

# Heathrow failures highlight NATM (abuse?) misunderstandings

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In February 1999 the heaviest fines ever imposed following prosecution by the British Health & Safety Executive were levied against Balfour Beatty and Geoconsult following collapse of NATM station tunnels on the Heathrow Express Rail Link Project at Heathrow Airport in London in October 1994. Balfour Beatty, tunnelling contractor on the £440 million project, pleaded guilty to violating two counts of the country's Safety at Work Act 1974 and was fined £1.2 million plus £100,000 toward prosecution costs and were given 14 days to pay.

Geoconsult, as specialist designer to Balfour Beatty for the NATM works on the project, denied the charges but was found guilty by a jury of 12 after a 26-day criminal trial at the Old Bailey Criminal Crown Court and was fined £500,000 with £100,000 towards costs and was given two-and-a-half years to pay.

The two charges laid against each company were for failing in their duty to ensure the safety of their employees during construction of the NATM station tunnels at the CTA (Central Terminal Area), and failing to ensure the safety of those not in their employ (the general public), by exposing them to danger. For Geoconsult the charge included technical supervision of the works.

Following a quite extraordinary trial - which has actually left no party to the proceedings unscathed - Geoconsult has lodged an appeal against both the conviction and the sentence. It claims that HSE "breached its paramount legal obligation to prosecute fairly" and that rulings on procedural orders "resulted in prejudice" against the company. Against the sentence it claims that the fine is excessive and overlooks guidelines that fines should reflect the gravity of the offence but should not imperil the existence of the company. The total £600,000 fine for Geoconsult is levied against an original contract value of £1 million and against a medium sized consulting engineering company. The £1.3 million total fine for Bal-

four Beatty is set against an original contract value of £ 60 million and against a company within a large corporation that accounts for about 10% to 15% of the group's £2 billion annual turnover. The fact that Balfour Beatty admitted guilt, the judge said, mitigated in its favour although it was made evident during the trial that Balfour Beatty "must bear greater responsibility for the collapse".

One of the major losers in this case is the prosecuting agency itself. The HSE was severely criticised by the trial judge for its conduct of the case and was awarded only £200,000 of the £880,000 claim for costs. In the opening days of the trial and by chance, the defence team found that much of the prose-

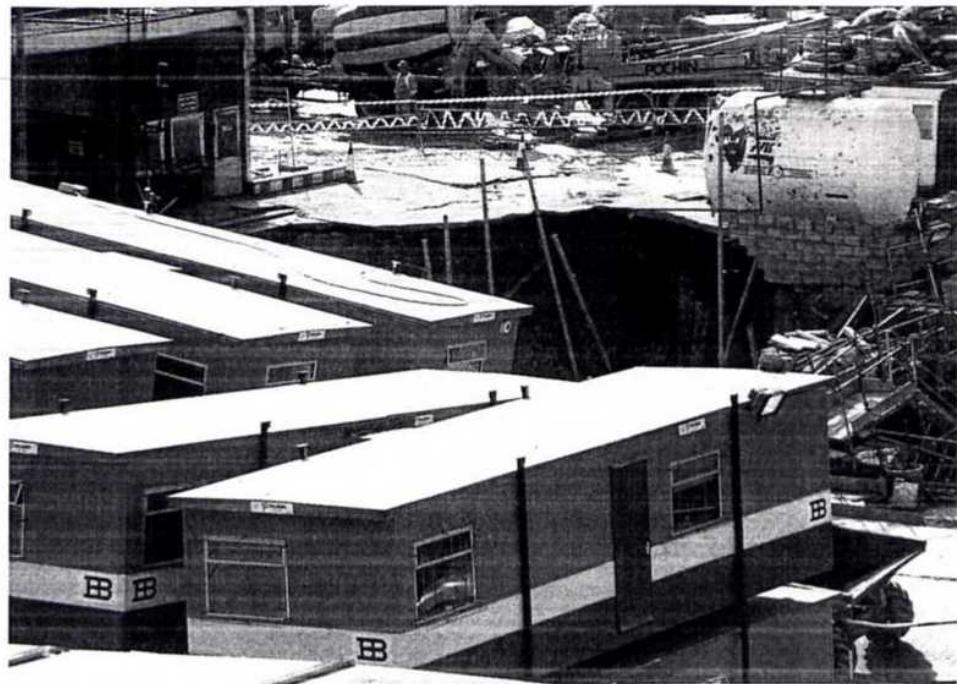
cution's main expert witness report had been directed and in some cases written by the leading HSE inspector. The report could not be relied upon as being independent and unbiased. As a result prosecution withdrew the report in its entirety and the court allowed prosecution to depend on the alternative expert witness of Sir Alan Muir Wood and of Prof John Hutchinson. These reports were introduced by prosecution at a preliminary hearing in November 1998, it was said, to support the original and subsequently withdrawn expert witness report submitted by Mr Guy Lance of WS Atkins. In response, defence made application for the case to be dismissed on the grounds of "abuse" and applied also for the expert witness of Muir Wood and Hutchinson to be disallowed as substitute. Both applications were denied and the trial proceeded. This matter is to be re-examined in Geoconsult's appeal. So although HSE obtained a conviction, it was effectively fined £680,000 - not including the cost of the Lance report.

## The trial

During the trial, evidence revealed extremely poor workmanship; major flaws in construction management; and questionable contractual arrangements. Miners in the tunnelling gangs told of difficulty in constructing the invert joint of the NATM side-wall drift

Balfour Beatty's lowest bid £60 million contract was to build 8.8km of shield-driven running tunnel and various NATM caverns including the underground station complexes at CTA and Terminal 4 on the estimated £440 million Heathrow Express Rail Link Project. Geoconsult was specialist NATM design engineer to Balfour Beatty. NATM was specified for design of the stations following a successful trial of the method in London Clay at Heathrow in 1992. The trial was designed and supervised by the UK office of Austria's Dr Sauer company and was built by the Kier/Lilley/Kunz UK/German joint venture. This was the first use of NATM in London Clay and the method was subsequently adopted for the Waterloo and London Bridge stations on the Jubilee Line Extension of London's Underground. At no time in the trial did HSE or prosecution suggest that NATM as verified by the trial tunnel or designed by Geoconsult for the Heathrow Express was defective in any way. Prosecution and the HSE in its report "Safety of NATM with particular reference to London Clay" stated that NATM is a safe and appropriate tunnelling method in London Clay "providing enough care is taken" and that the Heathrow NATM structures now open to the public since mid 1998, are safe.

excavation sequence; of problems with blockages and delayed delivery of shotcrete; of regular changes in the personnel in the gangs and of little continuity of routine. Construction foremen and shift engineers told of pressures from management to improve productivity and make up for delays. Site and supervising engineers raised concerns about over-excavation of rounds by the miners; inexperience and lack of skill in the crews; and higher than expected surface settlement leading to inspection and repair of invert where shotcrete was 50mm instead of 250 to 300mm thick; where there was insufficient overlap or no starter bars at all in construction joints; and where shotcrete was sprayed over rebound. Senior project management engineers questioned the apparent lack of an experienced supervision team; the apparent disregard of the many CARS (corrective action requests) raised by any engineer noticing poor workmanship; apparent disregard of SDNs (system defect notices) raised by the project management team for the attention of senior contract managers; the application of "self certification" as part of the construction contract; and early relaxation of the already disfunctioning auditing role by HEX of the contractor's self-certification system.

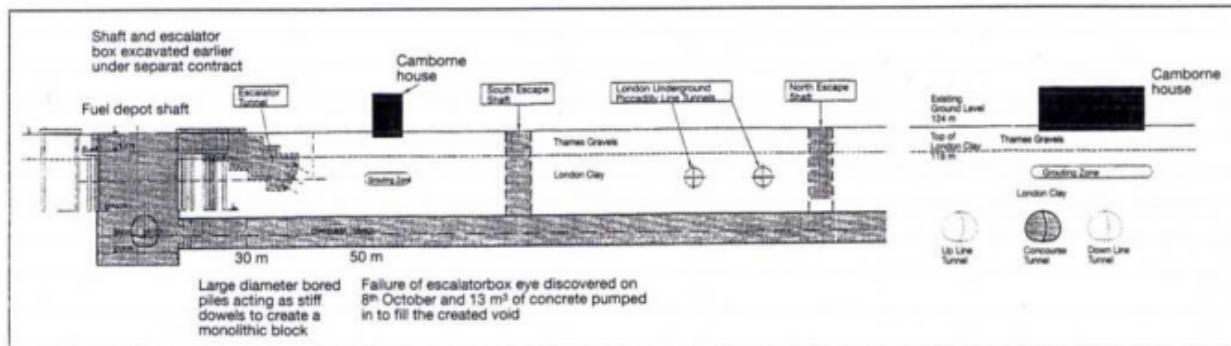


1 It was on the night of 21 Nov. 1994 that the Central Terminal Area station tunnels collapsed causing extensive damage to the surface

All of these flaws culminated in October 1994 with the ultimate collapse of the CTA NATM about 12am amid the sound of cracks in the shotcrete. Eventually the teams were ordered to vacate the tunnels at about 1am. Cracks in the shotcrete started to propagate faster and grew wider during the early hours of the night shift. At about 7pm the abandoned tunnels started to collapse and continued over the two following days being moved from one area to another to try and repair cracks causing extensive damage to and replace lumps of shotcrete. All stabilised as they fell and wire mesh burst through the green shotcrete of underground cavity infilled with earlier repairs.

### The prosecution case

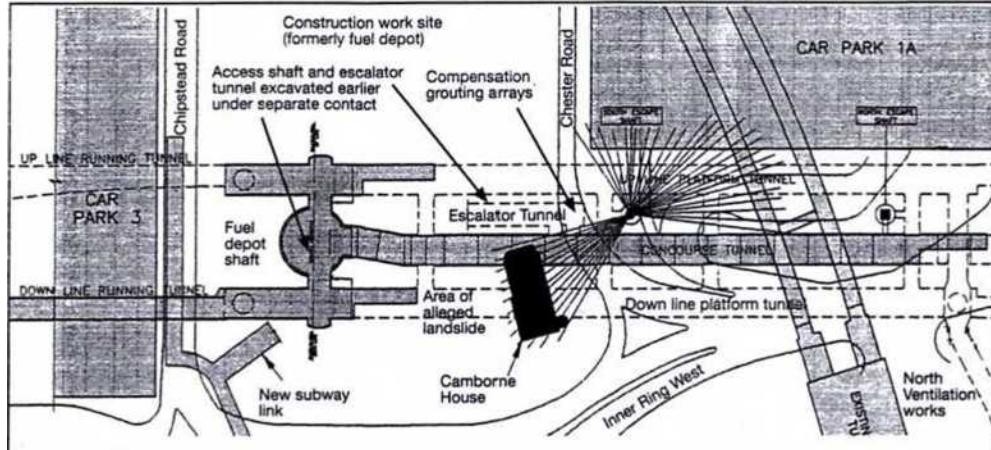
HSE as the prosecuting agency claimed that the collapse "was the worst civil engineering disaster in the United Kingdom in the last quarter of a century" and that it was only by chance that no-one was seriously injured or killed. As well as endangering the lives of the workers, prosecution suggested that the consequences for the public could



have been disastrous, if the collapse at one of the world's busiest airports had occurred during the day, and if the concourse tunnel had "unzipped" to beyond the Piccadilly Line tunnels of the London underground system which lie above the Express Rail Link tunnels and some 70m out in front of the collapsed zone (Figs 2 and 3). Prosecution claimed on the basis of expert witness that monitoring data indicated that the collapse was evident up to seven days before the event, that Geoconsult was "the watchdog that did not bark".

Sir Alan Muir Wood for prosecution stated that in his opinion, the collapse was caused by the defective invert. He claimed that recorded monitoring data and other contemporaneous evidence indicated that collapse was imminent up to 14 days before. He criticised the NEC form of contract as inappropriate for tunnelling contracts; that self-certification as a method of quality control had failed; and that (under cross examination) "it is very unfortunate for Geoconsult to find itself where it is" and that "morally it is very hard luck for them." He said that "the way in which the whole management of this contract was proceeding meant there was a great break between engineering and construction which, to my mind, is the fundamental ill effect which led to all these things happening". He said that liability for the collapse "should extend to those who were putting these sorts of contracts together".

Jonathan Allen, CTA area manager in BAA's (the private owners of Heathrow Airport) HEX (Heathrow Express) management team said that he was "concerned with the lack of understanding about self



3 Plan of the excavation works completed at the time of the collapse of the Central Terminal Area

certification in that Balfour Beatty felt HEX should not be involved". He felt, he said, that Balfour Beatty were paying "lip service" to self certification. In his read statement Bob Gee, engineering design manager in HEX, said other than increasing the initial prediction of 9.34mm of settlement over the concourse tunnel at CTA, the HEX team were satisfied with Geoconsult's NATM design and the baseline criteria and assumptions used. There was concern however of apparent lack of supervision and lack of experience in the construction teams as work started and a major concern that the process of self-certification and its audit by the HEX team was not working. He said that while compensation grouting had been used in August 1994 to counteract higher than expected (18mm) settlement under Camborne House above the CTA concourse tunnel as it passed underneath, the HEX team was not alarmed by monitoring data they had seen to date. "We did not spot the lead up to the collapse," he said, and that at the last progress meeting between HEX and Balfour Beatty on the day of the collapse, "neither settlement nor

on-going repairs in the invert of the CTA concourse had been raised", (in evidence Sir Alan Muir wood retorted that "Nero was fiddling while Rome was burning".) In defence, it was made clear that Geoconsult was acting as part of Balfour Beatty's own engineering department under manager Ian Massey; and that Geoconsult personnel were not invited to project meetings; were not on the distribution list of letters or meeting records; and were not party to various decisions including it was claimed the programme of compensation "jacking" under Camborne House in August 1994, nor the decision to stop concourse tunnel invert repairs in August rather than continuing back to the access shaft; nor the instruction to open the two parallel upline and downline station platform tunnels in late September to make up for delays of 28 days and 80 days on these headings. Further evidence read by prosecution from the Balfour Beatty section engineers log book prior to the collapse gives an indication of the climate on the site. Entries read: "Alan (more muck) Myers [Balfour Beatty's construction project director] demands we

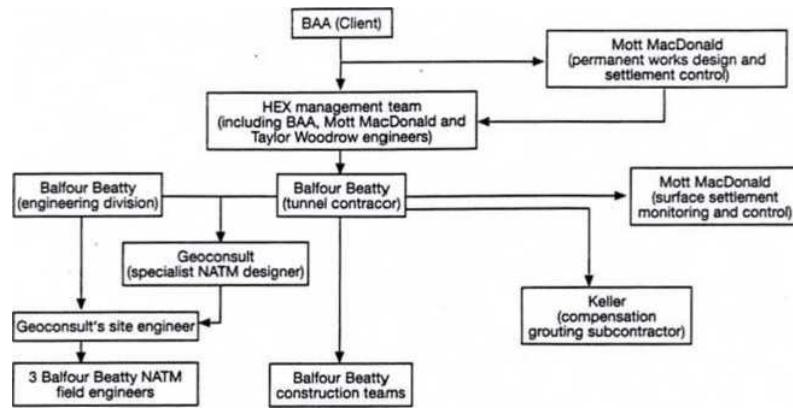
double production by the end of the week. He demands that we open all six faces. Panic all round". "Cracks in the temporary wall - expert foreign sounding gentleman to inspect and instruct." "Oh dear, oh dear, oh dear. Horizontal cracks in concourse tunnel. The witch hunt starts now." "Big movement in the concourse crown at chainage 31 to 40m. Time to open up the invert for a look see." "Work on invert [in section back to the shaft] still on-going. You might as well take the whole section out." In his evidence Muir Wood suggested that removal of a large section of the tunnel's infill clay over the defective invert (rather than in 2m sections as instructed and carried out for the earlier repairs), together with starting the parallel platform tunnels, initiated the collapse.

#### The case for the defence

Of all the collapse reports produced so far, perhaps the most thorough is that produced by defence expert witness Prof. Reinhard Rokahr of Hanover university. Sir Alan Muir Wood admitted that his report was prepared in a week

and used "rough back of an envelop" calculations; the Guy Lance expert witness report was withdrawn; an expert witness report produced by Profs. Mair and Potts of Cambridge University for Balfour Beatty was not made available, given Balfour Beatty's guilty plea; and the incident Report, called for by the UK government and being prepared as a statutory duty by HSE with input from Guy Lance of WS Atkins, Martin Thurgood of HSE, and Sir Alan Muir Wood among many others, is yet to be published.

Although Prof Rokahr criticised the lack of on-site NATM authority at Heathrow; lack of experience among the field engineers, the tunnelling foremen and the crews; poor quality of the monitoring instrumentation data; lack of full time geotechnical geologists within an NATM supervision team that already number too few; limited instrumentation data available; serious omissions in the installed instrumentation regime; and of the "inadequate" computer software system provided by Balfour Beatty for processing the instrumentation data; he did state that there was sufficient recorded data to indicate that: "In my view, the causation of the collapse, in all probability and I think bordering on certainty, is a large scale slide of the clay mass in the zone between the downline platform tunnel north heading and Camborne House (Figs 2 and 3)." The collapse, he claims, started as horizontal shear cracks in the walls of the advancing side wall drift of the downline platform tunnel. After losing support in the area of the downline platform tunnel, a monolithic block of clay created by a number of bored piles near the working shaft and acting like stiff dowels,



4 BAA, known in the UK as a progressive client, chose the New Engineering Contract (NEC) for the project and to adopt a system of "self certification" whereby contractors certify their own work and keep their own quality assurance records. To manage the project, BAA established the HEX team comprising engineers from Mott MacDonald, BAA's project engineer and designer of all the permanent works; Taylor Woodrow, appointed before contracts award as construction manager; and members of its own engineering and management staff, in addition, Mott MacDonald was appointed by BAA and under separate contract to monitor and control all surface settlement issues during construction of tunnels under the airport facilities. It undertook the same responsibilities for Balfour Beatty under a different contract and Keller was engaged as the specialist contractor to undertake compensation grouting to control surface settlement under sensitive structures. Following the collapse, all parties to the project remained engaged and in a truly single minded project oriented approach, some quite remarkable engineering and construction work, including NATM work in the stations, was undertaken to restore the situation and complete the project just 6 months later than schedule - but at what cost depends where you start counting

bore down on the concourse tunnel which, with its defective invert, could not act as a closed ring. This imparted heavy loads onto the upline platform tunnel where the new shotcrete could not carry the exceptionally high loads and failed. Thereafter the block subsided further and caused the defective invert of the concourse tunnel to fold in on itself and the upper part of the concourse to settle by approximately 2m but without leading to a complete collapse of the crown. The defective invert, said Rokahr, and its ongoing repair could not on their own have triggered the collapse. The report by Mair and Potts he said, declared that even with part of the invert completely removed, the tunnel, as designed, should still have stood up for up to 80 days. He suggested that a soft-

ening of the clay body caused by starting the two parallel platform tunnel headings, and a soaking of the clay through the collapsed eye of an escalator box (excavated overhead and under a earlier contract) could have initiated the landslide. He claims that deformation and settlement readings taken under Camborne House in August 1994, with an equally defective invert, were higher and did not cause collapse than those recorded, in the area that did collapse in October. All readings, including the last taken before the collapse, he stated, were well within the design's critical level criteria. Rokahr's expert evidence is based on the theory that some unforeseeable and completely unpredictable behaviour or geotechnical mechanism in the clay body is the only explanation

for the collapse given the circumstances of the work, the evidence, and the geotechnical data available. He said that the speed of collapse could not be predicted and that workers were not exposed to risk until immediately before the collapse.

Hutchinson, professor of geology at imperial College as an expert witness for prosecution, stated that London Clay is a well documented, largely homogeneous, uniform and extensive body of over consolidated sedimentary clay with very few discontinuities and none identified in the area of the CTA that could have caused a landslip such as the one described by Prof Rokahr. He did however criticise the site investigation carried out by Mott MacDonald as being "preliminary" and "surprising if a tunnelling expert

did not carry out a further investigation".

In a reverse of usual criminal prosecution proceedings, the burden of proof is on the defence to prove that all reasonably practicable was done by their staff to avoid the collapse and avoid endangering the lives of workers and the public. To this end Geoconsult argued that its responsibility on-site was greatly reduced by Balfour Beatty in that its original proposal for three full time employees (an experienced site engineer and two full time NATM construction foremen) had been reduced to one site engineer whose responsibility was to act as site liaison with Geoconsult's design office in Austria, prepare the NATM working sheets as required, interpret monitoring data, and advise Balfour Beatty accordingly. They further argued that the one on-site Geoconsult engineer, Adrian Kattinger, tried to exert the type of authority usually invested in the NATM site Engineer on the Continent and through a full team of equally skilled and experienced field engineers, but against all the odds.

Kurt Laubichler, Geoconsult's head of NATM work at HEX, said in an interview with HSE that Geoconsult was "requested in writing by Balfour Beatty, after award of contract I think, that we should propose one man to work within the framework of the services description". He said Geoconsult had no choice other than to agree. Balfour Beatty claimed that it had sufficient NATM experience from the Channel Tunnel and other projects and that it could provide all the necessary site foremen, shift engineers and field engineers. With only one Geoconsult engineer on-site, defence claimed it was implicit that Balfour Beatty had as-

sumed the role of construction quality control supervision. This was confirmed in a letter from Alan Myers, project director for Balfour Beatty, to the HEX management team a month before the collapse that: "The primary function of the NATM engineers is not quality control. Quality control is the responsibility of the construction teams. This is in accordance with our self-certification scheme, we repeat we have continuous NATM engineering supervision and we do not have project-wide quality problems as you suggest." Three engineers were provided by Balfour Beatty to assist Geoconsult's engineer in the field but these had little or no on-site or NATM design experience and had to cover all NATM areas of work on the full project.

In his efforts Adrian Kattinger warned of poor workmanship and the possible consequences to Balfour Beatty's engineering and management staff and to his colleagues in head office in Austria. He raised several CARs, and had his instructions overruled - a point clearly illustrated in the trial evidence when the NATM field engineer on night shift asks of his fellow engineer "Was it agreed on the day shift that there is no need to progress invert repairs in the concourse any further back toward the shaft?" A "NO!" in Kattinger's hand writing indicates the answer but regardless, repairs of the concourse tunnel invert (following excessive settlement and compensation grouting under Camborne House during August 1994) was stopped at chainage 54m. It was during subsequent repair of the invert from chainage 54m back to the working shaft in October that the tunnels collapsed.

### The verdict

After closing statements the jury was dismissed to consider its verdict. In his instructions, the judge asked the jurors to consider: Did Geoconsult endanger the lives of its workers and those of the general public and did they do every thing "reasonably practicable" to avoid such risks? If yes to the first part and yes to the second part - not guilty. If yes to the first and no to the second - guilty, it took the jury 10h - and a return to the court room to hear further evidence about the collapsed escalator box and the 13m<sup>3</sup> of concrete pumped in to fill the void created - before it returned a unanimous verdict of guilty against Geoconsult.

In the aftermath of the trial, the UK technical trade press has carried numerous letters and articles on various aspects of the case including criticism or support of the New Engineering Contract and of self-certification while in the meantime the actual cause of the collapse remains a point of professional dispute.

On addition other serious issues are being discussed. For example is a criminal court really the most appropriate venue for investigating such events? In an open letter to a UK technical trade magazine Geoconsult stated that had the collapse occurred in Austria, an official investigation would have been conducted but "it is improbable that criminal proceedings would have resulted in a case where nobody was injured or killed". The criminal case against the four construction site managers following the NATM tunnel collapse in Munich just weeks before the Heathrow collapse, and which killed four people,

was stopped near the end of the Heathrow trial by the judge on the grounds that even though the four accused were not on the site when they clearly should have been, the event and its consequences could not have been avoided. Equally, is judgement by a lay jury of such complex technical matters appropriate? The industry itself knows how difficult it can be to discuss technical engineering principals even among skilled professional engineers.

So, Although the trial is over, the debate continues. First the result of Geoconsult's appeal is awaited and at some stage, the international tunnelling industry will finally, after more than four years, have sight of the official HSE report into the incident itself.