PART 1

Labelye and his contemporaries

1735–1759

1

WESTMINSTER BRIDGE

. . . since I have lived in *Westminster,* I am grown very much out of love with this word *sinking.* It was in *Westminster,* how many years ago I forget, that the Church of St. John's *sunk* . . . it was in *Westminster,* about thirty years ago, that his late Honour invented the *Sinking Fund* . . . What can we infer . . . except that Westminster is a very bad place to lay foundations in?

A writer in the *Westminster journal* (12 September 1747)

The movement which led to the construction of the first Westminster Bridge began in 1734.[1] The fact that the construction did not start until 1738 shows that there were serious obstacles and the chief obstacle, for several reasons, was the old London Bridge. In the first place, Londoners were convinced that the decrepit old structure drew all the trade of the south of England to their town and they therefore resisted all the attempts to build other bridges across the Thames. Until 1729 they succeeded and there was no other bridge below Kingston; after 1729 the nearest was at Fulham. Both of these were timber pile bridges, rather narrow and very prone to damage and decay, but London Bridge, the only stone bridge over the tidal reaches of the river, was worse than either. It was narrow and dirty, its roadway contracted by houses and fouled by horses and cattle, and it was a major obstacle to the flow of the river and the movement of the numerous river craft (fig. 1). To the craft it was often a lethal hazard because of the narrowness of the passages between its piers and their further obstruction by 'starlings', which surrounded the piers to a little above low-water level but were covered and hidden, and therefore doubly dangerous, when the tide rose (see fig. 54). Such a bad bridge was an example ready to be cited by everybody who opposed the Westminster project, and even its owners, the magistrates and Common Council of London, tacitly admitted the great difficulties London Bridge made for boatmen when they claimed that the proposed new bridge would be 'a great prejudice to the navigation'.[2] The watermen of London and Westminster made similar objections, though their first concern was clearly the risk of losing cross-river trade. Uncommitted Members of Parliament were bound to find the argument plausible, and if London Bridge represented the best skill of English bridge-builders Parliament could not be expected to allow another stone bridge to be built at Westminster.

Many architects and tradesmen drew designs with the intention of showing that the new bridge could be made convenient for traffic and yet harmless to navigation, and five pamphlets published in 1735–7 all gave the same assurance. One of these pamphlets[3] was clearly written at the request of the men who led the movement for the bridge. They had worked in the customary way, first calling meetings of leading citizens with sympathetic noblemen and Members of Parliament, then raising subscriptions to pay for surveys of the river, for the drafting of a petition to Parliament and later a Bill, and for legal and technical witnesses to support the Bill when committees were formed to examine it in each of the Houses of Parliament. Their pamphlet was written by Nicholas Hawksmoor, one of the best-known architects of the day and a resident of Westminster. He came near to admitting that British architects were unfit to design or build the bridge, for when he sought instruction, both in books and in standing bridges, about the design and construction of such a large bridge he had found little in Britain and nothing near London to help him. Yet, paradoxically, his pamphlet contained a new and valid answer to the most serious question of debate.

He described the history and the wretched condition of London Bridge and referred to the medieval bridges of Rochester, Bristol and Burton-on-Trent, as well as several on the Severn, but for examples of arches of long span, such as he knew to be necessary in the projected new bridge, he had to look to the north of England at the old bridges of York, Durham (Framwellgate) and Bishop Auckland (Newton Cap), and the new waggon-way bridge south of Newcastle-upon-Tyne which has been called, at different times, Tanfield Arch and Causey Arch. He also noted the Brig' o' Balgownie at Aberdeen, an old arch of 80 ft span, and was aware of the ten years' work of road- and bridge-building which was just being completed in Scotland by General Wade,

1 London Bridge 1749. Engraving by S. and N. Buck.

a man who would soon be an active member of the Westminster Bridge Commission.[4] The only arch of long span in the southern half of England which he was able to mention was the one of $101\frac{1}{2}$ ft span in the park at Blenheim Palace, in the building of which he himself must have played some part as assistant to Vanbrugh, the architect.[5]

All the books about bridge design and construction which Hawksmoor found were from the Continent. The Italian writers, Palladio, Scamozzi and Serlio, gave some dimensions and ornamental details of the bridges of ancient Rome and of Trajan's great bridge over the Danube. Hawksmoor admired as 'exceedingly beautiful' the bridge which Palladio, a sixteenth-century architectural theorist, praised and copied, namely the Roman bridge at Rimini (fig. 2) – a bridge which, through Palladio's advocacy, was to influence many designs in Britain and Ireland. He quoted in summary Palladio's rules for the form, proportions and materials of arches, piers, cutwaters and abutments (see appendix 1A) and both Palladio's and Scamozzi's advice on the construction of foundations. Study of Palladio's book was greatly aided by the fact that an English translation had been published in 1715–16.

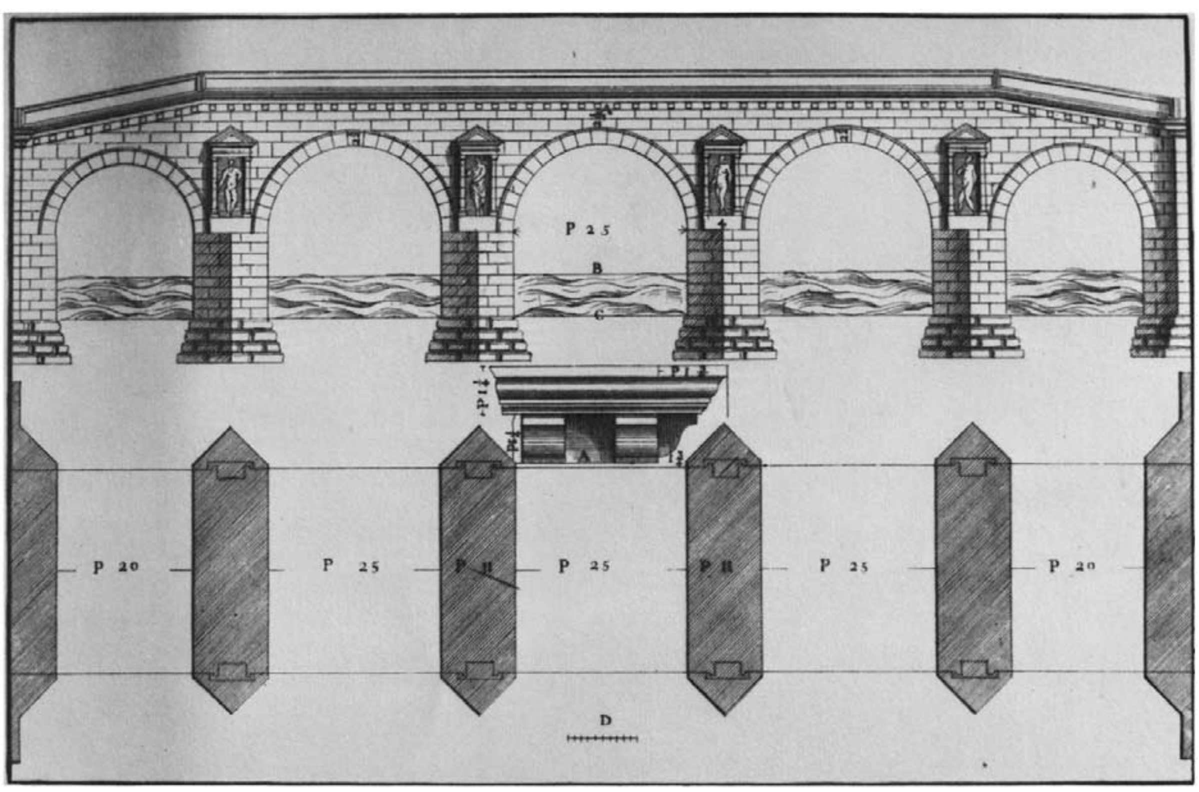
Hawksmoor's French authority, Gautier (see appendix 1B), was much more recent and gave him full specifications of two large modern bridges,[6] the Pont Royal at Paris, built in 1685, and the bridge of Blois over the Loire, an eleven-arch bridge finished in 1724 and designed by Jacques Jules Gabriel, the Premier Ingénieur of the Corps des Ponts et Chaussées since its inception in 1716. The bridge of Blois was of a similar type and length to what must be built at Westminster and it kept within Palladio's rule for the proportions of arch span to pier thickness, with ratios varying from 3.5 to 5.0, but it had elliptical arches, which Palladio had never considered. The foundations were laid on oak piles and the piers built up to water level in cofferdams, but Hawksmoor gave no details of these operations.

His own design for Westminster Bridge was of nine semicircular arches, the shape considered strongest since Roman times and by both Palladio and Gautier. His largest arch was to be 100 ft in span and the largest ratio of span to pier thickness 4.4. He followed the common practice of adding up the thicknesses of the piers as a measure of the obstruction offered to the river and also adding up the spans of the arches and comparing the total, 660 ft, with the existing width of the river, 830 ft. But as well as this he offered an entirely new kind of assessment of the effect of the bridge on the flow of the river, which had been made by Charles Labelye. Labelye was a Frenchman resident in Westminster who had been employed by the men who set the project in motion to supervise their soundings of the river and boring of the bed at the possible sites for the bridge.[7] He had been born in Switzerland, son of a Huguenot refugee, and had come to England about 1720 at an age between fifteen and twenty. He appears to have had some experience of construction work before 1736 but he was no ordinary tradesman, and probably not a tradesman at all. A survey map of the coast near Sandwich printed in 1736 is inscribed 'By Charles Labelye, Engineer, late Teacher of Mathematics in the Royal Navy';[8] and he had also assisted Dr John Theophilus Desaguliers either with scientific experiments or with his teaching. Desaguliers was himself the son of a forcibly exiled French protestant pastor but was renowned in London for his lectures on scientific subjects and especially 'experimental philosophy',[9] the subject which laid the foundations of modern engineering theory. Labelye was therefore fully competent in contemporary mathematics and mechanics and he had deduced or invented a method of calculating the 'fall', or difference of level between the surfaces of the water upstream and downstream of a bridge, caused by the piers obstructing the flow. His method, which was at least similar to that given in appendix 2, was, he said,

founded upon the doctrine of falling bodies, the principles of hydrostatics, a great number of observations made in several streams by the Reverend Dr. J. T. Desaguliers, several observations made last year on the greatest velocity of the stream near the place intended for the bridge, the greatest rise of the tide in the same place, and lastly, by a true and exact section of the river, obtained by three actual mensurations of the breadth of the river, and several boreings [i.e. soundings?].[10]

To introduce what is now called a 'factor of safety' or, as Labelye himself put it, 'to obviate or remove all difficulties and objections', he entered in his calculation a tidal rise one and a half times the greatest rise he had measured at the site and a velocity of water almost twice the greatest value he had measured. The result of the calculation for the bridge designed by Hawksmoor was that there would be a fall through the bridge of $4\frac{7}{10}$ in.; and he checked the method by applying it to the existing London Bridge when the answer agreed very closely with the fall observed there. At the worst the fall through London Bridge could be 4 ft 9 in.,[11] the sum of the widths of the openings being only 450 ft when measured above the starlings and 194 ft between the starlings, the latter being less than a quarter of the width of the river.[12] Labelye asserted, probably quite fairly, that a fall of less than 5 in. through the new bridge would 'never hinder any vessel or boat from rowing through, even against the swiftest tides'.[13] Hawksmoor printed Labelye's short report in his pamphlet and noted that the full calculations were available for inspection and were 'approved of by the Rev. Dr. Desaguliers, and others'. The 'others' included the mathematics master of Christ's Hospital, James Hodgson, who appears to have been acting as an adviser to the Common Council of London, and William Jones, Esq., who later proposed a simpler way of making the calculation.[14] It is Jones's method which has survived and is given in appendix 2.

This calculation by Labelye was the first important contribution by scientific theory to the art of bridge-building in Britain, and it must have made some impression on the committee in Parliament when the result was stated by Labelye and supported by Desaguliers;[15] but it did not go unchallenged. It was challenged by other calculations so simple that they could be understood by every member of the committee, but based on erroneous views of the flow of a river through a bridge. About a year before Hawksmoor's pamphlet appeared with Labelye's report, John Price the elder had addressed a pamphlet to the members of the House of Commons.[16] He offered a design of nine arches with the piers obstructing approximately one-sixth of the

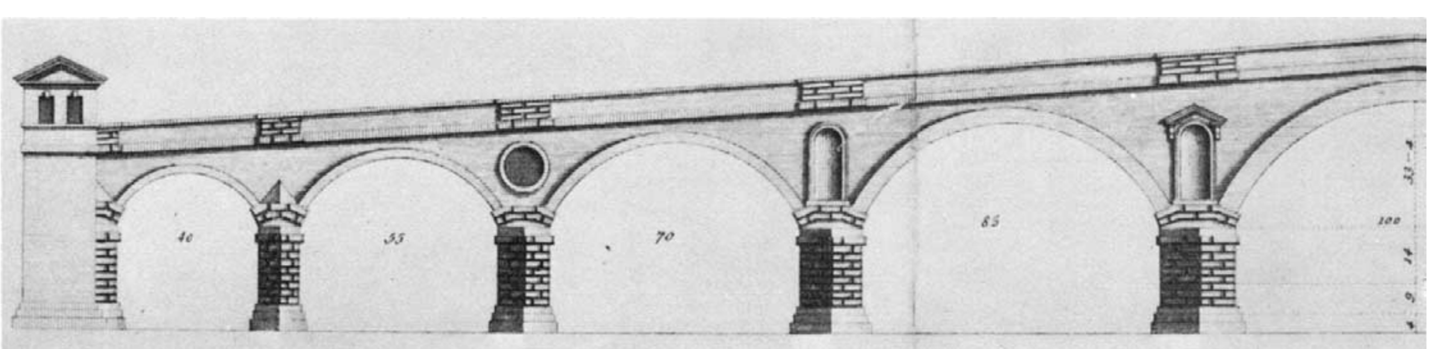


2 Bridge of Rimini. Drawing by A. Palladio, 1570 (reprinted 1965).

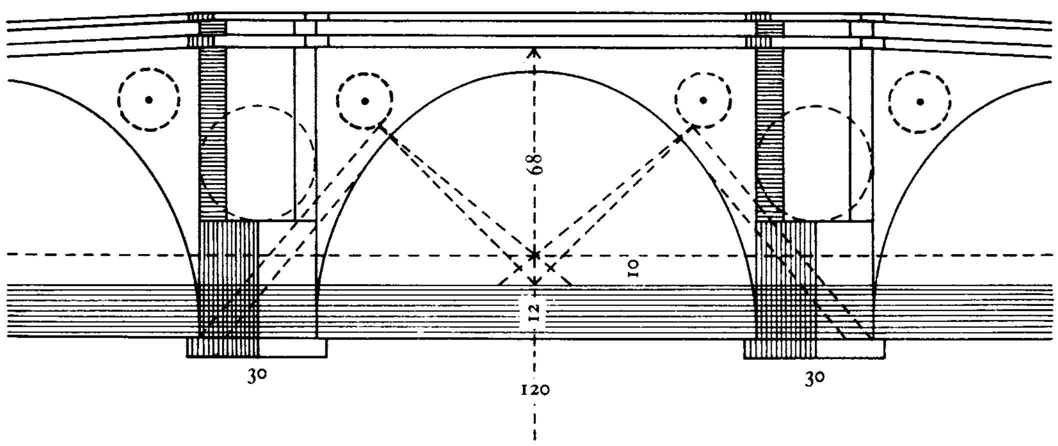
width of the river (fig. 3); he said that since one-sixth was obstructed the depth of water on the upstream side during the ebb of tide must increase by one-sixth, and as the depth was 8 ft at low-water there would be a fall through the bridge during the ebb of only one-sixth of 8 ft, that is, 1 ft 4 in. Even this fall he thought to be 'so inconsiderable, that boats may pass and repass at all times, without hazard or hind'rance', though one cannot imagine the boatmen agreeing. Were it not for the terrors of London Bridge, such a statement must have been thought imbecilic. The absurdity of the calculation was easy to prove, since the same rule could be applied at the turn of high tide when the depth could be as much as 24 ft and the fall therefore 4 ft; but there would be no flow at all at the turn of the tide and, logically, no fall. Such an argument does not appear in the parliamentary records and was not printed until July 1736 when Labelye's method had already gained a seal of acceptance by the passing of the Act.[17] It was used in a pamphlet by John James, architect, of Greenwich,[18] in which he reviewed the pamphlets of Price and Hawksmoor and another published in the previous month by Batty Langley.[19] Langley had given a much longer treatment of the question of the fall, but on the same premise as Price and with similar results, and he ridiculed Labelye's method. James's argument exposed the absurdity of Price's and Langley's calculations and he seemed disposed to believe Labelye's result, though he was clearly unable to follow the calculation.

James also offered a design, though without a drawing, and so there were now four designs in print. He shared Hawksmoor's preference for semicircular arches but he was satisfied with a maximum span of 80 ft and so required fifteen arches. His design was therefore the nearest in form to the bridge eventually built. Price was content (with Palladio) to let his segmental arches rise only one-third of their span, and so had a middle span of 100 ft no higher than James's semicircle of 80 ft. Langley, a prolific and often irascible writer on architecture and the building trades and apparently a successful teacher of those subjects, but with little experience of construction,[20] offered the 'scientific' curve of an inverted catenary, that is, the shape which a hanging chain would adopt naturally, turned over to form an arch which he believed would be stressed in pure compression. He proposed also to equalise the loads over the two haunches of each arch by forming cylindrical voids of unequal size through the spandrels; and to reduce the load on the foundations by another larger void directly over the middle of each pier[21] (fig. 4). The question of whether each arch could stand independently, that is, without the balancing thrusts of its two neighbour arches, was important, and Price intended that all the arches of his bridge should be built before any of the supporting centres were removed. But Langley argued that in his design, and only his, the arches could each stand alone, saying that 'their abutments are within the bases of their piers'. His diagrams (fig. 4) show that he derived this concept from the writings of French authors but without understanding them fully. For decoration Price used Palladian motifs (fig. 3), Hawksmoor a restrained classical form with heavily rusticated stonework, and Langley drew no ornament at all.

On the vital question of how to lay firm foundations in the bottom of a river which rose and fell by 15 ft at spring tides and was up to 24 ft deep at the highest spring tides, the four men also differed. John Price offered practical methods for founding the piers, but they were rather outdated and certainly difficult to carry out in such deep water; Hawksmoor and James made no firm proposals. Langley was original, proposing two alternative methods. If the bottom were found to be 'a strong clay' he would make a double-walled cofferdam round each pier and found the pier on driven piles capped by a platform of oak. If the bottom were 'firm gravel', which was actually much more likely, he believed the water would seep into a cofferdam too quickly for pumps to clear it and so he proposed to dig and level the gravel to 5 or 6 ft below the existing bed and build the first courses of the piers in a flat-bottomed vessel which he named a 'concave parallelopipedon'. (The use of a mathematical description instead of a nautical one was typical of Langley, and James saw fit to translate: 'in English, a hollow chest or coffer'. Langley himself wrote in another work that a parallelopipedon was 'also called a long cube, and by some a prism'.)[22] It



3 Design for Westminster Bridge by John Price, 1735.

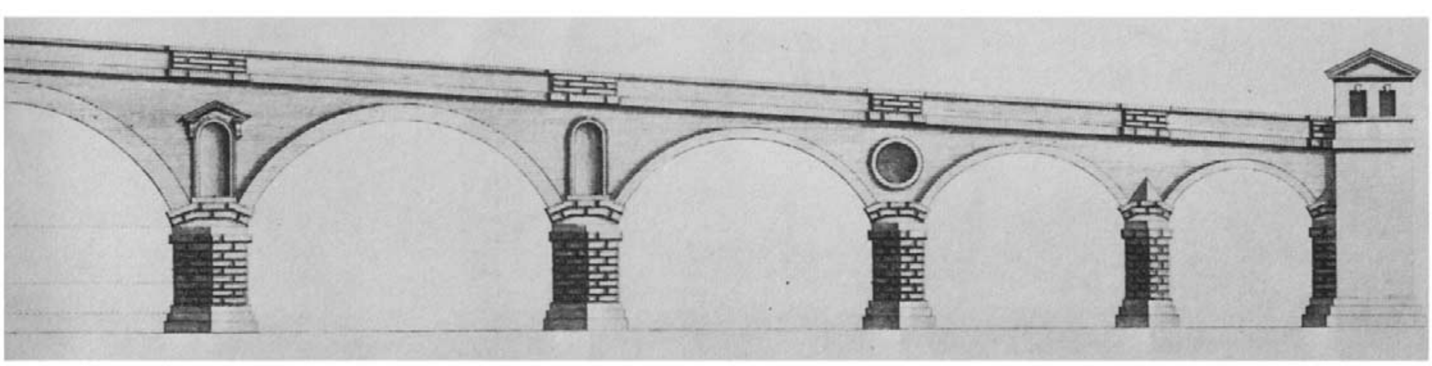


4 Batty Langley's arch.

was to be an open-topped box which would sink by the weight of the masonry and rest on the prepared gravel surface. Whether the sides were to be removed when the top of the stonework reached water level Langley did not say.

These pamphlets did nothing to establish their authors as contenders for the position of architect of the bridge. Both Price and Hawksmoor were dead before the Act was passed and James was well over sixty.[23] Langley may have seemed too clever. But the distrust of native talent, which the pamphlets may well have inspired, caused some of the promoters to write to the British ambassador in Paris.[24] He was asked to obtain designs for the foundation works from Chevalier d'Hermand, an engineer at the French Court, and to persuade the builder of the bridge of Blois, M. Lambotte, to come to London to contract for the construction. This seems to have come to the ears of some master tradesmen in London, for six of them signed a petition presented to the first meeting of the Westminster Bridge Commissioners on 22 June 1736 which said: 'with great concern they have heard it is apprehended there are not people in England capable of building the said bridge'; and begged to be allowed to build a stone pier at their own expense in whatever part of the river was considered most difficult, to prove their competence. Among the six were Andrews Jelfe and Samuel Tuffnell, masons, Thomas Phillips, carpenter, and George Devall, plumber, all of whom had been contractors in the building of the timber bridge at Fulham in 1729, Phillips holding the main contract.[25]

This offer was allowed to lie unanswered for a year because the lottery intended to finance the building of Westminster Bridge proved a failure and no action could be taken until another Act of Parliament had authorised a second lottery with better terms.[26] Then the tradesmen renewed their offer but the Commissioners were advised by Thomas Ripley, a former carpenter who was now Comptroller of the King's Works and was also a leading figure among the proprietors of Fulham Bridge, that they could have a timber bridge for £35,000 while a bridge of stone would cost £70,000. They decided in July 1737 to build in timber, being still unsure how much money they would have to spend. The surviving pamphleteers, James and Langley, submitted designs of timber along with at least six others, but Charles Labelye offered a design all of stone and declined to make a design of timber. Ripley introduced designs of his own for stone, timber and part stone and part timber, but after repeated discussions



and partly on Ripley's advice the Commissioners decided that they must adopt a step-by-step approach to the work. They asked Labelye twice, in September 1737 and May 1738, to explain to them a method he proposed for founding piers, and he in turn offered to found a trial pier by this method at his own expense. He admitted later that he had taken advice from Andrews Jelfe and a master carpenter named James King on this and other occasions[27] and Jelfe, with Samuel Tuffnell in partnership, and King appeared with him at his second explanation with offers to construct some piers by his method at stated unit prices. The Commissioners accepted.

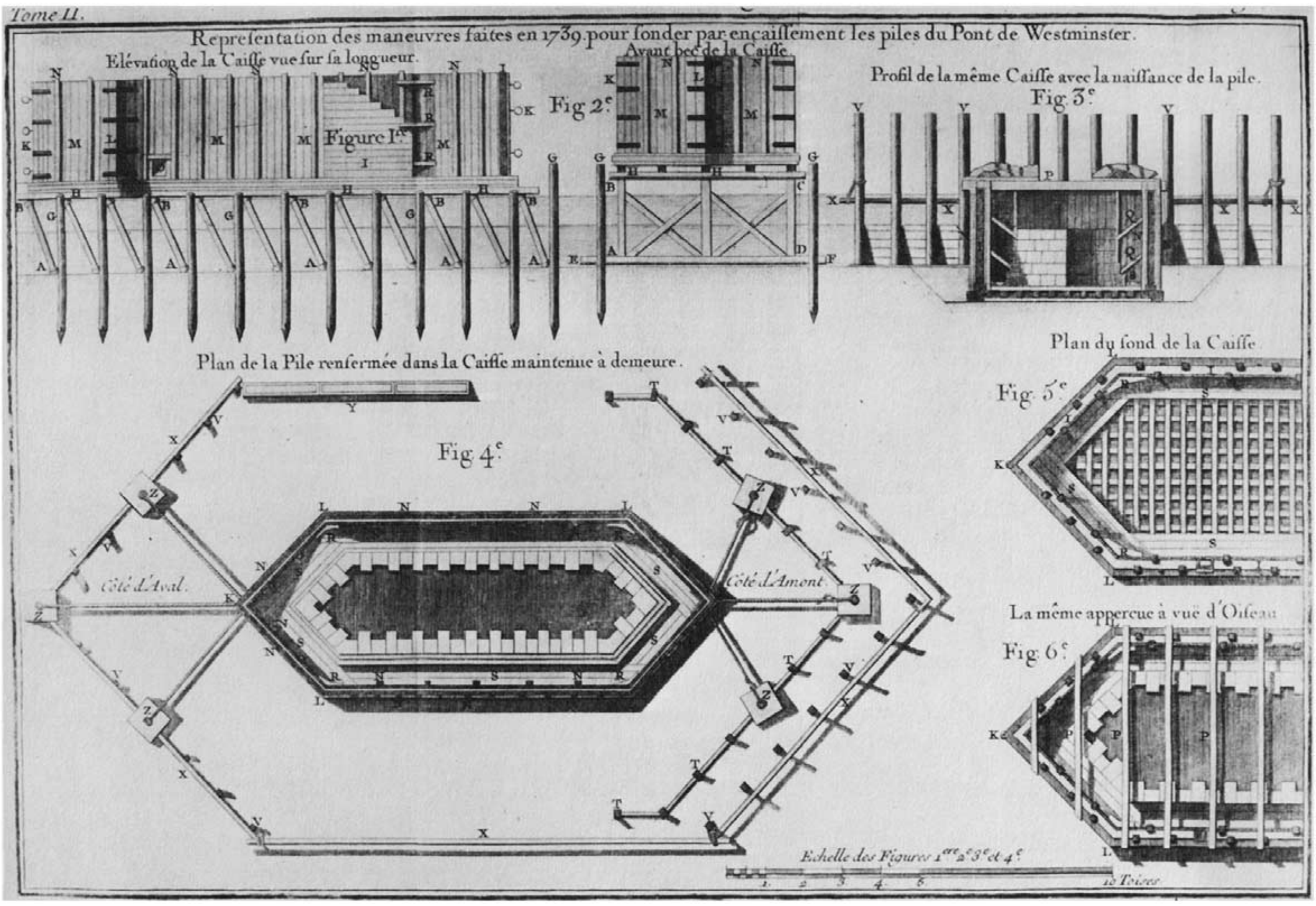
The method was the same in principle as that which Batty Langley had proposed in his pamphlet for use on a gravel river-bed. Labelye called the open-topped floating box a 'caisson' and it was sometimes referred to later as a 'case' or simply as 'the vessel'. Another tradesman collaborator was Robert Smith, a 'ballast-man' whose normal business was the supply of gravel dredged from the bed of the Thames; he had assured the Commissioners that he had experience of dredging to make a perfectly level bottom such as the caisson would need to rest on. Labelye did not claim complete novelty for the method, and boxes of masonry had been sunk before as the bases of structures, but the use of a box designed to be sunk and floated again as necessary, and of such a large size, was quite new.[28]

Labelye was appointed 'engineer' for the laying of the foundations in June 1738, and the title is significant. Nobody who called himself architect took any further part in the design or construction of the bridge and it seems likely that Labelye himself had suggested a title which was already common in France. He acknowledged early in the work that piles might be used to strengthen the ground under some of the piers, but as work went on he bored the bed of the river at the exact site of each pier and decided in every instance that the gravel was firm enough without piling. James King, however, held that they should have been piled and offered to supply and drive piles for all the piers for only £5,000 or £6,000.[29] Labelye judged both the nature and the strength of the strata by their resistance to the driving of a sharp solid bar, 'the point of which was not unlike that of a watchmaker's drill', after a few initial borings in which a different tool was used to bring up samples of the materials. He could distinguish 'dirt, sand, clay, or gravel' by 'the tremor of the bar, and the noise it made . . . which was communicated through the iron bar so as to be very sensible both to the ear and hand'.[30] Most, if not all, of the piers were founded on gravel several feet below the surface of the river-bed.

Fig. 5 gives the details of the caisson as engraved in Bélidor's *Architecture hydraulique* in 1752.[31] The height was originally proposed to be 30 ft but this was reduced to 16 ft from the top of the floor, or 'grating' as it was called when it became the base of a pier. The sides were of fir timbers laid longitudinally and sheathed with vertical 3-in. planking inside and out to give a total thickness of 1 ft 6 in. at the bottom and 1 ft 3 in. at the top. Vertical timbers, forty-six in number and 8 in. × 3 in. in section, were fixed to the inside and outside faces and had dovetailed ends at the bottom held in mortises in the floor timbers by iron wedges; the wedges were knocked out when a pier had been founded and the sides were then free of the bottom and could be floated off on a high tide. There was a sluice in the side for letting in the water to sink the caisson when required. The bottom was of 2 ft total thickness, made up of longitudinal timbers 12 in. square with 3-in. planking across their undersides and 9-in. square timbers across their upper sides. Both the 12-in. and the 9-in. timbers were spaced apart about twice their own widths so as to form an open 'grating'; what was used to fill the spaces between them is not recorded. To resist the inward pressure of the water on the sides there were braces across the top and these also carried a floor for stacking stones and other materials. A timber kerb 14 in. × 7 in. in section fitted tight between the bottom of the sides of the caisson and the face of the bottom course of masonry.

The caisson was built on twelve trestles which stood vertically until it was ready for launching but could then be made free, by the removal of braces between them, to rotate on their bottom members and drop the caisson into the water (fig. 5). This was done at high tide. It was then towed out to the site of the pier and anchored within 'guard works'. The caisson for the first pier to be founded was kept afloat while three courses of masonry were laid and cramped, but it was sunk several times by opening the sluice to check the regularity of the bottom of the prepared foundation pit. The pit had been dug by the dredging scoops of the ballastman Smith but needed some trimming where material had since fallen in. Planking attached to piles was used to prevent such falls and later on troughs filled with gravel were placed along the top of the slopes which surrounded the pits, as shown at Y in fig. 5. The arrangements at the first pier are shown correctly in the figure but they were simplified for later piers. When three courses of stone had been laid the caisson was grounded permanently and afterwards pumped dry at each low tide both day and night for the masons to work, until at least six courses had been laid. Every time the tide rose the sluice was opened to avoid danger of the caisson floating, and the masons stopped work; at high tide the top of the caisson was several feet under water. When the masonry was well above low-water level the sides were freed and floated away to be used again for the next pier.

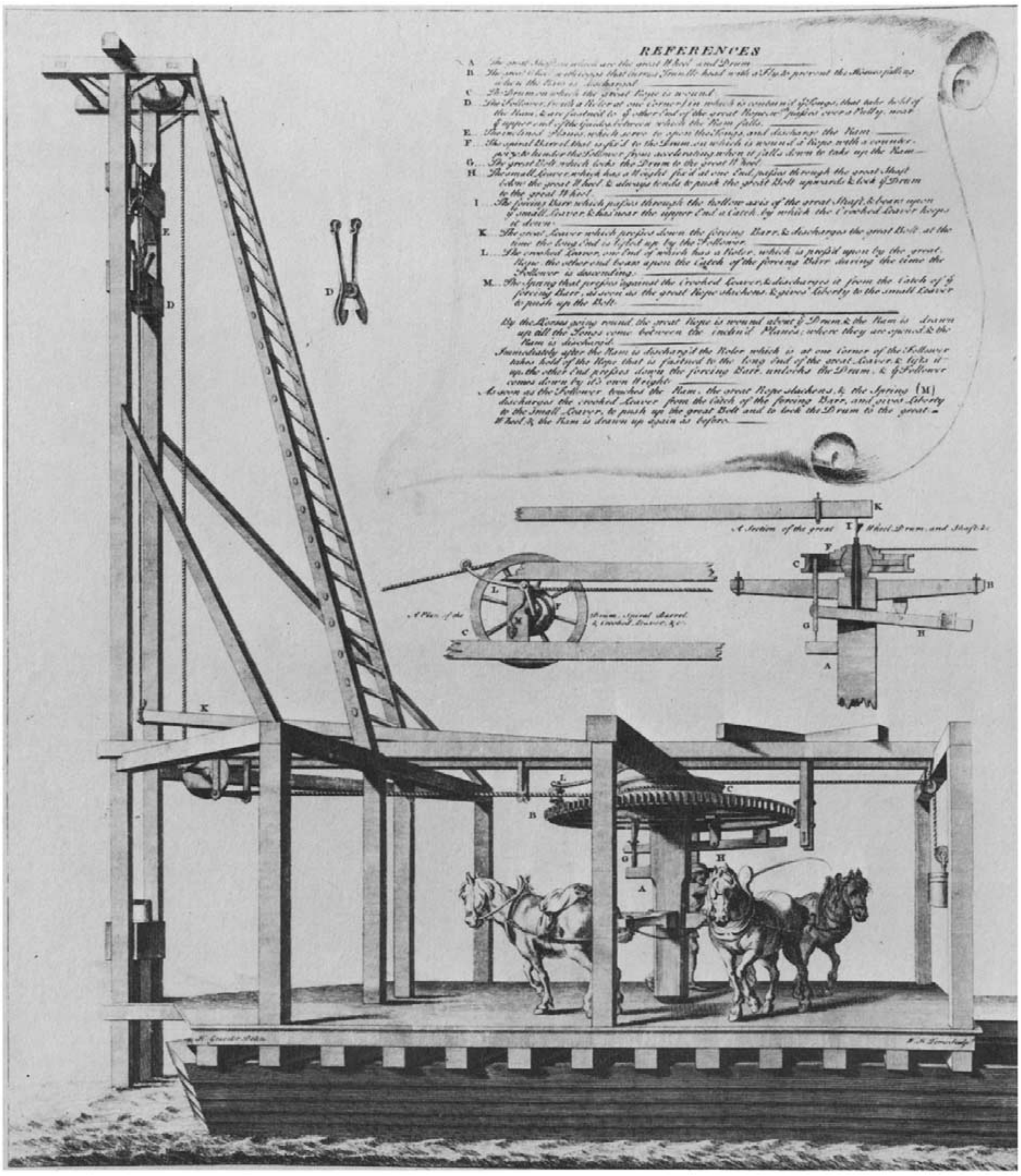
Although the number of piles required was relatively small the machine built to drive them was a very special one, more complicated and expensive than conventional pile-drivers but also of much better performance. It was designed by James Valoué, a watchmaker and acquaintance of Labelye, but was simplified somewhat by the engineer himself.[32] Its features were the use of sprung tongs to lift the driving weight of 1,700 lb,



5 Caisson of Westminster Bridge. Engraving in Bélidor, 1752.

automatic opening of the tongs to release the weight at the top of its lift, which was up to 20 ft above the pile-head, and the use of a clutch between the drum on which the lifting rope was wound and the shaft of the capstan which turned the drum. Valoué's print of the machine (fig. 6) shows the clutch operating automatically and it may be that Labelye's alteration was to make a simpler clutch for hand operation by the workman in charge, as explained by Bélidor in 1750 in a full description of the machine with good illustrations of the details (fig. 7).[33] The release of the clutch allowed the drum to reverse and the rope to run out, so that the tongs dropped after the weight to re-engage it and lift it again, without need for the capstan to reverse. As compared with other piling machines, this one had three advantages: first, the weight, or 'monkey', was large because it was lifted by a capstan instead of by men hauling on a rope over a pulley – the usual monkeys raised by that method being about 800 lb; second, the height of fall was much greater than the men could obtain, being limited by the length of their arms' reach, about 4 ft; third, the return of the tongs to the monkey after a blow was much quicker than in other capstan-driven machines where the capstan and its horses or men had to reverse their movement to pay out the rope after the monkey fell. The machine was erected on two barges fitted with a timber floor for the horses to walk on and both well ballasted to keep it as steady as possible in the water. Once it was well run in it could raise the monkey 150 times per hour to a height of 8 to 10 ft, using three horses 'going at a common pace'. Dr Desaguliers claimed in his *Course of experimental philosophy* that it did five times as much work (in equivalent time) as an ordinary piling machine.[34]

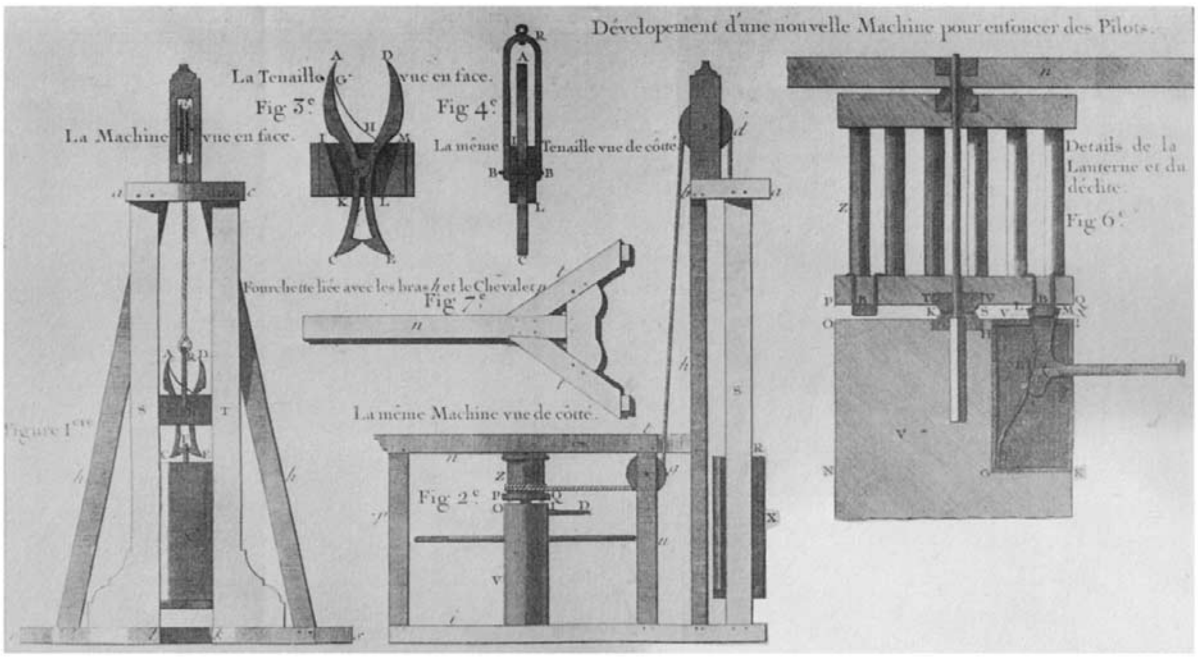
Labelye was ordered at the start of the work to make the foundations capable of bearing the weight of 'a stone bridge agreeable to his own plan'; but at the same time the Board of Commissioners made a contract with James King and John Barnard, carpenters, to build a superstructure of timber which was of the same overall dimensions as Labelye's design. It was designed by King and was to consist of thirteen trussed arches and



6 Pile-driving machine. Design by J. Valoué.

cost £28,000, but in the winter of 1739–40 when the Thames froze over for several weeks the damage caused by ice to the guard works prompted a reconsideration of this decision; and in February 1740 the Commissioners made a bargain with King and Barnard for cancellation of their contract and started to build the stone bridge designed by Labelye. They paid to King and Barnard £1,797 in compensation and £5,674 for timber already purchased. A little of the timber was used in the construction of the bridge and valued at £271; the remainder had to be sold for only £1,872.[35]

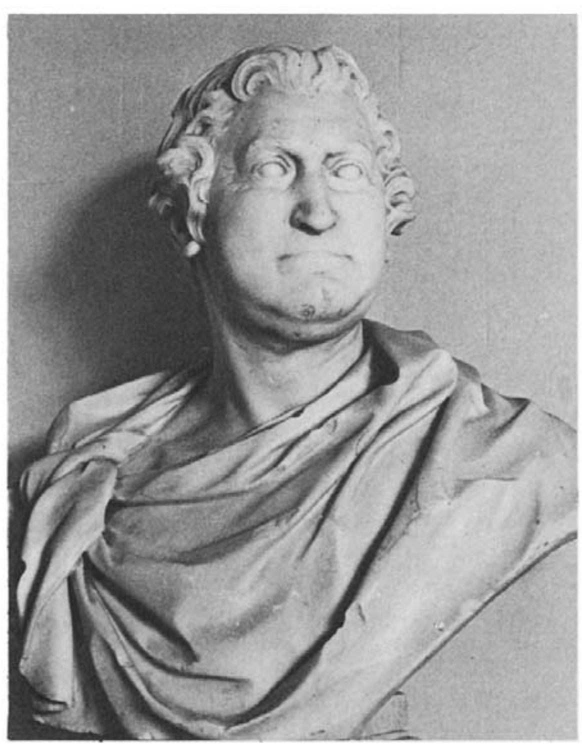
Labelye became 'engineer' for the whole construction, with power to suspend incompetent workmen and to direct all the work and certify its satisfactory completion for the purpose of payment. For this he was paid only £100 per year with a subsistence allowance of ten shillings a day when in attendance, but he received a gratuity of £2,000 when the bridge was finished.[36] The



7 Details of Valoué's machine. Engraving in Bélidor, 1750.

Commissioners had other salaried officers: a clerk, with one assistant at least, to keep records and deal with legal matters, a treasurer to handle money, a 'surveyor of streets' concerned with survey and purchase of property, and a 'surveyor and comptroller of the works', Richard Graham, whose duties came closest to the engineer's. Graham was responsible for drawing up contracts, measuring work done, checking accounts, and all financial aspects of the construction of the bridge. He was paid £300 per annum, but without the daily subsistence allowance and with only a small gratuity at the end; the other officers received similar but generally smaller pay. It was a remarkably complex organisation and it allowed the Commissioners to contract for the work in a piecemeal way, as they seem to have felt compelled to do, whether from fear of making mistakes or from uncertainty as to the continuance of the supply of funds. Their funds came from lotteries until 1741 and thereafter by direct grants from Parliament.

The most active Commissioner at most times between 1736 and 1750 was the wealthy and boisterous Ninth Earl of Pembroke (fig. 8). He was a very accomplished gentleman architect who had designed and was, in 1735–7, erecting the most famous of all estate bridges, the covered bridge in Palladian style in his own grounds at Wilton House.[37] An undated memorandum among his private papers lists the officers considered necessary for the construction of Westminster Bridge at the time when the foundations were started, foreseeing the division of responsibility between Labelye and Graham and using the term 'engineer'; there is also a drawing of the elevation of the middle arch which may represent his thoughts on the architecture of the bridge (fig. 9). He has actually been described as the architect[38] and it is not unlikely that he contributed some of the motifs on the facade of Labelye's design. He was clearly Labelye's chief supporter in all controversy and was given credit by both Labelye and Graham for the survival of the project and by Graham for his own employment there. He also gave security for James King's contract with the Commissioners for construction of the first centres. The letters of various officers to him suggest that he was allowed by the Commissioners to act almost as the bridge's patron.[39]



8 The Ninth Earl of Pembroke. Bust by L. F. Roubiliac.