INVENTING THE I-BEAM: RICHARD TURNER, COOPER & HEWITT AND OTHERS[1]

by Charles E. Peterson, F.A.I.A.*

For well over a century the I-beam, rolled first in wrought iron and then in steel, has been one of the most widely used building elements ever invented. The story of its development is still obscure at several points. But some notable achievements along the way can be reported as we pick up where the published work of Professor Robert A. Jewett of the University of Illinois left off a dozen years ago.[2]

The use of simple beams of wood or stone goes back in time beyond history. But we are unable to recall any *iron* beam earlier than one still buried in the front of an old brick furnace at Coalbrookdale on the Severn in Shropshire bearing the date 1638.[3] Home of the Abraham Darby's famous works and the great Iron Bridge — of which the bicentennial has just been celebrated — the valley of the Severn is rich in examples of engineering leadership in iron.

Thirteen miles to the northwest, in the Ditherington district of Shrewsbury, Charles Bage's innovative flax mill was erected in 1792.[4] Enclosed within its brick walls can still be seen a whole fireproof framing system composed of rows of columns and beams all of cast iron carrying shallow brick vaults to support the floors above. A great step forward from Bage's design came with the beam molded in I-form but still done in *cast* iron. Scientifically developed in the following years, cast iron beams eventually reached great size.[5] But, though tending to be fireproof, such beams were heavy and brittle and subject to hidden flaws and sudden failure as was tragically demonstrated in some spectacular collapses.

Once the advantage of the I-form was established, the question was how to produce it in malleable or wrought iron. The daunting technical challenge lay in building an apparatus strong enough to squeeze red hot iron into such a difficult shape.

The technique of *rolling* beams began with the invention of the modern railroad rail, a special form of beam,[6] and with rolling deck beams for ships. In those years the most enterprising ironmasters of England, France and America came to be pitted against each other in close rivalry; at times it amounted to an international trade war. Finally, in the middle 1840's — after struggles and disappointments at the mills — there came a leap forward. An order of true I-beams was rolled at West Bromwich, Birmingham in 1845 for a curved roof. But it took several years more to produce them commercially. In the meantime, the Americans had their own version — the bulb-tee — used from 1848 on for supporting fireproof brick floors and ceilings. By 1856 a true I-beam was rolled at Trenton, New Jersey and it was at once adopted for the new Federal buildings program across the country.

The Malleable Iron Deck Beam

Malleable iron — tough and fibrous — is a distinctly different metal from cast iron which it was to supercede as a framing material in the 1840's. The first advance beyond railroad iron came in the art of shipbuilding. John Grantham, a consulting engineer and naval architect, in 1842 reported to the Polytechnic Society of Liverpool the successful use of a wrought iron deck beam compounded of *three* L's rivetted together.[7]

The West of England continued to be the center of progress. Isambard Kingdom Brunel's iron ship *Great Britain* — the wonder of its time — was under construction at Bristol when engineer J.R. Hill carefully described it in the *Mechanics' Magazine* (London) for September 10, 1842. The screw-propelled monster was 320' long with a beam of 51' (Figures 1 & 2). The problem of supporting its heavily planked main deck was solved using compound beams of wrought iron (Figure 3) described as "bars of apparently 3 inch angle iron, with a joist bar of 5½ inches riveted on the side." The hull was floated in 1843 but the fitting out continued until December of 1844. The ship survived a grounding in the Falkland Islands in 1866 and other mishaps, and it was finally brought back to Bristol for preservation a dozen years ago. It now is unclear if any of the original deck construction survived the various remodellings undergone through the years.

While the *Great Britain* was under construction a Liverpool team secured patent No. 10,143 for "Certain Improvements" in shipbuilding. James Kennedy of the firm of Bury, Curtis and Kennedy and Thomas Vernon, Iron Ship Builder, illustrated in their document enrolled October 15, 1844 thirteen designs for iron beams (Figure 4). Among them at small scale is a true I-beam with equal flanges, rather squat in proportions (shown as "Fig. 5"). Whether that section was even produced commercially — if at all — is not known. But the 7-3/16" bulb-tee lithographed at full size was to have a life of its own when adopted for roof constructions ashore.

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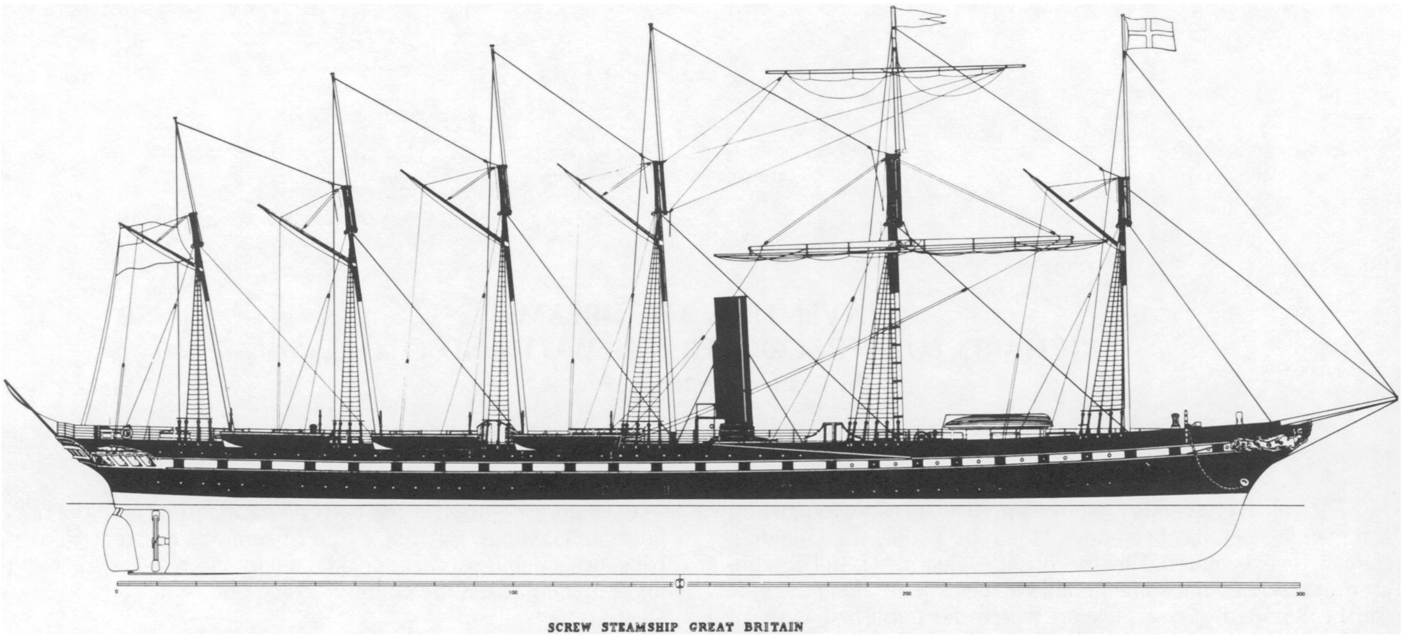
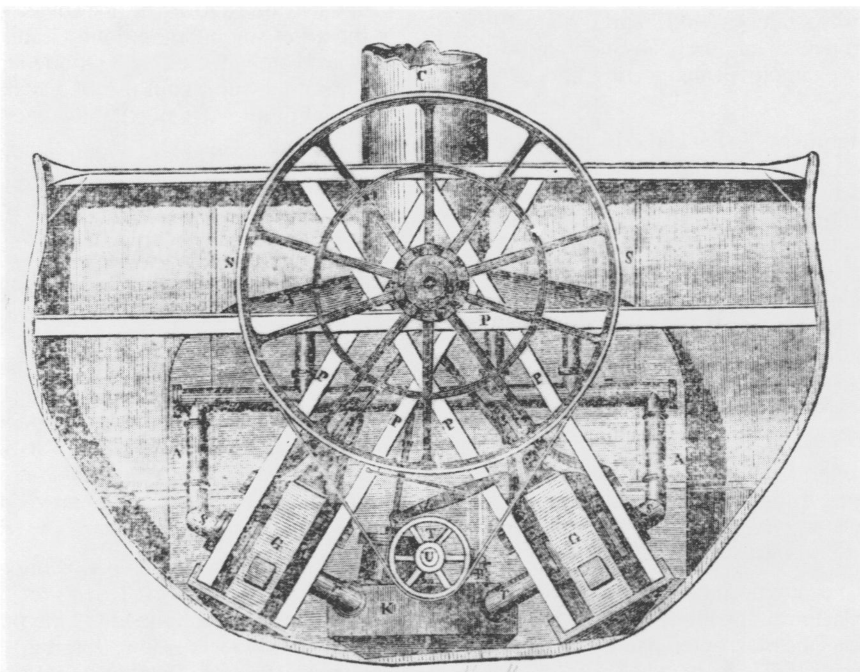


1. A modern drawing of the ship as now docked for historic preservation at Bristol. She has a length of 320 feet and a beam of 51 feet. The *Great Britain* underwent various alterations in a long, useful life, resting for many years in the Falkland Islands. (*From E.C.B. Corlett, "The Steamship Great Britain, Paper No. 1, The Royal Institution of Naval Architects, Spring Meetings, 1971." Courtesy of the author.*)



2. Cross Section of the engine room of the iron Steamship *Great Britain* under construction. To engineer/reporter J.R. Hill "the mould lines . . . appear to be beautiful proportion and harmony . . . and reflect the greatest credit on the nautical draftsman (I believe Mr. Paterson of Bristol)". The deck beams were a composite of rolled iron shapes rivetted together. (*Mechanics' Magazine [London] September 10, 1842, p. 219. Courtesy Library of Congress.*)

Plate I

The Iron Steamship *Great Britain* (1839-1843)

This phenomenal ship was built at Bristol under the direction of I.K. Brunel, famous engineer of the Great Western Railway. It was the first screw-driven vessel to cross the Atlantic (1845).

The superiority of a beam rolled all in *one* piece and strong enough to support a floor — if only it could actually be done — was clearly envisioned by Thomas Cubitt, a leading London builder, during the 1845 hearings which followed the collapse of a cotton mill at Oldham. The latter had, unfortunately, relied on the strength of cast iron. Although no subsidy for research and development was to be forthcoming from Parliament, the structural value of wrought iron beams and joists was clearly anticipated. Cubitt's statement is worth quoting here at length.

Much, if not all the risk involved in using iron for beams would be avoided, by the substitution of wrought for cast-iron; but, up to the present time, the anxiety for this change is not widely enough diffused to lead to any immediate practical result in the manufacturing of wrought-iron beams of such dimensions as are applicable to buildings of the largest size. And it may be remarked, that the larger the building is, there is generally greater danger of failure, with more deplorable results; consequently, the more urgent need there is for increased precaution in providing a corresponding amount of strength, the greater are the difficulties at present experienced, at least as regards wrought iron.

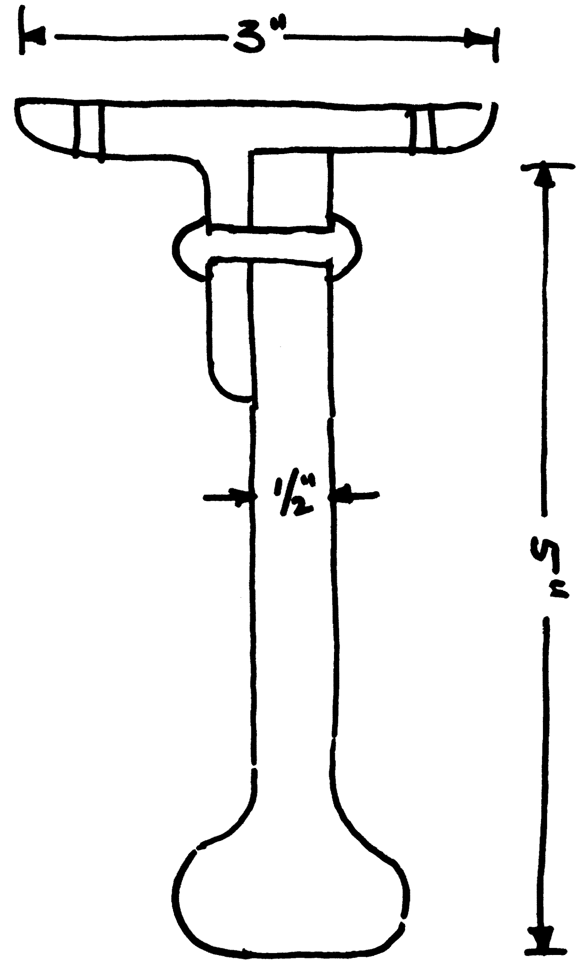
The expenses necessary to the production of large masses of iron, rolled in the form of beams, being more than a private individual might feel himself justified in incurring for his own use, and the demand from an inadequate conception of their value not being sufficiently pressing or extensive to secure the manufacturer from loss, it is to be feared that it will take some time yet before we shall be in possession of the many advantages which it may be expected will result from their manufacture, unless some stimulus be given in order to hasten the attainment of this very desirable object.

I therefore humbly suggest for the consideration of Your Majesty the expediency of devoting 1,000 £. or 1,500 £. to this purpose, and would propose that premiums of such sums as it may appear advisable, be offered for the best and strongest rolled-iron beams, calculated for the use of floors, to sustain a load not under 25 tons, with bearings not less than 24 feet apart.

And in order to ensure a steady progress in the improvement of the manufacture of iron generally, perhaps an exhibition once a year of the best samples with new forms, will forward the attainment of this end. Such samples might be tested in a proving house, which it may be thought expedient to establish for the accommodation of the public generally, where parties may be allowed to have beams or chains proved at a moderate expense, by which the value of the commodity and its fitness for the proposed work may be ascertained.

The cost of apparatus for proving beams only, being heavy, and requiring much practice in order to make such fully available and to arrive at correct results, it follows that those persons only who are extensively engaged in building, provide themselves with means for testing the strength of iron beams, whilst those whose use of them is occasional, have no convenient opportunity of proving them; and it would seem that such persons have greater need of this sort of assistance than those, who, from their extensive practice, become more conversant with the general strength of iron.[8]

As if in response to Cubbitt, within the next few years important new shapes in malleable iron were fabricated. The availability of wrought iron was much furthered by its fast-growing production for steam boilers and ships' hulls. The famous sheet iron tubular bridges over the Conway River and the Menai Straits in North Wales, on the rail connection to the Dublin packets, attracted wide attention. For their daring design the basic experiments were made on scale models at Millwall, London by William Fairbairn and Eaton Hodgkinson (working for Robert Stephenson of railway fame) and were widely reported. That famous collaboration began early in April of 1845[9] and the details were followed from across the Atlantic, the *Journal of the Franklin Institute* of Philadelphia printing an account of the proceedings soon afterwards.[10]

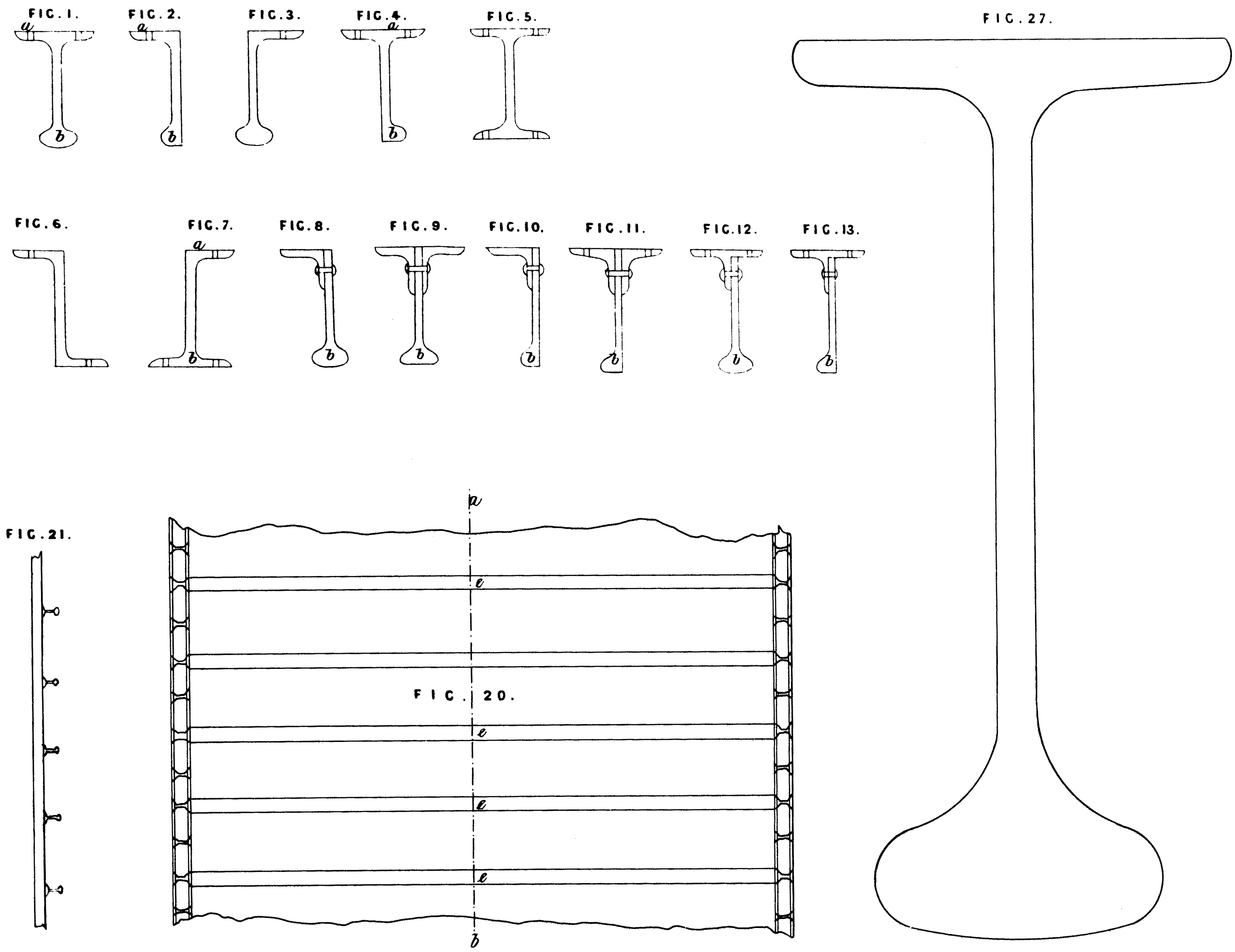


3. Section of compound wrought iron beam used c. 1842 to support heavy plank deck on the Steamship *Great Britain*, launched at Bristol the following year. (*Drawn by the writer from the J.R. Hill description of 1842.*)

Enter Richard Turner

A few months before Fairbairn's experiments, Thomas Grissell and Samuel Morton Peto, prominent London contractors, were testing in their Lambeth yards some highly innovative iron framing proposed for the new Palm House at Kew — something close to the one-piece deck beam newly invented by the Liverpool shipbuilders Kennedy & Vernon. The iron was destined for a contract undertaken by Richard Turner of Ballsbridge, Dublin. Bent into arch form, the beams were designed for the new Royal Botanical Gardens glasshouse, a very remarkable structure.

A most enterprising iron manufacturer, Turner of the Hammersmith Works had been pushing his way into the Kew project which was aimed to please Queen Victoria. This enterprise he came to share with the eminent London architect Decimus Burton, already at work on the design. For the Duke of Devonshire (a wealthy amateur horticulturalist), Burton had already built the so-called "Great Stove House" at Chatsworth. Her Majesty had been greatly impressed with that achievement and the management at Kew wanted to offer her something to match it. Turner, on

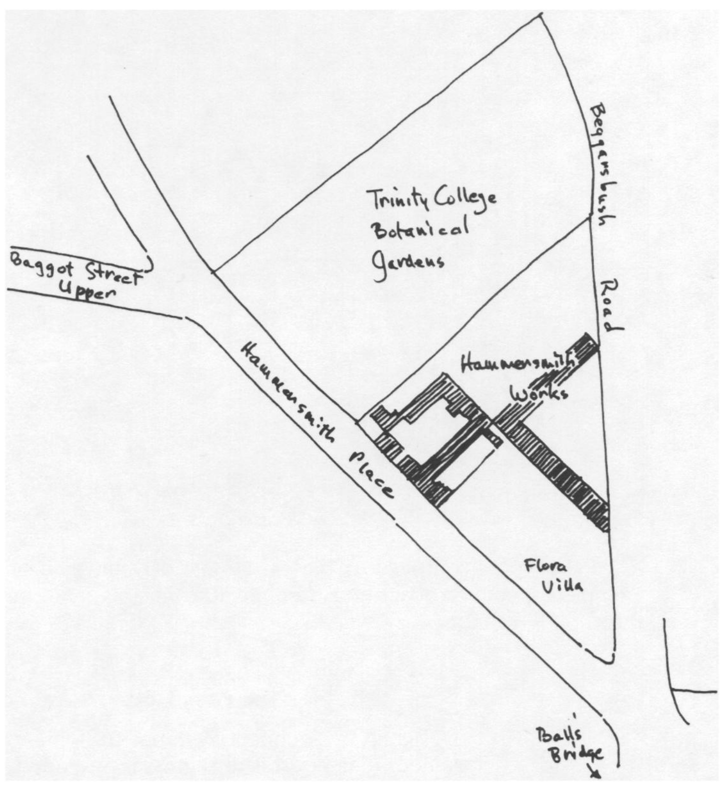


4. Part of annexed drawing delineating (Fig. 5) a true I-beam section at reduced scale and (Fig. 27) a "bulb-tee" that was later to be bent and used to support curved trainshed roofs such as that on the Lime Street Station, Liverpool by Richard Turner. (*Courtesy R.J.M. Sutherland.*)

Plate II

Kennedy & Vernon Patent No. 10,143 Specification, 1844

6. Turner's letterhead depicts the entrance to the works with the proprietor's house to the left. Much of it stood until recently. (*Courtesy G.C. Crampton, constructors, Dublin.*)

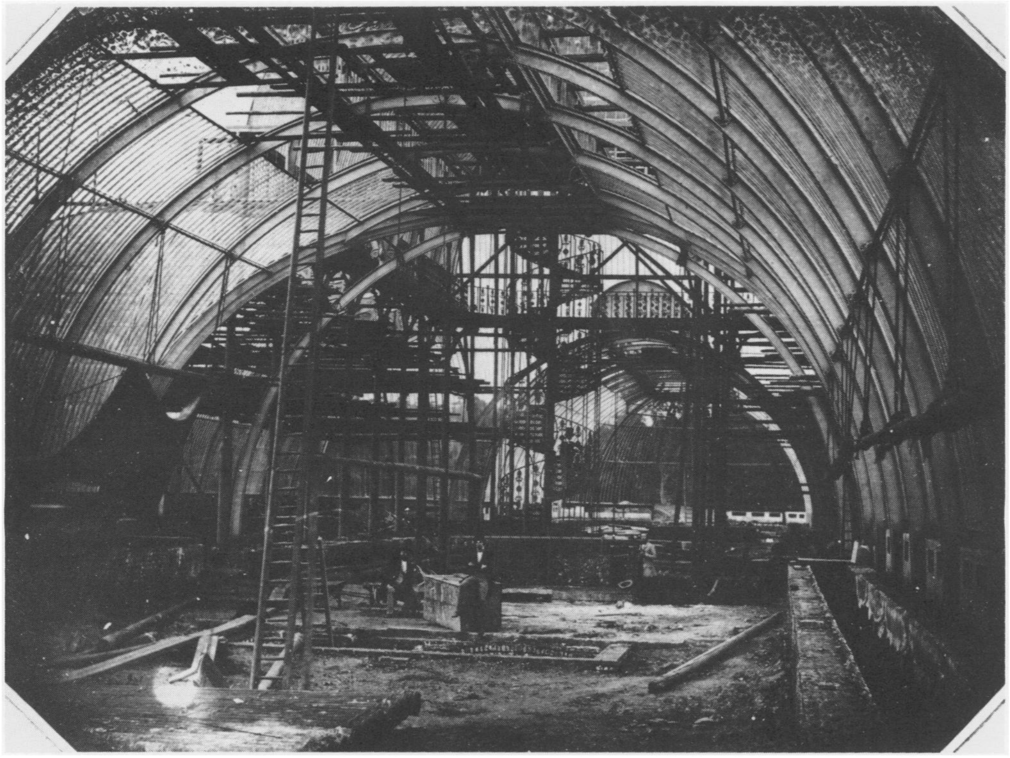


5. Location Map sketched from an Ordnance Survey of 1837 published by Her Majesty's Government (Dublin, Sheet 18). Turner's first involvement with glass houses may have resulted from proximity to the Trinity College garden.

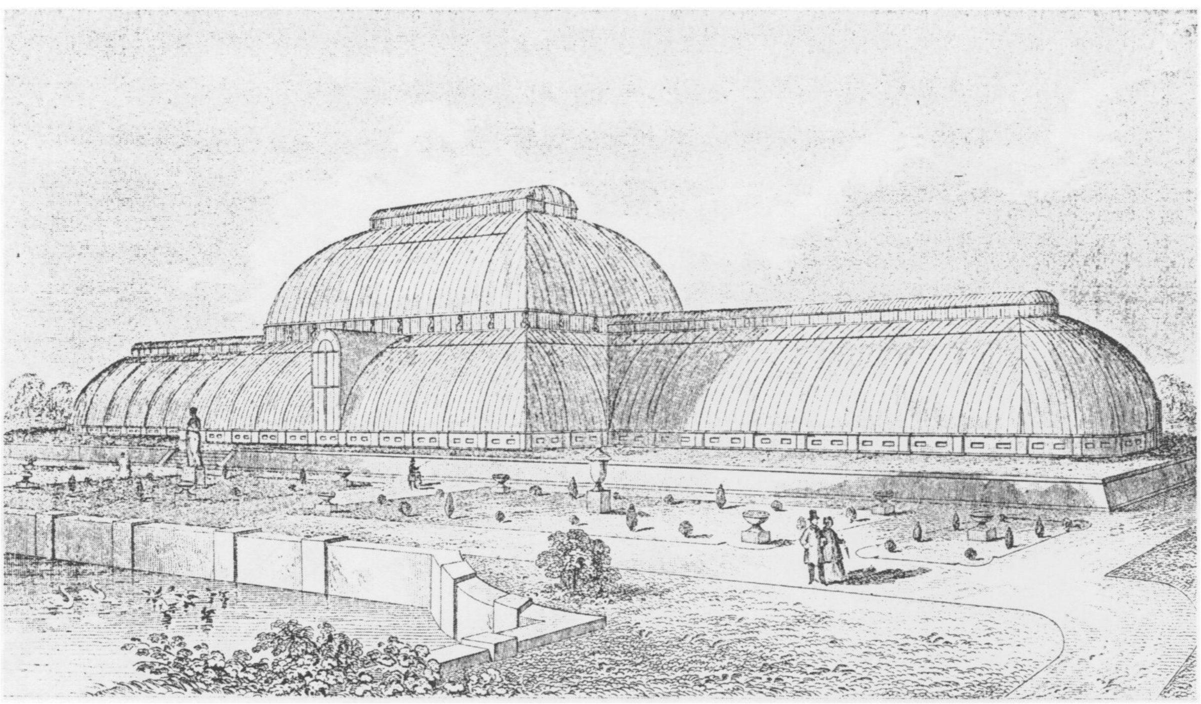
Plate III

The Hammersmith Works, Ballsbridge, Dublin

Here, at the southeast limits of the Irish capital, Richard Turner manufactured a variety of wrought and cast iron products. Historically, the firm was most noted for its plant conservatories and railroad sheds.



7. Daguerreotype of The Palm House under construction. Here we see 9" beams rolled by Malins of West Bromwich and prefabricated by Turner in Dublin into the arch ribs (cf. Fig. 9). (*Crown copyright, with the permission of Her Majesty's Stationery Office and of the Directors, Royal Botanic Gardens, Kew.*)

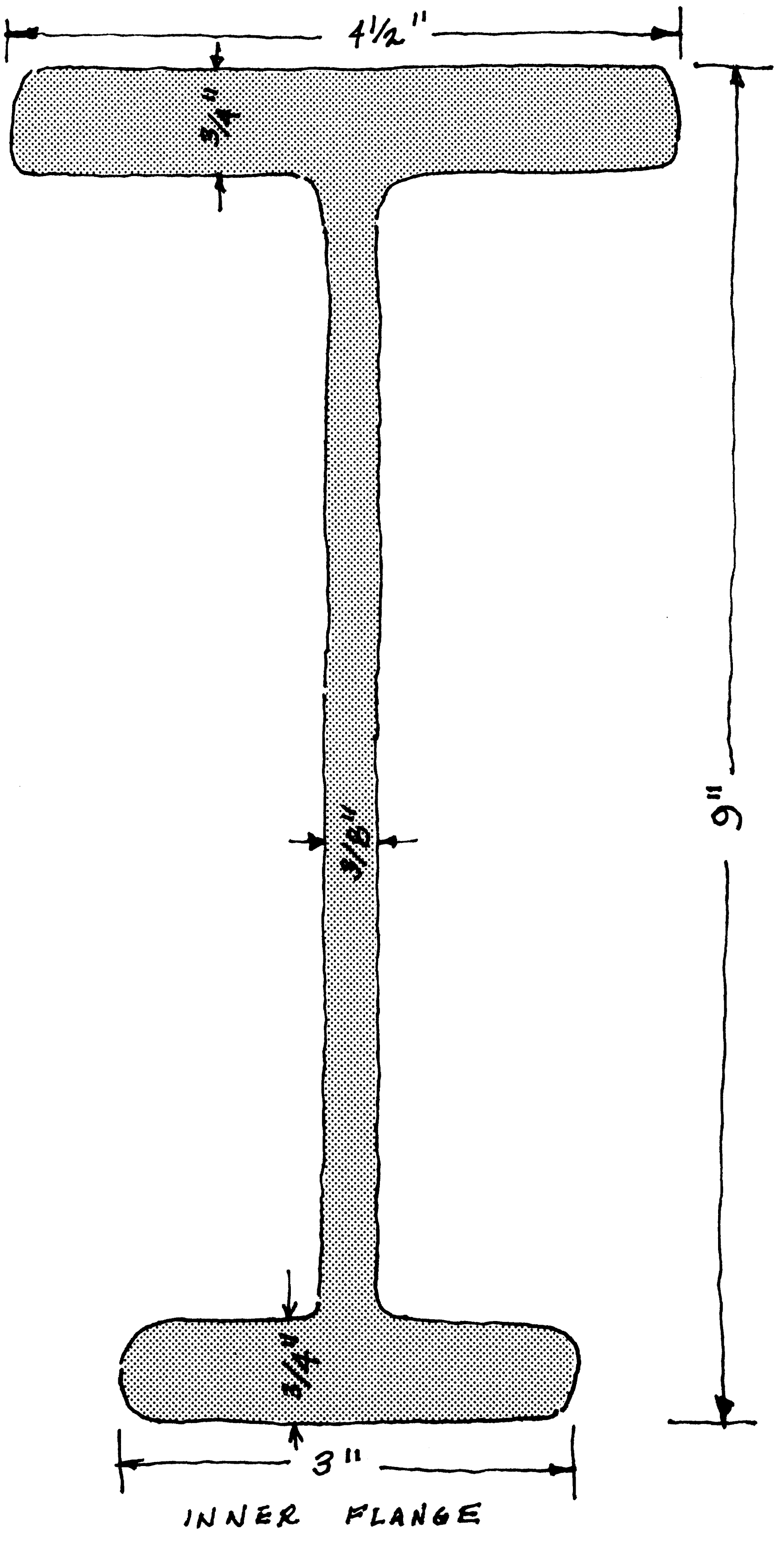


8. The Palm House completed. Charles M'Intosh of Dalkeith in his comprehensive work *The Book of the Garden*, 1853, called it "the most complete specimen of hot-house architecture that this or any other country can boast of." (*Courtesy, Library Company of Philadelphia.*)

Plate IV

The Palm House, Royal Botanical Gardens, Kew (1845?)

Designed by Architect Decimus Burton and Ironman Richard Turner, who also built it. The famous glasshouse still stands, in use and well maintained.



9. Section of one-piece wrought iron rib rolled by Malins of West Bromwich and prefabricated at the Hammersmith Works, Dublin, by Richard Turner for the Palm House, Kew. (*Measured at the site by the writer July 6, 1977.*)

his part, had already built two outstanding examples of conservatory: the Palm House in the Botanic Gardens of Belfast (begun 1839) and another big one for the Royal Dublin Society at Glasnevin in 1843-45.[11]

The Dubliner was an outstanding character in an age of entrepreneurs but he has not in our time had the recognition he deserves. In Dublin records it is possible to follow the Turner family of ironmen. One Tim Turner was providing grates, fenders and builders' hardware to Trinity College as early as 1729.[12] Evidently successful, by 1762 he was one of the builders of a row of houses on elegant Merrion Square.[13]

Our man Richard first shows up in Dublin directories in 1814 as Richard Turner & Co., ironmongers, at 4 Stephen's Green, north, remaining there until 1835. Three years later he is at the Hammersmith Works, Ballsbridge, as a partner in Turner and Walker, "manufacturers of apparatus of hot water, heating — and every description of iron works."

An Ordnance Survey map of 1837 shows the location of the Hammersmith Works (Figure 5) on the southeastern outskirts of Dublin. It was a substantial complex lying between Upper Baggot Street and Beggarsbush Road just above Ballsbridge itself.[14] The latter was a crossing of Dodder Creek which historically had powered a series of watermills.[15] The architectural character of the establishment was impressive as engraved on the company's billhead (Figure 6). By 1842 the products of Hammersmith included wrought iron gates, railings and conservatories, improved hot houses and iron sashes. So Turner was prepared for the Kew project and more than willing to take on the job.

What followed was a technological and professional struggle of uncommon interest. As so often happens following success, the competition over credit for the Palm House was to go on for decades. In fact, it isn't over yet. But there is no question that the innovative use of its rolled iron ribs bent in the form of arches belongs to Turner (Figure 7). The new glasshouse was famous at once and widely admired. Three hundred and sixty-two feet long, Charles M'Intosh — a contemporary authority — called it "the most complete specimen of hot-house architecture that this or any other country can boast of"[16] (Figure 8). John Hix in *The Glass House*, a recent and comprehensive survey of the subject, declared it to be "the most beautiful glasshouse in the world." For this study, it is important for its use of a true I-section rolling ahead of its time.[17]

The Public Record Office preserves part of the job correspondence[18] revealing that on March 8, 1844 Turner submitted to Her Majesty's Commissioners of Woods and Works two estimates for the "Centre House" of £9,230 and £10,880.[19] But architect Decimus Burton went ahead and completed his own plans and on August 27 the contract was let for the center portion to Grissell and Peto as a cast iron structure.[20]

Progress was slow; there were problems over design and cost. In the next few weeks the persistent Turner tendered another offer for £18,500 almost below the prime cost for, as he later confessed, he was "anxiously solicitous" for the job. "It [*he wrote*] Will Establish my Character in the Country, as Tradesman in this Particular Line of my Business, with which I am so peculiarly familiar."[21] In Dublin on July 1 he finally received notice of "the Sanction of the Lords of Treasury"[22] and he hastened back to London to get on with the work.

The struggle was to continue through the following year when Burton's cast iron plans were finally abandoned;[23] ribs of *wrought* iron had finally won out. The architect later explained how it happened in a letter addressed to the Commissioners. It is quoted here at full length for its crucial value as an historical document.[24]

Spring Green
June 16, 1845

My Lord and Gentlemen

Towards the later end of last year Mr. R. Turner of Dublin communicated with me on the subject of substituting wrought iron for cast iron ribs stating that in consequence of a recent important improvement that had been made in machinery, these ribs could be rolled of the necessary scantling for the Palm House roof, and that the diminished quantity of metal required would compensate for the greater cost of the material.

Considering that there would be a decided advantage in adopting the stronger material with reduced sized ribs, I had a conference in December last with Mr. Turner, Mr. Grissell and Mr. Malins of the firm of Malins Rawlinson & Co. of West Bromwich, and Mansion House Place London, Manufacturers for the Patentees (Mess. [sic] Vernon & Kennedy of Liverpool) of the rolled iron in question when it was arranged that the iron work for one Bay of the roof should be forthwith prepared in wrought iron and tested so soon as it could be erected. Much delay has subsequently taken place in consequence, chiefly, Mr. Turner states, of the great difficulty of welding together the several pieces to form each rib. These difficulties however he at length surmounted after great exertions by means of a new and powerful blasting furnace and of expensive and ingenious machinery which he constructed, and he sent lately one pair of the ribs which have been subsequently erected and tested with great care on Messers Grissell and Peto's premises, York Road Lambeth when the result proved entirely satisfactory.

I therefore called upon Mess. [sic] Grissell and Peto to state whether they would be willing without any extra charge to substitute wrought iron ribs, &c similar to those referred to — for the cast iron ones described in their contract dated the 27. of August 1844 and I beg leave to enclose a letter to that effect received from those parties. I propose therefore, with the Boards permission to procede with the building introducing wrought iron in lieu of cast iron ribs and cast iron columns of the reduced diameter the latter will now be similar to those I designed for the Great Stove House at Chatsworth.

I have the honor to be
My Lord and Gentlemen
Your most obedient
and humble Servant
Decimus Burton

To The R.[t] Hon[ble] & Hon[ble]
The Commiss[rs] of H.M. Woods, &c
&c &c &c

The Palm House and its heating plant — which was served by a coal railway tunnel and a huge architectural stack — were finally completed in 1849 at a total cost of £35,600.[25] The whole story, well worth following in detail, is only sketched here as background to the business of the new type of rolled ribs.

Although Burton's beautifully drawn and tinted plans for the structure as first conceived in cast iron have been carefully preserved in the Public Record Office, the drawings as actually built seem to have been lost. But today we can examine the building as it stands and this writer on July 6, 1977 went out to Kew to make a record of the 9″ rib cross section, as figured here (Figure 9). The shape was a remarkable premonition of the future I-beam which was not to be produced commercially in its final form for several years.

An American writer soon afterwards reported that

the whole of the materials of the immense structure at Kew were manufactured and fitted together at Dublin, and transported from thence to London . . . the material and workmen were all brought across the channel, costing nearly as much as if brought to America; yet the workmanship was superior, and the cost said to be less, — proving that practice and knowledge of details lessen the original cost of construction . . . Now it would have been just as easy, and perhaps a little more expensive, to have shipped them to New York or Boston, or Philadelphia, or Baltimore. When this is done in England, how long will American enterprise be behind them? We prophecy, not long.[26]

Viewed from another angle, this structure was an example of building prefabrication which has had a long history and in America actually goes back as far as Queen Elizabeth I.[27]

Turner's triumph reached its zenith in 1849 when Queen Victoria — for whom the Kew Palm House had been built — visited Dublin and Turner made the most of it. The royal cortege entered the city at Ballsbridge and passed through a huge decorated iron archway, 127′ wide and 92′ high, put up by Turner in front of his Hammersmith Works. All of this was glowingly reported by the *London Illustrated News* for August 11 which included a large engraving of the scene. At night the spectacle was continued as a great star and the initials V and A all done in gaslight blazed over the Works.

Turner continued his work with glasshouses. On April 16, 1845 he submitted a successful bid for the construction of the fashionable Winter Garden in Regent's Park completed a year later.[28] In 1850 he won international attention with a Special Mention for his iron framed scheme for the Great Exhibition in Hyde Park, an enormous structure 408′ x 1,940′. Although Joseph Paxton's famous design for the Crystal Palace was chosen for execution, Turner exhibited there three scale models: his Kew Palm House, the Lime Street Station at Liverpool and the Winter Garden.[29] He was soon recognized by election to the Institute of Civil Engineers in 1850/51 and he was published in its *Proceedings* in several issues.[30]

Turner Later

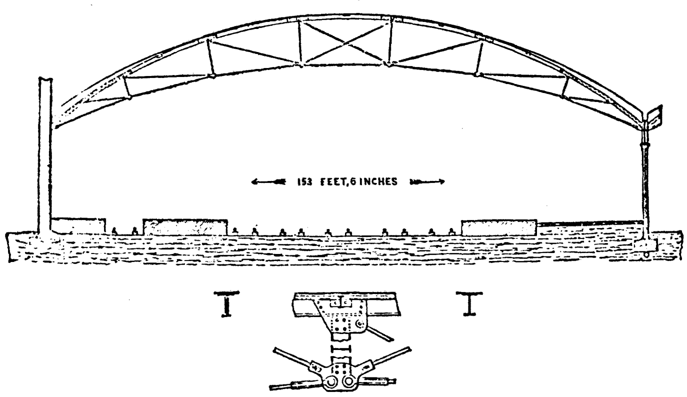
Before the completion of the Kew Palm House Turner, self-described as a "Wrought Iron Manufacturer", took out Patent No. 11,496 for "Improvements in the Construction for Roofs and Railway Stations and Roofs and Floors of other Buildings". His concepts included roofs with either straight or curved rafters. The latter were proposed to be of malleable iron deck beams — in the patent papers drawn full-size at 8-5⁄16″ depth, the covering to be of galvanized corrugated iron. In the words of the patent Turner explains:

For supporting floors and walls of buildings, in lieu of wood or cast-iron beams or masonry I propose using malleable iron beams of the section C, commonly called deck beams, from its being already applied to supporting the decks or floors of ships.[31]

The most striking example was Turner's Second Lime Street station trainshed (Figure 10) erected at Liverpool in 1849.[32] We have the drawn and engraved details for three other roofs by Turner put up in this period:[33] the 80′ span roof of the Galway trainshed of the Irish Great Western Railway erected by Turner in 1851 used 7″ bulb-tees;[34] a 70′ quay roof span at Glasgow (400′ long and covered with plate glass and corrugated iron) employed 5″ bulb-tee deck beams;[35] and a 40′ span roof for Joseph Whitworth & Co., at Manchester, 7″ deck beams.[36]

It should be noted that the 9″ I-beam of the Palm House was not repeated. It probably was much easier to use the deck beam, by

Fig. 27.



10. Lime Street Station Trainshed, Liverpool (1849?). Designed and erected by Richard Turner in ten months at a cost of £ 15,000. The span was 153′-6″, the length, 374′. "Each principal is composed of a wrought-iron deck beam, nine inches in depth with a plate 10 inches wide and ¼ inch thick welded upon the top." Sir William Fairbairn, 2Useful Information for Engineers 1, Third Series, 2d ed., London, 1874, p. 217. (2Courtesy National Museum of History and Technology 1.)

then standardized, and the ordeal of the West Bromwich rollings was not repeated.

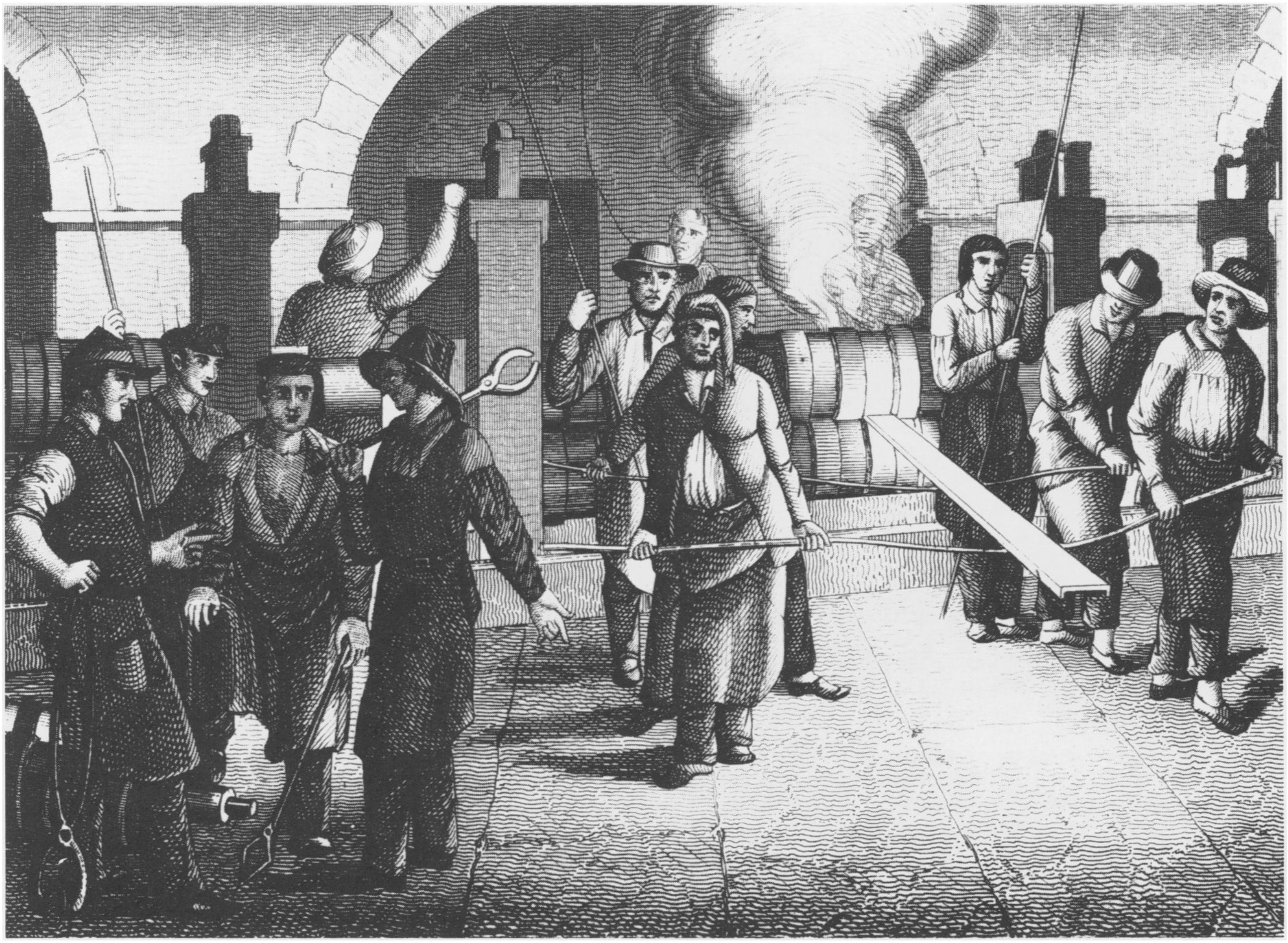
Malleable Iron Beams in France

While the deck beam revolution was unfolding in England there was a parallel development in France where *l'Architecture Metallique* had made progress long before.[37] But it was not until the carpenters' strike in Paris in the summer of 1845 that there was created a ready market for iron joists, giving the rolling mills a chance to compete with the lumber industry. At the same time the roof frames of several new theaters, public buildings and warehouses also took advantage of the new rolled iron.

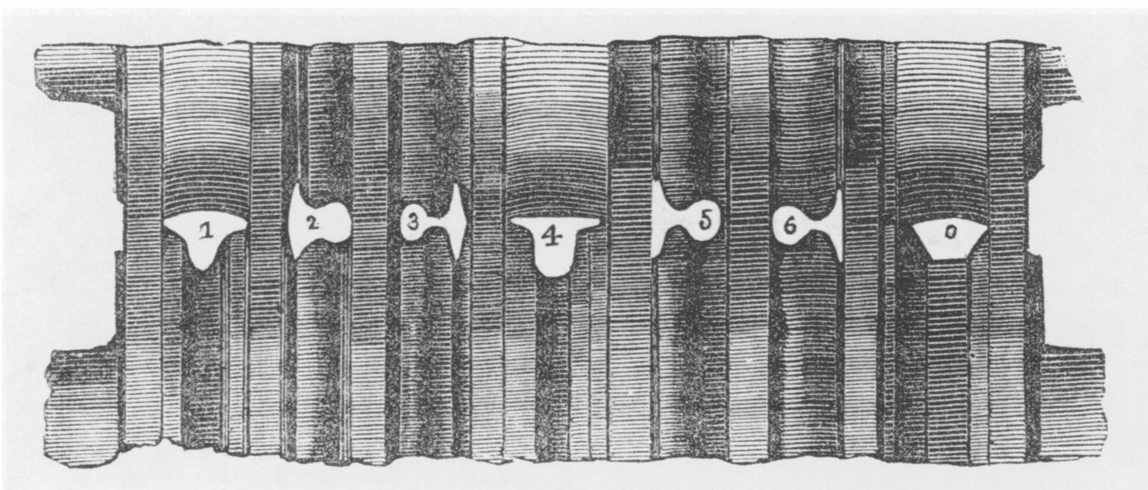
One of the leaders in this was Ch. Ferdinand Zorès of Paris. In an account written not long afterwards[38] Zorès described how previously there had been little contact between the iron manufacturers and the builders of the metropolis; middlemen were distributing the small amount of iron needed. There was, as might be expected, a great deal of reluctance encountered in breaking through tradition. But "give us orders so we can pay for the equipment [*cylindres* = rolls] and the production cost and we will make the iron you ask for" insisted the manufacturers[39] (see Fig. 11 as an example of an early rolling mill). In the emergency of the strike, progress came quickly. According to Zorès' account he first worked in 1847 with M. Bleuze, bidder for the construction of the hog abattoirs for the city of Paris. The next year, in October, with the well-known builder M. Dhibon he "perfected" the I-beam on paper. But it was not until February of 1849, working with one Kaulek, that the first beams were actually used in the floors of a house at No. 18 Boulevard des Filles-du-Calvaire.[40] From then on, progress was steady and by the 1850's numbers of mills were offering I-beams in graduated sizes, ready-made and delineated in catalogs.

In another account the civil engineers and builders Cesar Jolly and Joly [*sic*] Fils at Argenteuil (Seine-et-Oise) stated that the first I-beams ("*fers à double T*")

were fabricated in 1846 by M. Lagouette, master of the La Villette forges, for the frames of buildings to house the



11. Rolling a channel beam. Before the I-beam was rolled, two channels on edge rivetted back to back sometimes served the same purpose. This engraving by Krausse is from a larger plate (Taf. 28) which appeared in J.G. Heck, *Encyclopedia of Science, Literature and Art*, New York, 1852. It is reprint from an earlier work in German not located. No comparable illustration has been found for an American rolling mill. (*Courtesy, National Museum of History and Technology, through Robert M. Vogel*.)

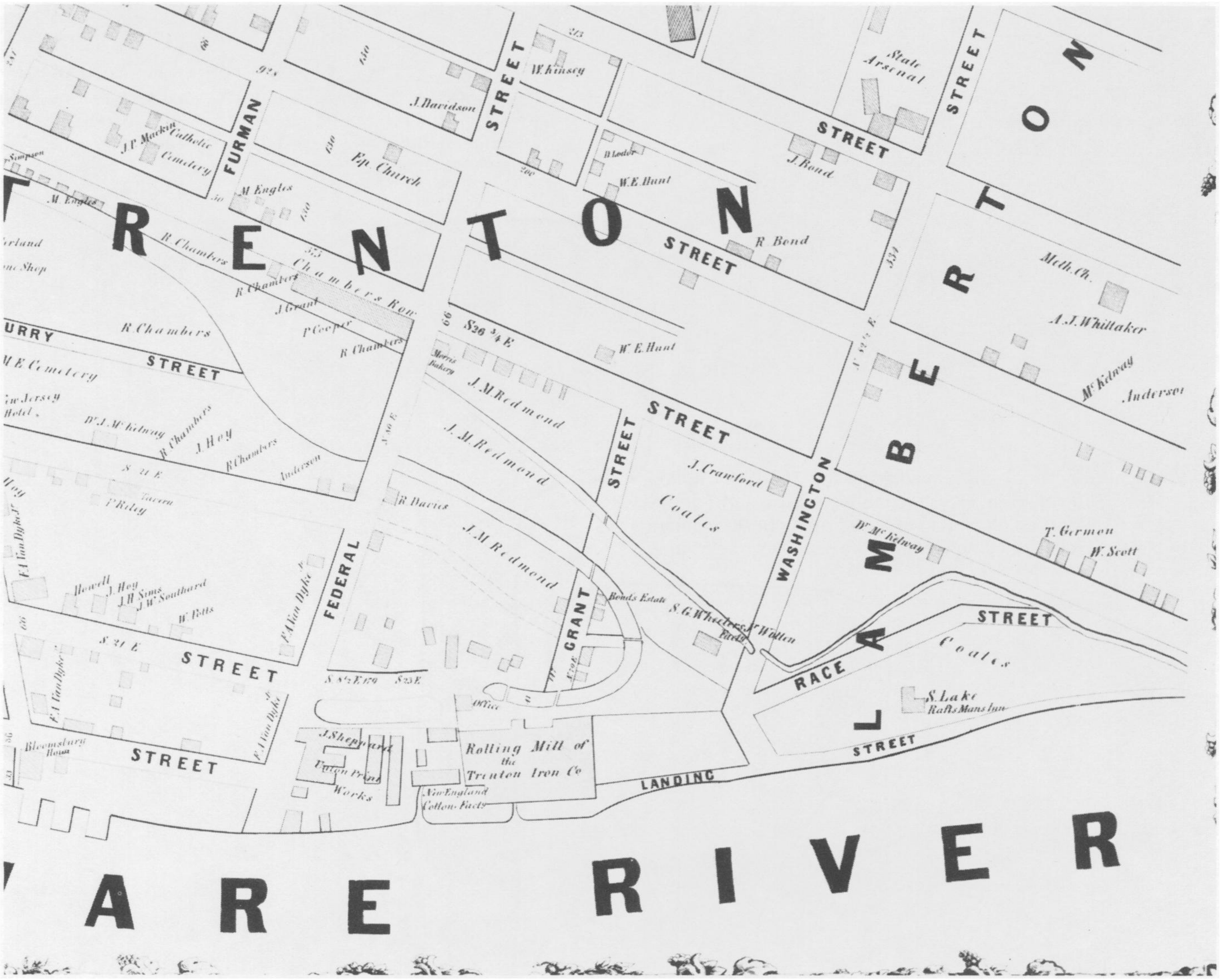


GROOVES FOR RAILROAD IRON.

12. The form of our first iron beams was invented for railroad trackage by Colonel Robert Stevens of Hoboken (1832?) and gradually accepted internationally. Such rails were laminated from wrought iron rods at red heat forced through cast iron rolls. Frederick Overman, 1849. (*Courtesy, The Athenaeum of Philadelphia*.)

Plate V

Rolling Iron Rails/Joists



13. Portion of the Trenton Riverfront, Sidney/Dripps Map, 1849. Cooper & Hewitt's rolling mill was located between the Delaware River and the waterpower raceway supplied from a dam above the city. Here was rolled the bulb-tee railroad iron that early served for fireproof joists. After long experimentation the true I-beam followed in 1856. John Roebling's wire rope walk lay a short distance to the north. (*Courtesy, Trenton Public Library*.)

fixed machinery of the Saint-Germain atmospheric railroad in Paris. At about the same time, the forges of Montataire produced two models used for the construction of the covered stations on the same railroad . . . The use of such iron was very limited up until 1849, when La Providence rolling mills in turn created a series of models which became widely used in the construction of floors.[41]

The full name of the latter firm, according to their 1861 *Album des Divers Fers Speciaux*, was La Societé Anonyme des Laminoirs, Hauts-Fourneaux, Forges, Founderies et Usines de la Providence, headquartered at Marchienne-au-Pont, Belgium with mills at Hautmont on the Sambre near Maubeuge in the Department du Nord, France. They maintained a warehouse at 208 Quai de Jemmapes, Paris.

The competition for professional credit recalls the jealousies that arose between Stephenson, Fairbairn and Hodgkinson over the great tubular bridges in Wales.[42] Contemporary French literature makes it clear that the proceedings across the English channel were being closely watched.

The 7" Rail Beam in America

The United States was watching, too. As the railroads spread westward rolling mills were built to share in the huge rail market then dominated by the British[43] (Figure 12). In 1845, a successful iron manufactory was founded by Edward Cooper and Abram S. Hewitt on a waterpower site in Trenton, New Jersey (Figure 13). Incorporated as the Trenton Iron Works in 1847, they completed a new plant by the end of the year declaring it to be "the best-rounded ironworks in the land."[44]

The next year they were able to roll for the Camden & Amboy Railroad (Figure 14) a heavy rail 7" high known to the trade as "92 pound rail" which was its weight per running yard.[45] It was very much like the new Kennedy & Vernon patent deck beam used in Britain, noted above. Fifteen miles of track were completed and laid out but it proved too rigid for the rolling stock of the time and was soon taken up. Prophetically, much of the C & A rail was disposed of for use as beams in fireproof buildings, one of which was the U.S. Mint in Philadelphia.[46] In 1855 railroad rail was used again in Nassau Hall at Princeton College (Figure 16) where, in

14. Wrought iron "T-rail" rolled by Cooper & Hewitt in 1848 for the Camden & Amboy RR but not a success for that purpose (NMHT 180.027). Rolled again in 1854 for the Cooper Union Foundation Building, New York City (*specimen section in writer's collection.*)

15. Wrought iron "pear rail" invented in the 1830's by Robert Stevens. Still rolled in 1855 for the New York and Erie RR (NMHT 180.225). Identical to rail used by Architect Notman in Nassau Hall, Princeton College, the same year (*specimen section in writer's collection.*)

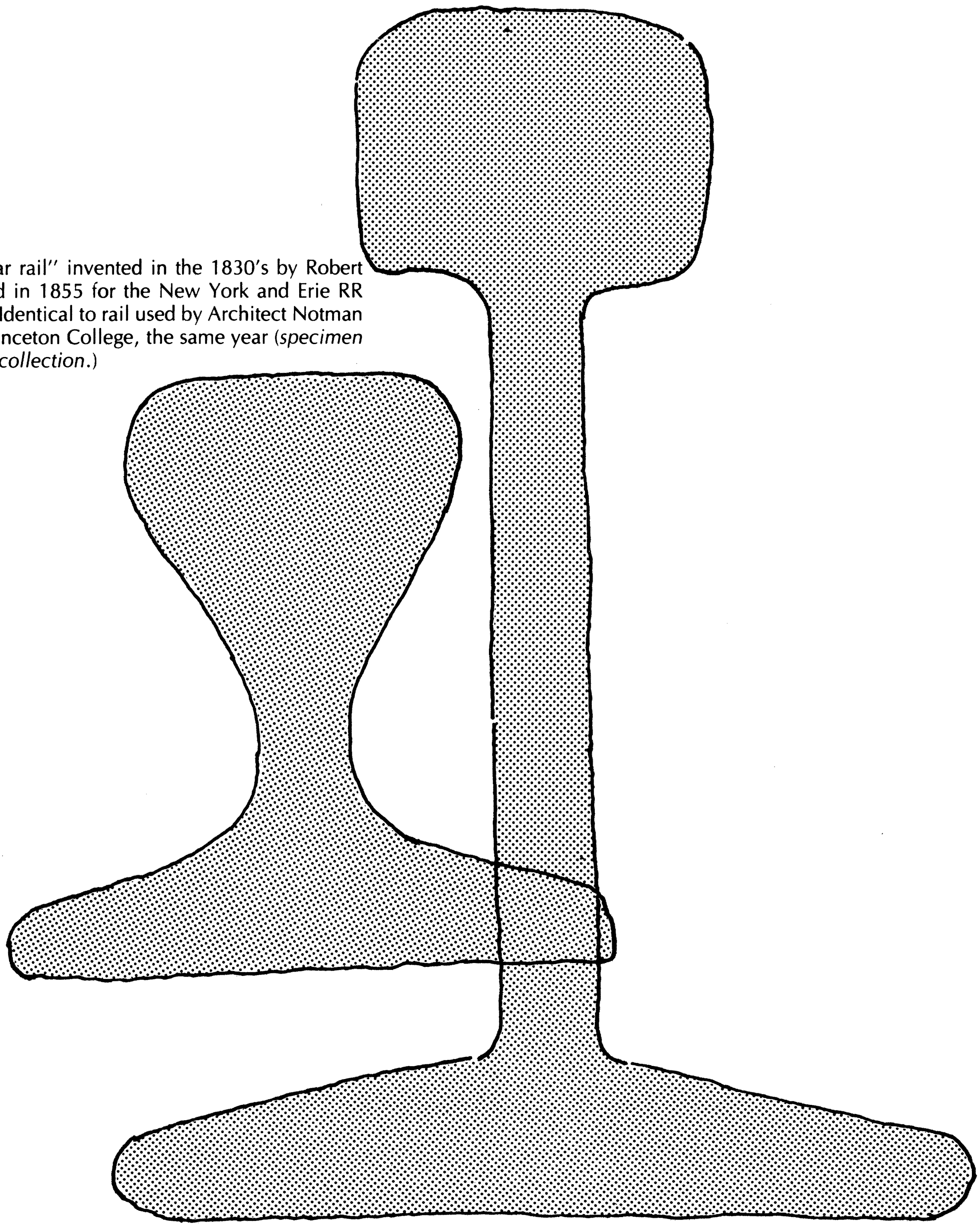
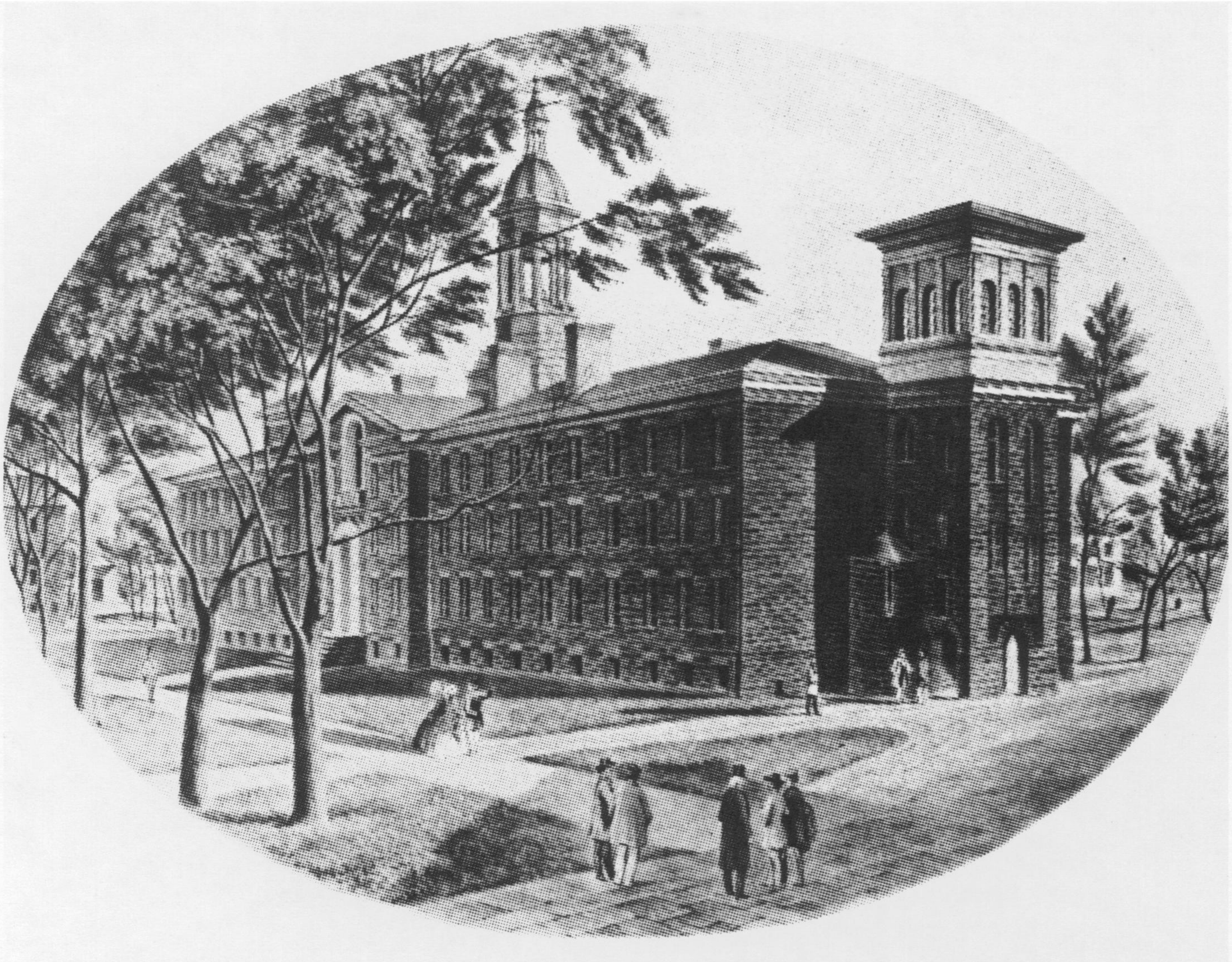


Plate VI

American Railroad Iron ("bulb-tees") used as Joists

In these examples rails were used to support shallow brick vaults to make fireproof floors. The whole was filled over to receive wooden flooring.



16. Nassau Hall, Princeton College as rebuilt 1855-56 after a bad fire. Architect John Notman used bulb-tee railroad iron from Cooper & Hewitt for fireproof, brick vaulted floors. The roof was framed with wrought iron trusses and the cupola executed in cast iron by Bottom & Tiffany of Trenton. (*Drawn by F. Childs and published 1860. Courtesy, Princeton University Archives.*)

rebuilding after a bad fire, Architect John Notman employed 3½" high railroad iron to support shallow brick vaulted floors[47] (Figure 15).

The success of the railroad iron so used did not go unnoticed and the bulb-tees were soon to be ordered especially for floor construction in *new* buildings. On December 10, 1853 the New York City premises of Harper & Company publishers was set afire by a plumber careless with a basin of camphene, a million dollar disaster.[48] The company decided to rebuild immediately in the fireproof mode and to use Cooper & Hewitt's 7" bulb-tees. The philanthropist Peter Cooper, financial backer of Cooper & Hewitt, had already begun construction of his famous Foundation Building at Cooper Institute (Figure 17) in the same city from plans by architect Frederick A. Petersen but the beams intended for it were quickly diverted to the Harper project (Figures 18 and 19).

The plant of the publishing house was spectacular in every way. *The Builder* of London described its construction in detail:

> *The fireproof floors consist simply of a series of long, narrow, flat brick arches, supported by wrought-iron beams, the ends of the beams being supported in their turn by girders of wrought and cast-iron, and these by a range of cast-iron columns, supported by a similar range in the story below. The number of cast-iron columns and girders in both parts of the edifice is over 250. The number of brick arches, averaging about 4 feet span, and 15 feet in length from girder to girder, with wrought-iron beams to support them, is about 2,000, and the whole area of floors thus supported in the different stories is between two and three acres. Mr. James Bogardus, engineer, was the constructor of the iron front of the building; Mr. John B. Corlies, the architect and builder; Mr. James L. Jackson, the designer and manufacturer of the iron columns and girders; and Mr. Abram S. Hewitt, of the firm of Cooper and Hewitt, manufacturers of the iron beams.*[49]

Two other New York buildings were put up almost simultaneously, likewise pioneering with the new beams: the United States Assay Office (1853-54) on Wall Street and the Cooper Institute Foundation Building (1853-59) in midtown (See Figures 20 and 21).

The U.S. Treasury Department's new Supervising Architect Ammi B. Young of Washington had designed the Assay Office[50] built to process the gold piling in from California. The National

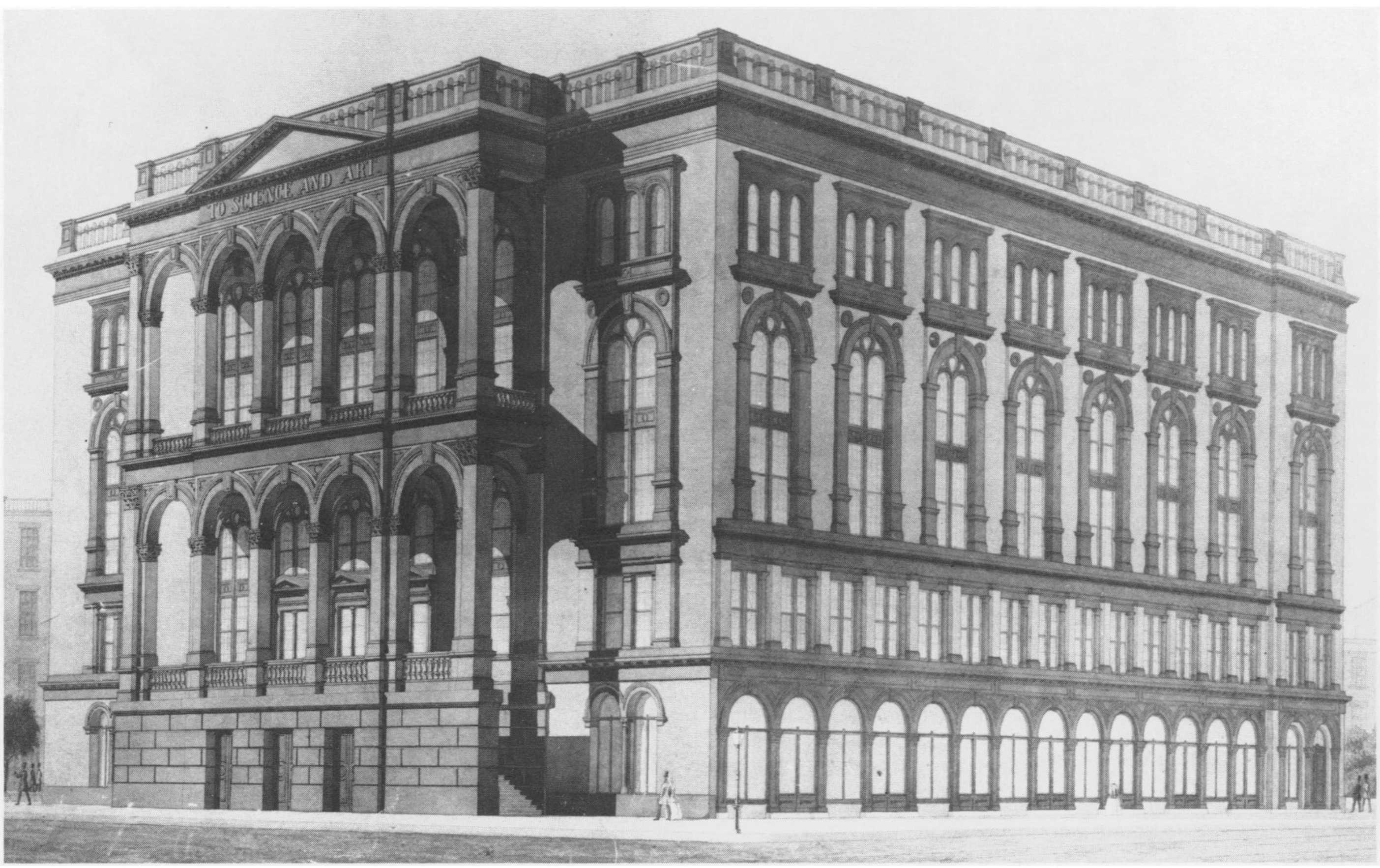
Archives preserves many of the particulars for this new type of construction soon to be exploited in a nationwide building program. The Assay structure was actually an addition to the rear of two existing bank buildings. It was authorized by an act of the Congress approved March 3, 1853; excavation began on September 9. The narrow confines of the lot, hemmed in by existing structures, and severe winter weather slowed progress. But the iron roof was completed early the following May.[51]

On October 7, Captain Alexander H. Bowman (Figure 22) of the Corps of Engineers in charge at the site — and feeling his way — reported to Washington:

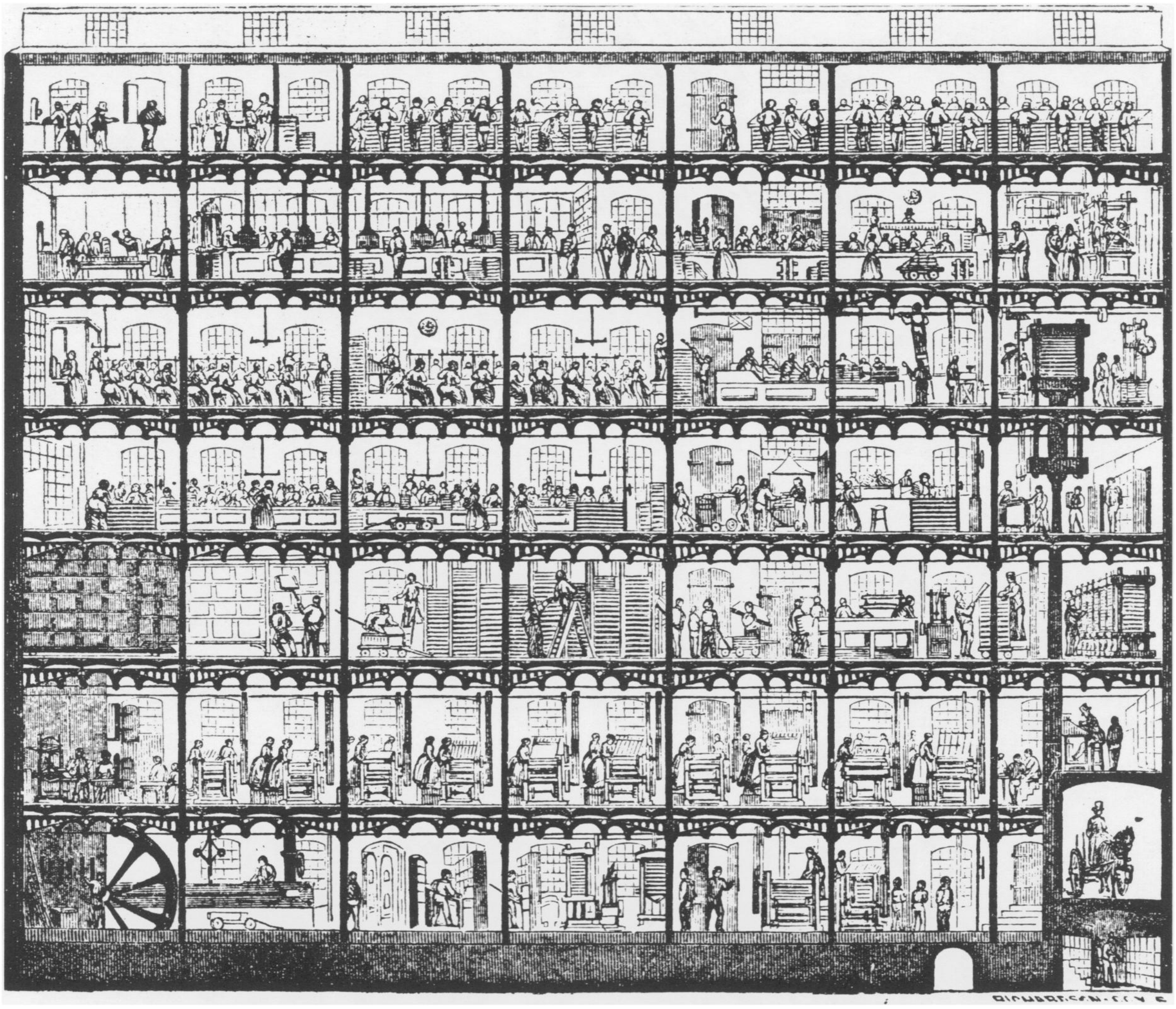
> *In relation to the floors, I have found some rolled wrought Iron beams, which are abundantly strong for our purposes, for less than half the price of the proposed 'made beams', & will cost about $1000 less per floor than the finest offer received. I have had a beam of this kind, fifteen feet between the supporters tested by 9000 lbs suspended from its middle point, without permanent deflection. In the floor which this beam is to support, it will be required to sustain, diffused over its whole length a weight of 3200 lbs between supporters 13'-9" apart . . . you will see that the time spent in communicating with all engaged in the Iron business has not been lost, since in the single item of floors it has lowered the price of each of the five floors from $9,900 which was the first received, to less than two thousand which they will cost by the adoption of the rolled beams, and this too without delaying for a moment the prosecution of the work. It is proper to state that the establishment from which I propose to get the rolled beams, say they can deliver the beams for the whole five floors, five or six days after they get the order. The cost of a 15 foot rolled beam, weighing 390 lbs is $17.55.*[52]

By June 3 all of the ironwork (both wrought and cast and including iron doors, shutters, sash, gratings and stairs) was in place[53] and on August 4 the whole project was reported within a week of completion.[54] Although an extra story had been added to the project — as well as fire-proof shutters and sash — it was believed it could be completed within the original appropriation of $100,000. Captain Bowman was then transferred to duty in Washington where he was to fill a national role in promulgating iron construction.

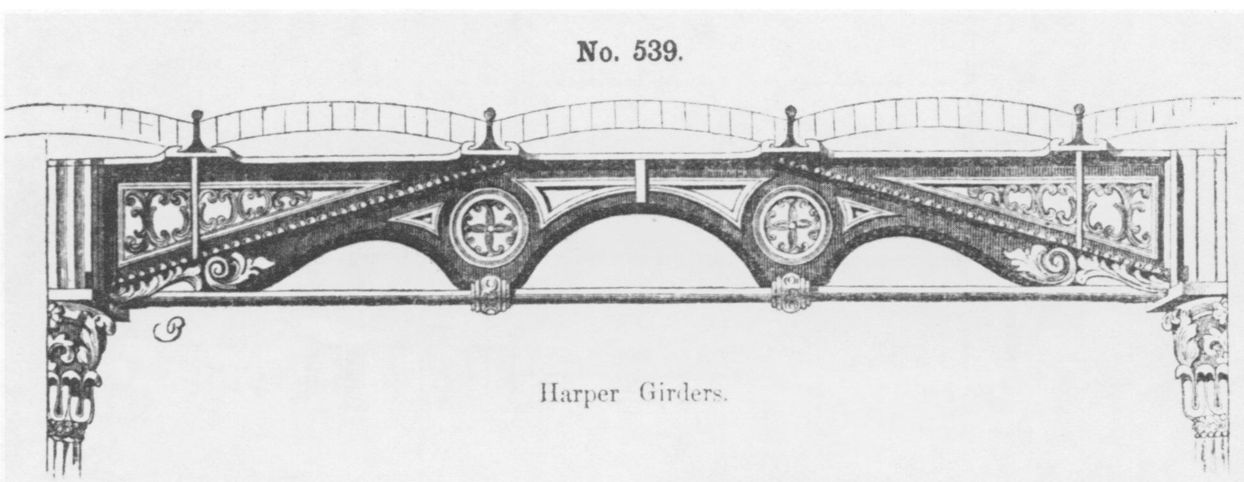
This writer was unable to locate all of the original file, especially the drawings once a part of them, but the fragmentary



17. The Union or Foundation Building, Cooper Institute, New York City, erected 1853-59. The philanthropist Peter Cooper's gift to "Art and Science," was designed by architect Frederick A. Petersen using the new iron beams rolled by Cooper & Hewitt at Trenton. The fireproof floors are still supported by the original bulb-tee joists. Construction was delayed by diversion of the first iron to the Harper & Brothers building (see Figs. 18 & 19). *(Architect's rendering courtesy Cooper Institute.)*



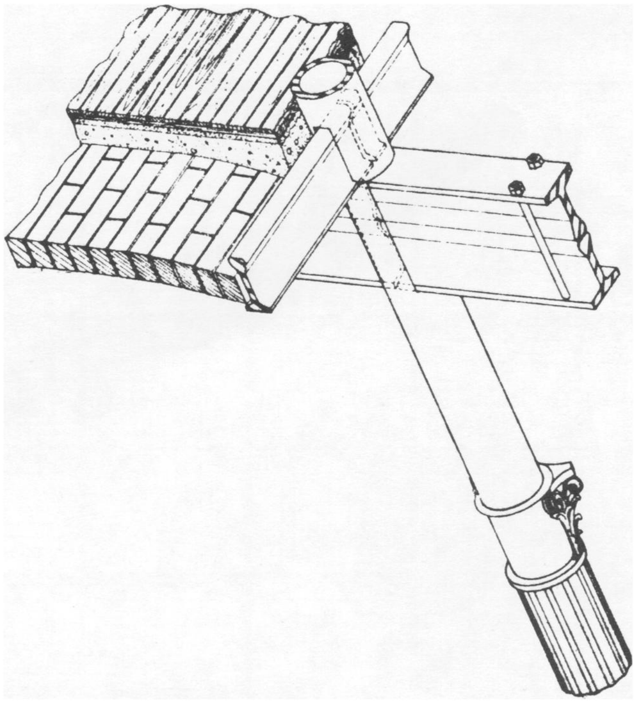
18. Cross Section. (*Harper's New Monthly Magazine, Vol. 32, 1865.*)



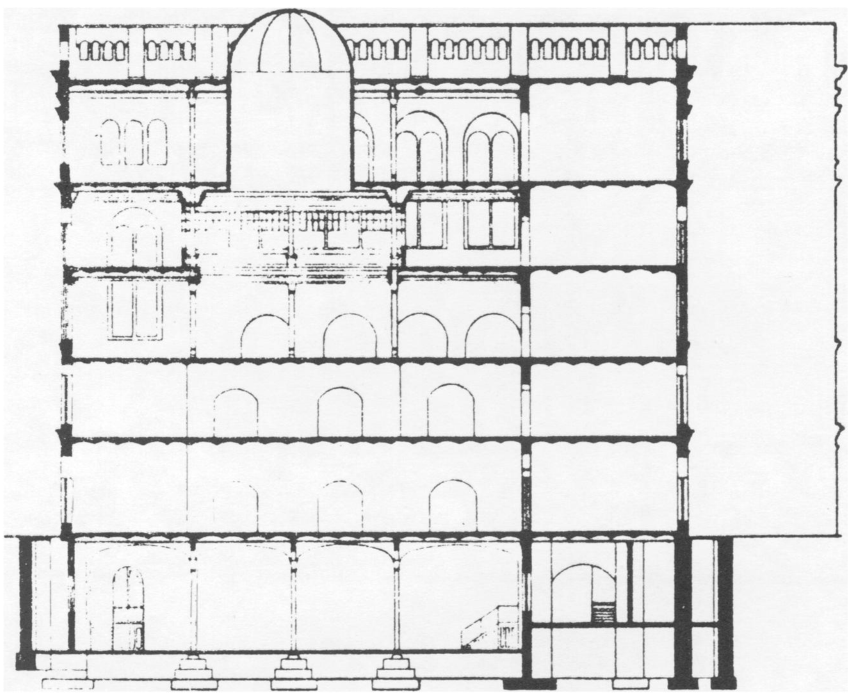
19. Concealed in the ceiling above the fancy cast iron girders is the new system of wrought iron joists supporting shallow brick vaulting. The whole was levelled off with concrete. Catalog of the New York Wire Railing Works, Landauer Collection. (*Courtesy New York Historical Society.*)

Plate VII

Harper & Brothers Building, New York, 1854



21. Interior Framing Detail 1½" = 1'-0". Note girders at Reading Room were made up of "two deck beams each 7 inches deep put bulb to bulb and held by bolts through the flanges."



20. Cooper Union Building. East-West Section, scale 1⁄16" = 1'-0".

Plate VIII

Cooper Union Building

Details from measured drawings by Willy Selarsic, 1971 for the Historic American Engineering Record, a 20 sheet project organized by William Rowe III. (*Courtesy Library of Congress.*)

details are interesting. An undated summary of bids, received by Captain Bowman for "Iron floors" lists

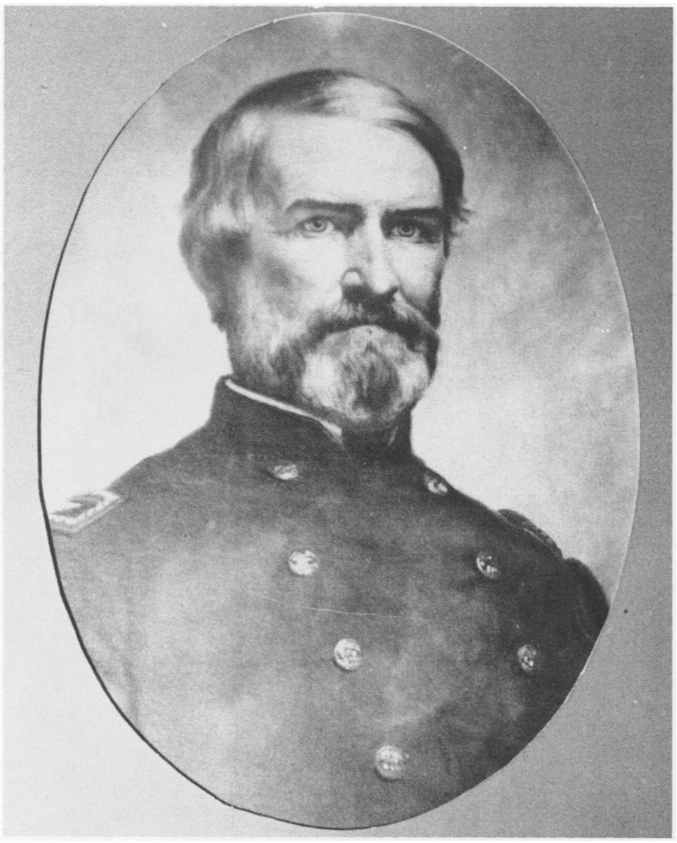
S.B. Althouse & Co.	*$2,500 per floor*
G.R. Jackson & Co.	*2,500 per floor*
Do. cast iron	*9,922 per floor*
Bogardus & Hoppin do.	*5,000 per floor*

The Althouse bid, noted as Lowest and dated September 30, 1853, included

> *2 Wrot [sic] Iron Beams each 35 feet long by 27¾ inches high as per [?] Nº. 103 — made in the Strongest manner*
> *Weight of Each = 5920 lb @ 12½¢ $740 $1480*
> *or*
> *We will furnish two beams, same length as the above by 14¼ high*
> *Weight of each 3200 lb @ 12½¢ $400 $800*

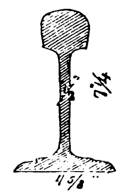
The above particulars may be interpreted in several ways but twenty years later, when acid corrosion had weakened the structure, government inspectors Steinmetz and Schumann made an investigation and reported their findings:

> *It appears that when the building was erected for the purposes of an Assay Office, the business transacted there, was done on a much smaller scale than at present. The iron used inside of the building was of very light construction, but was, possibly, of sufficient size to maintain the weight at that time imposed upon it. The girders are constructed of 7" and 8" channel iron bolted together and the 8" floor beams are butting against these girders and fastened thereto with angle irons and bolts. The brick arches between the floor beams have a rise of 2" to the foot, which brings the arches about 3" above the top of beams, which again increases the weight upon the beams and girders unnecessarily.*[55]



22. Major Alexander H. Bowman, USA (West Point, 1825). Bowman was in charge of the Office of Construction, U.S. Treasury Department during its great building program of the late 1850's, collaborating with Supervising Architect Ammi B. Young. (*Courtesy U.S. Military Academy Library.*)

Date.	No. of experiment.	Weight added.	Total weight applied.	Deflection.	Permanent deflection; weight removed.	Remarks.
		Pounds.	*Pounds.*	*Inches.*	*Inches.*	
1854.						
Dec. 21	1	2,240	2,240	.0937	0	
	2	2,240	4,480	.1875	0	
	3	2,240	6,720	.5625	.0625	
	4	2,240	8,960	.7187	.125	
	5	2,240	11,200	1.25	.375	
	6	2,240	13,440	....	....	Ex. 6, R. No. 1.



23. Lt. Alexander's tabulation of Trenton experiments, December 21, 1854. From letter, Secretary of the Treasury to Senator Hunter, Chairman Committee on Finance, February 1, 1855, from *Senate Executive Document No. 54, 33d Congress, 2d Session*, p. 4 (see note 57.)

The Cooper Institute's cornerstone was laid on September 17, 1853 but construction was held up, as we have seen, while its iron beams were diverted to the Harper Building. The Institute was not opened until 1859 but it has since then remained in use until the present day. Recently, the removal of some of the original beams during a remodelling made it possible to saw off thin cross sections for historical mementos. Figure 14 is taken from a specimen received by the writer several years ago.

The reports from the Trenton Iron Company (Figure 23) reflect advances in technique. In 1854 it was related that

> *a very large amount has been expended in perfecting the machinery for the manufacture of wrought iron beams, for which the price is nearly double that of rails. This machinery is now in daily successful operation; and the Directors have reason to believe that the demand for beams will ultimately absorb the entire product of the mill. If this should occur, the profits of the mill would largely exceed those derived from the furnaces, or any other source, and make the stock of the Company the most productive and valuable ever offered to public, — the exclusive use of the invention by the United States Government in the city of New York, and the extensive buildings of Messrs. Harper & Brothers, erected to replace those recently destroyed by fire, have demonstrated the facility and economy with which structures perfectly fireproof can be built. The Treasury Department have decided, after full examination, to use them in all the Government buildings, of which a large number are now in progress.*[56]

On August 12, 1854 Cooper & Hewitt wrote to Colonel Montgomery C. Meigs of the U.S. Engineers then working on the new wings of the U.S. Capital in Washington:

> *You are correctly informed that we have machinery adapted to the manufacture of beams for floors and roofs — for more than two years, we have devoted our entire*

No. 17 Burling Slip New York Sept. 1st 1854

[name of addressee missing]

We beg leave to call your attention to the annexed plate, showing the practical mode of using our solid wrought iron rolled Beams, wrought iron girders, and brick arches in the construction of Fire Proof Buildings.

Fig. 1 is a longitudinal section through the girder showing a cross section of the beams and arches for a span of 20 ft. Any greater space can be arranged in the same manner. Fig. 2 is a longitudinal section of the girder showing the mode of tieing it in the main side wall of the building. Fig. 3 is a cross section of the wrought iron girder constructed on the most approved philosophical principles developed in the thorough experiments of Messrs. Stephenson, Hodgkinson, and Fairbairn, made in reference to the construction of the Great Tubular Bridge over the Menai Straits. Upon the girder is a longitudinal section of the wrought iron beams, with an allowance for play.

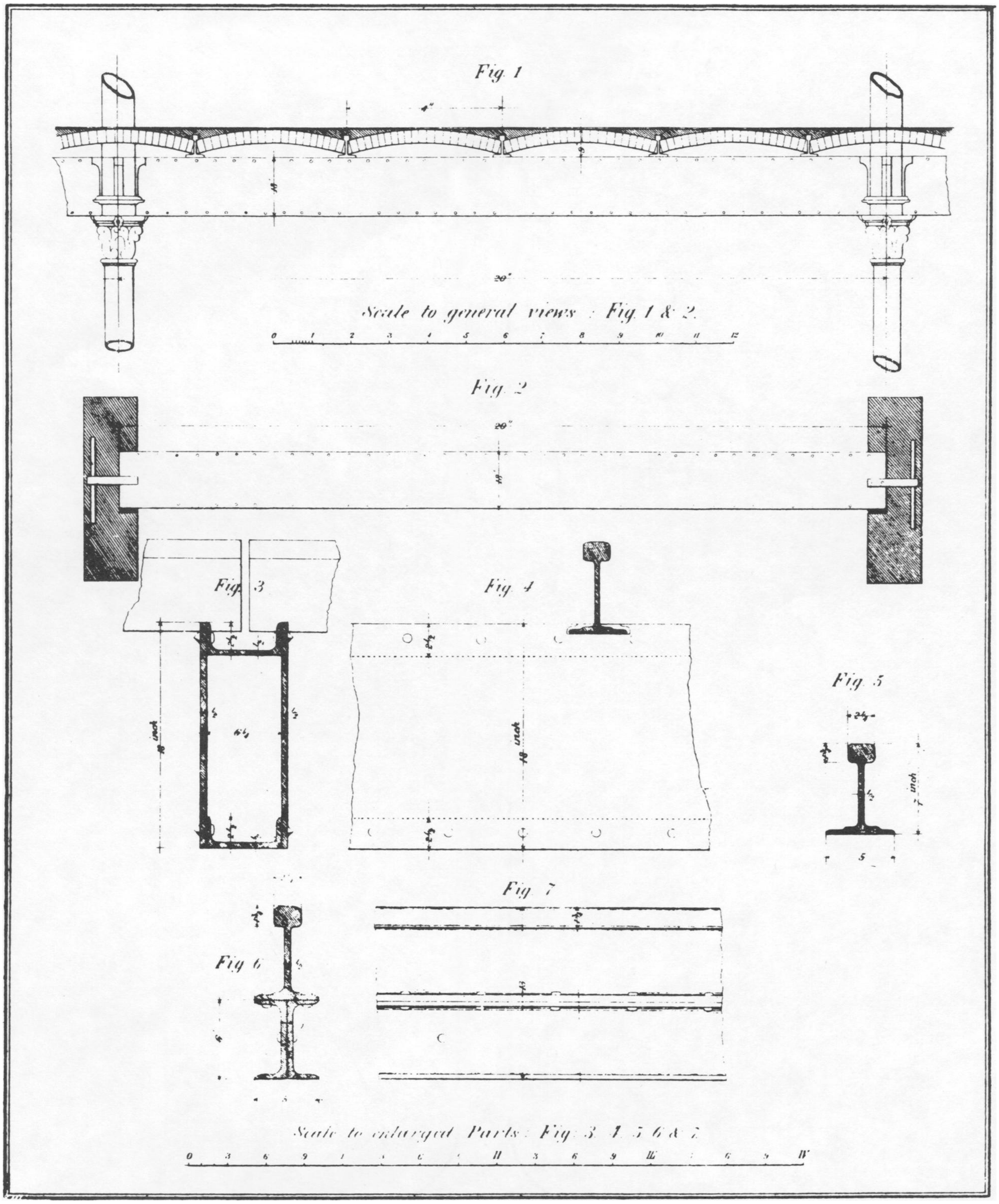
Fig. 4 is a longitudinal section of the girder, and cross section of the beam showing the mode of holding the latter in the girder thus relieving the wall of the building from the side thrust of the arches -- Fig. 5 is a cross section of the solid wrought iron beam, of a pattern which we are now making -- other patterns will be soon prepared - Fig. 6 is a cross section of another form of girder, not so perfect as the first, but useful for some purposes, and less expensive -- Fig. 7 is a longitudinal section of the same girder.

It will be observed that the mode of construction is extremely simple and at the same time perfectly secure. The advantages are 1st Economy - costing only one half more than wooden beams, floors and girders, 2nd Security - making a completely fire proof structure, 3rd Durability - being made of an indestructible material, 4th Convenience in removing as the building may be taken apart without injury to the beams and girders - Our arrangements for supplying the beams are on so large a scale that we can offer them at about half the price pr lb of rivetted beams and of less weight and greater strength. They have been used by the U.S. Government, and in the new buildings of Messrs. Harper & Bros. which for strength, security, and durability, combined with economy are not equalled by any buildings in this city. We shall be happy to furnish any further information, and soliciting a careful examination of this plan of building, which we believe will prevent all danger of great conflagrations in the large cities, we are

Very respectifully your obt servts,

Cooper & Hewitt

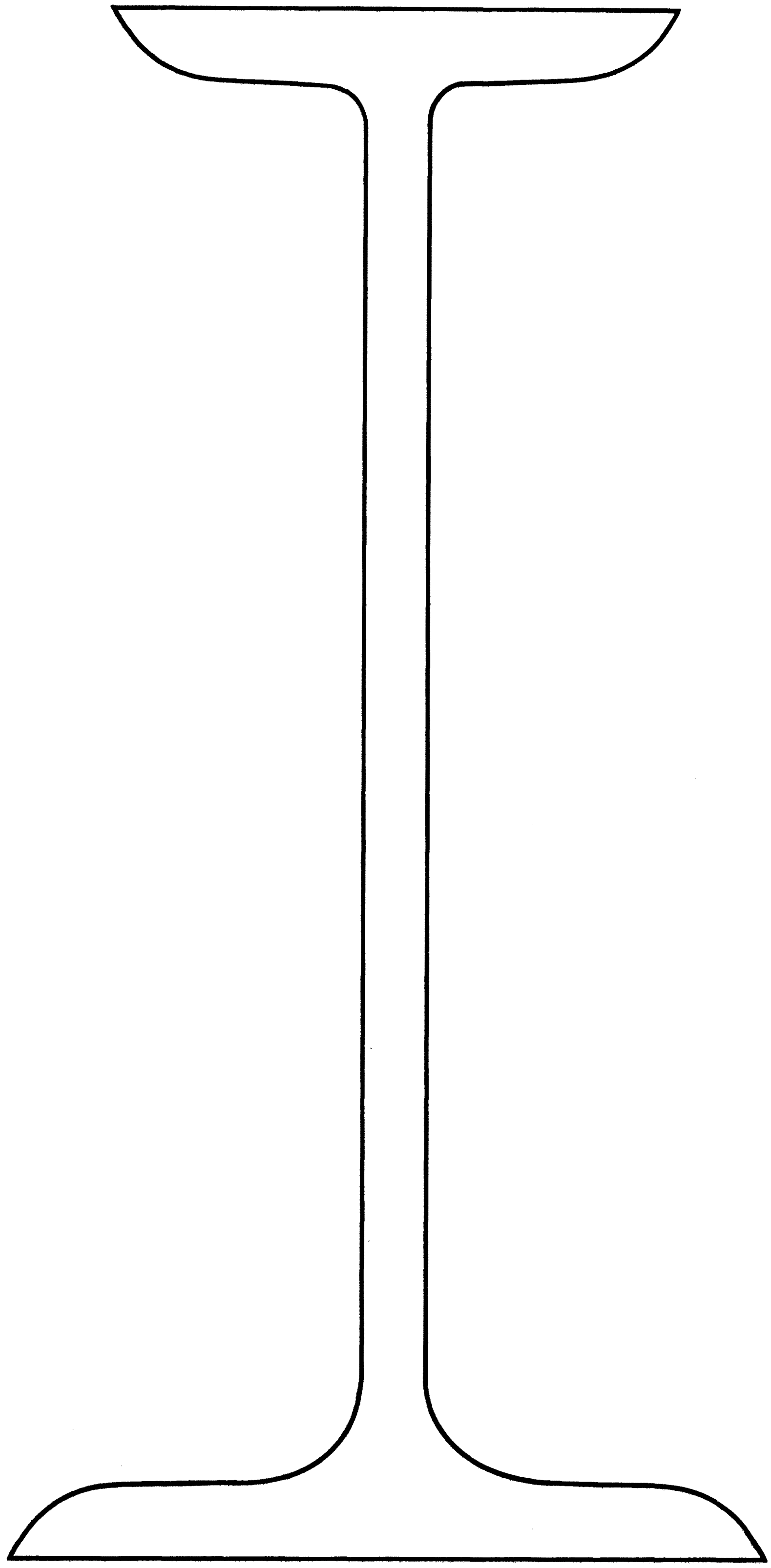
24. A longhand letter [transcribed above] promoting the use of the new iron beams, found in the Old Army Records, Record Group 77, at the National Archives, Washington, transmitted the engraving reproduced opposite (Fig. 25.)



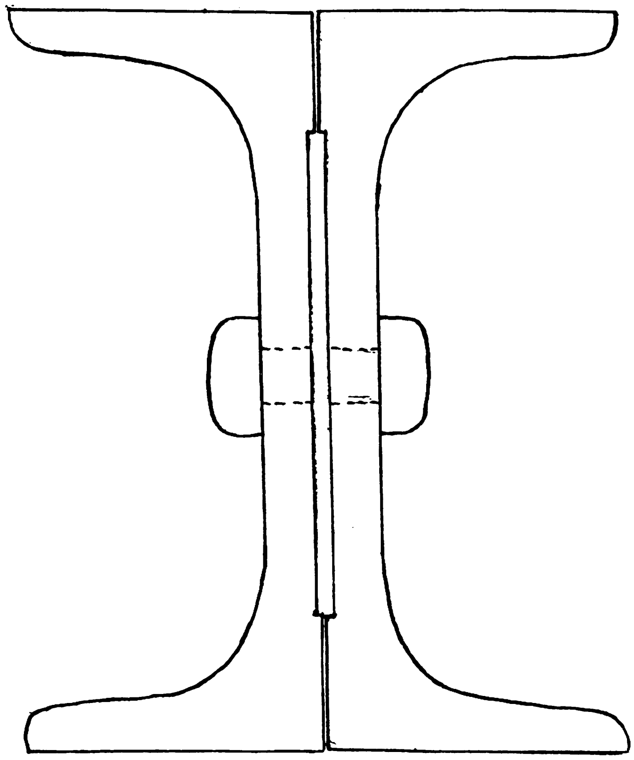
25. Copy of Engraving of Cooper & Hewitt products. [Author's Note: Figs. 1-3 incorporate the 7" bulb-tee as rolled for the Camden and Amboy Railroad in 1848. Fig. 4 details what today is called a box girder. Fig. 6 is a composite of a bulb-tee superimposed on two channels back to back as employed in the Chelsea, Massachusetts Marine Hospital, 1855.]

Plate IX

Broadside by Cooper & Hewitt/Trenton Iron Company



27. Full size section drawing from Cooper & Hewitt, August 14, 1854. Two unequal flanges, 8-$^{3}/_{16}$" deep. "Approximate sketch of beam for which rolls are now under weigh [*sic*] — weight 20 lbs per foot". (*Courtesy, Architect of the Capitol, Washington.*)



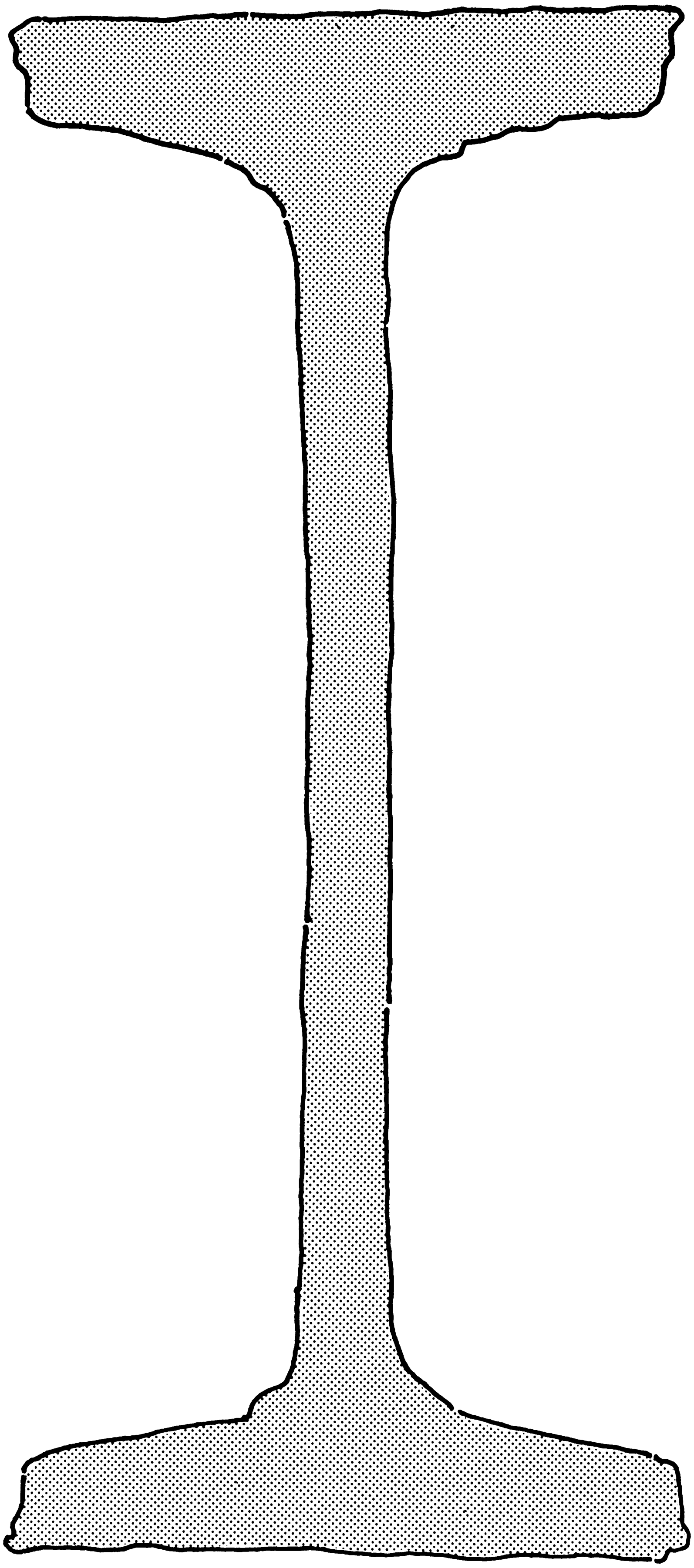
26. "Compound Beam — weight rivetted 30 lbs per lineal foot – depth 6½ inches — half beam can be used for rafters" Offered by Cooper & Hewitt August 14, 1854.

attention to this business, and have now the satisfaction of stating that we have brought the machine to perfection, although at an expenditure of over one hundred and fifty thousand dollars —[57]

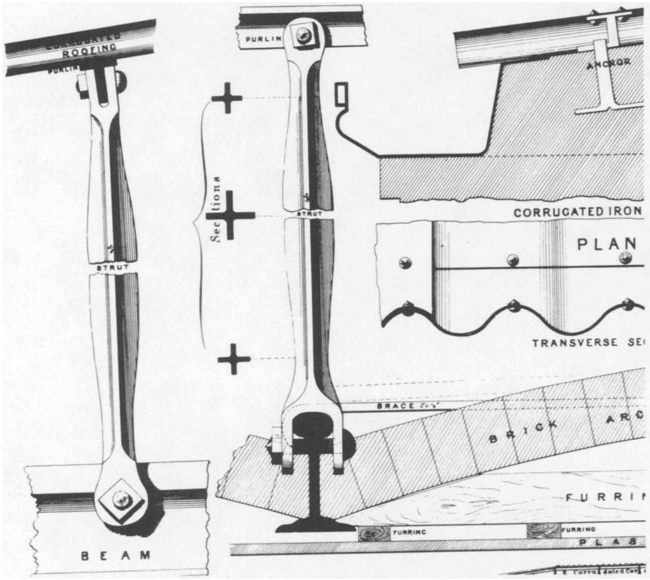
(Figures 24 & 25 illustrate the sales efforts of Cooper & Hewitt). Trenton was successful in selling to Meigs but continued to work on their rolls in order to increase the depth of beams (Figure 26). On October 29, 1855 they reported that "we have not commenced rolling the 8" beams but the work is progressing — we expect to make them 9" & certainly not less than 8½" in height"[58] (Figure 27).

The success in New York came just in time to be exploited in the Treasury Department's great public works building program across the country. One of the first projects was the Custom House at St. Louis, where the levee on the Mississippi was now lined deep with steamboats carrying western immigrants and their goods. Construction had begun early in 1852 under plans by local architect George I. Barnett and with St. Louis ironmen Kingsland & Cuddy and McMurray & Pawley involved. But plans had to be adjusted to accommodate unexpected foundation problems and trouble in locating a suitable freestone for exterior masonry. The delays permitted use of the new iron technology and by April 5, 1855 plans had been made to incorporate Trenton girders and beams. By the middle of July Cooper & Hewitt billed Secretary Guthrie from New York for the first floor girders and 117 iron beams. As late as October 16 iron was being loaded on the steamboat Kentucky. The accounts show that Kingsland & Cuddy not only cast the iron columns locally but they also hoisted and set the imported beams. Interior fittings (which included the setting up of a post office) were not completed and the accounts settled until the Civil War closed in.[59]

28. Cherry Street, Philadelphia "fireproof" factory of Cornelius & Baker, maker of lamps, chandeliers and gas fixtures in 1856. The brick floors were supported on Cooper & Hewitt iron joists. (*Drawn on stone by W.H. Rease, courtesy Library of Congress.*)



30. The American I-Beam at Last! Full size section of Cooper & Hewitt beam as installed in Wheeling, West Virginia, Custom House, 1856. Equal flanges, 9" deep. *(Courtesy, Professor Emory L. Kemp.)*



29. Chicago Custom House Ceiling and Roof Detail, 1855. The Trenton bulb-tee here supports a cast iron strut which in turn connects to a wrought iron purlin. The whole is part of a low-pitched, hip roof covered with galvanized iron. (*Courtesy, Library of Congress.*)

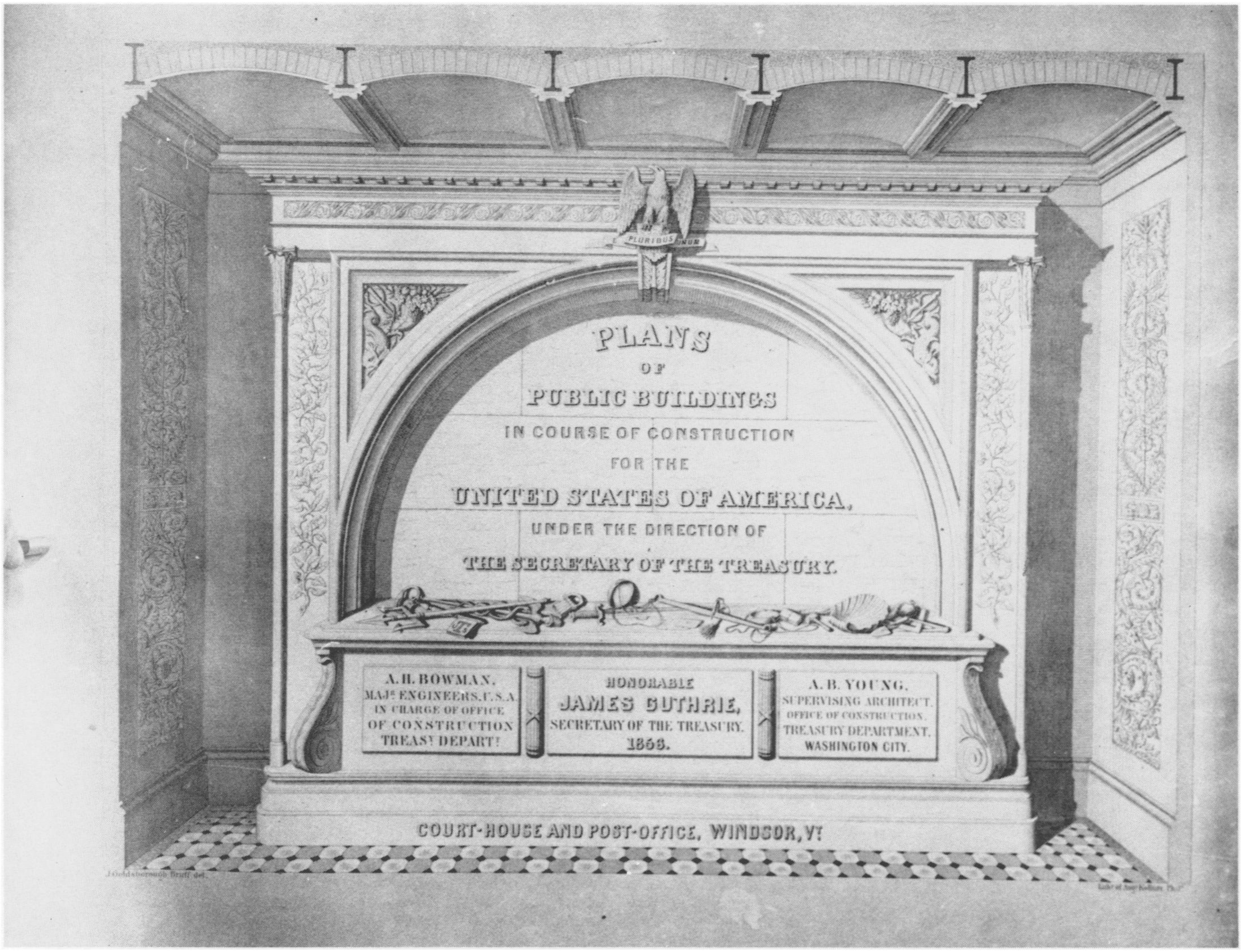
The I-form Supercedes the Bulb-Tee

By the summer of 1855 Captain Bowman was able to report on the triumph of the new beams.

> *The use of wrought-iron, whenever it can be made to take the place of wood or cast-iron . . . has been extended to all the works now in progress, and each day's experience in its use serves to simplify its application to building purposes and to enlarge the sphere of its usefulness. Beams, girders, window-sash and shutters, sash-cord, doors, etc. etc., are now made of wrought-iron, and at a cost comparatively small over the cost of the same articles of wood and cast-iron. The rolled beams thus far used in these public buildings have been limited to seven and a half inches in height. Rolls are in preparation, and are expected to be in full operation by the 1st of January, 1856, for producing twelve-inch beams. As the strength of beams of equal sections and lengths is in proportion to the cube of their depth, this addition of four and a half inches will so far increase the strength of the new beam as to permit its substitution for the more expensive hollow girders now used.*[60]

Typical of the designs in this period was the "fireproof" factory of Cornelius & Baker in Philadelphia (Figure 28). Also typical of this period, the 1856 specifications for the Custom House, Post Office and Court Room at Wheeling (now) West Virginia advised bidders that the Treasury Department had already purchased the ironwork which would be delivered at Trenton to the contractor, presumably wharfside. Itemized were 175 beams up to 20′ 9″ long at 5½¢ per pound and 44 girders at 7¢ per pound for use in floors and ceilings.[61]

31. Parliament Buildings, Ottawa. Working drawing for fireproof floor by Fuller & Jones of Ottawa and Toronto dated October 21, 1859. The detail calls for rolled iron joists on which a slab of concrete is poured. (*Courtesy Public Archives Canada.*)



32. Windsor, Vermont. Court House and Post Office, 1856. This decorative cover sheet by J. Goldsborough, delineator, appropriately gives credit to Treasury Secretary Guthrie, Architect Young and Major Bowman. Across the top may be seen a series of fully developed I-beams supporting flat brick arches. The new beams superceded the iron bulb-tees used earlier; today they are rolled in steel. (*Courtesy Avery Library, Columbia University.*)

By studying the plans closely, it will be perceived that in the *1855* drawings the old 7" rail beam or bulb-tee was still specified (As shown in the detail from the Chicago Custom House, Figure 29). But the *1856* drawings for the Alexandria, Virginia Custom House and the Georgetown, D.C. Custom House and Post Office (still standing) delineate the symmetrical I-beam we know today — that is, one with equal flanges (Figure 30). This seems to date the final configuration of the modern I-beam. In a dozen years, American practice had finally caught up with the Malin/Turner I-beams introduced at Kew. But this time the new model was here to stay (Figure 31).

An example may be seen on the handsome lithographed cover of the 1856 plans for the Courthouse and Post Office at Windsor, Vermont (Figure 32) which displays a cross section of a floor where the I-beams show in their modern form of two equal and flat flanges.[62] Alexander Bowman, promoted to Major and in charge of the office of Construction of the U.S. Treasury Department, enjoyed equal billing with Supervisory Architect Young[63]. Together with Cooper & Hewitt, they had achieved the cooperation between government and private industry that Thomas Cubbitt dreamed of a decade earlier.

After the Civil War, when the Bessemer process made steel cheap enough to frame buildings[64] and the great forests of the Eastern United States had almost melted away, the I-beam increasingly triumphed. Once it was found to be economically feasible, the skyscraper soon became the very hallmark of American civilization.

NOTES:

1. Many years ago, being heavily involved in the restoration of American buildings, the writer began to collect textual source material and specimens of craftsmanship. Then, in 1964, he introduced a course called "The Technology of Early American Building" at the Columbia University School of Architecture. The historical importance of both Concrete and Structural Wrought Iron as building materials soon brought them into a strong focus. As history they are much neglected subjects.

   The esssay ofered here is a spin-off of a commitment to the Association for Preservation Technology to report on the evolution of wrought iron in building construction. Many structural elements now made of steel were first thought out in iron.

   Special thanks is here registered to engineers John G. James of Twickenham, Middlesex, and R.J.M. Sutherland of London, and to Professor Eugene S. Ferguson of the Hagley Foundation and Curator Robert M. Vogel of the Museum of History and Technology, Washington for substantial contributions and encouragement over recent years.

For a valuable essay related to this study see Sutherland, "Pioneer British Contributions to Structural Iron and Concrete: 1770-1855" in Charles E. Peterson, ed., *Building Early America*, Radnor, Pa., 1976, pp. 96-113.

2. Robert A. Jewett, "Structural Antecedents of the I-Beam, 1800-1850," *Technology and Culture*, Vol. 8 (July, 1967) pp. 346-362 and "Solving the Puzzle of the First American Structural Rail-Beam", *Ibid.*, Vol. 10 (July, 1969) pp. 370-391. Mr. Jewett's extensive documentation will not be repeated here.
3. Arthur Raistrick, *Dynasty of Iron Founders*, London, 1953, p.30. The configuration of its cross section is not known.
4. Turpin C. Bannister, "The First Iron-Framed Buildings", *The Architectural Review, London*, April, 1950, pp. 231-246. I owe my initial interest in iron construction to Dr. Bannister, F.A.I.A., and to John A. Bryan, A.I.A. of St. Louis.
5. The iron ceiling beams over the King's Library in Robert Smirke's British Museum (1824) were cast in pieces as long as 50'. J. Mordaunt Crook, *The British Museum*, London, 1972, p. 141.
6. The modern railroad rail was invented in 1830 by an American, Robert Stevens, president of the Camden and Amboy Railroad which crossed New Jersey to connect Philadelphia with New York City (with the help of steamboats). Of "bulb-tee" configuration — and spiked to wooden cross ties — Stevens' rail soon superceded all of the many European models and, finally, rolled in steel, it is still with us. It will be seen below that railroad iron without modification could be used as joists and girders before the modern I-beam was rolled.
7. John Grantham, C.E., *Iron as a Material for Ship-Building*, London, 1842, p. 46, Plates 1 and 2. The development of rolled L's and T's is still historically obscure. Some years later Grantham wrote of iron beams: ". . . they possess many advantages over timber beams, which are not only more bulky, but require large knees of timber or iron to secure them at the ends. The iron beam is made of different forms, and as the art of ship-building progresses, attempts are made to roll iron of the exact-form required, but this has not yet been accomplished to any great extent."

   John Grantham, *Iron Ship-building with Practical illustrations*, London, John Weale, 1858, p. 27.
8. *Mechanics' Magazine*, (London) Vol. 43 (September 27, 1845), p. 221.
9. William Fairbairn, *An Account of the Construction of the Britannia and Conway Tubular Bridges*, London, 1849, p. 2.
10. For instance, a cross section drawing of a test model sent by Fairbairn to Stephenson on October 15, 1845 (*Ibid.*, p. 19) was published in Philadelphia a few months later. *Journal of the Franklin Institute*, 3 ser., Vol. XII, No. 1 (July, 1946), p. 27. On October 10, 1845 iron bulb T's 8.38" and 9.44" deep were tested at Millbank but no comments were recorded. Fairbairn, pp. 248, 249. Designated Experiments XXX and XXXI, were they imitating Grissell and Peto?
11. John Hix, *The Glass House*, Cambridge, MA, 1974, p. 121. The Belfast structure is discussed in Eileen McCracken, *The Palm House and Botanic Garden, Belfast*, Belfast, 1971. The Dublin structure in Edward J. Diestelkamp and E. Charles Nelson, "Richard Turner's Legacy, the Glasnevin Curvilinear Glasshouse", *Taisce/Journal, Ireland's Conservation Magazine* (Dublin) Vol. 3, No. 1 (Feb-April, 1979), pp. 4-5.
12. Dublin, Trinity College Archives, *Manuscript Series P4*, Folder 34.
13. Maurice Craig, *Dublin, 1660-1860*, 2nd edition, Dublin, 1969, p. 190.
14. It is not clear whether Turner built the works or bought it more or less complete.
15. Francis Elrington Ball, *An Historical Sketch of Pembroke Township*, Dublin, 1907, pp. 23, 49.
16. Charles M'Intosh, *The Book of the Garden*, Vol. I, Edinburgh & London, 1853, p. 119. That writer also gave great credit to the director of the Gardens, Sir William Jackson Hooker and to Curator Smith. The structure is also notable for its use of special glass to control the selective transmission of heat waves.
17. Hix, *loc. cit.*
18. Coincidentially, the PRO's tremendous manuscript collections were recently moved from Chancery Lane in London to modern quarters in Kew, not far from the Palm House.
19. PRO, *Works*, 16/29/8. An earlier estimate (referred to but not found) was for £9,400 for a structure 140' long, 80' wide and 50' high.
20. PRO *Works*, 13/3. The working drawings dated April, 1844 are still present in the files. They consist of a site plan, building plans, elevations, transverse and longitudinal sections and four sheets of details.
21. *Ibid.*, May 17, 1844.
22. Turner to Decimus Burton, July 1, 1844. *Works*, 16/29/8.
23. Grissell & Peto, Lambeth, to Decimus Burton, June 13, 1845.
24. PRO *Works*, 16:29. Thirteen shapes illustrated in the Kennedy & Vernon 1844 patent document are delineated in Sutherland, p. 111. Figure 5 is a stubby I-section but whether such a section was ever rolled — or if any survive — is not known to this writer.
25. J. Mordaunt Crook and M.H. Port, *The History of the King's Works*, Vol. VI, London, 1973, pp. 441-446.
26. Robert B. Leuchars, Garden Architect, *A Practical Treatise on the Construction, Heating and Ventilation of Hot-Houses*, New York, 1859, P. 105. The preface is dated Boston, October 3, 1850.

   The year before an iron-roofed vinery at Cincinnati was reported. *Ibid.*, p. 103.
27. Charles E. Peterson, "Early American Prefabrication", *Gazette des Beaux Arts*, January, 1948, pp. 37-46.
28. Hix, pp. 121-122.
29. *Ibid.*, pp. 127-129.
30. He resigned in 1858/9. I owe these references and much help to Mr. John G. James.
31. Enrolled June 15, 1949. Printed 1857. Turner was then doing business both in Dublin and at Bath Place, New Road, Middlesex.
32. The design, which the *London Illustrated News* called a "monster roof", is presented in John Weale's *Atlas of Engraving to Illustrate and Practically Explain the Construction of Roofs of Iron*, London, 1859. "At the time of its execution it was considered one of the boldest pieces of construction in existence." Turner described his design at a meeting of the Institution of Civil Engineers on February 19, 1850.
33. These designs were precisely engraved for an appendix to the fifth edition of Thomas Tredgold's prestigious *Elementary Principles of Carpentry*, London, 1870. Appendix by Peter Barlow, F.R.S.
34. Tredgold, plate 53, p. 324.
35. *Ibid.*, plate 51 (not dated).
36. *Ibid.*, plate 52 (not dated).

   The Turner firm continued for some years in Dublin at Ballsbridge and elsewhere. The city directory for 1857 lists "Turner and Gibson, designers and contractors for wrought-iron conservatories, roofs for railway terminals and hot water engines." By 1870 Richard had become "esquire", still living at Ballsbridge and William Turner his son is there with him. After 1875 Richard disappeared from the Dublin directories entirely, though William continued at the Works. In 1880 Richard was reported as "still extant and vigorous, although advanced in years". Thomas Drew, Dublin, to Editor, *The Building News*, London, Vol. XXXVII (March 19, 1880).

   The Hammersmith Works was finally acquired by Crampton, a leading organization of builders. In recent years the Works was demolished and Hume House, a modern office building, now stands on its site. The most notable landmark of the vicinity today is the new American Embassy, directly across the street from the site of the Works.
37. Louis Hautecoeur, *Histoire de l'Architecture Classique en France*, Vol. VII, Paris, 1957, pp. 300-320, offers a sketch of iron construction from 1778-1865. He states (p. 302) that I-beams (*fer en double T*) and channels (*en U*) were fabricated as early as 1836 but does not document it.
38. "Notice" dated January 1, 1853 in Ch. Ferdinand Zorès, *Recueil de Fers speciaux. . . Leurs Diverses Applications dans les Construction*, Paris ed. Appert Fils et Vavasseur, 1853.
39. Zorès named many of them: Roussel, Kaulek, Travers, Joly, Jacquemard, Bleuze, Brou, Thuasne and Deschers.
40. Between the Place des Voges and the Place de la Republique. Third Arondissement.
41. *Etudes Pratiques sur la Construction des Planchers et Poutres*, Paris, ed. Dunod, 1863, p. 13. Planche No. 11 in the album shows at full-size two I-beams 9¼" tall weighing 45 and 62 kg. per running metre.

   The structural engineer for the Saint Germain railroad was Eugene Flachat (1802-1878) a leading innovator. He designed the roof of the Gare de Montparnasse and the Paris terminal sheds for the Rouen and the Western railroads. The Rouen station (c. 1854) used small I-beams 4½" deep for the rafters. With a web ⅜" wide the design is detailed in John Weale, *Atlas of the Engravings to Illustrate and Practically Explain the Construction of Roofs of Iron*, London, 1859, Plate 2. It was adjudged there (p. 1) to be "a very elegant wrought-iron roof. . . of a very simple and economical style of construction."
42. Another engineering controversy reaching a high pitch — a bit later but not settled even yet — is analyzed in George S. Emmerson, "L.T.C. Rolt and the Great Eastern Affair of Brunel versus Scott Russell", *Technology and Culture*, Vol. 21, No. 4 (October, 1980), pp. 553-569.
43. The first American mills to roll the so-called "T-iron" were in Pennsylvania: the Montour Iron Works at Danville and the Great Western Works at Brady's Bend between 1840 and 1843. (Benson J. Lossing, *History of American Industries and Arts*, Philadelphia, 1876, p. 177). Conflicting with that claim, Willis P. Hazard in *Watson's Annals*, Philadephia, 1927, Vol. III, p. 480 states that the first in Pennsylvania was made in 1846 in the Thomas Hunt mill at Gray's Ferry using rolls "designed, turned and prepared by two engineers James Moore and Isaac S. Cassin" at the Bush-Hill Iron Works, Philadelphia.
44. Allan Nevins, *Abram S. Hewitt*, New York, 1967, p. 83-87.
45. J. Elfreth Watkins, *The Development of the American Rail and Track, as illustrated by the Collection in the U.S. National Museum*, Washington, 1891, p. 674.
46. *Ibid.*, by 1850 Frederick Overman, ironmaster and authoritative trade writer, declared that rails heavier than 75 lbs were no longer in use by the railroads. (*The Manufacture of Iron*, Philadelphia, 1850, p. 359).
47. Constance M. Greiff, *John Notman, Architect*, Philadelphia, 1979, pp. 202-206.
48. *The Dairy of George Templeton Strong*, Nevins and Thomas, eds., New York, 1952, Vol. II. pp. 139-140
49. "An American Bookselling Establishment", Vol. XII, No. 659, September 22, 1855, p. 455. A more recent account is Ada Louise Huxtable, "Harper and Brothers Building — 1854", *Progressive Architecture*, New York, Vol. 38, (February, 1957) pp. 153-154.
50. Letter, Bowman to Guthrie, New York, September 12, 1853. Washington, National Archives, Record Group 121. Office of the Supervising Architect, *Incoming Letters*.
51. U.S. Congress, 33d Congress, 2nd Session, Executive Document No. 2, Washington, 1854, p. 357, "Report of the Secretary of the Treasury on the State of Finances for the Year Ending June 30, 1854."
52. Washington, National Archives, Record Group 121. Office of the Supervising Architect, *Incoming Letters and Reports* (MS), Bowman to Guthrie, New York, October 7, 1853. The "made beams" were presumably plate girders.

53. *Ibid*, Bowman to Gurthrie, June 3, 1854.
54. *Ibid*, Bowman to Guthrie, August 4, 1854.
55. To A.B. Mullett, Esq., Supervising Architect (from New York) August 5, 1873.
56. The gross sales of the rolling mill from January 1 to June 30 were $339,999.72, n.a., "Documents Relating to the Trenton Iron Company" (pamphlet), New York, November, 1854, p. 12. Copy at Cooper Union Library, New York City.
57. New York Historical Society, Cooper & Hewitt Papers, *Letter Press Book No. 15*, p. 642. Just how much Cooper & Hewitt iron was used at the Capitol this writer has not yet determined. The manuscript *Register of Letters Received* for the period 1854-55, still in the Office of the Architect of the Capitol, shows that by September 4, 1854 an order had been sent East. The undated drawing "Details of Roof on South Wing . . . No. 1208" signed by Captain Meigs and reproduced in Charles E. Peterson, "Iron in Early American Roofs," *The Smithsonian Journal of History*, Vol. 3, 1968 shows (Fig. 19) Cooper & Hewitt bulb-tees used as purlins.

In the manuscript *Letter Book 2* of the same collection Meigs (Oct. 11) advised that he would need to order the iron for the Senate roof in a few days. He complained that if he didn't get Cooper & Hewitt samples for testing at once he would have to go back to the supplier of the "Representatives Roof." He also adds "Iron is falling I believe can you reduce your price?"

Later the same month Lieutenant B.S. Alexander of the Corps of Engineers was up at Trenton to experiment with the Cooper & Hewitt iron. Just before Christmas the 7¼" bulb tee was tested, both freestanding and confined between brick arches. The results were carefully tabulated and forwarded to Senator R.M.T. Hunter, Chairman of the Committee on Finances on February 1, 1855 — with a request for further funds (U.S. Congress, 33rd Congress, 2d Session, Executive Document No. 54). The letter is a succinct account of the advantages of the new iron and seems worthy of quoting entire:

Sir: The law of the last session of Congress appropriating money for the erection of certain buildings to be used as custom-houses, United States courts, post offices, &c., requires them to be fire-proof. In carrying out this wise provision of the act, it has become necessary to use wrought-iron in very large quantities, and in combinations hitherto untried. Wrought-iron beams are now rolled of such sizes and lengths that, by combinations with made wrought-iron girders, they can be adapted to the largest-sized buildings. The economy of using this material instead of cast metal is equal to its greater security.

At the request of this department, the enterprising and public-spirited proprietors of the only establishment where the heavy beams are rolled, instituted a series of experiments for testing, on a limited scale, the strength of these beams and girders. I communicate herewith the results as ascertained by an officer sent by this department to witness the experiments. The very large amount of rolled iron required in the construction of buildings now authorized by Congress, renders it desirable that a more extended series of experiments should be made. To secure the requisite stability, the beams and girders of a fire-proof floor should not be placed too far apart, while economy forbids that more than are necessary should be used. To show the importance of accurate information on this point, I beg to state that, in the smallest-sized building authorized by Congress at its last session for custom-houses, an increase of six inches in the space between each two beams. decreases the cost of building $1,724.80.

It is proper to state that the beams now being used are entirely new to builders, and hence the absence (except the limited experiments herewith enclosed) of practical knowledge of their capacity.

In view of the importance of this subject to the economical expenditure of the money placed at the disposal of this department for the buildings in question, as well as the interest builders generally feel on the subject, I beg leave respectfully to suggest that an appropriation of three thousand five hundred dollars be made to meet the expenses of a complete series of experiments to test the strength of wrought-iron beams and girders of all dimensions required in the structures above referred to.

It is also proper to add, that the liberal owners of the rolling-mill have offered samples of the various sized beams and girders for the proposed tests, free of charge to the government.

I have the honor to be very respectfully,

JAMES GUTHRIE,

Secretary of the Treasury

58. *Ibid.*, Book 21, p. 272. On November 3 they sent Colonel Joseph G. Totten, Chief of the Corps, a copy of the broadside reproduced here.
59. This account was prepared by the writer from his own typescript of January 5, 1940 titled "Calendar of Correspondence Pertaining to the First St. Louis Custom House" from the files of the U.S. Supervising Architect, Washington loaned to St. Louis for study.

The Custom House was demolished in 1941 for the widening of Third Street and the development of the Jefferson National Expansion Memorial. At that time no one knew enough about structural history to examine and record the ironwork uncovered.

The building of the Custom-House, Post Office and United States Court Rooms at Sixth and King Streets, Wilmington, Delaware likewise happened in this transition period of fireproof floor design. The site was acquired on May 27, 1853. The backward-looking specifications by Supervising Architect A.B. Young, published in Washington that year, called for (p. 9) cast iron columns and wrought iron trusses in the cellar and *cast iron girders* to support the shallow vaulted brick floors above the entrance story. A contract to build was entered with William Graves on August 4. There were delays in appropriations by Congress but the structure was completed in 1857 and is still standing. I am indebted to Robert L. Raley AIA of Wilmington for key documents in this case.
60. U.S. Treasury, "Report of the Secretary of the Treasury on the State of the Finances for the Year Ending June 30, 1855", Washington, 1856, p. 218.
61. The Wheeling plans and specifications were reproduced in the APT *Bulletin*, Vol. V, No. 1 (1973), pp. 76-101. In this case the floor beams have the bulb-tee outline. The box girders are made up of metal plates separated and connected by channels. The Wheeling structure has lately been undergoing an extensive restoration, according to Professor Emory L. Kemp of West Virginia University.

The year before, specifications covering a larger installation of beams and girders for the Providence, Rhode Island Custom House stated that they would be delivered "upon a suitable wharf at Providence" at Government expense.

A set of these letterpress specs by the Public Printer in Washington may be seen at the Avery Library, Columbia University. Its index is in damaged condition but still lists the following buildings: (No.1) Portland, Maine; (No.2) Richmond, Va.; (No.3) Providence, R.I.; (No.4) Belfast and Ellsworth, Maine; (No.5) Gloucester and Barnstable, Mass.; (No.6) Burlington, Vt.; (No.7) New Haven, Conn.; (No.8) Newark, N.J.; (No.9) Oswego, N.Y.; (No.10) Buffalo, N.Y.; (No.11) Chicago, Ill.; (No.12) Milwaukie, [sic] Wis.; (No.13) Chelsee, [sic] Mass.: (No.14) Detroit, Mich.; (Nos. 15 & 16 missing); (No.17) Pensacola; (No.18) Pensacola and Petersburg, Va.; (No.19) Bath, Maine; (No. 20) Waldoboro, Maine; (No.21) Wilmington, Del.; (Nos. 22, 23 and 24 missing); (No.25) Sandusky, Ohio; (No.26) Toledo and St. Marks; (No.27) Wheeling, Va.

No. 15 is missing from the index but the specification is present; it is for the Marine Hospital at Vicksburg, Mississippi (1855). No. 16 is not identified at all Nos. 22, 23 and 24 are both missing and unidentified.

Parts of the Chicago Custom House drawings (1855) are reproduced in Charles E. Peterson, "Iron in Early American Roofs", *The Smithsonian Journal of History*, Vol. 3, 1968, pp. 48-49.
62. The printed drawings, of which an original set was found at Windsor, were photographed for the HABS record of that building. Another set is in the Avery Library collection. See Osmund R. Overby, "Ammi B. Young in the Connecticut Valley", American Notes, *Journal of the Society of Architectural Historians*, XIX, No. 3 (October, 1960), p. 121-123.
63. Bowman was noticed in a letter of December 2, 1856: "With a view to a more efficient management, application was made to the Secretary of War for a scientific and practical engineer to be placed in charge of the construction of these buildings, and Captain Alexander H. Bowman, of the Corps of Engineers, was detailed and assigned to that duty . . . The compensation paid to Captain Bowman has been fixed at $8 per day, less his pay as captain, with his travelling expenses whilst inspecting the works; and the architect has also been retained, to aid the department in his particular line . . . " (U.S. Congress, "Report of the Secretary of the Treasury on the State of the Finances for the year Ending June 30, 1856," Washington, 1857, House Document No. 3).

Another figure in the Trenton story should be recalled. Washington historian Donald J. Lehman, working in 1973 on the history of the Galveston, Texas Custom House, noted in an untitled essay sent to this writer:

As early as December 1856 the Secretary dispatched to Major Robert Anderson at Trenton, New Jersey, the drawings of the building's beams and girders and the details of their connections with columns and antae, the latter being Treasury's preferred term for buttressing piers or pilasters. Anderson was the artillerist in command at Fort Sumter when its bombardment precipitated the Civil War within three weeks after the completion of the Galveston building. He was a career Army officer, one of Bowman's West Point classmates, whom [Secretary of War Jefferson] Davis also lent Guthrie to further Treasury pioneering with iron. Anderson entered Treasury service on July 20, 1855, and was assigned at once to Trenton where he held the post of "Inspector of Iron" until November 15, 1859. The scope of his duties apparently was delineated in a letter from Guthrie which has not come to light. Subsequent correspondence indicated that inspection was only one of his tasks. He ran tests on structural iron, wire rope, and riveting, occasionally procured special items, and kept a set of books on the iron beams and girders Treasury was buying for all its buildings from Cooper, Hewitt & Co., one of the Nation's first large ironmakers. The location of its new rolling mill at Trenton dictated the inspector's station. The dispatch of the drawings to Anderson was tantamount to ordering the beams and girders for a swift start on a building already delayed by the necessity of going through three buildings.

The whole story of the Corps of Engineers' contribution to the evolution of iron construction in this period is long overdue for a definitive study.
64. Philip W. Bishop, "The Beginnings of Cheap Steel", *Contributions from the Museum of History and Technology, Papers*, Smithsonian Institution, Washington, 1959.

Iron and mild steel could — and were — roled in the same mills. W.K.V. Gale, "The Rolling of Iron", *Newcomen Society Transactions*, XXXVII (1964-65), London, 1967, p. 35.