Report overview

S1. At about 4 pm on Sunday 21 May 2000 two crane erectors and a crane driver died when the top of a tower crane erected at the HSBC construction site in Canada Square, London E14 overturned and fell about 120 metres to the ground.

The crane and climbing equipment

S2. The Wolff 320 BF tower crane, one of several tower cranes on the site designated DS2, had been erected by Hewden Tower Cranes Ltd in August 1999 and was used mainly to assist steel erectors. As construction of the building progressed the height of the crane had to be increased. This was done by adding crane mast sections using externally mounted climbing equipment, consisting of a nine metre high 'climbing frame' incorporating a long stroke hydraulic cylinder.

S3. The 'climbing frame' was guided by two sets of four grooved guide wheels that ran on the corners of the mast legs. Each new mast section to be inserted was lifted onto a platform at the front of the 'climbing frame' before a climb sequence started. The hydraulic cylinder was then used to raise the top of the crane creating a gap sufficient to move a new mast section in place. Each 'climb' raised the height of the crane by 4.5 metres.

The incident

S4. On the weekend of the incident, the erection crew had worked both on this crane and a sister tower crane on the other side of the building. Climbing of the other crane was completed at around midday Sunday. At the time of the accident, the erectors had just inserted the final new mast section and were starting to lower the crane top to make the final connection to the mast. After testing, the crane would then be ready for normal use.

S5. At this point in the climbing procedure, an erector suddenly became aware that an upper guide wheel – probably the north east guide wheel - was twisting around the corner of a crane mast leg. The climbing frame now seemed to be tilting about the mast leg. The mast started to shake violently before the 'climbing frame', hydraulic cylinder, new mast section and the top of the crane overturned, falling about 120 metres into the construction site below. Michael Whittard, Peter Clark and Martin Burgess fell with the top of the crane and were fatally injured. Two erectors managed to survive by jumping into the mast at the start of the incident.

The HSE investigation

S6. Inspectors from the Health and Safety Executive visited the site on the evening of the incident and a formal investigation started the next day with support from a specialist engineering inspector. The team was subsequently joined by staff from the Health and Safety Laboratory (HSL) and an HSE lifting specialist. HSE inspectors met with detectives from the Metropolitan Police and agreed that a joint investigation should be undertaken, in line with the 'Work-Related Death' protocol.

S7. Initially, HSE had to agree a plan with the contractors to remove or make secure damaged steelwork. Once a suitable plan had been developed, recovery work on the main area of wreckage began on 25 May. The HSL team oversaw the operation to ensure that potential evidence was catalogued and safely removed to HSL's site in Buxton for examination. HSE inspectors and Metropolitan Police detectives then began interviewing the various witnesses. The evidence provided by witnesses and by physical examination of the wreckage together with analyses by HSL staff suggested a number of possible factors that might have been causative of the collapse.

Pre-existing defects

S8. Metallurgical examination of the wreckage by staff from HSL did not reveal any evidence of significant fatigue cracking in the climbing frame members or guide wheel supports. HSE cannot rule out the possibility of a pre-existing defect, as any such defect might have been obscured by the damage caused when the climbing frame struck the ground. The survivors did mention the existence of a slight 'bow' in the climbing frame, a few metres above the top set of guide wheels; but this seems to have been present for some time and appears to have been too high up the frame to account for the collapse. However, its significance could not be assessed directly because of the damage caused by the impact.

S9. Close examination of the wreckage suggested that there was still a gap of about 350 to 400 mm (14-16") between the new mast section suspended from the top of the crane and the mast at the time of the incident. The uppermost guide wheels at the front of the climbing frame had both experienced high twisting forces causing plastic deformation; one had become detached and fallen to the ground. The climbing frame held together for long enough to enable this plastic deformation to occur to the guide wheels suggesting that any pre-existing defect in the frame had not compromised its overall integrity.

S10. A few weeks later, HSE established that the climbing frame had not been thoroughly examined. An enforcement notice was served on Hewden Tower Cranes requiring all remaining climbing frames to be subject to thorough examination. Further enquiries suggested that this might be a general problem within the industry. A press release was issued on 14 June 2000 to publicise the matter.

Slewing the crane

S11. Witness evidence tended to support the survivors' view that the crane had not been slewed shortly before the incident and it was not 'windy'. There was, however, no anemometer on the crane and the crew had relied on information about wind speed from drivers of neighbouring cranes.

S12. The power cable to the motor of the hydraulic cylinder had not been connected to the indicated socket on the counterjib in accordance with the manufacturer's instructions. This arrangement was designed to prevent the operation of the slewing motor during a 'climb'. The special connector for the power lead to the hydraulic motor was said to have been damaged and could not be used. It would therefore have been possible to slew the crane during climbing. The only

other accident of this type known to have occurred (in San Francisco in 1989) had been blamed on powered slewing of the crane by the erectors combined with pre-existing defects. The investigators therefore carefully considered the possibility that the erection team:

- deliberately slewed the crane to 'jiggle' the last mast section into position, causing excessive loading on the guide wheels, or
- failed to prevent the unintended rotation of the crane arising from a sudden side wind acting on the crane jib and overloading the guide wheels.

However, the physical evidence and modelling considered by HSL strongly suggested that the crane was not slewed. In addition none of the witnesses recall the crane being slewed.

Loads producing backwards overturning moment

S13. HSL established that a substantial backwards overturning moment must have acted on the top of the crane, producing stresses at the upper guide wheel supports large enough to cause localised failure. However, it was not clear how such a large overturning moment had developed. HSL considered the main sources of overturning moments that might have been sufficient to cause gross overloading of the guide wheels and their supporting brackets. The structural integrity of the climbing frame was examined. HSL developed models to explore the stresses and deformations likely to occur and a dynamic model to simulate how the crane would react under various conditions. On their own, these stresses were not large enough to result in failure without a particular combination of circumstances. If, however, the wind speed had exceeded the maximum permitted at the start of climbing then reversed direction by 180 degrees during the course of the climb **('double wind hypothesis'**) a substantial backwards overturning moment might have developed.

S14. Before climbing work resumed at the site three months after the accident, discussions were held with the manufacturer and the user to ensure action was taken to strengthen the system of work and to improve instructions to erectors and the supervision of climbing operations.

S15. Subsequent work by the Building Research Establishment (BRE) concluded that the 'double wind' scenario was unlikely to have occurred. Nevertheless, BRE calculated that the average wind speed at the time and place of the incident might have approached the maximum allowed by the manufacturer, although this did not tally with the clear evidence of those on or adjacent to the DS2 site including the two survivors of the incident.

Independent specialist advice

S16. External specialists were commissioned to review HSL's work and to suggest new lines of enquiry, where appropriate. First, a Professor of engineering reviewed the witness and documentary evidence, considered HSL's test results and calculations and saw parts of the wreckage held by HSL. He suggested some additional work including a test loading of an undamaged guide wheel. This test was carried out at the end of 2002 and suggested that the guide wheel supports were somewhat stronger than had been thought.

S17. The Professor concluded that the overturn must have been caused by an abnormal event. He found it difficult to explain how the guide wheel supports could have been overloaded and why no similar event had occurred previously during a climb. He suggested that the climbing frame had lost its support on the side of the mast nearest the building. He argued that the mast would then have sprung forward causing the top of the crane to move backwards, increasing the guide wheel forces and leading to the overturn **('yoke disengagement hypothesis'**). He said it could not be proved that this had happened but he felt that this was the most likely cause. However, it did not appear to be consistent with the available physical and witness evidence.

S18. Separate advice was then commissioned from a tower crane consultant recommended by the Occupational Safety and Health Administration of the USA. The OSHA Consultant reviewed the documentary evidence and suggested that a series of events, omissions, conditions or actions may have combined to cause the overturn on this occasion and not earlier climbs (**the 'multi-factor hypothesis'**).

S19. This consultant saw the main factors as including:

- the degree of vertical misalignment of the mast
- the 'balance' of the crane assessed by the erection crew before each climb
- non-uniform clearances between the guide wheels and mast
- the stiffness of the climbing frame (which has a large open space at the front, relatively light bracing and is prone to twisting in significant side winds)
- the stiffness of the mast, taking account of the ties to the structure
- wind forces and directional effects, which can be complex
- design and manufacturing tolerances of various components
- the condition of the guide wheel assembly

S20. The OSHA Consultant agreed with HSL that the overturn probably started at the upper guide wheel that failed. However, he warned that exact details to explain the collapse might never be found to a satisfactory degree of engineering certainty. A further review of all the specialist work was undertaken by an HSE lifting specialist who had had no previous involvement with the investigation. He suggested a further possible explanation (the **'jammed guide wheel hypothesis'**). Again, the available evidence did not tend to support this explanation.

Conclusion about the cause of the accident

S21. At the conclusion of the main investigation, the Crown Prosecution Service (on the basis of a report prepared by the Metropolitan Police) concluded that there was insufficient evidence to pursue a charge of manslaughter against any party. The Coroner's inquest in November 2003 returned open verdicts on the deaths of the three Hewden Tower Crane employees, Michael Whittard, Martin Burgess and Peter Clark.

S22. Some of the witness evidence given to the Coroner's inquest and the report from the OSHA Consultant received just before the inquest suggested further issues to explore; these were followed up. However, by the end of 2004, HSE concluded that even these lines of enquiry had been thoroughly exhausted.

S23. The investigation proved to be particularly technical and complex. Having explored the evidence extensively and evaluated potential causes, HSE found no convincing explanation to account for the precise cause of the collapse. Four specialist engineers had put forward different hypotheses to explain the incident but none fitted the witness evidence and the physical damage observed sufficiently closely. This is a considerable disappointment, especially for the families of those who died.

S24. During the investigation, HSE found several unsatisfactory aspects to the arrangements for tower crane climbing; appropriate improvements were sought and agreed. These aspects included the following points:

- the manufacturer's instructions were not being followed closely in certain respects, e.g. in the arrangements for balancing the crane prior to climbing
- the special arrangements for supplying power to the hydraulic motor were not used so it would have been possible to slew the crane during a climb
- the crane was not fitted with an anemometer so there was no reliable indication of wind speed at the crane top prior to starting a climb
- the climbing frame had not been thoroughly examined and there were no formal arrangements for ensuring that the equipment was in good order and defects were properly investigated
- the erectors seemed to be working unreasonably long hours of work with the potential to increase fatigue and errors
- planning of specific climbing jobs was insufficient with inadequate assessment of risk and specification of control measures
- erectors had not received formal training or instruction about the risks and the control measures required, although an experienced supervisor had led the team
- there was insufficient overall monitoring and supervision of climbing operations by senior management.

However, none of these matters can be said to have caused the collapse. The investigation also suggested some aspects of the design and supply of such equipment that could be improved to minimise the risk of a future incident.

Legal issues

S25. HSE undertook a detailed review of all the evidence and sought the advice of Counsel. Careful consideration has been given to enforcement action in the line with the Code for Crown Prosecutors and the Health and Safety Commission's Enforcement Policy Statement. HSE has decided not to institute legal proceedings in relation to the incident because:

- as regards any criminal charges directly concerned with the collapse and the three deaths HSE has concluded that there is insufficient evidence to provide a realistic prospect of conviction and
- in respect of more 'technical' breaches of health and safety legislation HSE has concluded that it is not in the public interest to proceed with criminal charges that are not linked to the collapse of the crane and the three deaths.

Sharing lessons learnt

S26. As part of the investigation, HSE conducted a wider review of the different climbing systems in use in the UK. In February 2003, HSE published a discussion paper to publicise the lessons learnt from that review. At the time, HSE recognised that little was known about the use of 'climbing frames'. The relevant British Standard did not include specific guidance about their use. HSE made the responses to that paper available in summary form to the chair of the British Standards Committee dealing with cranes.

Development of standards

S27. Action has now been taken to develop a revision to British Standard BS 7121: Part 5 Tower Cranes partly in order to give clear advice on the use of climbing frames. Representations have also been made to the relevant European CEN and International ISO standards committees about appropriate standards for the design of climbing frames. HSE has assisted the Construction Industry Training Board (CITB) to establish, with industry support, a new training course for tower crane erectors that includes the use of climbing frames. Also, HSE has supported work by the Construction Industry Research and Information Association (CIRIA) concerning tower crane stability including the design and the safe use of climbing frames.

Final conclusions

S28. While HSE has been unable to establish precisely how this incident occurred, the investigation has shed light on work practices for which there was little public guidance at the time of the incident. HSE has identified a number of actions that crane designers, manufacturers, suppliers and users could take to minimise the risk of future incidents. This report discusses the factors that may help to secure improvements to the Wolff system for climbing but many of these factors will also be relevant to other designs of climbing frame.

S29. HSE believes that the work now being undertaken by the British Standards, CEN and ISO committees and by CIRIA will lead to safer 'climbing' operations in future. The CITB training course for tower crane erectors – supported by manufacturers' product-specific training - should also make a significant contribution to the competence of erectors. HSE would urge crane operating companies to ensure that they have robust management arrangements for crane erection that extend to infrequent crane climbing operations. For crane climbing in particular, paragraph S24 above sets out the key issues that require close management attention.