ENGLISH HERITAGE

THE BLOCK MILLS,

PORTSMOUTH NAVAL DOCKYARD,

HAMPSHIRE

AN ANALYSIS OF THE BUILDING

Historic Buildings and Areas Research Department
Reports and Papers B/016/2003

NMR Buildings Index No: 108861
NGR: SU 6285 0083

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Survey: May-September 2003
Report: November 2003

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INTRODUCTION

This report is partial and provisional; it is not intended that it should be read in isolation. It is partial because it is an adjunct to other reports, a general historical account, and accounts of the machinery that gave the Portsmouth Block Mills their great renown.[1] It is provisional firstly because any separate analysis of building fabric in a situation where there is rich historical documentation (as there is for the Block Mills) can be nothing else, pending the integration of documentary with physical evidence. While this report does incorporate understandings based on available documentation, including some that have been newly researched, there is still more to be done in reconciling the building with the documentary evidence. This report is also provisional because the circumstances of its making have imposed limitations. Closer investigation than has been possible is needed to draw out and refine understandings of certain aspects of the building's history (see Appendix 2). This is particularly so with regard to what might be surmised from the building about the history of its power transmission and the placement of machines. The floors need careful recording, especially in relation to the heads of the vaults below, ideally to generate a three-dimensional drawn reconstruction. Closer analysis would also be likely to be rewarding with regard to the former steam-engine houses in the south range of the building; if intervention to reveal hidden surfaces becomes possible, much might be learned.

ACKNOWLEDGEMENTS

This report comprises building analysis, but it depends extensively on research by and discussions with Jonathan Coad and Tony Woolrich. Other acknowledgement due for assistance in the making of this report is essentially identical to that made in the sister report, Jonathan Coad *et al*, 'The Portsmouth Block Mills: the start of a revolution'. It is not, therefore, repeated here, though our particular debt to Graham Annells and his team at HM Naval Base, Portsmouth, for their co-operation over access arrangements should be specifically noted.

CHRONOLOGY[2]

1690-8 – construction by Edward Dummer of the Upper Wet Dock or North Basin

1699 - channel on west side of Upper Wet Dock converted to be a gated dry dock

1737 – channel rebuilt as the North Stone Dock (latterly No. 6 Dock) making the Upper Wet Dock a closed basin

1770 – conversion of Upper Wet Dock into a reservoir for draining dry docks; construction at west end of its south side of a stone and brick platform for a well and culverts, with two horse-gins driving chain pumps in a 'pump house'

1798-9 – Samuel Bentham replaces the east horse gin on the pump platform with a single-storey steam-engine house, incorporating a 12hp table engine designed by James Sadler, an internal boiler and a chimney to the east (used to drive chain pumps and, in principle, a saw or saws)

1800-2 – whole reservoir built over with two tiers of brick vaults, affording storage space and building ground over the continuing reservoir

1800-1 – replacement of the west horse gin on the pump platform with a two-storey engine house for a 30hp Boulton & Watt beam engine with a boiler house to its south, Bentham intending (and perhaps starting) to build a steam-driven wood mill around the two engine houses

April 1802 – authorisation to construct the wood mills, designed by Samuel Bunce and begun as twin three-storey ranges separated by an enclosed yard, the south range incorporating the engine houses

August 1802 – authorisation to manufacture Marc Isambard Brunel's block-making machinery, leading to the building over of the intended yard between the twin ranges to be a single-storey workshop

1803 – the above three building phases are completed with water cisterns atop the three-storey ranges. The first set of Brunel's machines is operational. Bentham suggests the addition of a workshop.

1804-5 – sawing machinery installed in the north range, and all three sets of Brunel's block-making machinery in use by March 1805, all driven by the steam engines via underdrives in the vaults to vertical shafts in the workshops and longitudinal shafts overhead. The single-storey central range is enhanced by a pedimented brick façade to the west and a small workshop addition to the east, first proposed in 1803, but perhaps designed by Edward Holl in early 1804. In July 1805 Bentham is despatched to Russia, and on 14 September 1805 Lord Nelson visits the Block Mills just before sailing towards Trafalgar.

1806-7 – the 12hp (Sadler) engine in the east engine house is replaced with a 30hp Murray & Wood table engine, planned and ordered in 1805; new boiler house and chimney to south-east

1830 – the Murray & Wood table engine in the east engine house is probably replaced with a beam engine, perhaps leading to relocation of the main lateral and vertical driveshafts to their present positions

1837 – the west engine is replaced by Boulton & Watt. At about this time the mills are extended to the north, with a saw-mill building linked to the north range by a lean-to grindstone house, another engine house being added beyond. These extensions have been demolished.

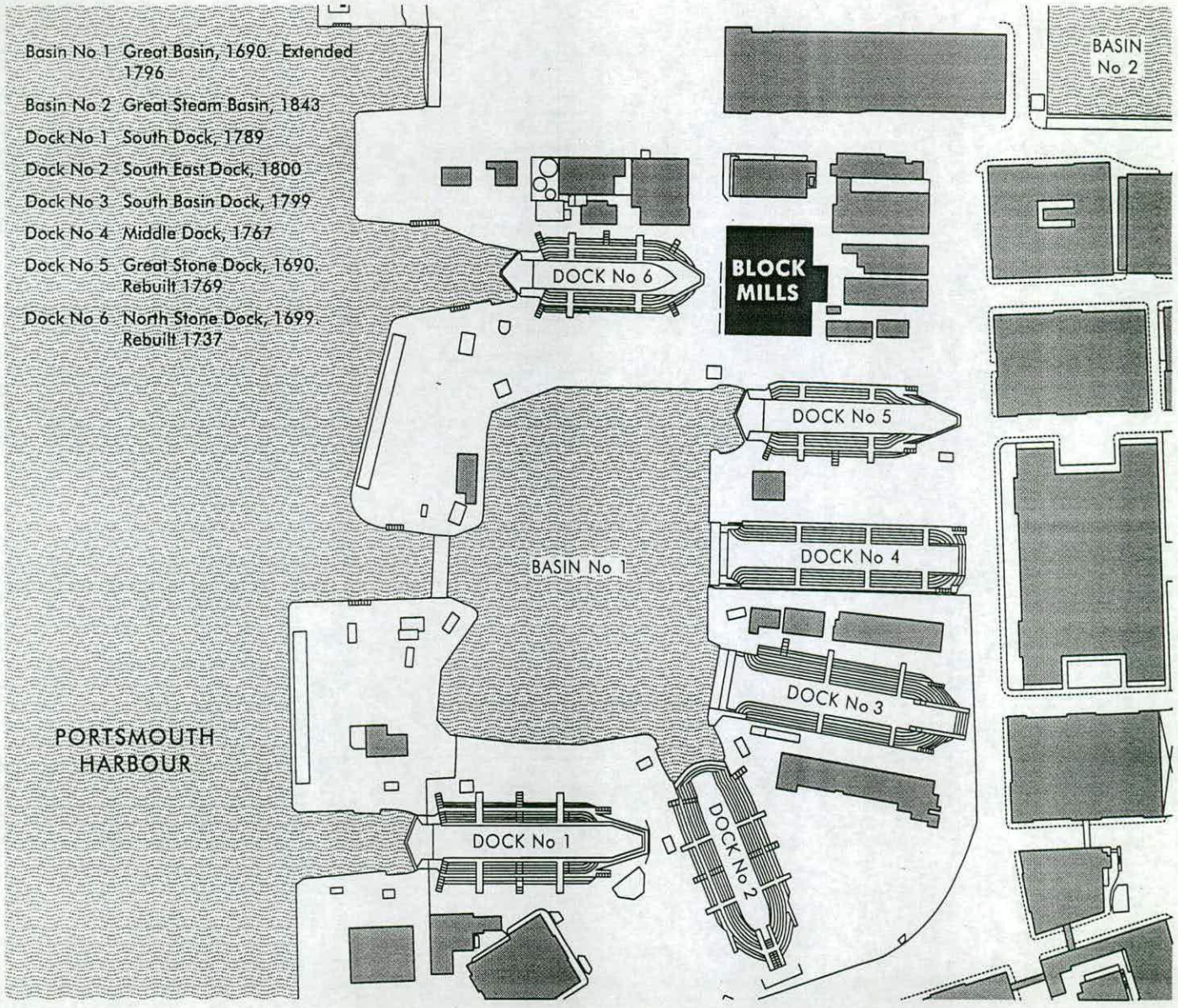
LC19 – north and south range roofs rebuilt as hipped attics; that to the south range survives

*c.*1900 – conversion to electricity by 1908, both chimneys truncated and disused, well sealed

1916 – external staircases added

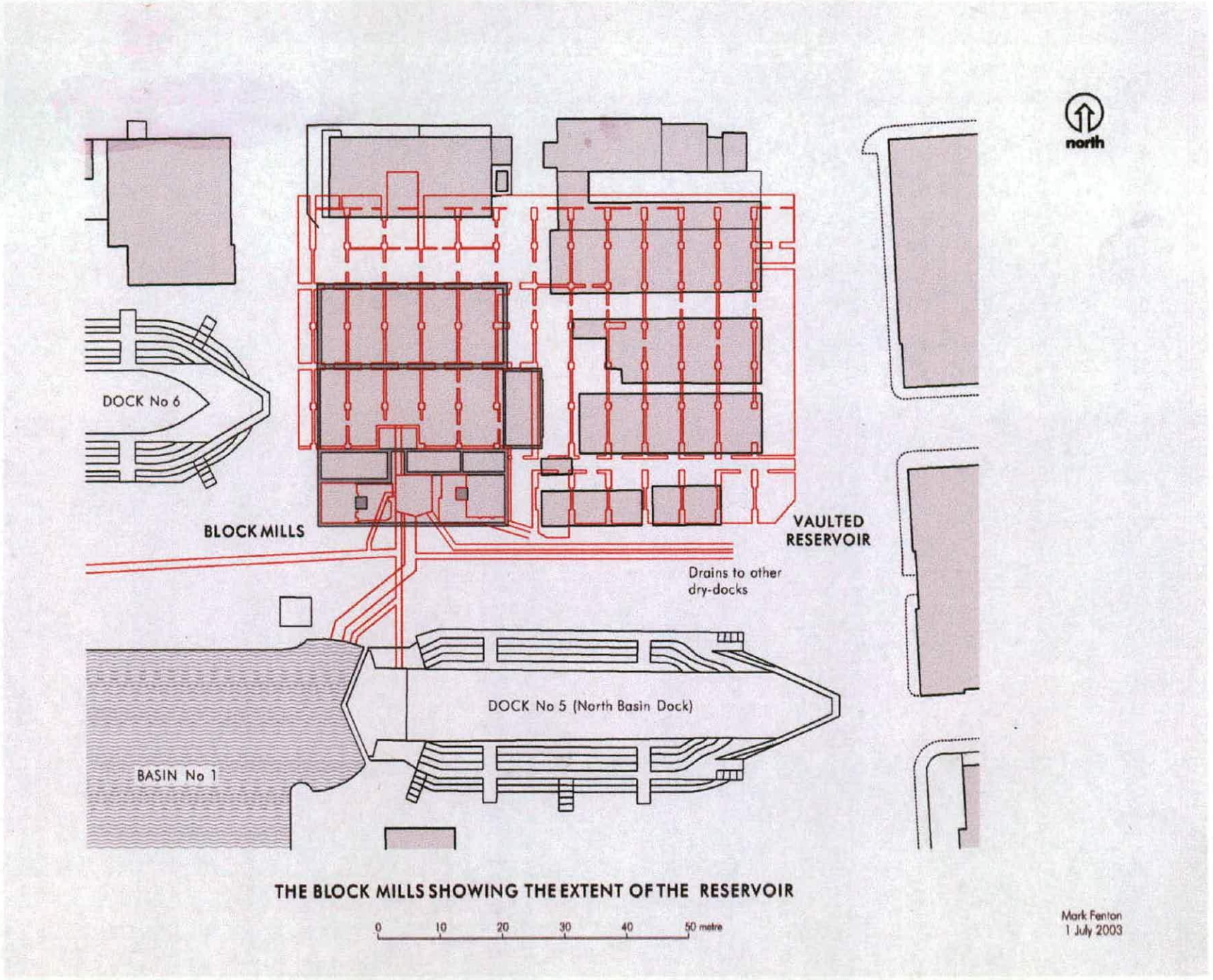
EC20– north range roof replaced and gable ends added after 1908

1965 – closure, save for leatherworking



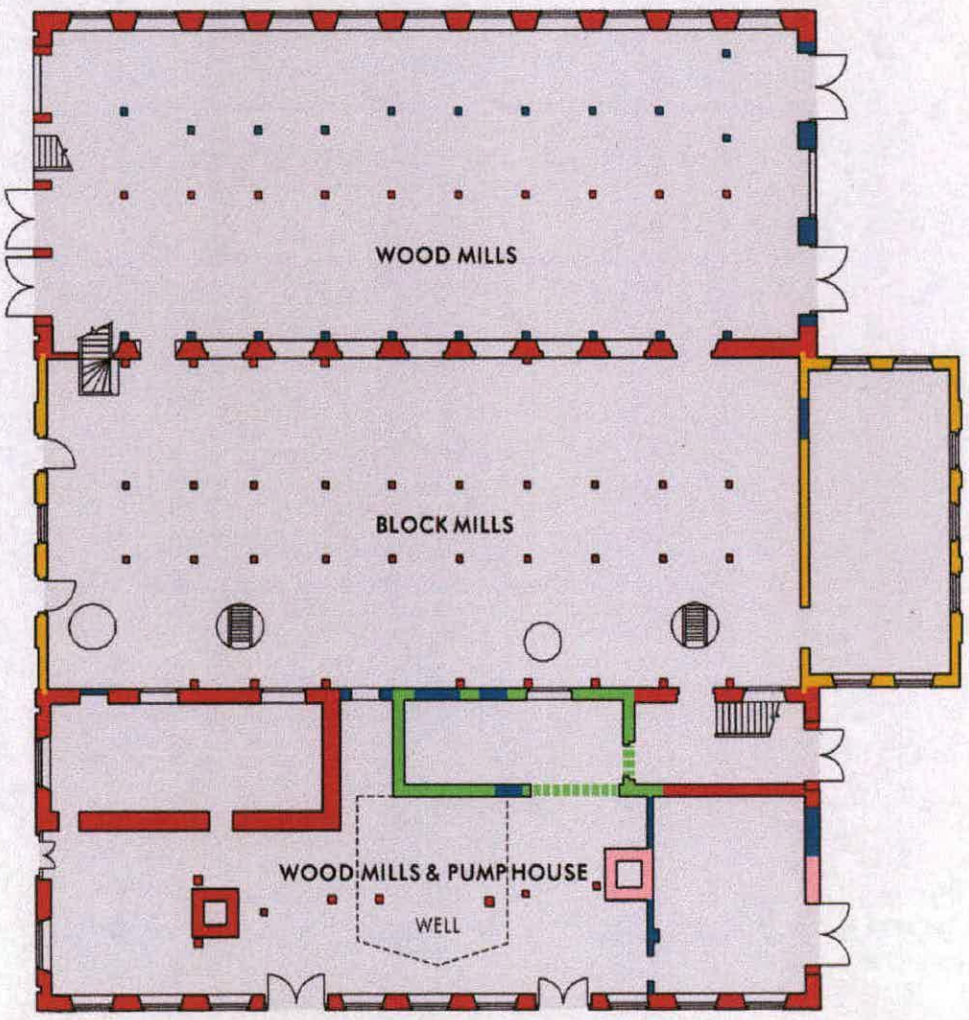
PORTSMOUTH HARBOUR, BASINS, DRY-DOCKS and the BLOCK MILLS

Mark Fenton
3 July 2003



THE BLOCK MILLS SHOWING THE EXTENT OF THE RESERVOIR

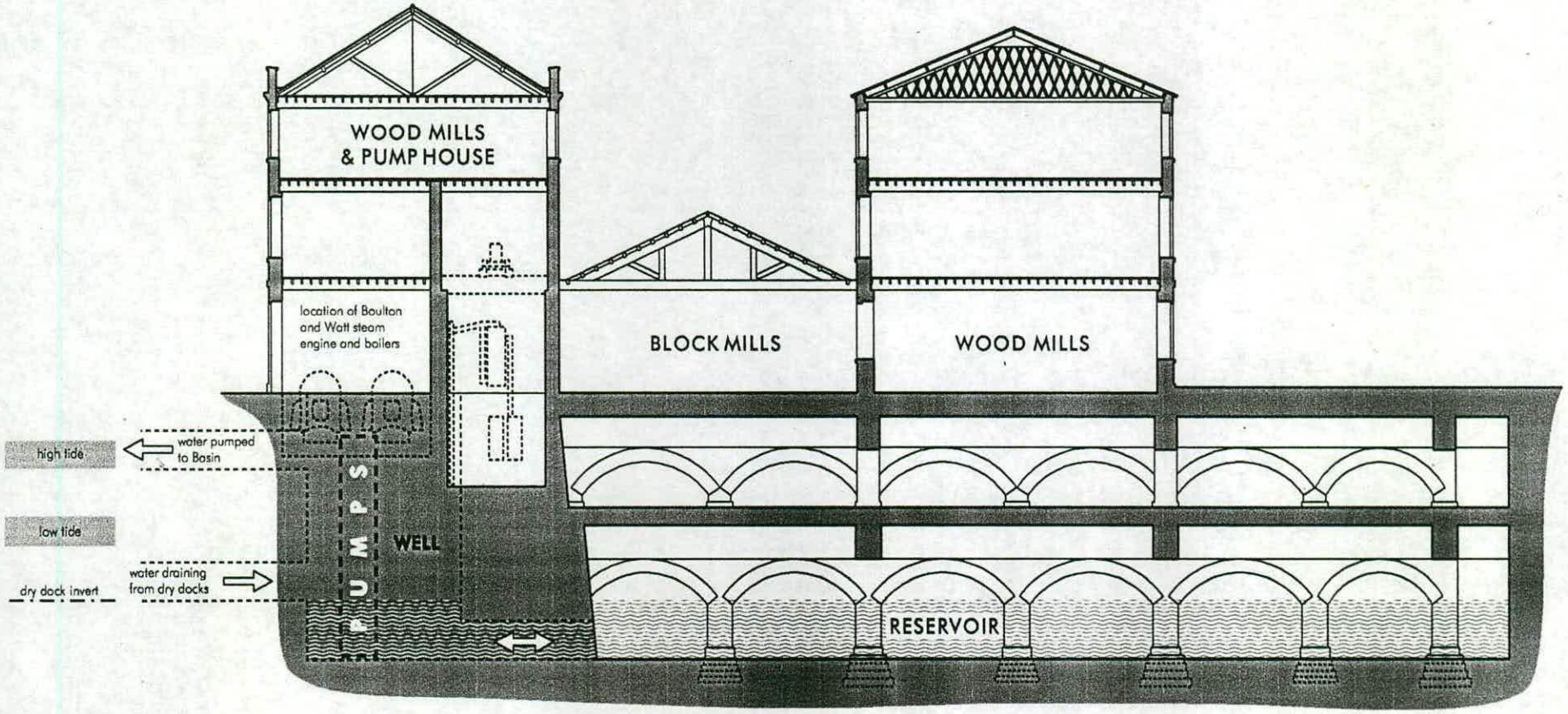
Mark Fenton
1 July 2003



GROUND FLOOR PLAN SHOWING DEVELOPMENT

0 5 10 15 20 metre

Mark Fenton
1 July 2003



SECTION THROUGH BLOCK MILLS AND RESERVOIR LOOKING WEST

0 5 10 15 20 metre

Mark Fenton
1 July 2003

UPPER WET DOCK

The quay walls of Dummer's Upper Wet Dock of the 1690s appear to survive. Some brick walling of an early character is just about discernible immediately east of the pump platform of 1770, but this may be of that or a later date given that it is not at right angles to the platform, as the Upper Wet Dock wall would be. Similar brick walling, comparably difficult to see, also extends north of the platform to the west. This may be from the blocking of the channel into the wet dock in 1737, when the end of the dry dock (now No. 6 Dock) was closed, making the Upper Wet Dock an enclosed basin.

PUMP PLATFORM AND WELL

The pump platform of 1770 is about 100ft (30m) long and 37ft (11m) deep, which dimensions determined much about the subsequent scale and proportions of the Block Mills. The platform is largely ashlar faced and has battered sides with a semi-pyramidal projection midway along its north side, evidently built to house and provide a surface for the turning operation of a penstock (sluice) to control the flow of water into the reservoir (See Elevation and Fig. 1). Eighteenth-century plans indicate that on the platform there was a 'pump house', perhaps a polygonal timber structure covering the central chain-pump well and flanking horse gins. The north-east corner of the finely

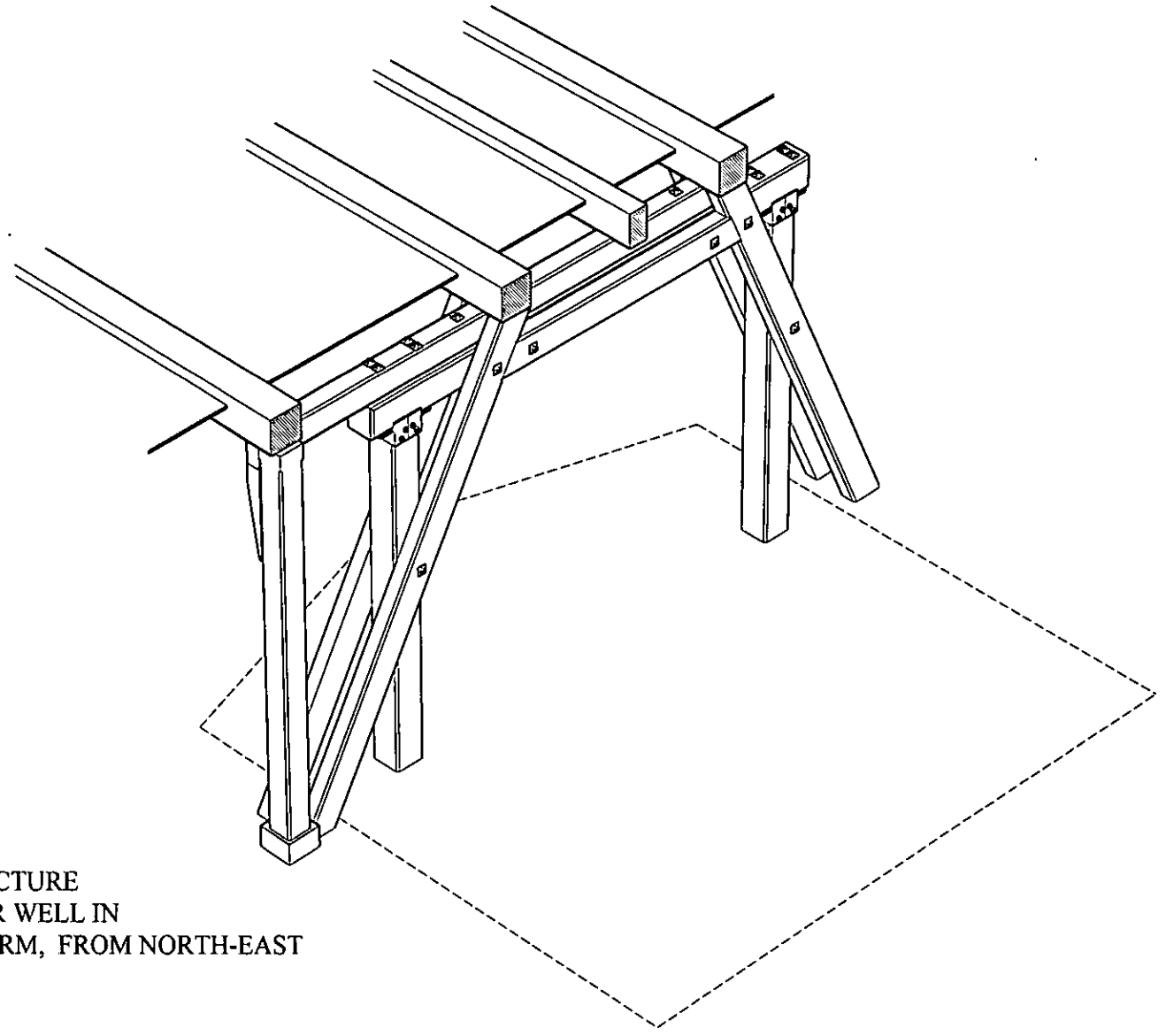
Figure 1 - the ashlar-faced pump platform wall of 1770, as seen from the north end of vault 3 (English Heritage, AA042381).

constructed platform was originally canted, perhaps reflecting a desire for greater structural solidity or buttressing in the structure's more outward parts, as well, perhaps, as the proximity of a dry dock (No. 5 Dock) to the south. Accordingly, it seems, the structure is brick rather than stone faced to the west of the semi-pyramidal penstock projection, save for a single stone block

part concealed by later vaulting. About 10-15ft (3-4.5m) east of the projection brickwork is visible at the head of a vault, perhaps indicating the position of the gearing for the east horse gin. An old mooring ring remains *in situ* near the former canted stone corner. This corner was squared off, presumably in 1802-3, by the addition of a triangular section of brick with outer faces about 5ft (1.5m) long to support the north-east corner of the south range of the wood mills.

At the heart of the platform is the void that housed the chain pumps, generally referred to as a well. This risks misrepresenting what is an impressive piece of engineering, an immense stone-lined space of pentagonal plan about 20ft (6m) across and about 30ft (9m) deep, more a cavern than a shaft. The well has been sealed with a steel and concrete floor since *c.*1900, and has not been properly inspected. The space above the well was divided into small offices by timber partitions. Originally a regular hexagon, to judge from early plans, it was made pentagonal, its north side being squared off to make space for the first steam-engine house of 1798-9. Heavily worn stones in the south range floor mark the east side of the well. The cyclopean backs of the equivalent stones on the well's west side can be seen in what became the west engine house's basement stoke hole.

All trace of the chain pumps has gone, at least from areas that could be inspected. I-section steel beams frame the inserted concrete floor that capped the well. In the south-range ceiling above the well there remain numerous associated eye-bolts for lifting, concentrated in two approximately 8in.-square bead-edged inserted beams, one running north-south and one running east-west that is suspended in wrought-iron straps of an early-19th-century character. Just north of the latter and supporting the south end of the former there is another similar beam that rests on brackets from the main structural posts of the south range of 1802-3 (see Ground-Floor Plan). Under and evidently supporting this evidently early-19th-century beam there is a curious timber structure (Fig. 2). A lintel and two posts are joined by bolted angle plates of late 19th- or early 20th-century character, and are all fixed by further bolts between two A-frames or trestles, with pairs of timber braces that bear



TIMBER STRUCTURE
OVER FORMER WELL IN
PUMP PLATFORM, FROM NORTH-EAST

Fig 2

diagonally onto the well's east and west side walls and which appear to be tenoned into the ceiling beams that are integral parts of the south range of 1802-3. This construction seems to bear no close relationship to that shown in drawings of the well and the first engine of 1797 and 1799, nor is it shown as present (or necessary) in drawings of the chain pumps from 1807.[3] The fact that it is made up of timber seems to indicate an early date, but it is more likely that it is of *c.*1900, perhaps inserted for the removal of the chain pumps or structural reinforcement that took the capping of the well as an opportunity to strengthen the load-bearing capacity of the first floor in the south range, perhaps to permit the housing of heavy machinery there such as would not previously have been possible.

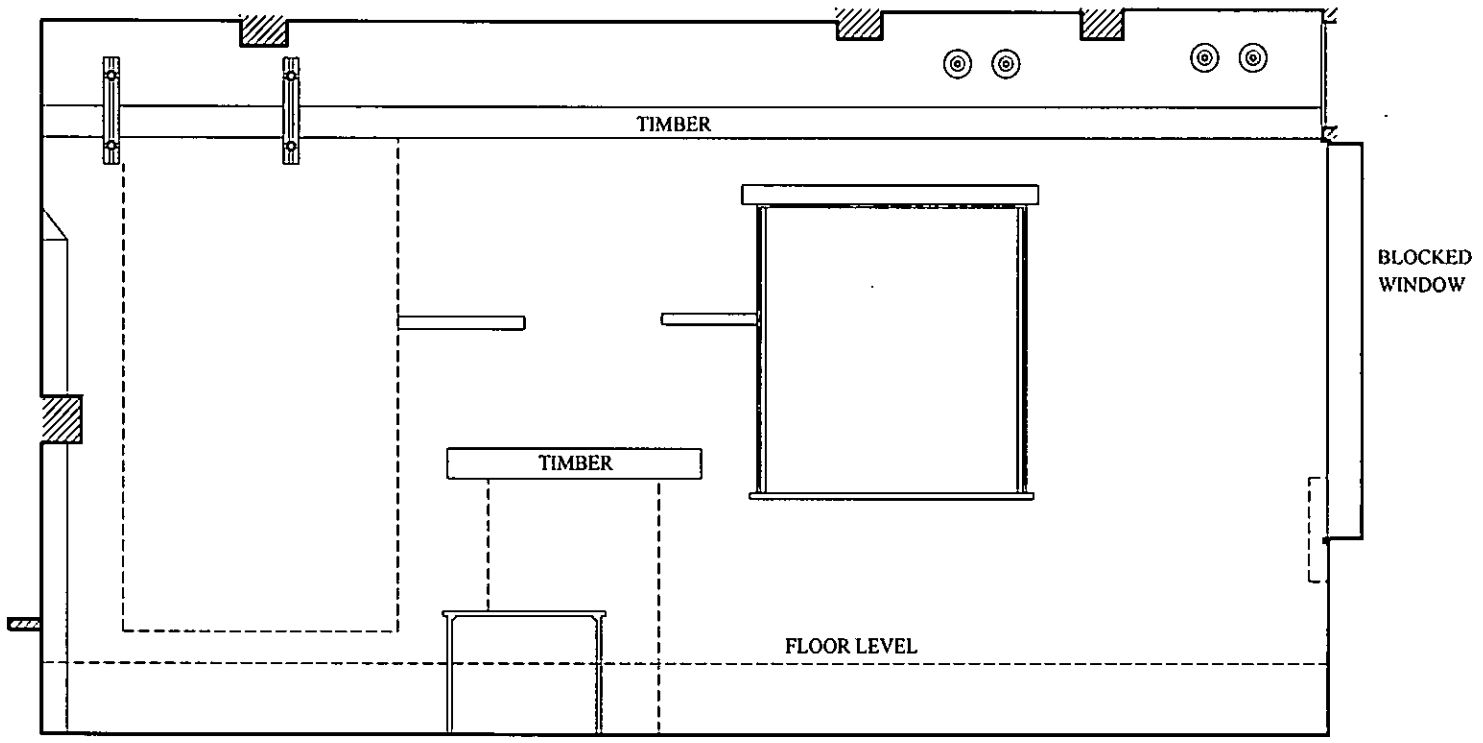
There has evidently been a penstock/sluice gate to the north of the well in line with its west side since 1770, situated between the engine houses and just inside the north wall of the south range after 1802-3. The existing penstock in this position, operated by a handle and gear between the engine houses, appears to be of relatively recent date. Another, apparently disused, penstock has left trace on the south wall of the south range, where stones and metal fixings at the foot of the wall are in line with the channel from No. 5 Dock. The link to the dry dock can be further discerned in the surface of the road between the mills and the dock, where metal panels and timber baulks cover openings over the channel. The channel conduits can be seen clearly where they emerge (or begin) near the north-west corner of No. 5 Dock and in a finely finished stone arch near the north-east corner of the Great Basin.

EAST ENGINE HOUSE

Bentham's plans for the Navy's first steam engine were approved in April 1798 and Sadler's 12hp table engine, relocated from Bentham's works at Redbridge, began pumping in March 1799. The brick walls, though no more, of the first single-storey engine house survive, with much alteration, embedded in the south range of the Block Mills. Early drawings[4] show an engine house on the east side of the platform on its north side, measuring about 30ft (9m) by 12ft (3.6m), dimensions largely determined by the positions of the well, the north penstock and the platform's canted corner. The engine was in an excavated basement and the earliest boiler was also internal, at the east end of the rectangle, with the first chimney beyond at the south-east corner of the engine house. Walls in the south range now enclose an equivalent space and, significantly, seem to be less thick than walls elsewhere in the south and north ranges (see Ground-Floor Plan). These walls bear closer consideration. References to bay numbers here and throughout this report are based on the 11 bays of the larger buildings, numbered from west to east. Similarly the vaults below are numbered 1 to 5 from west to east.

Available early plans are inconsistent as to the nature and positions of openings in the engine house walls. This may be because the planes of the plans differ, or because some of the drawings represent unexecuted proposals. Nevertheless, taking the drawings together with the evidence of the building it is possible to conclude that what was built in 1798-9 was a simple and unobtrusive structure, essentially a brick cuboid. It appears to have had a blank wall with an approximately central door facing the greater part of the dockyard to the south. To the north, overlooking what was still then a basin, there were three openings, two windows flanking a narrower and lower hatch or doorway. The east and west end walls were evidently blind. No evidence for the form of the roof has been seen.

The north wall of the engine house now faces out to the central workshop of 1802-3 (see Elevation). Its north-east corner is marked by a straight joint in bay 9, the wall having been extended eastwards in 1802-3 to enclose the south-range staircase. On the first floor a low-level break in the brickwork further marks the north-easternmost extent of the engine house. Back on the ground floor a boarded-up 5ft (1.5m)-wide window in bay 8 of the north elevation appears to be the last essentially unaltered opening of 1798-9. In bay 7 the narrower and lower opening has been bricked up, with soldier-course bricks at its head about 4ft (1.2m) above present ground level. Projecting stone 'impost' bands near its head appear to be an architectural feature, seemingly having linked the three original openings. The middle opening perhaps lost its lower part in 1800-2 when the vaults were formed, though it may have continued to serve as a hatch giving ladder access between the centre-range workshop and the once much lower floor of the engine house (see below). A change from stone to brick in the vault (see above) may indicate the original base of the opening, suggesting a clearance of about 8ft (2.4m). An iron 'box' in the engine house wall and straddling the centre-range floor cuts across and postdates the blocking of this middle opening, and is perhaps to be associated with mid 19th-century changes in the power transmission system (see below). Another floor-level iron 'box', about 3ft6in. wide and bricked up, is immediately below the present main lateral overhead driveshaft in bay 6. This evidently housed gears linking the engine house's flywheel shaft of 1830 to a vertical shaft that took power to the overhead shaft (see below). Also in bay 6 there is another straight joint in the east engine house north wall that represents the west jamb of another 5ft-wide window, bricked up with its east jamb hidden behind the post between bays 6 and 7, but visible on the inner side (Fig. 3). Near the floor there is an iron plate embedded in the wall reaching from the bay 6 straight joint to the north-west corner of the east engine house (see Elevation). Below this plate there is another straight joint, with closing bricks on its east side. These features are not readily intelligible, unless perhaps they relate to rebuilding of the corner of the engine house in 1802-3. Such limited rebuilding seems also to be indicated by the fact that the corner is chamfered below a moulded stone corbel that matches another corbel on the opposed corner of the west



ELEVATION OF EAST ENGINE HOUSE INTERIOR WALL
LOOKING NORTH

Fig 3

engine house, above which corbels the brickwork rises homogenously across an arch just above first-floor level, which arch was partially bricked up in the later 19th century.

Despite the possibility of some rebuilding here the absence of any other joints seems to suggest that the west wall of the east engine house is largely unreconstructed. There is a high-level bearing box near the north corner. A low-level stone projection near the south corner gave clearance to the flywheel within (see Ground-Floor Plan). The south wall of the east engine house is comparatively plain. A straight joint about midway along its length, more clearly visible on the inner side, probably marks the former west jamb of the small doorway that was evidently the only early opening in the wall. This doorway was blocked before its other jamb was lost when a large segment-arch-headed opening was formed in the east part of the wall, perhaps in 1830 for the insertion of a beam engine. On the east side of this large opening the wall continues beyond the south-east corner of the engine house, a part of the chimney that was in this position having been incorporated into the wall that separates the south range staircase of 1802-3 from the later boiler house to the south, the joint that marks the extent of the chimney being visible from the north. The east return wall of the engine house has a window near the south corner that was present by 1858, but which can only have been inserted following removal of the chimney that was made redundant, probably in 1807 (Fig. 4). The outer side of the engine-house wall further north has large low-level iron plates of unknown purpose. The former chimney position has a concrete winch bed, with rigs above and in the doorway to the centre range. This hoisting mechanism permitted the transfer of goods to and from the vaults through an opening in the floor in bay 10 of the central range. No other internal hoists for handling goods between levels were seen.

The interior of the east engine house reveals little about its former use, in large part because the floor level has been raised considerably, in further part because some of the upper internal walling is obscured from view (Figs 3 and 4). The three successive steam engines in the building were all largely

Figure 4 - the east engine house interior, viewed from the west (English Heritage, AA042399).

situated in the 'basement' that has been filled to within two steps of the mill's floor level. Drawings indicate that only about a third of the first engine's flywheel rose above the head of the well or present floor level, and that the flywheel shaft was nearly 4ft (1.2m) below this level. Thus the low stone projection from the south end of the west wall was high enough to provide clearance for the head of the flywheel, as can be readily appreciated inside

the engine house. The position of the flywheel did not change as the engines were upgraded. A large stone just above the floor on the north wall may relate to the housing of the flywheel shaft, and aligns with the bricked-up iron bearing box on the other side of the wall in bay 6. Another iron bearing box at floor level near the west end of the south wall housed the north end of a shaft that ran across the well to engage with a vertical shaft driving the chain pumps. The ceiling of the engine house has three cross beams with large eyebolts for lifting.

Outside the engine house the east part of the south range on the ground floor was used initially as a 'small saw mill'. On 30 July 1805, when he was planning to upgrade the east engine, Simon Goodrich wrote that 'The erection of the Boilers for this new Engine in the east end of the Pump house building similar to those at the West end will remove the present small saw Mill for converting wood for the Wood Mills'.[5] This was because his plans included a boiler house and chimney immediately south-east of the east engine house.[6] However, progress was slow, perhaps because of Bentham's return to Russia at about this time. As Goodrich wrote on 3 August, 'the bustle of the General's preparations for his departure has of course thrown our business a little back'.[7] The work was completed in 1807 when the 30hp Murray & Wood engine was installed.[8] The boiler house and chimney had been built as had been planned two years earlier, with a stoke hole to their west. The 'small saw mill' moved to the north range, or 'North Wood Mill Building'.

The chimney of 1806-7 survives within the south range, with hefty iron straps around its lower courses. The west wall of the boiler house to either side of the chimney appears to have been rebuilt, perhaps for replacement of the boilers in 1817 or 1830.[9] Within the former east boiler house there are two north-south timber ceiling beams, perhaps of 1802-3, reinforced by mid-to-late-19th-century composite wrought-iron box girders. An east-west braced timber beam runs from the chimney to the west wall between the two boiler positions, which section of the west wall may have been inserted in 1806-7. There is also a steel travelling crane. The former stoke-hole basement to the

west of the chimney has inserted timber posts, steel beams and iron-plate flooring; this area could not be properly inspected.

UPPER VAULTS

The reservoir that had been the Upper Wet Dock was entirely built over with two tiers of vaults in 1800-2. These vaults extend up to the pump platform of 1770 and thus underlie the central and north ranges of the Block Mills (Figs 1 and 5). The lower tier of vaults that is still used as a reservoir could not be safely investigated, but inspection would be unlikely to resolve outstanding questions relating to the Block Mills. The upper tier of vaults is more accessible, though it is unlit and has surfaces, particularly floors, which are otherwise obscured, and so not entirely susceptible to profitable investigation.

Figure 5 - vault 3, view towards north end (English Heritage, AA042383).

There are five approximately 20ft-wide vault bays under the Block Mills, divided by a cross wall into two lengths of about 37ft each corresponding to the central and north ranges above. The vaults are all brick-built with limited stone dressings. Of those under the Block Mills all but the western bay have continuous stone keys. These vaults were used for storage, with large circular

openings along the south side of the floor of the central range providing access from within the Block Mills. Timbers, all but entirely decayed, ran across the vaults at their springings, to support ceilings or shelving. A plan of 1814 indicates use 'to receive Pitch Tar, Turpentine, Oil, Wood, etc, etc', and reference elsewhere to 'cells' in the vaults has raised the possibility of gunpowder storage.[10] Extant painted signage indicates later use for the storage of valuable lignum vitae, the hardwood used to make pulley block sheaves, the signs indicating classification according to size. Inserted brick walls are probably blast walls from the 1939-45 war. Evidence of adaptation and alteration at the heads of the vaults, for power transmission and the fixing of machines, is discussed below, though only to a limited degree. Closer investigation of these spaces is needed.

WOOD MILLS (north and south ranges including west engine house)

The north and south ranges of the complex are its largest parts. They are outwardly closely comparable, each being about 100ft by 37ft (30m by 11m) on plan with three storeys of English-bond brick, eleven-by-three-bay elevations of flat-headed windows, and stone string courses over the lower storey (Fig. 6). If there is anything striking about this it is the utter plainness of the architecture. There is no suggestion that the wood mills so designed (and so called) were aiming to attract anybody's attention. While the designs are due to Samuel Bunce, whose architectural 'style' is otherwise unknown, he was presumably working to Bentham's instructions.

Figure 6 - Portsmouth Block Mills from the southwest (English Heritage, AA042456).

With the exception of the east engine house, as described above, there is seeming constructional unity through the whole south range, including the west engine house which has in the past been understood as having been separately built. This does not in fact appear to be the case, so the west engine house is treated here as a part of the south range.

A number of drawings for the west engine house date from 1800 and there is a suggestion that its 30hp Boulton & Watt engine was installed in 1801, prior to the authorisation for the building of the wood mills in April 1802. Yet it is clear that the preparation of plans for the second engine house and the enveloping south range of the wood mill were interwoven and, to some degree, simultaneous, one drawing sent to Boulton & Watt from the dockyard in early 1800 having 'ticked lines showing a building hereafter to be erected',[11] and Bentham referring in September 1801 to 'this building containing the two steam engines and other machinery'.[12]

Up until at least May 1800 proposals were for an engine house about 30ft (9m) long by 17ft (5.1m), about 6ft (1.8m) distant from the east engine house across the penstock position along the west part of the north side of the pump platform.[13] Later plans, one of which was signed by Bentham on 17 November 1800, show the engine house extending about 8ft (2.4m) further west, that is as built, and again as part of the larger south range building, the design of which had evidently developed but remained unresolved, having, for instance, an 8-bay south elevation.[14] The engine was shipped by Boulton & Watt in September 1800, but parts were lost; it is said not to have been installed until well into 1801.[15] If the engine house was built in 1801, it was either wholly rebuilt in 1802-3, an inherently unlikely proposition, or it was built to and anticipating approval of developed plans for the wood mills as a whole. The mills themselves may even have been begun before their construction had been formally approved. Bentham was not notably deferential to his naval masters and he was ordering woodworking machines in anticipation of the wood mills. It would be artificial and misleading to consider the south-range building works as anything other than a single extended campaign.

Accordingly, it is not evident that there are two construction phases in the regular three-bay west elevation of the south range, only the northern bay of which corresponds to the west engine house (Fig. 6). Only a large stone block under the northern first-floor window, perhaps a pad to support the beam gallery, is a hint of internal differentiation. A door in the centre bay is a late-19th-century cutting down of a window. The north wall of the engine house

lines through with that of the east engine house and, as has been seen, was unified with it through opposed chamfered corners under identically moulded stone corbels and a linking first-floor arch, with brickwork in the upper storeys of the north elevation that is entirely continuous, if irregularly fenestrated in the upper part of the two-storey engine house, two windows being spaced, as below, to either side of the steam-engine beam's fulcrum (see Elevation). The ground-floor north elevation of the west engine house (inside the centre range and comparatively little altered) was evidently conceived as being external, to face a yard, with a doorway towards the west, now bricked up, and two windows with stone sills that survive. A straight joint near the west end of this elevation relates to a rebate, probably for a timber screen that would have been intended to close the west end of the yard, preceding the brick façade of what, in the event, was made the central workshop range (see below).

The south wall of the west engine house has two doorways, that near the centre perhaps an original way through to the boiler house, that to the west inserted *c.*1900 (see Ground-Floor Plan). On the first floor there is no evidence for any openings on the south side in a wall that has perhaps always been internal. This is anyway consistent with the largely blank treatment of the east engine house on this side. On the east return, however, there is a first-floor opening with a stone sill, rebated for a window frame, and subsequently part cut down to form an internal doorway. While an internal opening here makes sense in terms of borrowed light, the 'external' treatment is an oddity, perhaps explicable simply as the result of uncertainty in the execution of overlapping building phases. A stone block under the sill corresponds to that on the west side. Another first-floor internal doorway that was inserted near the south-east corner was later closed with an early two-panel door on H-L hinges on the inner side and used from the east as a cupboard.

Inside the engine house to the east of its centre a moulded cast-iron entablature of 1837 with housings for twin columns survives *in situ*, fixed in position by large plates on the outer sides of the north and south walls.[16] The beam of 1801 was evidently in the same position on a timber entablature, both engines having had their cylinders to the west. Centred on this

entablature the ceiling retains an infilled cast-iron beam-well surround of about 20ft (6m) in length. The flywheel of 1801 is shown on drawings as having been 21ft (6.3m) in diameter, fixed just inside the south wall at its east end, and projecting into the open 'penstock' bay.[17] Its replacement of 1837 was seemingly in the same position.[18] There remains a substantial stone surround to an iron bearing box in the south wall, visible both above ground and at basement level from the former stoke hole. This probably housed the flywheel shaft. Openings in the east wall from which the flywheel and gears would have emerged have been blocked with large stones. Internal partitions and an iron staircase in the south-east (flywheel) corner of the engine house are insertions from after 1908. Earlier access to the beam gallery was by stairs south-west of the beam. The upper-storey ceiling has two beams with lifting eyebolts.

The western boiler house was in the south-west corner of the south range. Its basement is covered by recent timber flooring supported on 19th-century cast-iron brackets. The chimney to the east of the boiler house survives and is of comparable dimensions to the later east-engine-house chimney, that is about 6ft (1.8m) square. The stoke-hole area in the basement to the east of the chimney has a stone floor and a concrete and iron jack-arch ceiling of *c.*1900.

Moving on from the west engine house to consider the south range as a whole, the 11-bay south elevation facing No. 5 Dock was originally symmetrical, though not quite conventional in its bay rhythm (Fig. 6). On the ground floor there are two wider bays with double doors under fanlights in bays 4 and 8, a necessary arrangement to provide access to either side of the chain-pump well. On the upper storeys centre-bay loopholes appear to be original. The hoisting of goods to and from the upper storeys was evidently external rather than internal. Door openings on to external escape staircases in bay 3 on the first floor and bay 5 on the second floor are alterations of 1916, when the escape staircases appear to have been erected.

The east elevation of the south range has undergone alterations on the ground floor, related to adaptation of the interior for the eastern boiler house

in 1806-7 and thereafter (see above). There were originally probably four pairs of timber doors under an all-but full-width timber lintel, as surviving on the west elevation of the north range (see Ground-Floor Plan). The northernmost of these doorways, in front of which there is York-stone paving, has always given access to the south-range staircase. The other three doorways would originally have opened into the 'small saw mill'. The central of these was blocked first, probably in 1806-7 when the boiler house was formed, in brown brick incorporating granite plinth blocks and some tooled limestone above, strengthening to support the weight that was to be supported from a timber cross beam inside the boiler house. The doorway to the north of this was blocked in a more orange brick in the late 19th century. The first-floor brickwork on this elevation has perhaps been entirely rebuilt as like-for-like repair.

Much of the ground-floor interior of the south range has already been considered, in relation to the chain-pump well, the engine houses and the boiler houses. Of this area it remains only to draw attention to the internal timber construction of 1802-3, the posts and beams of which are irregularly situated to take account of the earlier and contemporary features, the west chimney stack being framed by beams in a manner that is not true of the inserted east chimney stack. A post just south of the western chimney rises through the basement and ground floor more than 20ft (6m) in a single length. Above the jack-arch ceiling over the former western stoke hole there is a single *c.*1900 hollow-cylindrical cast-iron column.

The space immediately east of the east engine house was given over to a spacious staircase when the south range was built in 1802-3. This staircase survives with little alteration save the recent addition of an outer handrail that follows the simple and robust profile of the original inner handrail. The staircase cuts across window openings as it rises to the second floor, an awkwardness that is perhaps attributable to a functional approach to architectural design rather than to alteration.

The first floor of the south range was designed for mixed warehouse and light workshop use, the latter being traditional hand-manufacturing rather than mechanical processes. In 1811 John Farey described the upper storeys as comprising 'warehouses for containing the immense stock of finished blocks . . . and several workshops with common lathes'.[19] Save for the upper part of the west engine house and the two chimneys (see above) the space was open with a double row of posts, those to the west again arranged around the earlier chimney. The posts have plain arrises, that is they are unchamfered, perhaps because there was no expectation of heavy handling such as might catch post corners. Latterly the space was used as a metal and leatherworking mill, with partitions having been inserted for offices. The introduction of heavy machinery on this floor may have necessitated structural reinforcement over the capped well (see above and Fig. 2).

The second floor of the south range has a similar double row of unchamfered posts, with both chimneys continuing up through what was originally a storage rather than a production space. In bay 5 a staircase has been inserted, rising up to a roofspace. This is clearly an alteration as the joists have been cut to admit the staircase. The only other sign of access to the roofspace is a small hatch near the head of the original north-east staircase. Triangulated reinforcement at the corners of the second-floor ceiling is consistent with framing for a hipped roof, but it is clear that this too is an alteration, joists having been cut. In keeping with these indications the hipped roof of the south range appears to be an addition, seemingly of the late 19th century (Fig. 7). It has king-rod trusses, with timbers of notably thin scantling (compare the early-19th-century roof over the centre range). The wrought-iron king rods link cast-iron fittings that house the bases of struts and the heads of the principals, the upper housing being designed also to receive a ridge piece, the whole being a construction of distinctly Victorian character. Both the chimneys have been truncated to fit within this roof, presumably *c.*1900 when steam was decommissioned.

Figure 7 - roofspace in the south range, looking east (English Heritage, AA042424).

Investigation of the fabric provides no evidence as to what preceded this roof, nor does the north range offer any clues. However, Simon Goodrich's diaries reveal that both ranges were originally topped by open cisterns or water tanks, along with which there was early provision for drying block shells. Bentham devised a scheme for a rooftop water tank with a capacity of 200 tons, to supply a fire-main around the whole dockyard. Referring to plans for the south range in September 1801 Bentham wrote that 'there is formed a cistern extending in lieu of a roof all over it'.[20] This was approved in 1802 and clearly implemented. In May 1804 Edward Holl, recently appointed as Bunce's successor, wrote to Goodrich 'about the reservoirs over Buildings and Airing rooms'.[21] The cisterns were recorded as being 98ft10in by 41ft8in, and 99ft by 38ft, that is the full extent of both ranges. Both were reportedly generally filled to a depth of about 18in, which would mean each held about 150 tons of water.[22] Two years later Goodrich decided to make a 'louvre boarded room' over one of the ranges, for drying block shells.[23] Accordingly, in 1811 John Farey wrote that 'Upon the roof leads at the top of all, are racks for setting up

the very large blocks to season by gradual exposure to the weather', and 'At the top of one building is a large water cistern, kept always full by a pump belonging to the engine, and provided with pipes which conduct the water to every part of the works, and [*sic*] are in every room furnished with service taps'.[24] Perhaps one of the cisterns had already been dismantled, or Farey simply failed to register the second.

The otherwise structurally unnecessary deployment of double rows of posts in the upper storeys of both ranges is thus explained by the former existence of the heavy cisterns. However, it is not clear that the iron water pipes that run through the building, linking all parts and levels to the reservoir, are other than later replacements of the original fire-main pipes. It would be interesting to compare any other known water or gas pipes of comparable antiquity. The originally flat-roofed mills may have had some brick parapets, as survive above a dentil cornice in rebuilt form on the south range, though the weight of the cisterns would perforce have been supported by the main walls.

The north range has, to start at the top, an early-20th-century gable-end roof, probably replacing a late-19th-century hipped roof like that in the south range (Fig. 6). The gables at the east and west ends are obvious alterations, in paler brick. The west end wall has a ground floor that is largely unaltered, with four pairs of timber doors under fanlights and a continuous and all-but full-width lintel. On the first floor the central bay has an original loophole that would have given direct access to the workshop at this level. An equivalent loophole on the second floor is an altered window opening.

The north wall of the north range appears to have begun as a uniform 11 bays of windows. There have been doorways in bay 1 at ground and second-storey levels, in bay 6 on the first floor, and another ground-level doorway in bay 8. This elevation also shows evidence of the mid-19th-century northwards extension of the mills, in the form of scars from a single-storey lean-to roof.[25] Other blocked openings were for power transmission, as, for example, via a bearing box below the central ground-floor window, and in the jambs between other ground-floor windows.

The east elevation of the north range has had its ground floor wholly rebuilt. From beginnings as a quadruple doorway like that surviving to the west it was remade *c.*1850 as triple round-headed double doorways, that to the centre later being partially bricked up to leave a lunette window.[26] This side of the building originally faced a timber yard, and the central loopholes on both upper storeys appear to be original features.

The south side of the north range was intended to be an entirely external elevation, again largely regular as 11 bays of windows. The ground-floor openings that now face the centre-range workshop were clearly conceived as windows, with sills and rebated inwardly splayed embrasures, the opening in bay 4 having always been a doorway (Fig. 8). This seems to confirm that the

Figure 8 - bays 2 to 6 in the south elevation of the north range (English Heritage, AA042402).

building of the wood mills had begun soon after (if not before) approval in April 1802, and certainly before August 1802 when it was decided that the centre range should be built. However, there are no traces of what would have been

gauged-brick window heads, even though the openings are about 4in. (10cm) taller than the windows on the first floor and in the south range. Instead there is a continuous scarfed timber plate on which the tie beams of the centre-range roof are supported (a construction not replicated to the south – see Elevation). It seems unlikely that window heads would have been built and then almost immediately entirely removed, and rather more likely that when the go-ahead for the centre range was given construction had not advanced beyond the heads of the jambs of the ground-floor windows. Bay 1 of this wall, where a staircase comes through, has been wholly rebuilt, the windows of bays 2 and 10 have been made into doorways, and the window in bay 11 has been blocked and partially re-opened.

The north range was the 'Saw Mill Building' in 1804, during the latter part of which year Goodrich was installing saws on the ground floor.[27] The first floor had steam-driven machinery associated with blockmaking and other small processes, and the upper storey was given over to storing blocks.

The quadruple doorways at either end meant that the ground-floor interior could be largely open and well lit. There was originally just a single row of timber posts down the middle of the building, minimising impediments to the handling of large pieces of wood to and by large mechanical saws (Fig. 9). The single row, unique on the floors of the mills, was constructionally daring, 37ft-span beams supporting a floor carrying heavy machines (though this loading was perhaps not initially anticipated), being given intermediate support only at their midpoints, by posts with unusually long cushions at their heads. It may not have been long before additional posts were inserted, in an erratic row on the north side, and along the south wall, their secondary nature betrayed by the absence of cushions and by patched mortice slits that had to be cut in the beam soffits for the post-head tenons to be raised into place (see Ground-Floor Plan). All these posts are chamfered, perhaps reflecting the cruder, or at least primary and heavier, nature of the work carried out here.

Figure 9 - the ground-floor interior of the north range, viewed from the west (English Heritage, AA042428).

According to Farey, in 1811 this floor was 'appropriated to seven large sawing machines for cutting up the trees'. At least one of the saws was framed into the ceiling and thus perhaps provided some limited additional structural support. A vertical driveshaft powered a nearby capstan to haul logs in from the yard. The yard was to the north and east, so the logs were probably brought in through the east doors, the sensible position for the shaft and capstan being well inside, perhaps in bay 6 where, near one of the inserted north posts, there is a bollard capstan that has been in this position since at least 1858 (see Ground-Floor Plan). The existing capstan is driven from below by gearing from a cast-iron pulley mounted at floor level in an adjacent stone-lined pit, the convex soffit of which is visible in vault 3 (see below and Fig. 5). This pulley was belt driven from overhead lineshafting. A 20th-century steel gantry for a travelling chain hoist was inserted over the south-east floor area. Another 20th-century steel gantry, over a late-19th-century planing machine to the north-west, incorporates some Indian (Tata) steel.

The great or straight cross-cutting saw was in bay 11 to the centre and north in the 1950s, explaining the irregularity of the posts here. It had perhaps always occupied this position. The *Edinburgh Encyclopaedia* of *c.*1811 relates of it that 'the tree is brought through the window against which the machine is placed' This account was evidently not based on a site visit - 'The building or block mill is of great length, having the steam-engine in the centre, . . . which is a large and tall house, for the engine, and two wings for the mills', so the reference to trees coming through a window need not be taken too faithfully; it almost certainly refers to one of the east doors. This saw had an L-shaped arm in a pit slotted into the floor. This pit may be that still to be seen in vault 5, about 2ft (60cm) square and stone lined, rising to the floor of bay 10 about 12ft (3.6m) from the north wall.

The other large saw was 'the great reciprocating saw for cutting up trees lengthwise'. This was evidently a long contraption, perhaps running along the south side of the range, but more centrally situated.[28] It worked by a crank on an axis beneath the floor, which may be related to substantial stone-lined 'pits' at the head of vault 4 at the south end of its north section, the largest of which 'pits' is marked above on the floor of bay 8 at its south end by a rectangle of timber boarding (Fig. 10). The stonework at the head of the vault is shaped for a complex assembly that is not readily intelligible. There are two 'pits', of about 18in. (45cm) square and about 18in. by 4in. (45cm by 10cm), their east and west sides having quadrant curves, with outer recesses for fixings. Given the sub-floor crank it probably relates to sub-floor power transmission (see below).

Farey described five circular saws including the cross-cutting circular (or swing) saw that endured in bay 11 on the south side. 'The timber is brought as before, through the window',[29] for which window we should again read east door. Later use of this saw was via an overhead drive and wooden pulley sheaves that remain *in situ* in the centre range. Other circular saws were in bay 7 and between bays 5 and 6 in the 1850s. The former may relate to a

Figure 10 - detail of stone-lined opening at head of vault 4, looking up to the floor of bay 8 in the north range (English Heritage, AA042387).

squarish stone-lined pit cutting diagonally upwards from the head of vault 4 to the north-range floor in the middle of bay 7 between the central posts.[30] Brunel installed a patent large circular saw for trials in 1805, moving it down to the ground floor a year later, where Goodrich complained that it was 'very much in the way'.[31]

The upper storeys of the north range are accessible from two staircases, both at the west end in bay 1. The more northerly of these staircases rises only one storey giving direct access to the first floor from the west front, and would appear to be a late-19th-century insertion. The staircase to the south rises from the centre range, and has done so since at least 1840.[32] Its handrails look early, and from at least 1804 there would have been logic in direct intercommunication between the main blockmaking floor in the centre range and the related manufacturing processes of the first floor of the north range. The first floor has a double row of chamfered posts, always having housed a machine workshop, with longitudinal line shafting and some important machines remaining in position (Fig. 11 and see below). The second floor is

Figure 11 - the first-floor interior of the north range, viewed from the east (English Heritage, AA042411).

reached by a dogleg from the early stair rising into the south-west corner of the range. Plans from 1908 indicate that at about that time the racks on this floor, on which blocks were stored, were removed for temporary conversion of the space to use as a rigging loft. There were then two rows of posts supporting an attic in a hipped roof, as survives on the south range. Sometime

not long thereafter these upper parts were rebuilt as an open floor with a lattice-truss timber roof, its tie beams and principals being laminated, as is characteristic in this essentially economical constructional form, a poor relation to the Belfast truss.

The north- and south-range first floors are linked by a covered passage across the roof of the centre range in bay 8 (see Elevation). The doorways at either end of this passage appear to be unaltered, not windows cut down (a doorway in this bay on the second storey in the north range is an alteration). Further, above the passage there are small and separate 'fanlights', their heads in line with adjoining windows. This seems to indicate that the doorways were not intended to be loopholes for the transfer of material from a central yard, but that the upper storeys were always (or always intended to be) linked by a covered way here. In keeping with this interpretation there is mention of a letter from Holl to Goodrich in May 1804 with 'a sketch of the passage from the block shop to saw mill'.[33] Further, a drawing of *c.*1804-5[34] shows a break in the longitudinal timbers running through the centre-range roof in bay 8, leaving space for access to and across the central roof, if not a passage proper. This link would have eased communications between the upper storeys of the outer ranges while also providing for maintenance of the centre-range high-level power transmission system, as well as a means of overhead superintendence of the work in the central workshop. Provision for this link might tend to confirm that the building of the centre range was underway by the time the first floors of the taller blocks were being built, though it is, of course, possible that the connection was initially envisaged as simply crossing an open yard.

BLOCK MILLS (centre range and smith's shop)

The genesis, layout, use and embellishment of the Block Mills should be understood not only in relation to the undoubted significance of the innovative machinery introduced therein, but also in terms of the significance of Bentham's administrative and mechanising reforms for labour history. In the 1770s Admiralty pressure for changes in working practices at the naval dockyards increased, with growing criminalization of petty transgressions, and Lord Sandwich's attempt to impose 'task work', that is restructuring of the shipwrights' self-elected working groups and the abolition of day rates of pay. In 1775 this was resisted in what was perhaps the most serious of many 18th-century strikes by dockyard shipwrights, one, it has been argued, that may have compromised the effectiveness of the British response to the American rebellion. The skills possessed by the shipwrights and other artisans gave them great power, and the changes were rescinded.

From at least the early 17th century vast volumes of the waste timber, offcuts or 'chips', generated in naval dockyards were customarily used as payment in kind for the workforce. Varying estimates all hold that the greater part of timber brought into the dockyards came out as 'chips'. Through the eighteenth century the Admiralty's attempts to abolish what it saw as an expensive perquisite if not theft, and what the workforce regarded as a right or part of basic pay, were a constant source of grievance and conflict. 'Chips' are also the source of the expression 'a chip on the shoulder' as representing resentment against authority. When she visited Deptford in 1786 the German tourist Sophie von la Roche was struck by the naval dockyard men there, 'seeing the carpenters go out through the gate for lunch, each carrying his ration of wood on his shoulder, while a number carried a large net full of shavings. A nice sight indeed, this crowd of family fathers with their domestic provision of tinder going to their midday soup, weary from their labours and honest toil. God! How small a portion of these six million guineas they help to earn, falls to their lot! They were mostly fine-looking fellows; many of them with the eye of a mathematician, still making calculations. In them I saw

embodied the fine English schools, where the citizen's son, like the son of the aristocrat, is taught all kinds of mathematics and really good Latin. I am sure many of them will be reading the papers this evening and talking of the common welfare . . . The respect with which our coachman had to treat these working-people, not being allowed to turn in the narrow street until they had passed, gave me time to consider and contemplate them.'[35]

This provides an important corrective to any notion that dockyard men were no more than thieving reprobates against whose transgressions Bentham's reforms and innovations were overdue justice. Bentham introduced new rigour, and at a time when food prices rose by 90%, hunger overrode defiance, and efficiency won out over liberty. His initiatives fundamentally altered the social topography of the dockyard towns, making shipbuilding less labour-intensive and more flexible, to conform with a doctrine of individual responsibility that left no place for collectivist traditions. The final removal in July 1801 of the long-standing entitlement to 'chips' is interwoven with the establishment of the wood mills. The mills meant that wood that would previously have been 'chips' could be used in the making of blocks. It was also intended that the otherwise labour-saving steam engines should be fuelled in part with 'waste wood chips'.[36] The replacement of 'chips' with chip money was more than a shift from an economy that linked skill, materials and remuneration to one that prioritised wage labour. It was also clearly understood as a symbol of declining artisan independence, an obvious corollary of the beginnings of mass production. Bentham also instituted new divisions of labour to get round the collective strength embodied in apprenticeship traditions and trade boundaries. Carpenters, joiners, and others all became 'woodmillers', specialisation via mechanisation meaning not just reduced demand for labour but the deliberate replacement of the skills that had been a source of dignity as well as power, and the cowing of a whole class of workers. As an Ur-management consultant, an original downsizer, Bentham provoked widespread opposition from all sides. The Block Mills are the seminal monument to the long-term effectiveness of his perspicacity. It seems clear that he foresaw their potential in this regard.[37]

Before arriving at last at the heart of the building, the centre range that really was the block mill, it is worth pausing to address the existence of the gap between the three-storey blocks. In devising the layout of the wood mills (note the plural) Bentham might simply have raised a single larger block around the steam engines. One reason for not doing this might have been a desire to reduce fire risk by separating power generation from the handling of wood. But this had not been a concern in his earlier drawings for adapting a single steam engine to joint use as a pump and a saw. Another motivation might have been secure storage. The separation of the two blocks enabled the creation of an intermediate timber yard that would have been both convenient and secure if its ends were closed off. The width of such an interval was effectively pre-determined by the lines of the vaults being built in the reservoir; while the south range stands on the pump platform, the long walls of the north range stand above the substantial cross walls that divide the vaults.

There are straight joints near all four corners of the centre range on the north and south walls (see Ground-Floor Plan). In addition the brickwork of the west façade to the centre range and of the smith's shop to its east passes behind, and does not course through with, the brickwork of the north and south ranges at all four of these corners. Taken together what these junctions seem to betray is the former presence of single-storey high rebates at the ends of the inner walls of both tall ranges. These rebates of about 2ft 3in. (70cm) width probably housed timber screens that would have controlled access to what was probably intended as an open but secure yard for storage of the timber, access to which and ownership of which was so controversial. Indirect confirmation for this seems to come from Goodrich who, on 30 July 1805, proposed, with Bentham's approval, 'a Yard at the Wood Mills surrounded by paling occupying a part of the Ground over the Reservoir on the east, and north sides of the Woodmill Buildings for the stowage of Timber for the Wood Mills'.[38] The conversion of the central yard for block making would have necessitated the formation of a comparably enclosed yard elsewhere. In October 1805 Brunel proposed building a three-storey building here, but following Goodrich's preference, Holl was asked to design a shed instead.[39]

As it antedates outward alterations it is appropriate to consider the interior of the centre range before its exterior. Leaving questions of machinery and power generation aside what is immediately striking is the columniation (Fig. 12). The bay divisions here are not made by posts, chamfered or otherwise, but by a double row of finely turned classical ('Tuscan') columns, giving the always top-lit space an elegance that is markedly distinct from the utilitarian character of the flanking ranges. The delicacy of these slender (7.5in. or 19cm

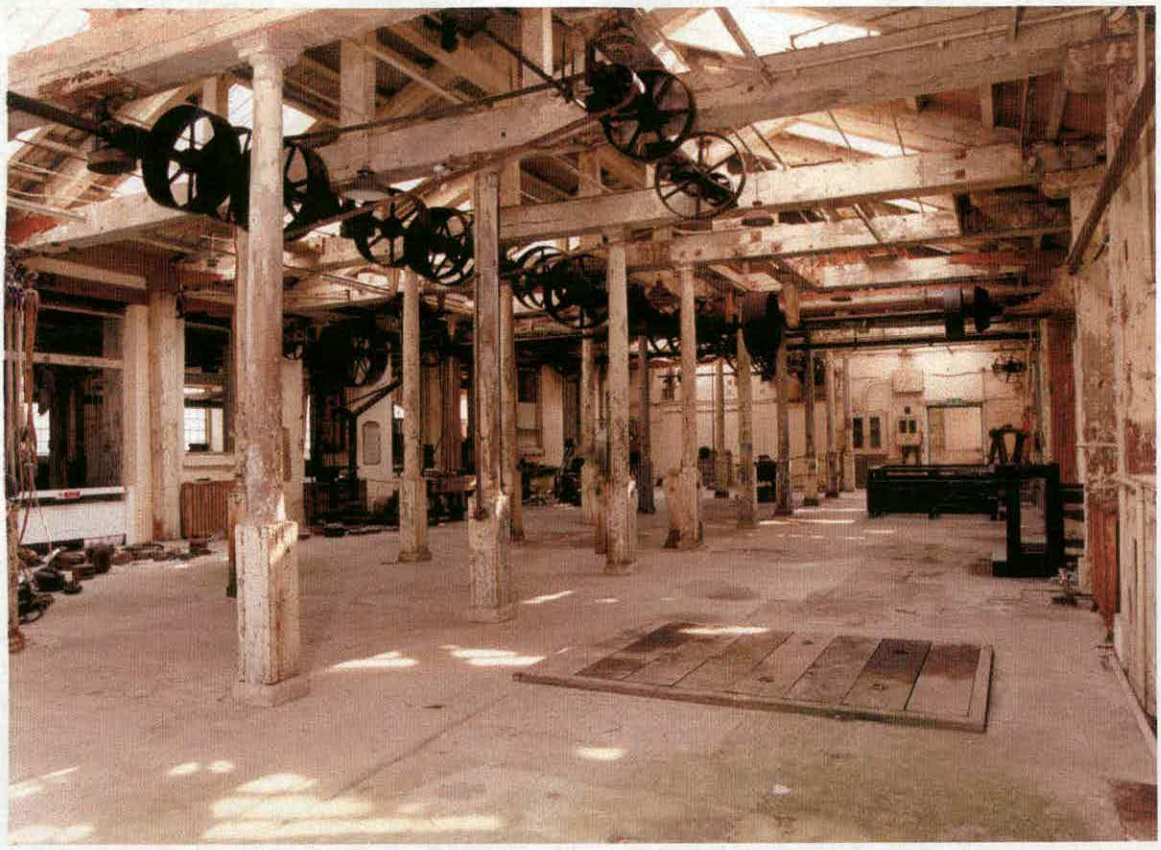


Figure 12 - the centre-range interior viewed from the southwest (English Heritage, AA042405).

diameter) columns is particularly surprising in the industrial context of a naval dockyard where robust, but unostentatious and economical construction was customary, as is manifest in the standard simplicity of the posts in the adjoining buildings. The columns are so striking that it is easily overlooked that a double row of columns in a single-storey shed of such relatively modest span (about 40ft or 12m) would probably not have been necessary had it not been for the use of the roof trusses to support lineshafting. Their functional purpose is not so much loadbearing as stabilising. The high column plinths are odd, even ecclesiastical. Perhaps longer columns could not be turned, but

this does seem a deliberately aesthetic gesture. In late-17th- and 18th-century English churches column bases were typically placed on high plinths, so as to be seen above pews. Perhaps the columns are so placed here so as to be seen above Brunel and Maudslay's machines, many of which were embellished with similar columns. The showiness here was studied, building and machines designed together to look snappy and polite, to attract approving attention. Bentham's career depended on success here and he knew it. As he later explained: 'I had considered it highly conducive to the hastening of the introduction of a general system of machinery, that public opinion should be obtained in its favour, and that this was likely to be more surely effected by a display of well arranged machines, for the accomplishing of one particular object, I determined, as the machines which it might be expedient to employ exclusively for blockmaking, admitted of a pleasing arrangement in point of appearance as well as use.'[40] This contrasts with the less public-relations conscious attitude of Brunel who complained in the summer of 1805 that 'This frequent admission of visitors is of great hinderance to the men at work' and asked Bentham to fence in the mills to keep 'intruders' out.[41]

The bay lengths in the centre range are slightly uneven, and the roof trusses are not precisely parallel, irregularities that reflect the fact that the roof was inserted between pre-existing walls (see Ground-Floor Plan). The beaded tie beams of the centre-range roof are supported, columns apart, on chamfered timber posts at their ends. These posts stand on tall stone bases and have cushion caps to the south. Where there was an opening between the engine houses there is no post, the tie beam having carried through to be supported on a cross beam bearing between the two engine houses and concealed by inserted brickwork (see Elevation). The posts are on lower stones to the north and do not have cushion caps, instead being built into the adjoining wall (see above). The king-post roof trusses are of notably robust construction with double principals, another attempt perhaps to minimise movement. The tie beams all have mortices and pegs to either side of the king posts, the purpose

of which is apparent in the two eastern bays where an assembly that was once continuous (except in bay 8) survives (Fig. 13). Short posts rise or rose from the tie beams to support substantial timber baulks that ran the length of

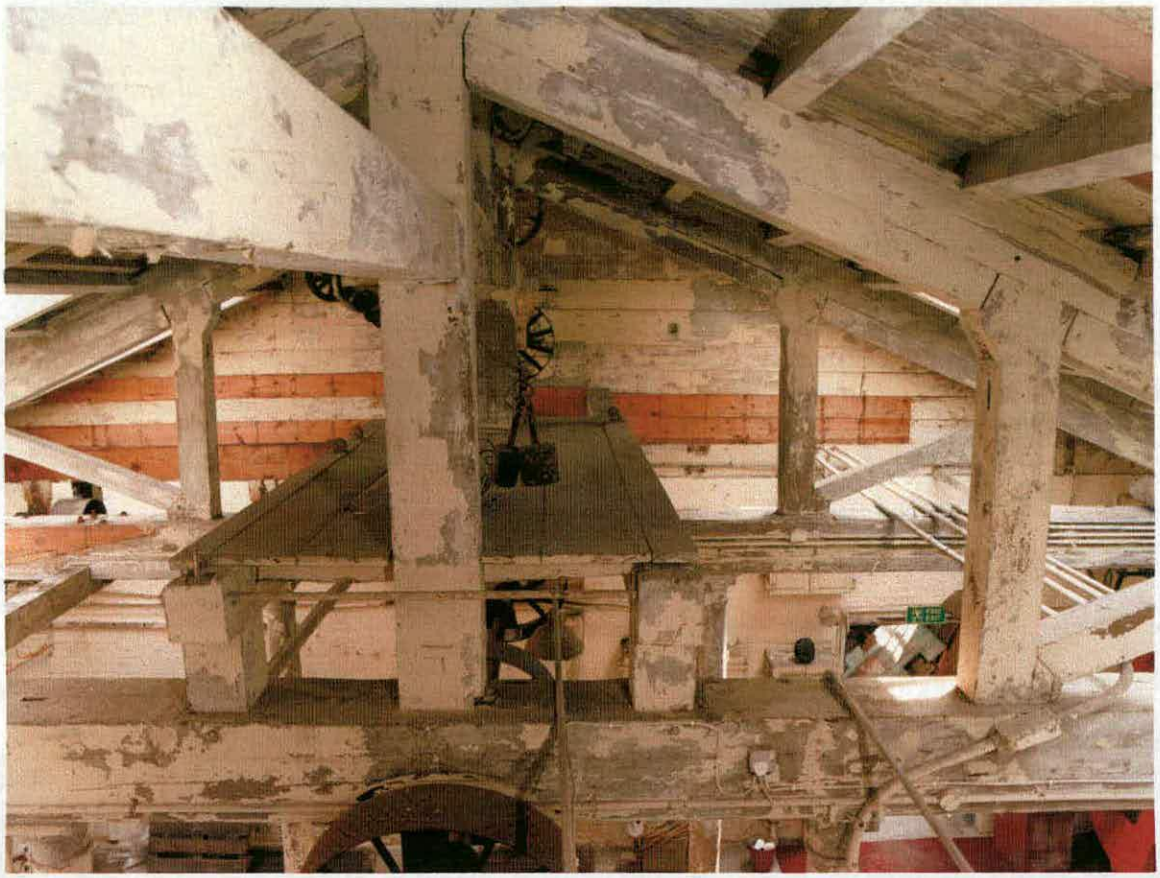


Figure 13 - the centre-range roof, view towards the east end (English Heritage, AA042417).

the building to either side of its centre. These baulks were held in place laterally by horizontal braces to the king posts, the mortices for which can be seen throughout. Queen struts also have inner empty mortices near their heads, as well as cut tenons in their joggles. Perhaps there was additional outward bracing to hold the longitudinal baulks in position. The purpose of these longitudinal timbers, and the desirability of bracing, is made clear in a longitudinal section drawn *c.*1804-5.[42] They were part of the original power transmission system, being supports for secondary pulleys from the drums on the original longitudinal lineshafting. They were complemented by a single run of comparable timber baulks at a higher level, fixed into and linking the king posts. These supported smaller pulleys the tops of which were fixed at the ridge. A pulley still in this upper position in bay 9 latterly held the works bell. Another such pulley survives in bay 11; the high-level platform resting on the

lower baulks in bays 10 and 11 is a later adaptation. The roof thus not only supported the main longitudinal shaft and drums, suspended from brackets as is its successor, but also housed a complex and layered system of high-level pulleys amid three rows of timber support on different axes. The same early drawing also shows tie beams to either side of bay 6 linked by a length of timber jointed into the upper sides of the tie beams, which timber supported an intermediate hanger, necessary because power transmission was not originally to a single longitudinal shaft but to two separate but linked lengths. Rebates for this assembly remain visible. In lieu of columns two shaped stone corbels, one of which survives in the west brick wall, supported the westernmost roof truss.

As has already been indicated, this wall, the west façade of the centre range, is an early alteration, an afterthought. This is confirmed by an annotation on the same drawing of *c.*1804-5 where it is written on the section through this wall, 'To observe – not to bring this wall nearer in than the present distance to the beam'.[43] The drawing also indicates that the two western bays of the centre-range roof are replacements of a hip, relative to which it is perhaps notable that the west truss is the only one seen to carry carpenters' marks/numbers.

The west façade is strikingly more architectural than the main wood mill blocks, if not quite a *tour de force* of neoclassicism (Fig. 6). Twin doorways flank a sash window, with relieving arches over flat heads, all in a slight projection under a thinly dressed pediment with a lunette through which, awkwardly, a king post is visible. There are recessed link bays with a small window of unknown purpose to the north. Such a polite façade with its two narrow doorways, for people not materials, carts or large pieces of lumber, is as if designed to welcome visitors. It is also neatly centred on the same axis as No. 6 Dock. The piecemeal implementation of Bentham's 'wood mills' vision saw its concluding flourish here in 1804-5. The façade is unlikely to have been designed by Bunce, who had died in 1803. Perhaps the designer was Bentham himself, providing a finishing touch to a project that mattered a great deal to him, and the appearance of which is known to have concerned

him (see above). He was, after all, appointed to be the Navy's Architect and Engineer. It is ironic, or perhaps not, that this embellishment came when Bentham was riding for a fall, about to be despatched to Russia for having been too troublesome. Alternatively, perhaps the designs are due to Edward Holl, who had been appointed as Bunce's successor in early 1804, and who we know made a sketch for the passage between the north and south ranges in May 1804.[44]

At the other end of the centre range is the small eastwards addition of a 'smith's shop', so-called on plans of *c.*1804-5 and 1814, but first suggested by Bentham in June 1803 as a workshop for the intended resident engineer, and initially used for the maintenance of the wood-mill machinery.[45] The flank walls of this extension are tucked inside the outer ranges so as to suggest that the earlier timber screen was slightly recessed, as to the west (see Ground-Floor Plan). The internal partition between the addition and the centre range was clearly never external, comprising a thin brick wall with two doorways (that to the north blocked) under an early timber truss. The smith's shop did not have independent external access, a door having been formed on its north side only since 1964. Blocked windows notwithstanding the east face of the extension is architecturally consonant with the west façade, having a similar triple relieving arch, with a wider elliptical arch to the centre, under another thinly dressed pediment, this one broken by a segment-headed sash that may have been designed as another lunette to judge from internal brickwork. These similarities point to the works at either end of the centre range being parts of the same building phase, probably datable to 1804-5.

The 'smith's shop' had come by *c.*1840 to be used as a testing room.[46] There were evidently twin columns in the middle of this space, presumably supporting a roof truss as in the main range (see 1908 plan). The columns and this main truss have been removed. There are cross-wise timber trusses with wrought-iron straps, ties having been replaced with steel beams, perhaps associated with clerestorey lighting that may be an early alteration.

POWER TRANSMISSION

An analysis of the Block Mills as a building would not be complete without interpretation of the way that power was transferred from the steam engines through the building to the block-making and other machines. The machines and the line shafting that served them are addressed in separate reports.[47] However, at the risk of overlap, it is necessary to attempt to address the latter here, both as it survives and as it may previously have been arranged. Description of the existing arrangements is relatively straightforward. Yet it is clear that there have been significant alterations, though when and from precisely what alternative arrangements remains uncertain. This aspect of the way the building worked, above others perhaps, needs further study and survey. The lineshafting itself has not been radically changed, but it seems clear that the main drives have been. There may have been a single major change in the primary lateral drives, perhaps in 1830 or 1837. Further, while the survival of early fittings is extensive, the building still holding many remarkably early pulleys, countershafts and other power-transmission fittings, any or all of these are likely to have been moved around at indeterminable stages.

The existing primary lineshafting comprises a lateral (north-south) overhead shaft across the centre range and the north range on the east side of bay 6, and a separately powered longitudinal (east-west) overhead shaft down the middle of the centre range (Figs 9 and 12 and see Ground-Floor Plan including Lineshafting). The latter drove a secondary lateral overhead shaft in bay 11 that formerly ran to the centre of the north range to a vertical shaft, now lost, that powered a longitudinal shaft on the first floor of the north range that remains *in situ*. All this was in place by 1858, when the power transmission system was drawn. Many of the centre-range parts of it can be seen in a much-reproduced photograph of *c.*1910 showing the centre-range interior from the south-east. The drawing of 1858 reveals that the primary (bay 6 east) lateral shaft was powered directly from the flywheel shaft of the east engine house, bevel gears in the 3ft6in. (1.07m) wide floor-level housing on

the engine-house wall, taking the power to a vertical shaft that had a bevel gear to the lateral shaft just below the surviving wall bracket (see Elevation). Bevel gears on the lateral shaft in the north range, one of which remains, drove staggered longitudinal shafts there that have gone, though an end bracket remains in the east wall. The primary longitudinal (centre-range) shaft was powered from the west engine house via cogwheels and a shaft that emerged into the centre range in bay 5 at floor level, further cogwheels linking to a lateral shaft in the floor thickness on the west side of bay 6 that ran to bevel gears to a central vertical shaft. The bevel gear that met the head of the latter is still in place, and patchy concrete repair in the floor reveals where the floor-level shaft was. The two main drives were linked by a short floor-level shaft near the engine house wall. In this system power transmission was entirely overhead, with the exception of the floor-level transfer to the vertical shaft in the middle of the centre range, meaning limited loss of floor space, near the engine houses and at the east end of the north range. The vaults were not used.

The main longitudinal shaft in the centre range is quite unlike its two-part predecessor as drawn *c.*1804-5.[48] The continuous shaft has a diameter of about 3.5in. (9cm) at its west end and is dimpled at its east end. Its ends are housed not on stone brackets as in the early drawing, but in cast-iron fittings of an evidently later character. The hangers are cylindrical with moulded heads and quadrant webs, not the cruciform type shown in the early drawing. There are none of the early wide drums, but 26 narrower pulleys, of which 23 are cast iron and of an early-19th-century character. These are wedged onto the shaft in what looks like adaptive reuse. The other three pulleys are clearly later, of built-up sheet metal clamped on to the shaft. There is iron striking gear in bays 3, 4 and 10 the slender proportions of which indicate early origins. There are also secondary cast-iron pulleys on countershafts on what are evidently early brackets on the south side of the centre range in bays 1, 3, 4 and 11 (others have been removed from bay 2), and on the north side in bays 5 and 10 (others removed in bay 7) (see Elevation, Ground-Floor Plan including Lineshafting and Detail of Auxiliary Shafts).[49]

The main lateral shaft across the centre and north ranges is housed at its south end in a substantial cast-iron bracket at the head of the east-engine-house wall (see Elevation). The south end of the shaft, which has a diameter of about 3.875in. (9.8cm), is dimpled. The shaft holds seven wedged cast-iron pulleys, and one clamped sheet-metal pulley. The cast-iron hangers are like those described for the lateral shaft, excepting the southernmost, which is of I-section with an open web, perhaps an earlier type reused. Over a muff on the shaft just north of the bevel gear in the north range there is a glass oil bottle, the last remnant of a lubricating system that survived more extensively until recently.[50] There are substantial cast-iron plates in the ceiling of the north range on the west side of the shaft, from which the bevel gear ends of the longitudinal shafts were hung (Fig. 9). The larger of these plates is marked 'P^{o}↑Y' (presumably designating Portsmouth Naval Dockyard), a symbol that is also to be found on one of the first-floor cast-iron pulleys above the trenail lathe, on the later base plate of the Brunel/Maudslay cornering machine, and on the spile machine that is said to have been made in 1859-60. It may be a mark for which date termini can be established.

Bevel gearing at the wall bracket at the east end of the main longitudinal shaft transfers power to the eastern (bay 11) lateral shaft, which is 3in. (7.6cm) in diameter. There are three pulleys, two of cast iron and one of sheet-metal. The shaft has been cut, but it is obvious that it formerly ran through a bearing box into the north range. At the centre of the east wall in that range another substantial cast-iron bracket survives where gearing would have taken the power to a vertical shaft rising through the first floor, in which the relevant hole is visible, to the overhead lineshafting of the storey above.

Both of these lateral shafts are absent from the long-section drawing of *c.*1804-5, and all of the ironwork, with the exception perhaps of the cast-iron pulleys and the I-section hanger, is not obviously earlier than *c.*1830 in character. It was all in place by 1858.

The longitudinal shaft on the first floor of the north range has a diameter of 2.5in. (6.4cm) and a plain, that is undimpled end to the east. The hangers are of the supposed later type, with a single I-section hanger that may be earlier. The shaft holds 28 cast-iron pulleys, two of sheet metal and one of wood (Fig. 11). There are three early countershafts on side-wall brackets, with cast-iron pulleys and belts still *in situ*, in part for operation of the lignum-vitae saw (to the north) and the trenail lathe (to the south) in bays 9-11. There are other brackets in bays 4-6.

In the former smith's shop there is lateral lineshafting, driven from a west-wall pulley from the centre-range longitudinal shaft. This looks like an entirely late-19th-century addition. The shaft has a dimpled end, and all the pulleys are of sheet metal.

While it does seem clear that the existing arrangements are not original, knowledge of what preceded them is more elusive. The drawing of *c.*1804-5 illustrates the main longitudinal arrangements at that date, but it does not show how power was transferred from the engines or to the north range. It is also not clear how long the arrangements illustrated endured. Farey's account from 1811 is not particularly helpful: 'power is transmitted by a train of wheel-work to an horizontal shaft, extending along the centre of the middle building very near its roof'.[51] This confirms the general character of what the drawing shows, but throws little further light.

Through 1804 Goodrich referred to and sketched what can only be understood as underdrives in the vaults below the north range and its saws.[52] Other drawings from 1800 and 1807 indicate that at both those dates the primary lateral drive from the engines into the centre range was aligned just inside bay 6 on its west side, that is close to the north-west corner of the east engine house.[53] This shaft was driven by cogwheels from both engines, that to the east on the flywheel shaft that is known to have been about 4ft (1.2m) below the present floor level. This implies that the original primary driveshaft was inside the semi-pyramidal penstock projection, a space not open to inspection. The long-section of *c.*1804-5 shows, in pencil rather than the wash

used for other features, a vertical shaft on the east side of bay 5, to which the annotation 'a new shaft and drum' perhaps refers. In the absence of any alternative indications it must be assumed that the longitudinal lineshafting in the drawing was powered from this vertical shaft. Midway across the centre range there is a large rectangular stone in the floor in the position that this vertical shaft would have occupied, that is just north-east of the centre of bay 5 (see Ground-Floor Plan including Lineshafting). It shows signs of having served as a bed for a machine (this was the site of a bandsaw in the 1950s), and there is a concrete surround. This position and the stone can be discerned in the head of vault 3 below, where there are three ashlar blocks, just east of the vault centre (Fig. 1). About 12ft (3.6m) further south and slightly further east there is a single stone block at the head of the vault where it abuts the semi-pyramidal penstock projection of the pump platform. It is unclear how it might have been engineered, but it may be that power was transferred from the primary drive shaft, which would have been very close to this line and level, to a lateral shaft in vault 3 that connected to the base of the vertical shaft shown in the long-section drawing.

From the first a vertical driveshaft and a capstan were close together on the ground floor of the north range, the former presumably rising upwards to drive the machines on the north-range first floor. However, it is unclear what drove the shaft and the capstan or where they stood, though a position near that of the existing capstan in bay 6 seems likely (see above). While there would have been power in the north range from the outset, that is 1804 if not 1803, there is no reason to suppose that the design and engineering of the power transmission antedated the decision to build the centre range and equip it for steam-driven machines. The original north range drives do not, therefore, need to be understood as having existed independently of whatever drove the centre-range machines. The long section of *c.*1804-5 has four pulleys in bays 1-5 annotated 'to the drum north building', and the centre-range vertical shaft in the drawing has what looks like a pulley sheave at about head height on its east side, and a wheel structure on the floor on its west side, though neither is obviously for the transfer of power northwards. Perhaps the absence of pulleys from the centre-range lineshafting in bays 6-11 suggests that this

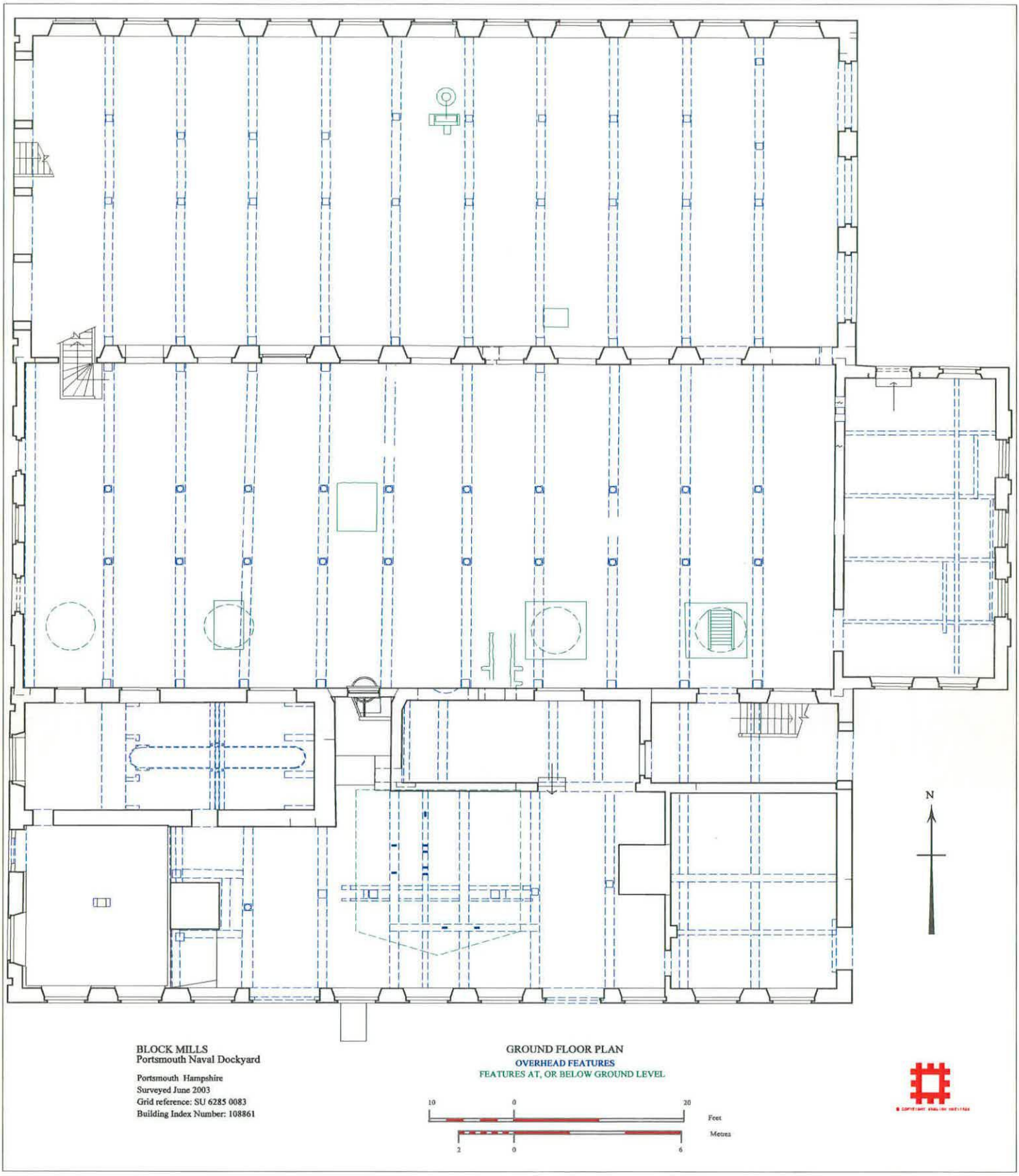
eastern part of the north range had another source of power, that is the vertical shaft and the capstan.

Given that there may have been vault-level transfer from the engine houses to the centre-range vertical shaft the possibility of further vault-level transfer on the same line arises. For this, however, scant evidence has been seen. Jottings by Goodrich indicate a lateral horizontal shaft on the east side of vault 3, that is under bay 6, and tolerably close to the line of the low-level shaft already posited for the centre range. The original configuration here remains unknowable in the absence of further documentation as the northernmost section of vault 3 has been wholly rebuilt, evidently at some time prior to 1858 by when the existing capstan was in place (Fig. 5). Power transmission along vault 3 would have had to have been low-slung to have passed through the doorway in the otherwise unopened dividing wall, unless of course this wall has been rebuilt, something that is not evident. Goodrich indicates that the horizontal sub-floor shaft was 6ft6in. (1.95m) below the mill floor, but it would have had to have been about a foot (30cm) lower and rather further west than the line sketched by Goodrich to have passed through the doorway. At the far north end of vault 3 there are stones with small openings that may relate to the end fixings of the underdrive. Immediately above in bay 5 of the north range there is a bearing box near the floor in the north wall, but this does not look likely to be of a particularly early date.

At the south end of vault 4 there is a bearing box in the pump platform wall just east of the head of the vault, that is on the west side of bay 8 in terms of the spaces above. It is conceivable that the vault 3 lateral shaft transferred power to vault 4 and there to another sub-floor lateral shaft, though if so the link would again have had to be slung low to clear the head of the dividing arch. A low shaft in vault 4 might have run through to link with whatever device was fixed to the stonework under the south end of bay 8 in the north range (see above and Fig. 10). This has been suggested as being the position of the great reciprocating saw, which Farey said was powered 'by means of a crank on an axis beneath the floor'.[54]

The nature of early power transmission in the vaults remains ambiguous and open to further investigation. There needs also to be an explanation for the iron box that sits astride the floor in bay 7 of the east-engine-house north wall and for the similarly aligned bearing box in the south wall of the north range, both in line with a shaft shown as dotted on an 1807 drawing.[55]

It is evident from Goodrich's diaries that through the early years the machinery in the Block Mills saw more or less constant repair, refinement and upgrading as a new and experimental system gradually bedded down. For example, in August 1805 an already worn wooden cogwheel was replaced with one of iron.[56]



BLOCK MILLS
Portsmouth Naval Dockyard

Portsmouth Hampshire
Surveyed June 2003
Grid reference: SU 6285 0083
Building Index Number: 108861

GROUND FLOOR PLAN
OVERHEAD FEATURES
FEATURES AT, OR BELOW GROUND LEVEL

10 0 20 Feet
2 0 6 Metres

N

10 0 20 Feet

2 0 6 Metres

BLOCK MILLS
Portsmouth Naval Dockyard

Portsmouth Hampshire
Surveyed June 2003
Grid reference: SU 6285 0083
Building Index Number: 108861

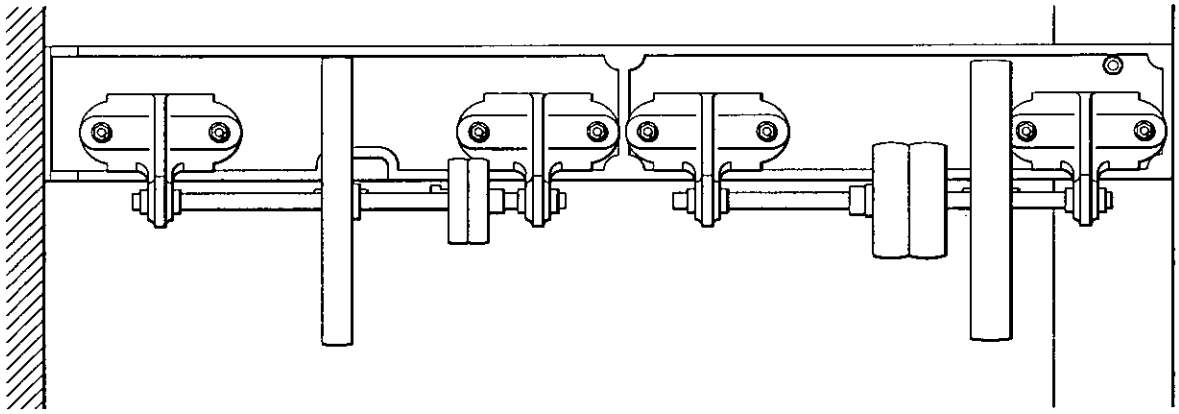
GROUND FLOOR PLAN
OVERHEAD FEATURES
OVERHEAD LINESHAFTING

BLOCK MILLS
Portsmouth Naval Dockyard

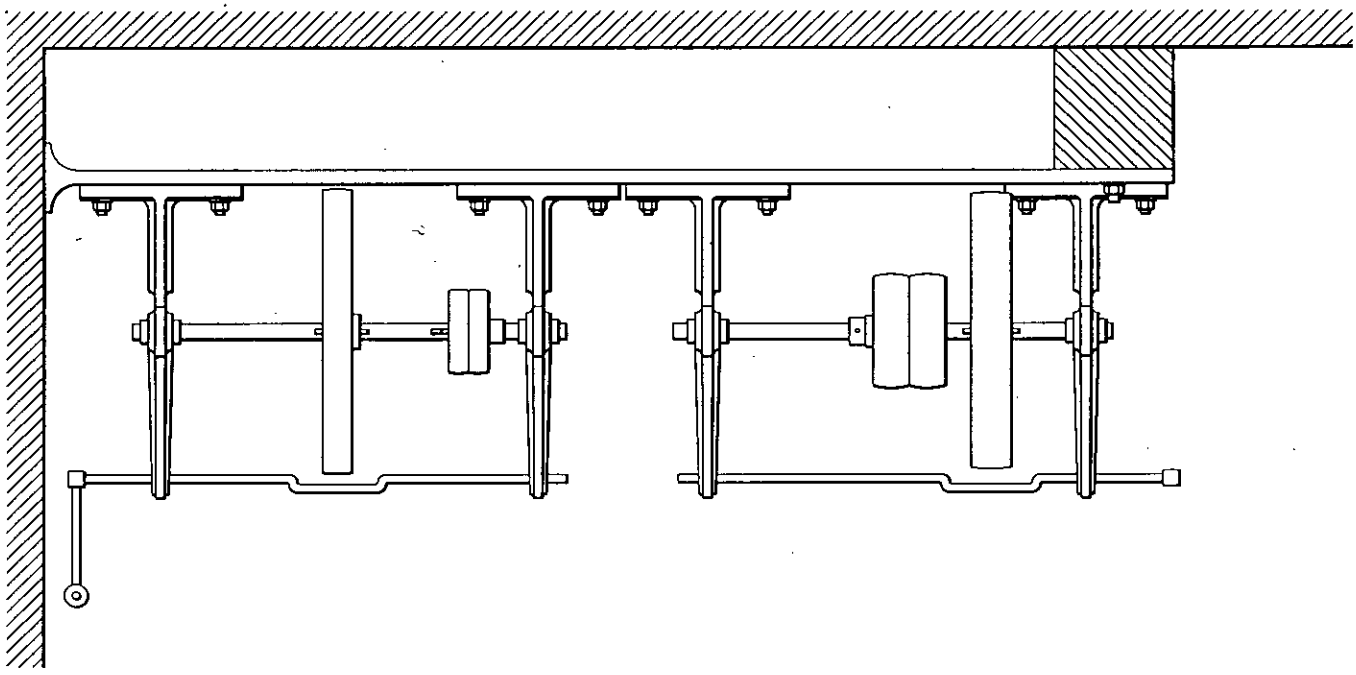
Portsmouth Hampshire
Surveyed June 2003
Grid reference SU 6285 0083
Drawn by A.D.
Buildings index no. 108861

ELEVATION OF NORTH WALL OF SOUTH RANGE SHOWING ENGINE HOUSE WALLS
ABOVE RESERVOIR AND PUMP PLATFORM WALLS IN UPPER VAULT
LOOKING SOUTH

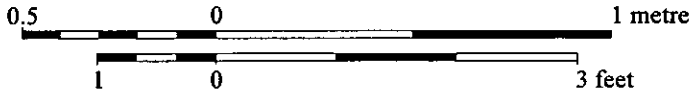
1 0 5 10 15 20 metres
5 0 30 60 feet



FRONT ELEVATION
(BELT CONTROL BAR OMITTED)



TOP VIEW



DETAIL OF AUXILIARY SHAFTS AND BELT PULLEYS
IN SOUTH-EAST CORNER

NOTES

1 - See Jonathan Coad *et al*, 'The Portsmouth Block Mills: the start of a revolution', English Heritage, July 2003, and Tony Woolrich, 'The Mechanisation of Naval and Military Production and the place of the Portsmouth Block Mills' and 'Report on the Literature relating to the Portsmouth Block Mills', prepared for English Heritage, June 2003, as well as notes prepared by Tony Woolrich on the Block Mills' power transmission, steam engines, machine drives and saw-mill machinery, and his transcriptions from the Science Museum Library Goodrich Collection Journals.

2 – This chronology is largely derived from an earlier version written by Jonathan Coad.

3 - Science Museum Library, Goodrich Collection (hereafter SMLGC), Drawings C101-2.

4 - National Archives (hereafter NA), WORK 41/381-2 and SMLGC, Drawings C76-7 and 102.

5 – SMLGC, A155.

6 – SMLGC, Drawings C76-7.

7 – SMLGC, A157, as noted by Ann Coats.

8 - SMLGC, Journals, Book 14.

9 - SMLGC, Drawings C215-7.

10 - Portsmouth City Record Office, R. S. Horne Papers.

11 - Birmingham Public Libraries (hereafter BPL), Boulton and Watt Collection, copy of otherwise unreferenced drawing mounted in Block Mills.

12 - Unsourced quotation from Jonathan Coad.

13 – SMLGC, Drawing C16, the counterpart of which drawing from the Boulton & Watt archive is dated 26 March 1800; NA, ADM 140/503.

14 - NA, WORK 41/381-2.

15 - Information sent to Tony Woolrich by Tim Proctor, Archivist, BPL.

16 - BPL, Boulton & Watt drawing of 25 March 1837 as transmitted by T. Woolrich.

17 - NA, WORK 41/381-2.

18 - BPL, Boulton & Watt drawing as above.

19 - Abraham Rees, *The Cyclopaedia*, xxii, 1812.

20 – Unsourced quotation from Jonathan Coad.

21 - SMLGC, Journals, Book 5.

22 - SMLGC, Journals, Book 12.

23 - SMLGC, Journals, Book 18.

24 - Rees, *op. cit.*

25 - NA, WORK 41/415 and 1858 drawing.

26 - NA, WORK 41/415 and 1858 drawing.

27 – SMLGC, B 6a.

28 - SMLGC, B 6a, pp. 18-20.

29 - David Brewster, *The Edinburgh Encyclopaedia*, iii, *c.*1811.

30 - Compare the pit for 'sawing machinery' drawn at SMLGC, B 6a, p. 9.

31 - SMLGC, Journals, Books 12 and 14.

32 - NA, WORK 41/415.

33 - SMLGC, Journals Book 5.

34 - SMLGC, Drawing C12.

35 - (trans.) Clare Williams, *Sophie in London, 1786. Being the Diary of Sophie von la Roche* (London, 1933), p. 253.

36 - BPL, correspondence on drawing from Goodrich to Boulton & Watt, 6 April 1800.

37 - See R. A. Morriss, 'Samuel Bentham and the Management of the Royal Dockyards, 1796-1807', *Bulletin of the Institute of Historical* Research, liv/130, Nov. 1981, pp. 226-240; Carolyn C. Cooper, 'The Portsmouth System of Manufacture', *Technology and Culture*, xxv/2 (1984), pp. 182-225; Peter Linebaugh, 'Ships and Chips: Technological Repression and the Origin of the Wage', *The London Hanged: Crime and Civil Society in the Eighteenth Century* (London, 1991), pp. 371-401; William J. Ashworth, '"System of terror": Samuel Bentham, accountability and dockyard reform during the Napoleonic Wars', *Social History*, xxiii/1 (Jan. 1998), pp. 63-79; Roger Knight, 'From Impressment to Task Work: Strikes and Disruption in the Royal Dockyards, 1688-1788', and Roger Morriss 'Government and Community: The Changing Context of Labour Relations, 1770-1830', in (eds) Kenneth Lunn and Ann Day, *History of Work and Labour Relations in the Royal Dockyards* (London, 1999), pp. 1-40.

38 - SMLGC, A155.

39 - SMLGC, Journals Book 10.

40 - Samuel Bentham, *Services Rendered in the Civil Department of the Navy in Investigating and Bringing to Official Notice Abuses and Imperfections; etc* (1813), as quoted by Ashworth, *loc. cit.*, pp. 71-2.

41 - M. I. Brunel, as quoted in Carolyn C. Cooper, 'The Portsmouth System of Manufacture', *Technology and Culture*, xxv/2 (1984), p. 213.

42 - SMLGC, Drawing C12.

43 - SMLGC, Drawing C12.

44 - SMLGC, Journals Book 5.

45 – Unsourced reference from Jonathan Coad.

46 - NA, WORK 41/415.

47 - See Tony Woolrich's notes.

48 - SMLGC, Drawing C12.

49 - These assessments of age derive from Tony Woolrich.

50 – J. G. Coad, *The Royal Dockyards 1690-1850* (Aldershot, 1989), p. 232.

51 - Rees, *op. cit.*

52 - SMLGC, B 6a, pp. 7, 9, 11, 12, 19.

53 - NA, WORK 41/381; SMLGC, Drawing C102.

54 – Rees, *op. cit.*; SMLGC, B 6b, pp. 18 and 19.

55 - SMLGC, Drawing C102.

56 - SMLGC, Journals Book 10.

APPENDIX 1: MACHINES IN THE BLOCK MILLS IN 2003

North range first floor

1 - Lignum vitae saw (yard no. 1908), said to be of 1804

2 - Trenail lathe (yard no. 651), said to be of 1802

3 - Cornering machine (yard no. 1902), 180?, sitting on a later 19th-century base marked P⁹↑Y

North range ground floor

4 - Bollard capstan and floor-level pulley drive (yard no. 66), early-mid 19th century

5 - Large planing machine (yard no. 648), said to be of *c.*1885; maker's mark: Saml Worssam and Co, Oakley Works, Chelsea, London

6 - Clam-shell printing press (no yard or maker's marks), treadle shaped as the letter 'G' (perhaps for Glockner or Golding)

Centre range

7 - Spile cutter (yard no. 682), said to be of 1859/60, marked P⁹↑Y

8 - 1-ton Travelling Crane (yard no. 406), 20th century, maker's mark: Herbert Morris, Loughborough

9 and 10 - hand winches in bays 6 and 9 (yard nos B41 and B42)

also: clearly marked in stone on the floor at the south end of bay 7 are the footings of a Brunel and Maudslay morticing machine, aligning exactly with the blocked door/hatch opening at the centre of the north wall of the east engine house.

Smith's Shop

11 - Lathe (yard no. 663), said to be *c.*1830, maker's mark: W. Collier and Co., Salford, Manchester

South range ground floor

12 – Pillar drilling machine (yard no. 50), maker's mark: Corona, Fk Pollard and Son, L(eicester?)

APPENDIX 2: SOME RECOMMENDATIONS FOR FURTHER WORK

This is a list of some possible avenues for future building investigation and recording, work that was beyond the scope of the present investigations, both in terms of the time available and the prevailing physical circumstances.

1 - There is extensive evidence of latter-day if not original machine positions in the heads of the vaults, particularly in the shape of bolts and bolt positions for attaching the machine frames. These might be recorded and related to comparably detailed recording of the floor above, perhaps by means of a 3D drawing. This record could then be compared with the known dimensions of the block-mill machines to aid reconstruction of machine layouts of early and late dates.

2 – A detailed survey of the east engine house (the Navy's first steam engine house), when surfaces are more exposed and intervention might be possible is desirable, using drawings (historic and current) to reassess early form and development.

3 – Investigation of the well should be undertaken (health and safety requirements permitting).

4 – A cross-section of the whole complex showing extant line shafting should be drawn.

5 – A long section of the south range showing the well and engine houses should be drawn.

6 – A comparative assessment should be made of the existing water pipes and of the historical importance of the original water cisterns.

7 - A 3D reconstruction of the centre-range roof and line shafting, and a conjectural 3D reconstruction of the earlier pulley system should be attempted.

8 - Further documentary research should be carried out to look for early accounts of the mills by visitors, and records of alterations. Trawls should be made through holdings in the National Archives that may relate to the post-1840 use and adaptation of the building.

9 - Further historical research regarding Samuel Bentham's planning of the block mills, with particular regard to the implications of his administrative and mechanising innovations for labour history, is desirable.

10 – There should be further research into the flow of work around the building.