The "B of The Bang" Sculpture

On Thursday 12th May, 2005

By Mr R Packman & Mr P Madin

This was a joint presentation given in two parts. Ron Packman of Packman Lucas, who carried out the engineering design work, spoke first and described how the inspired imagination of artist Tom Heatherwick was engineered and transformed from a dream into a 56 metre high, massively imposing spiky steel object in Manchester. Paul Madin, technical support manager from AK Heavy Engineering as was (now Davy-Markham Ltd), spoke next and described how the 175 Tonne fabrication was manufactured at their works in Sheffield and then transported over the Pennines to be welded together on site. The following account is a précis of the presentation from Paul

How the B of the Bang was made

Paul first described the circumstances whereby an engineering company renowned for making enormous steel rolling mills, huge tunnel boring machines, hydro-power turbines, moving bridges and other large capital plant, came to be involved with a work of public art. The reason was that the company had recently lost a certain 'in-the-bag' contract to the Far East and had several months' spare capacity in the 40-man strong fabrication shop. Rather than risk having no work and possibly having to shed some of their highly skilled fabricators, the company decided to 'buy' the contract and consciously put in a bid that was 20% below their estimated price in order to secure it.

The order was to receive free-issue materials from the main contractor, the William Hare Group, to fabricate the 75 Tonne Core of the sculpture, the 175 tapered steel Spikes and the 5 supporting Legs to be then assembled on site by others. The Hare Group also provided a detailed fabrication assembly method that had been derived using X-Steel 3D modeling software. Without this advanced tool, used mostly for building construction, the Core fabrication might have been impossible to make, or at the very least would have taken an order of magnitude longer to build. The Core fabrication turned out to be the most complex and challenging project ever undertaken by a team of fabricators and welders that were already very experienced with making large and difficult assemblies. More than 15,000 man-hours were consumed in fabricating the Core and the Spikes.

The steel used throughout, generally known as Cor-Ten in the U.S and Weathering Steel in the U.K, is a low carbon copper-containing structural steel with enhanced corrosion properties. After repeated wetting and drying cycles, the rust that develops is different to the porous iron oxide that normally forms on low carbon steel, in that it forms a more dense and tightly adhering oxide layer that retards further corrosion. It is the small amount of copper, about 0.5%, that causes the iron oxide crystals to grow and interact in such a way that further penetration by water molecules is significantly reduced. This steel is finding increasing applications in bridge and building construction and also works of art, such as the Angel of the North and now the B of the Bang.

The thickness of steel used was in the range of 3mm to 40mm. The tubular sections were made from rolled steel plate, cold-formed using press brake machines into half diameters up to 7 metres in length and then welded together longitudinally to form a full diameter. These were then welded together circumferentially into the required length. The actual cross-section profile of the spikes and legs is more like an old three-penny bit rather than a true circle due to the process of cold forming using a press brake. The sub-assembly components were welded using the Submerged Arc Welding (SAW) process for steel thickness 10-40mm; Flux Cored Arc Welding (FCAW) for thickness 4-10mm and Pulse Arc Welding for the 3mm thick spike end sections. The welding consumables for each process were selected following discussions with ESAB, who had been involved with the manufacture of the Angel of the North when early fabrication problems, in the form of micro-cracks had been observed during weld procedure approval tests. The problem was with the MAG welding process using a filler with matching composition and was thought to be a liquation-type

cracking mechanism due to the copper content. The solution was to use a filler material containing 2% nickel, which has, and has proved to be the case with the Angel, similar enhanced corrosion properties. This cracking feature was not observed in the Submerged Arc process, probably due to the much higher heat input and dilution. Consequently, following the advice of ESAB, the 2% nickel filler was used for all FCAW and Pulse Arc joints and a matching filler for the SAW process. No cracking problems were encountered at all during manufacture.

Having formed the tubular sections for the Core, the next stage was to profile burn the joint intersections to a precise shape to a profile that was generated by the X-Steel software. The means of transferring the computer-generated profile to the steel tubes was via very large paper templates, up to 3 metres long, that were wrapped around the sections and centre-popped to enable a profile to be scribed that was subsequently hand-burned using conventional oxy-propane cutting torches. This was very labour intensive due to the very tight tolerances required for a good fit whilst maintaining the required angle of intersection. The process of shaping the intersections became even more complicated as the Core fabrication progressed due to the inevitable distortions as a result of welding the Spikes in place – this was something that the X-Steel software was not able to predict nor compensate for.

The actual process of constructing the Core started with fabricating a 10 metre x 5 metre x 1 metre high steel platform from which to build off. Various key datums were established in 3 dimensions and digital theodolites were positioned away from the platform and the Spikes were set to XYZ co-ordinates provided by the computer model. The five 40mm thick Leg sections were the first to be assembled and welded in place. This was followed by fully welding, one-by-one, each of the 175 Spike sections into position in a sequence again provided by the X-Steel model. Extremely difficult access was a common feature throughout, but the beauty of 3D modeling software, whereby the image can be fully rotated and individual Spikes taken out or put in to view the real perspective to prove that welding access was possible, was invaluable. Without this type of tool, the B of the Bang could not have been fabricated as designed.

Fifteen thousand man-hours later, the Core was fully welded and the 175 tapered steel Spikes up to 26 metres long were fully welded, inspected and passed by client before delivering to site. It was not without its problems to say the least. One unexpected technical problem with the 5 Legs was particularly expensive to put right. The problem was identified when it was found that very low Charpy toughness properties were revealed in the cold-formed 40mm thick Leg sections. Due to the small radius of bending (150mm), and the subsequent welding together of the formed sections, a strain-ageing effect was identified to be the cause of the low toughness (10 J @ minus 200C). The solution was to normalize the welded Leg sections and this was where the main cost was incurred. There are not many 15 metre long normalizing furnaces in the U.K so premium rates for heat treatment, transport costs, corrective straightening, mechanical tests and repeat NDT, consumed about £30,000. However, no compromise could be taken since the 5 Legs were clearly a critical item. There was some additional weld reinforcement required since the normalizing treatment carried out to the already welded Leg sections, reduced the tensile strength of the weld metal by about 25%, which was anticipated. For example, the weld fillet size joining the bottom of the Legs to the steel anchor plates in the ground was increased from 30mm to 45mm.

Delivery of the Core to site was quite a spectacle with the BBC2 Newsnight team recording all along the way, complete with a helicopter buzzing around. Media coverage of the entire project was skillfully organized by the London-based project managers Manage Ltd, which resulted in several hours of prime-time national TV and newspaper coverage. Once delivered to site, the responsibility of the Sheffield fabricators ended and it was handed over to a team of people whose job it was construct and weld the whole thing together. Needless to say, further project delays were encountered, mostly due to the atrocious windy and rainy weather that Manchester seems to have a reputation for during summer. All of the site welding was carried out using low hydrogen stick electrodes of matching composition, with a very strict regime controlling drying of electrodes. Six months later the welders had finished their job and the sculpture was complete – they had spent about 25% of their time sitting in the portacabins waiting for the conditions to become safe enough to climb the 30 metre high scaffolding to practice their art.

The much-publicized Grand Unveiling in January 2005 was marred by an incident the week before, when a 2-metre long end section of a Spike broke off and came crashing to the floor. The structure was immediately cordoned off and investigations began. These are still ongoing but the immediate diagnosis was that the harmonic resonance's induced by the wind in a specific number of Spikes, had caused a fatigue fracture to develop in the 3mm thick end section. The Spike involved was one of a number of Spikes that had been fabricated differently from the others: a weld had been used to join two pieces of plate together before cold-forming (the sub-contractor had run out of the required 7-metre long plate for the end sections, and had been granted a design concession to introduce the weld) and failure had occurred at this weld. This incident was given much media attention, quite rightly so, given the public safety concerns and the B of the Bang was in trouble again.

Ron Packman immediately devised an ingenious dampening mechanism that could be invisibly incorporated into the ends of the Spikes to counteract the effects of the wind. Although earlier wind-tunnel testing on a scale model had confirmed the design of the structures' ability to cope with 100mph winds, it was clear to him that additional safety measures had to be introduced to deal with unforeseen design/manufacturing/ operation and service duty interface problems. The dampening mechanism comprises of a steel tube containing metal disks in close contact with each other that dissipate the wind energy though friction and minimizes the harmonic resonance effect. It appears to have been very successful, although only time will tell. The winter of 2005 was particularly windy, with wind speeds of around 80mph recorded, but even in moderate winds a number of Spikes continue to resonate in a way that concerns those with a knowledge of metal fatigue. It was suggested by Paul that there may be other influences at work following his encounter with a local Octogenarian who happened to pass by in the early days of site construction. He asked me what was going on so I told him it was a huge metal sculpture that would symbolize the explosion of energy from an athlete doing his stuff. He said this was very interesting because when he was a lad, his grandad used to take him up on the fields with willow dowsing rods that used to twitch like mad in this area. He told me that there are two Ley lines that converge on the site of the new stadium and that his pigeons used to get confused and often get lost. Subsequent investigations by a skeptical metallurgist via web searches confirmed that there was some truth in what he said.

Paul finished his presentation with a brief recital on a didgeridoo – the same one that he had used to entertain his welders in Sheffield when they had fabricated the first 26-metre long Spike – the amplified sound that came from the end of the Spike was something to behold, much to the hilarity of the welders and also to the approval of Jeremy Paxman following his BBC2 documentary on the B of the Bang.

The evening was very well attended by an appreciative audience and thanks are due to the MAE for organizing the event.

Paul Madin MSc.CEng.MWeldI

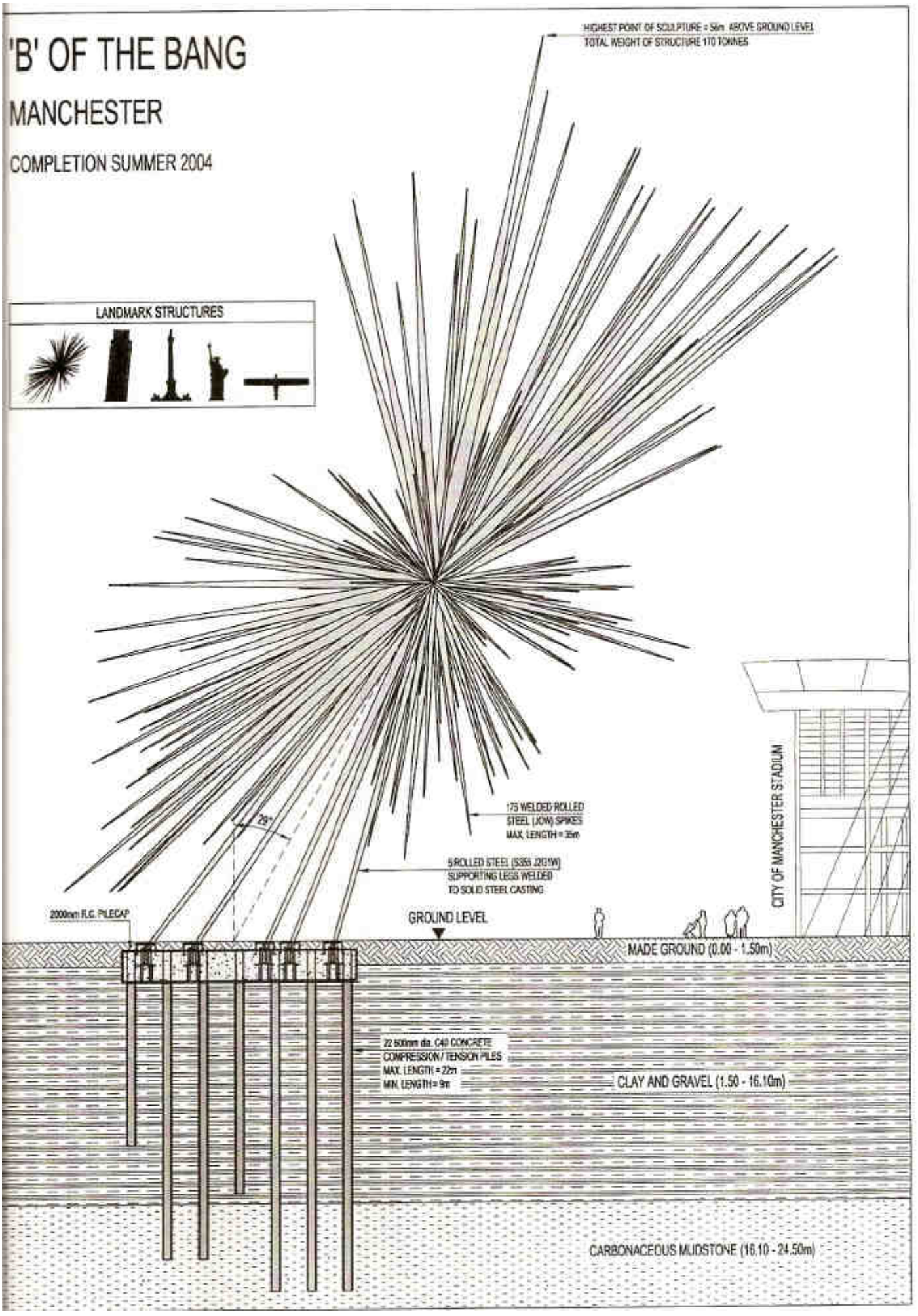
January 2006

Illustrations and specifications follow on the subsequent pages

'B' OF THE BANG

MANCHESTER

COMPLETION SUMMER 2004



PACKMAN LUCAS | **Structural Designers**

E: info@PackmanLucas.co.uk
W: www.PackmanLucas.com
T: +44 (0) 20 7378 7391

Butlers Wharf West
42 Shad Thames
London SE1 2YD

'B' OF THE BANG KEY FACTS:

180 SPIKES INCLUDING 5 LEGS

TOTAL STEEL WEIGHT OF 165 TONNES: CORE 60 TONNES, LEGS 55 TONNES, SPIKES 50 TONNES

MAXIMUM COMPRESSIVE LEG FORCE OF 300 TONNES

THE FOUNDATIONS CONTAIN OVER 1000 TONNES OF CONCRETE

MAXIMUM HEIGHT OF 55.9 METRES (184 FEET) – AROUND 20 STOREYS

THE LONGEST SPIKE MEASURES 35.0 METRES (115 FEET)

THE SHORTEST SPIKE MEASURES 2.9 METRES (9.5 FEET)

EACH SPIKE HAS THE SAME EXTERNAL GEOMETRY IN PROPORTION TO ITS LENGTH

LAID END-TO-END THE SPIKES WOULD STRETCH 3072 METRES (10,105 FEET) – JUST UNDER 2 MILES OR 7 TIMES THE HEIGHT OF THE EMPIRE STATE BUILDING

THE 'B' OF THE BANG IS MADE FROM WEATHERING STEEL – STEEL WITH A LITTLE COPPER ADDED TO FORM A STABLE AND PROTECTIVE PATINA SO THAT IT WILL NEVER NEED PAINTING

THE SCULPTURE LEANS AT APPROXIMATELY 30 DEGREES TO THE VERTICAL – THE LEANING TOWER OF PISA LEANS AT ABOUT 4 DEGREES