cave is full of water or uncompacted debris.

The gravity anomalies revealed by the survey may be related to the sizes of caves that are characteristic of the Nottingham sandstone, and also matched the old street pattern of the site (Fig. 1). The large central anomaly is probably due to caves, now under 5 metres of cover, that were beneath a factory east of the old Cherry Place; in size and extent the caves may resemble those known just to the east, south of Woolpack Lane. The southern, double anomaly appears to relate to a group of caves that was under Queens Place and the terrace of houses between it and Kings Place; these now have a cover of about 4 metres, and could have been domestic cave cellars or caves from adjacent factories. The northern anomaly is an odd shape and its data could not be modelled for depth as it extended out of the survey area, but it lies under the site of old houses and factories either side of an alleyway south from Hockley. No anomaly was found under the north side of Barker Gate, where old, house cellar caves might have been expected; any caves may have been unroofed or tightly filled with demolition rubble which would almost eliminate their gravitional effect.

A small incomplete anomaly on the edge of the survey (not marked on Fig. 1) lies over the approximate position of the corner of the cistern cave. Though this cistern is not accessible it is known to lie at the water table; it is therefore beneath about 7 metres of rock, and at that depth would create a less detectable gravity anomaly.

The gravity survey produced useful data, but all the anomalies required drilling to prove their interpretation. However it had already become clear that a bored tunnel was not going to be practicable through such cavernous ground. It was thus found more economical to realign the Barker Gate sewer so that it lies beneath non-critical parts of the expanded ice stadium. The survey had cost several thousands of pounds (including the costs of traffic control), a sum which approached 4% of the project cost; this proportion is not unusual for a tunnel project where "unforeseen ground conditions" can be disastrously expensive. Drilling was abandoned, and more about these caves will probably never be known.

Many thanks to City of Nottingham Environmental Services for providing access to their survey data, which was produced by Geotechnology (of Aberdulais, Neath).

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