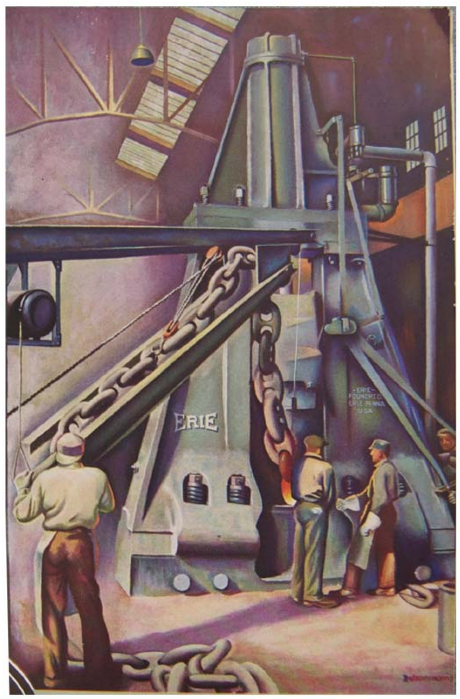
RABER ASSOCIATES
CONSULTANTS IN THE HISTORICAL AND SOCIAL SCIENCES

SPECIAL RESOURCE STUDY, CHAIN FORGE MACHINERY IN BUILDING 105

BOSTON NATIONAL HISTORICAL PARK, CHARLESTOWN NAVY YARD



CHAIN ASSEMBLY AT HAMMER "BIG BARNEY"
source: Erie Foundry Company 1938

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EXECUTIVE SUMMARY

The Chain Forge (Building 105) is a contributing resource to the Boston Naval Shipyard (BNS), within the boundaries of Boston National Historical Park (BNHP). Building 105 has the most intact assemblage of BNS equipment from the era of shipyard operations which ended in 1973, and has national significance for its long role in providing anchor chain to the United States Navy using a die-lock design developed at BNS. The structure was transferred to the Boston Redevelopment Authority (BRA) in 1978, but the federal government retains ownership of the equipment. Previous plans to preserve the main Chain Forge shop area as an industrial museum have not succeeded, and the BRA and the BNHP now believe the building is better suited for commercial redevelopment, and would be more attractive for such efforts if some of the equipment could be relocated to allow adaptive reuse of the structure. In 2013, the Boston Preservation Alliance (BPA) was contacted by the BNHP and Kavanagh Advisory Group (KAG) about managing a special resource study of the equipment in the Chain Forge, as part of planning for proposed redevelopment of the building as a hotel. The goal of the study was to assess the rarity, significance, and interpretive potential of the equipment, and provide recommendations for equipment retention, relocation, or other disposition. To conduct the study, BPA hired Raber Associates, which assembled a team expert in industrial history, metallurgy, heavy industry, and interpretation of historic industrial sites.

Raber Associates completed tasks and reached conclusions summarized below:

- The Chain Forge is significant not only as a maker of die-lock chain, but for its manufacture of a wide range of military products including large anchors, and for its numerous shop-floor innovations and patents.

- The report synthesized a broad range of material to provide an intimate understanding of the development and evolution of the forge, the materials made there, and the work processes necessary to understand the role and significance of each piece of equipment.

- Field investigations allowed for creation of the first definitive inventory and plan of equipment currently in the Chain Forge, confirming and correcting earlier data.

- Assessment of significance was based on a variety of factors associated with periods of innovation in wrought iron and steel alloy chainmaking c1914-1930 and c1949-1953, and with periods of expansion of American naval forces c1914-18, c1935-44, and c1949-1959. Within each of these periods the Chain Forge, the people who worked there, and the equipment they used played nationally significant roles in American history. Criteria utilized to evaluate each piece of equipment are:

    1. Rarity, uniqueness, and age relative to known examples in industrial or museum settings. Equipment of unusual scale, innovative pieces built on site by Navy Yard personnel and special-purpose commercial equipment associated with master designers would all fit within this criterion.

    2. Distinctive pieces or assemblages of equipment associated with important forge products and significant periods of innovation or American naval history, even if individual pieces in such an assemblage may have been typical of contemporary technology.

    3. Examples of once-typical commercial equipment associated with distinctive shop-floor innovation or management techniques for production of important forge products, including atypical, innovative equipment applications.

- The team identified 162 pieces of mechanical equipment in the Chain Forge, including 18 significant pieces (some in groups or assemblages which should remain together) recommended for retention in place or as close to original position as possible, and 20 significant pieces (some in groups or assemblages which should remain together) recommended for retention in new locations which could include areas beyond Building 105. While physical condition and environmental issues were not part of the study scope of work, the team noted how such issues could impact final decisions to retain or remove various equipment from the site, including the fact that previous site mitigation work did not address environmental/hazardous waste issues inside machinery. In some cases artifact conditions, size or weight may make on-site retention extremely costly and potentially non-viable, in which case additional mitigatory documentation would be necessary.

- Interpretive and educational potential is high within a re-purposed, non-museum setting such as the hotel currently being considered. Public interaction with historical collections in such a setting is sometimes more engaging than in a specialty museum. Many specific interpretative recommendations are presented for interior and exterior displays. The largest hammer on site, for example, is an awe-inspiring piece of equipment that could successfully be moved and exhibited outside the building, with great interpretive effect as has been accomplished in other locations. Only a few large hammers are currently on public display in the United States. None have the scale or visual power of this iconic machine. Several have proven successful, stable, and durable in Europe.

ACKNOWLEDGEMENTS

National Park Service personnel provided critical support in completing this study. Duncan Hay, of the Northeast Regional Office, shared his extensive experience working with the Chain Forge and its artifacts. At the Charlestown Navy Yard, Boston National Historical Park, Chief of Cultural Resources Dr. Martin Blatt and Preservation Specialist Stephen P. Carlson offered advice and clarification on numerous points of recent management issues related to the Chain Forge, and Museum Curator David J. Vecchioli provided very extensive archival and logistical assistance without which the study could not have been done. Justine Christianson, Historian at the Historic American Engineering Record who recently drafted an excellent history of the property, was extremely generous in providing a wide variety of inventories and archival material collected during her research. Alisa McCann, Architectural Historian at the Northeast Regional Office, offered valuable comments on our draft report. At the Boston Preservation Alliance, Executive Director Gregory Galer helped direct our efforts and reviewed our evolving draft documents. Kavanagh Advisory Group managers Lee Nilsson and Thomas Miller provided some critical logistical support during our field investigations. To all these people, our thanks.

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I. INTRODUCTION

The Chain Forge (Building 105) and its surviving equipment is a contributing resource to the Boston Naval Shipyard (BNS)[1] which was designated as a National Historic Landmark in 1966. Building 105 has the most intact assemblage of BNS equipment from the era of shipyard operations which ended in 1973. The structure was transferred to the Boston Redevelopment Authority (BRA) in 1978, and included within the boundaries of Boston National Historical Park (BNHP) in 1980 (Figure 1). The federal government retains ownership of the equipment as part of BNHP collections administered through the National Park Service (NPS), and has a 1977 Memorandum of Agreement with the BRA establishing a process for joint planning on issues of mutual interest including preservation of the Chain Forge. This process led to 2002 preservation guidelines which envisioned preservation of the main shop area and its equipment as an industrial museum.[2] Structural deterioration, some hazardous conditions, and the lack of a financial model to convert the facility to a successful museum continue to preclude public visitors. The BRA and the BNHP now believe the building is better suited for commercial redevelopment, and would be more attractive for such efforts if some of the equipment could be relocated to allow adaptive reuse of the main shop area. The agencies also believe that more visitors are likely at a publicly accessible commercial venture infused with interpreted material from the historic operation than would be attracted to a museum of chain making.

In mid-2013, the Boston Preservation Alliance (BPA) was contacted by the BNHP and Kavanagh Advisory Group (KAG) about managing a special resource study of the equipment in the Chain Forge, as part of planning for proposed redevelopment of the building as a hotel. The goal of the study was to assess the rarity, significance, and interpretive potential of the equipment, and provide recommendations for equipment retention, relocation, or other disposition. BPA was contracted for this work by KAG in early 2014, and subsequently hired Raber Associates to complete this project. Raber Associates conducted research, field investigations, and preliminary interpretative planning between January and May 2014. Michael S. Raber acted as project manager, working with co-principal investigators Patrick M. Malone, Robert B. Gordon, and William F. Johnson.

II. STUDY ISSUES AND METHODS

A. Issues

Recent studies have provided much useful information on the history, architecture, and U.S. Navy context of the Chain Forge, principal and secondary products including patent data, summaries of equipment use and forge processes, equipment identification and makers, and documentary sources.[3] Additional research issues addressed by this Special Resource Study included:

● *Final inventory and plan of existing equipment*. There was no definitive inventory or plan of equipment currently in the Chain Forge. The two most recent plans and inventories were prepared during building remediation efforts c2002, and during preparation of draft documentation of the building by the Historic American Engineering Record (HAER) in 2012-2013.[4] The former set of data was no longer completely current following remediation measures including movement of some equipment. The HAER floor plan, apparently based largely on one BNS drawing, shows equipment in last known working positions but is not necessarily a plan of current conditions.[5] The HAER plan also notes approximately a dozen unidentified pieces, which have Navy inventory numbers. In addition to mechanical equipment, there is some surviving equipment such as chain dies which have not been mapped, and in some cases are stored in other BNHP facilities. Some but not all of the dies, other portable equipment, and examples of forge products have been inventoried by NPS.[6]

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[1] The shipyard was often called the Boston Navy Yard until 1945; Charlestown Navy Yard is a less official term used by the National Park Service as noted in Carlson 2010, 1: ix. In this study the term Navy Yard is sometimes used to indicate the facility.

[2] Boston Redevelopment Authority 2002.

[3] Black 1988; Carolan 2003; Carlson 2010; Carolan *et al*. 2012; Christianson 2013. Duncan Hay of the NPS compiled what is probably the most detailed inventory of extant non-portable equipment during hazardous material remediation efforts conducted c1992-2002.

[4] Stone and Webster Engineers & Constructors, Inc. 2002b: Figure 2; Warren and Oldenberg 2013: Sheet 5 of 7.

[5] Boston Naval Shipyard 1965-1973.

[6] Boston National Historic Park n.d.a-n.d.d; personal communications, David Vecchioli.

● *Sufficient documentation of processes associated with existing equipment to identify any distinctive modifications for Chain Forge operations or surviving evidence of tooling.*

● *Comparison of surviving equipment made at BNS with contemporary commercially-available equipment of the same type, and identification of any unique or rare pieces made at BNS or by commercial suppliers.*

● *Comparison of commercially-supplied Chain Forge equipment with contemporary equipment used for analogous operations elsewhere, and preliminary identification of surviving examples of similar equipment in industrial or museum settings.*

● *Comparison of Chain Forge products, notably Die-Lock Chain, with products made for similar purposes in naval and civilian use, including products made after closing of BNS.*

B. Methods

Methods deployed for the study included documentary research, several inspections of the Chain Forge and of related artifacts held elsewhere by NPS, and consultations with historians, manufacturers, and retired Navy officers and shipbuilders:

- Documentary sources included published and unpublished reports on Chain Forge and Navy Yard history, Navy Yard newsletters reviewed from 1936-1973, Navy records and drawings, photographs, interviews, and television film footage held by NPS; detailed equipment inventories prepared for earlier studies or maintained by NPS; patent records; trade catalogs of manufacturers who made Chain Forge equipment;[7] contemporary publications on pertinent manufacturing processes; historical studies of such processes within American industry; and studies of vessels and associated equipment prepared by government departments and historians. The budget and schedule of this study precluded review of materials held in National Archive centers, though several earlier Chain Forge and Navy Yard studies have made extensive use of such materials.

- Based on floor plans with equipment locations prepared in 2002 and 2013,[8] detailed site inspection in 2014 mapped current conditions, photographed equipment which appeared potentially significant, and located surviving dies or other equipment associated with former Chain Forge operations. Notes on equipment were keyed to specific products or operations based on documentary sources, and evidence of equipment customization was sought. The 2013 plan was modified to reflect current conditions, which include 162 pieces of equipment (Figure 2; Table 1).

- Dies, tools, and samples of chain and other Chain Forge products held by NPS were inspected and photographed, including some chain samples not formally accessioned by NPS.[9]

- Major work processes and shop evolution, keyed to specific equipment, were described as feasible for different periods of Chain Forge history.

- The significance of individual pieces was assessed in terms of uniqueness of design or use relative to Chain Forge products, or as survivals of typical equipment which is now rare or nearly extinct. Assessment included review of available literature, and personal communications with industry managers, museum curators, and industrial historians.

- Recommendations for equipment triage were developed, distinguishing what should be retained in place, what is significant but ideally can be kept on site in non-original locations inside Building 105 or

[7] Extensive trade catalog data was graciously provided by HAER historian Justine Christianson.

[8] Stone & Webster Engineers & Constructors, Inc. 2002b; Warren and Oldenberg 2013; the latter drawing was based on Boston Naval Shipyard 1965-1973.

[9] Boston National Historic Park n.d.a – n.d.d.

at nearby exterior locations, and what can be removed due to relative lack of significance. For some large significant pieces, cost or other issues could make retention in any non-original locations extremely difficult, and could require other mitigation measures if such pieces are scrapped. For pieces identified as candidates for removal, preliminary recommendations addressed other possible institutions or manufacturers which might take some pieces.

- Preliminary interpretative recommendations were developed within the proposed hotel context, identifying possible themes, locations, media, historical equipment and display content.

III. SUMMARY OF CHAIN FORGE HISTORY AND SIGNIFICANCE

The 1800-1974 history of the Navy Yard, and the architecture and functions of Building 105, have been treated in detail in prior studies and are only addressed here as needed to meet the objectives of this study.[10] This section summarizes the context and sequence of major developments at the Chain Forge, noting the numerous innovations which improved naval hardware and secured Navy Yard jobs.

A few years after the United States Navy began building an all-steel fleet in the early 1880s, the Navy Yard in Boston secured the job of providing all the fleet's anchor and chain. Equipment for making these and other wrought iron naval hardware at this time have not been documented in detail for this study. Anchors were made in the Rolling Mill and Machine Shop (Building 40) erected 1864-7, and six sizes of hand-welded chains and other hardware were made in the 1857 Foundry and Machine Shop (Building 42). As the Navy expanded at very end of the 19th century, the Navy Yard developed plans for a significant expansion of its hardware facilities with a complex of new buildings in the eastern end of the yard, including a Chain and Anchor Storage Building (Building 103), a Shipfitters Shop (Building 104), a Smithery & Power House (Building 105),[11] and a Metalworkers Shop (Building 106). Congress funded these projects in 1900, which included machine shop improvements to Building 42 (Figure 1).[12]

As completed in 1904, steel-framed brick-walled Building 105 had a tripartite plan with an approximately 96-by-111-foot 1-story hip-roof power house on the west end,[13] a 25-by-90-foot 2-story rectangular connector with offices, bathrooms, and storage space, and a 329-foot-long, 100-foot-wide two-story smithy. The large shop was a gabled block topped by a full-length monitor and bisected by a gabled 2½-story transept. The 1-story north and south sections of the smithy were approximately 28 feet wide and 17.5 feet high, with Howe roof trusses. The 2-story center bay was 52 feet wide and 43.3' high to the interior pinnacle of the monitor, with round-bottomed Howe roof trusses. In part because of its later fame as the Chain Forge, this visually striking space has been called a Cathedral of Industry.[14]

The smithy initially had five small steam-powered drop hammers, serviced by the power house in the building, to make an undocumented range of hardware. After the 1908 consolidation of Navy Yard power production in a new central plant in Building 108, the power house in Building 105 was dismantled, and all power machinery in this shop was thereafter operated by compressed air. Wrought-iron chain production, which Navy Yard mechanics were beginning to mechanize by 1910 as discussed below, was moved into Building 40 in 1907. As discussed in Section VI of this report, all chain and anchor production was transferred to Building 105 beginning in 1913, including an 800,000-pound lever-type chain testing device. Installation of chain and anchor production in the large smithy shop led to creation of a new smithy/blacksmith shop in the former power house in 1916. During World War I, increased construction of larger ships led to demands for larger, stronger chain,

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[10] Principal secondary sources on these topics include Black 1988, Carolan 2003, Carlson 2010, Carolan *et al*. 2012, and Christianson 2013.

[11] The original designation of Building 105 may be somewhat confusing for modern readers, who will find smithery defined as the work done by a smith in most dictionaries. A smithy is usually defined as the place where smithery is done. However, in British and American naval shipyards, a building in which smith-work was done was called a smithery into the late 19th and early 20th centuries (Oxford English Dictionary; see Adams 1974 for another American example).

[12] Black, 1988, I: 199-100; Carlson 2010, 1: 63, 70, 2: 506-12, 554-6.

[13] Per BNHP convention, the directions used here are not true cardinal directions, in which the north elevation would actually be the northwest elevation.

[14] Carolan 2003: 6-7; Carlson 2010, 1: 77; Christianson 2013: 4-5.

and the Navy replaced the testing device in Building 105 with a two-million pound device made by the Tinius Olsen Machine Company in 1918. Installed using the same trench in the shop floor used by the first test machine, the Olsen device was the largest of its kind in the world, and served the Chain Forge through the rest of its operations.[15]

Despite this and other enhancements of wrought-iron chain production discussed in Section VI.A, the slow manufacturing processes led to a search for stronger chain which could be made faster, especially in the larger sizes. Beginning in 1917, the Navy and private manufacturers experimented with other materials and methods. National Malleable Castings Company of Cleveland developed a process for making cast alloy steel chain using an electric melting process, with results much stronger than wrought-iron chain. Cast steel chain was made the new standard for Navy ships in 1921, and the Norfolk Naval Shipyard was designated as the manufacturer.[16]

The transition to cast steel chain threatened the jobs of workers in Boston whose skills and equipment were tied to obsolete wrought iron chains.[17] Albert M. Leahy (1883-1952), who became Master of the chain forge in 1928, said that "In 1921 the chain industry at Boston was practically out of the picture and not less than two hundred skilled men were forced out of employment, all chain orders going to Norfolk and outside concerns"[18] Although Boston's chain forge earned a reprieve that year with its patent approval for a superior detachable chain link made of forged alloy steel, discussed below, its long term survival was still in doubt. The Washington Naval Treaty of 1922 cast another shadow on the yard, as that international agreement placed severe limitations on the size of the U. S. fleet and the tonnage of its capital ships.

By 1926, Leahy, Master Blacksmith James Reid, and Navy Yard metallurgist Carlton G. Lutts (1891-1957) developed a "novel method" for forging entire ninety-foot shots of "die-locked" chains from bars of alloy steel.[19] This crucial innovation, involving both the design of the chain links and the dies for assembling it, put Boston back into position as the chain maker for the Navy. Die-lock chain proved to be twice as strong as wrought iron chain and 50 percent stronger than cast steel chain. Its first successful use was the 1927 replacement of the wrought iron chain made for the Panama Canal in 1914, while the first die-lock chain patent was under consideration. As noted in Section VII of this report, the design for the new Panama Canal fender chains was unusual and difficult to manufacture, with alternating detachable and "solid" links made from steel bars.[20]

Between 1928 and 1936, die-lock chains became standard for all sizes of Navy anchor cable. Improvements in design and manufacturing discussed below, authorizations for development of die-lock dies for more chain sizes, and expanded Navy ship construction programs beginning c1933 all strengthened the role of the shop as the service's premier forging operation. Building 105 was re-named the Forge Shop at this time. Between 1934 and World War II, the shop added new equipment and expanded its workforce to meet the increasing demand for its chains (Table 1). In 1936, Leahy proudly claimed that "The yard is now equipped with a modern chain plant which will adequately take care of the Navy in any emergency. Nearly all of the cruisers, submarines, destroyers, etc., built by the Navy during the past six years are equipped with Boston made die lock chain."[21] The Chain Forge's central role in chain production was further strengthened c1938-39, after the makers of NACO cast steel chain demanded comparative tests with die-lock chain. The testing, conducted in part in the Chain Forge, included development of a "Shock Tension Test" simulating actual service condition, and demonstrated the great superiority of the forged die-lock product. Navy Yard workers evidently built two testing devices for this contest, which remain in place as discussed below (Figures 2, 14).[22]

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[15] Tinius Olsen Testing Machine Company 1919, c1955; Lutts 1920; Carolan *et al*. 2012: 25-7, 35-7, 59-60; Carlson 2010, 2: 506-14; Christianson 2013: 14-15, 29-30
[16] Ivas *et al*. 1950: 8-10.
[17] Carlson 2010, 2: 550.
[18] Leahy 1936.
[19] Ibid; a shot in American nautical terms is a length of chain equal to 15 fathoms (90 feet).
[20] Carlson 2010, 1: 107; Ivas *et al.* 1950: 14.
[21] Leahy 1936.
[22] Ivas *et al.* 1950:19-20

Preparations for World War II made the manufacture of chains and anchors a high priority. Many private industrial firms suffered during the Great Depression, but innovations in chain production and increased fleet size retained and created jobs at the Navy Yard. The attack on Pearl Harbor made the need for chains and other forged products even more urgent. Purchase or Navy Yard construction of much new equipment followed rapidly, and the side bays of the main shop were enlarged in 1943 (Table 1). Employment levels in the forge soared to 550 workers working three shifts, including women who were entering this formerly male space for the first time.[23]

Wartime demands for chain and other products exceeded the enlarged capacity of the Chain Forge, and the Navy also relied on private manufacturers, several of whom acquired the technical capability and the rights to make die-lock chains. Civilian industry performance proved that it could supply most of the expanded military's wartime needs, and after the war posed a threat to continued work at the Chain Forge and other Navy Yard shops as the federal government looked for private suppliers to meet peacetime needs. It appeared for a time that all die-lock chain might be produced by Baldt Anchor & Chain, in Chester, PA.[24]

Once again, evolving naval needs, the innovation of Navy Yard staff, and the nature of private manufacturing converged to keep the Chain Forge open for another generation. Soon after the war, it became clear that jet fighters and new potential conflicts would require much larger aircraft carriers, using larger chains and anchors than seen on the carriers and battleships of World War II. In 1945, research began at the Navy Yard on making larger chain which would not kink, leading to a 1950 patent application by Leahy and Lutts discussed below. By 1949, the Navy Yard was tasked with planning production of a manufacturing line for the 4¾" chain needed for the new carriers, even before the first ship had been approved. Although the first "super-carrier" was cancelled that year, the outbreak of the Korean War in 1950 provided the necessary stimulus to design the *USS Forrestal*, the first in a new class of attack carriers (CVAs).[25] The Navy initially attempted to contract for the very large new die-lock chain with private manufacturers, all of whom rejected the idea:

> "..when they first decided to build these carriers, they started out with the *Forrestal*, CVA59, and they sent invitations to bids to Chrysler and Ford and General Motors, Kaiser and Baldt to manufacture the 4 ¾ chain for the carriers. And they turned the invitations down….They didn't want to do it; they figured there wasn't enough money in it, or there wasn't enough production involved." (They would be making only) "a ship's worth of chain or two ship's worth of chain, and then they'd have to shut down the plant because there wouldn't be another ship under construction."[26]

The private companies were correct. Even with an accelerated program of ship construction, the Navy was planning to make only one carrier a year, starting in FY 1952. The cost of setting up a special production line and making new dies for the big chain (with patent approval pending) was high, and the financial return was likely to be sporadic and subject to delays or cancellations. The non-kink link patent, awarded to Leahy and Lutts in 1954, and Chain Forge experience with large chain manufacture, helped keep the shop open. The slow construction of the *Forrestal* allowed the Chain Forge to secure the job of making the new chain, which required difficult installation of very large equipment including a 25,000-pound hammer and 8-inch upsetter already owned by the Navy, and a new 440-ton trimming press. Planning for shop reorganization included some equipment relocation discussed below, and construction of an enormous foundation for the hammer. Assembly of the new chain manufacture line delayed production of the 4¾" carrier chain until 1953. The *Forrestal*, begun at Newport News shipyard in 1951, was launched in late 1954 and commissioned in 1955. It was the largest warship ever built up to that time.[27]

[23] Mitchell 1979a: 1-2; Carolan *et al*.2012: 30; Christianson 2013: 8-9.

[24] Mitchell 1979b: 2-3; Perry 1993; Hyde 2013. Baldt reportedly acquired rights to make die-lock and detachable link chain from Navy Yard patent holders in the mid 1920s, but the details of such rights and transfers remain undocumented.

[25] Ivas *et a.l*. 1950: 20-22; Anonymous c1952: 1; Pater 1968: 73; Friedman 1983: 239, 253-7.

[26] Mitchell 1979b: 3.

[27] Anonymous c1952; Anonymous 1960: 16, 63-7; Friedman 1983: 252-7; Anonymous 2014.

Although most or all other die-lock chain production went to private firms such as Baldt, the Chain Forge became sole supplier of the 4-3/4” carrier chain for the *Forrestal*-class carriers and their successors. The shop also continued to make a wide range of products, including an improved carpenter stopper (a wire rope cable grip), made many forged items for new carriers, and got the job of forging the anchor shanks and assembling the 60,000-pound anchors used by these ships.[28] It was a busy workplace in the 1950s and 1960s. Paul Ivas was most responsible for the efficient and well-ventilated layout and the improved transport of materials along the 4¾” line, with an overhead conveyor, better flooring, and use of fork lifts.[29]

Patent records, published articles, project reports, and the testimony of shop masters indicate that there were three periods of significant innovation at the Chain Forge: c1914-1918 in wrought iron chain making as discussed in Section VI.A, and c1921-1930 and c1949-1953 in development of steel alloy chain. The latter two periods began with the shop under serious threat of closure or radical shrinkage, but innovation and hard work helped to turn the tide and keep people on the job. Desperate times produced exceptional needs for good ideas and effective action. Managers and workers on the shop floor contributed to that creative environment.

The shop’s work also made significant contributions to enlargement of U.S. Navy fleets during World War I, c1935-1944 before and during World War II, and c1949-1959 during the Cold War. The work before and during World War II was notable for remarkable enhanced output of chain and other products, rather than development of new designs. Wartime demands are best served by improvements in production, not radical changes in design for which new manufacturing methods may be needed.[30]

Although the federal government did close the shipyard on July 1, 1974, it was not because the need for giant chains and anchors had disappeared. Quite to the contrary, the chain forge was still the only shop in the world that could produce a 4¾” die-lock chain, and continued to do so until the last order completed in 1973 for the nuclear carrier *USS Eisenhower* (CVAN 69).[31] The great irony of the chain story is that the Navy closed its chain forge in 1974 without any other supplier of the largest anchor chains. To this day, the Navy takes Boston-made 4¾” chains off scrapped or decommissioned aircraft carriers and recycles them for use by new carriers. Most if not all new chain used on Navy vessels is flash-butt welded,. The welded chain is cheaper than the forged chain, and apparently has adequate performance for at least smaller ships. Despite recommendations to develop welded chain for the largest sizes, the Navy is evidently not convinced this is a viable plan.[32] The innovative ideas, and the aging products, of the Chain Forge are still helping to keep our Navy’s ships in action, but it is too late to bring back the jobs lost when the government shut it down.

IV. FORGE PRODUCTS

Chains had multiple uses on shipboard and off. The chain forge at the Boston Navy Yard was best known for its anchor cables, made with die-lock links for great strength and toughness. Design and manufacturing issues associated with die-lock chain are more fully summarized elsewhere in this report. Die-lock links formed cables with shots of ninety feet, available in sizes from ¾” to 4¾” (the measure being the diameter of the steel rod used to make chain). Detachable links connected the shots of long cables. The largest chain (4¾”) was developed in the early 1950s for *Forrestal* class aircraft carriers, as noted above. Die-lock chains also made the best mooring cables and were important in towing vessels. Welded chains (with or without studs)[33] were not as strong, but they apparently worked well in hoists, in cargo handling functions, for securing aircraft on carrier decks, and for

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[28] Boston Naval Shipyard n.d.

[29] Mitchell n.d.: Box 2, Folder 3 (an 83-page report on the carpenter stopper); Mitchell 1979: 3-4; Ivas 1979: 12; Christianson 2013: 9-10).

[30] E.g., Raber *et al.* 2008.

[31] Mitchell n.d.: Box 1, Folder 1..

[32] National Materials Advisory Board 1980; Dujardin 2007; Carlson 2010, 1: 194.

[33] A stud is a cross-piece in a chain link. It is perpendicular to the long sides of the link. Studs were added in order to stiffen links, thus preventing severe deformation when a link was overloaded in tension or subject to a crushing force. Studs also helped to prevent kinking and thus were particularly valuable for anchor chains used with windlasses. When a chain was made of wrought iron, smiths could insert studs in the closed links and weld them into place either by hand or with powered hammers. In the early transition to steel chains, studs could be formed with each cast steel link. The parts used to close a detachable link of forged steel also produced a stud. In the successful development of the die-lock chain, an upsetter created an integral stud with flowing steel as it forged the recesses in a socket member.

the bridles used with accommodation ladders. The versatile blacksmiths in Building 105 had the capability to make or repair many types of chains, but after 1926 the chain forge and its machine operators concentrated on die-lock chains and detachable links with a wire diameter of at least ¾."

Some die-lock chains had unusual applications. In 1927, the forge supplied steel replacements for the original chains that it had made of welded wrought iron to protect the lock gates of the Panama Canal, as discussed below in Section VII. It made chains of special non-magnetic steel alloy for use on mine sweepers and supported American harbor defenses in World War II with chains for anti-submarine nets.[34]

The forge was not just in the business of making chains and detachable links. Paul Ivas, a former master of the forge, estimated that work on chains amounted to about 60% of the shop's total effort.[35] Building 105 produced much of the Navy's ground tackle (equipment used in anchoring and mooring, with anchors and buoy mooring with chain and appendages).[36] It evidently forged the shanks for, and assembled, all the heavy anchors for Navy ships beginning c1914. It produced various types of appendages, including shackles, swivels, turn-buckles, strong backs, and pelican hooks). All of these devices were associated with the use of anchor chains, but the men in the forge made a wider range of both standard and customized products for the Navy and occasionally for other branches of the military. They worked closely with the machine shop in Building 42 whenever forged appendages and other items required some machining,[37]

Both Ivas and Kenneth Mitchell, the last forge master, described many products: watertight door dogs, flanges, hooks of various kinds, crank shafts, propeller shafts, rivets, rings, elbows, valve fittings, wing nuts, etc. Mitchell put together a big panel filled with drop forged items that the shop made for its customers.[38] This display board, in the National Park collections, no longer has tags on the various items, but they are numbered. NPS curator David Vecchioli has located the handwritten key that identifies each numbered object. The panel clearly demonstrates the versatility of the shop (in both machine and hand production of forged goods). There are 70 forged products on it, and only a few are duplicates. Included, in addition to the things already named by Ivas or Mitchell above, are eye bolts, hinges, tees, a locking pin, a drop bolt, a cleat, a mooring hook, handles, a wrench, a stanchion pad, a high pressure T, and a socket. Most of these were for ships, but the shop also supplied other departments in the shipyard and Navy shore facilities in many other places.[39] The *Naval Ship Systems Command Die Book* of June, 1968 was intended to "facilitate the ready interchange of forging and sheetmetal dies."[40] It lists and gives basic dimensions for hundreds of dies, many of which were surely stored at the chain forge in Boston before its closure. From such extensive lists, one begins to appreciate how important forgings were to the Navy.

Dies that have survived in the forge also testify to the bewildering diversity of manufactures. Although marine suppliers and private shipyards did make many of the same items, the forge took pride in the quality of its work, and the Navy often preferred its own products. In critical work such as anchoring or towing a ship, the Navy needed to be sure that all appendages had exceptional strength, toughness, durability, and corrosion resistance.

Among the great assets of the chain forge and its integral smithy was its ability to turn out special orders, experiment with product designs, and repair or replace equipment for ships, naval bases, and other government agencies. If only one item was needed, a blacksmith might make that by hand with his hammer, swedges, tongs, anvil, and furnace. Or he might use a powered hammer or press to make the work easier. If enough items of the same form were needed, machine operators might work with a die sinker to make dies for drop forging– or the shop manager might even set up a production line with multiple machines and special tooling.

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[34] Mitchell 1979a: 48-9; Ivas 1979: 13.
[35] Ivas 1978: 10-12.
[36] Department of the Navy 1979: 76.
[37] Mitchell 1979a: 24-33, 38-9, 61.
[38] Ivas, 1978: 11; Ivas 1979: 9-10; Mitchell 1979a: 34, 38-39, 63.
[39] Carolan *et al.* 2012: 37-8.
[40] Department of the Navy 1968.

On a second panel, Mitchell put a selection of hand forged products and tools. The blacksmith shop made most of the tools for the chain forge, most notably the tongs of many sizes and types that were so essential in the forge. A wide variety of wrenches and hammers were also needed in the shop and on shipboard, but only a few were represented in this display. Mitchell pointed out to his interviewer most of the things on the second panel: a grab hook, pneumatic gun chisels, swedges, a boring or cutting bar for the pattern shop, a hinge pad, a refrigerator door handle, a jaw bolt and tie rod for life boat cradles, an iron boom end, a hatch cover spring, a caulking tool, a triangle link maker, a staple bender, a shackle bender, etc. There were even a few products and tools on the panel that he seemed unsure of or just could not identify.[41] The panel selections represented a small sampling of the range of things made at the chain forge.

Some of the more unusual forge jobs appear in the interview with Mitchell. He mentioned developmental work and special orders done for Army arsenals, including forgings for an 8-inch shell, tank axles and towing hooks, helicopter rocket holding devices, gun trigger mechanisms, and aluminum ogives (shells with roundly tapered ends) for bombs. When private industry failed to make proper gun cams for Rock Island Arsenal, the Boston chain forge stepped in and succeeded. Mitchell was proud of that achievement. Once his shop experimented with titanium forgings for Watertown Arsenal and even worked with uranium for the Atomic Energy Commission. He said they did lots of forgings for Navy ordnance plants [42]

The chain forge at the Charlestown Navy Yard was a very busy place with creative artisans who could forge almost anything the Navy needed and who sometimes served other government branches as well. Its work ranged from mass production, to special orders, to experimental development. Incremental improvements in products and manufacturing processes were part of the normal operations. Traditional hand forging remained important in the blacksmith shop, but the chain forge, particularly in World War II and after, was also an up-to-date workplace with highly capable machinery, furnaces, and testing equipment. It turned out an incredible number of products, competing effectively with private industry for many years before ultimately losing most of its chain business (other than the 4¾” die-lock chain, which only it could make). The Navy Department shut it down with the surrounding shipyard, in a cost-saving measure that left naval shipbuilders without a supplier of anchor chains for the largest aircraft carriers, and the military in general lost an innovative and flexible supplier of materials of great diversity.

V. SHOP EVOLUTION

There appear to be few available building plans showing equipment from the first years of the power forging era which began in this shop c1914. One 1915 plan shows chain making in the east section of the main shop’s north bay, and a drop forge plant in the west section of the south bay. With modified equipment, these arrangements continued until 1974, with other functions for enhanced or new production and testing added to other shop areas (Figures 3-4). Sources including c1952 and 1965/1973 plans, historic photographs, equipment inventories, 1978-79 interviews with forge masters Kenneth Mitchell and Paul Ivas, manuscript accounts of die-lock chain development and installation of equipment of 4¾” chain manufacture, and recent reports on the building suggest the following key points about shop evolution:

- The former powerhouse at the west end of the building was converted to blacksmith shop use c1916, with the south half later converted to railroad equipment repair to which the entire powerhouse area was devoted c1931-1941, after which the north half reverted to blacksmith shop use

- Only three pieces of equipment survive at known or probable original locations from before 1930, when all basic methods for subsequent die-lock chain manufacture were established. Taken together with the evidence of later plans and pre-World War II photographs, the location of these three pieces -- the Tinius Olsen chain tester and two small heat treating furnaces near the southeast corner of the main shop -- suggest that many basic functions remained in place through the operating life of the forge in the central and south bays, the northeast shop section, and the northwestern corner of the shop. Many other pieces of equipment were moved one or more times, however, to support these functions.

[41] Mitchell 1979a: 63-80.
[42] Ibid: 40-42.

- Following the advent of fully forged die-lock sockets in 1929, much new equipment was installed prior to World War II. Many pieces including bending and upsetting machines appear to have been replaced during the war, when the main forge was expanded to the north and the scale of operations increased dramatically. Much of the surviving equipment including a number of heat treating furnaces dates to the war, with most of the rest associated with the introduction of the 4 ¾" die-lock chain for *Forrestal*-class ships c1949-1953. The latter program was associated with some movement of smaller pieces of war-era equipment into the northeast corner of the expanded shop, and with improved ventilation and partial concrete floor installation in the main shop. There were no significant later changes to the chain forge complex prior to its closure in 1974. Except for removal of several large pieces of equipment soon after the closure, and movement within the shop of approximately a dozen smaller furnaces and other items during remediation c2000, current conditions reflect the forge largely as it was at the end of the Korean War (Figures 5-10).

VI. DIE-LOCK CHAIN DEVELOPMENT AND WORK PROCESSES

A. Wrought Iron Chain Manufacture and Issues

From the time that chain replaced fiber anchor cables until the early twentieth century, wrought iron was the material of choice for making chain. Individual links were forged from wrought iron bar, interlinked with others, and then welded shut by smiths wielding hand hammers and sledges. Wrought iron was particularly suitable for this application since it included slag particles which made it self-fluxing. It was easily welded by traditional smithing techniques. Since it was iron free of carbon, it was a low-strength but ductile, tough material. (However it could be embrittled by phosphorous if badly made.) It had a reputation for corrosion resistance that persisted despite a lack of supporting evidence. Making chain by hand required heavy labor. For the largest sizes a smith and two strikers had to work together to close the links that had been heated to welding temperature in a forge fire. A certain lack of uniformity in the product was unavoidable.

When Building 105 was completed in 1904 as the Navy Yard's smithy, all chain manufacturing for the Navy was still confined to Building 42. Chain and anchor work were consolidated in Building 40 in 1907. The versatile smiths in Building 105 did a wide variety of forging jobs, but the chain makers in 40, concentrated on welded, wrought-iron chain. That process was already partially mechanized by 1910, when an illustrated article in *Machinery* described "Making Heavy Chain and Anchors for Uncle Sam." A rolling mill converted iron stock into rod of the required diameter for the chain links, and a circular saw cut the still hot bar to proper length and produced the angled end surfaces known as scarfs, which were crucial in welding as they brought the ends into an alignment of surfaces which facilitated a quality weld when the link was bent and looped onto the chain. Machines "designed by Commander Parmenter and made in the machine shops of the Charlestown Navy Yard under his supervision" then bent the bar into an open link.[43] However, in normal practice, the final critical step, welding the link closed, was done as it always had been, by hand. Each link was heated in an open forge fire, looped into the end of the growing chain, and welded shut by two strikers directed by a master smith as he maneuvered the link on an anvil with his tongs and the strikers pounded away with sledge hammers.

This hand welding was typical in both America and Britain at the time. It is interesting that one of the long time employees at Boston came from a family of British chain makers (men and women, young and old); Bill Homer started work outside Birmingham at 14 in 1909 and was apparently still producing some small chain by hand in Boston 47 years later. Shop master Paul Ivas recalled working with a hammer team under the supervision of a skilled chain maker (perhaps Bill Homer) as they made wrought iron links to repair an old 2 ½ inch chain in the late 1930s. They were "swinging sledge hammers to hit, one right after another, in a welding heat." [44]

Mechanization was making inroads on these hand processes when *Machinery* reported on the chain shop. Although a photo showed a "chain gang" closing heavy links by hand, the article noted that "For some of the chain a welding machine is employed."[45] It is not clear what machine or what size of chain this refers to, but

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[43] Lucas, 1910: 447-49.
[44] "Let's Take a Trip," 1956; Ivas 1979: 10.
[45] Lucas, 1910: 448

managers at the shipyard were aware that hand welding had serious limitations. Later in the same year, a report detailed those concerns and described steps being taken to address them: "It is believed that the point has been reached in the process of making chain when it is no longer possible to strike a sufficiently hard blow with a hand-sledge to insure a proper weld. The heaviest and strongest men attainable are now used in the making of three-inch chain." Looking for a powered hammer that would closely resemble the actions of men with sledge-hammers, the shipyard experimented with a Bradley helve hammer. Tests "demonstrated that it is possible to make the weld much more rapidly than by hand." This promised to improve the rate of chain production and, at the same time, to avoid unwanted cooling of the iron before it was fully welded.[46] Drop forging was also proving valuable by this time. The stud inserted in each hand welded link was described in *Machinery* as a "drop forged block, and a "20-ton Steam Hammer" forged the crowns of large anchors. Since 1909, chain appendages had been forged with machinery.[47]

Showing workers how to make the best use of new machinery was essential. Once the Bradley hammer was installed in an "experimental plant," the Construction Officer explained to the Commandant that "it will be necessary to expend further material and labor in training men to operate the machine."[48] It appears that mechanized welding of large links remained experimental for a few more years. Chain makers were still clinging to hand practices when the Navy Department tried to introduce some of the principles of Scientific Management at the shipyard in 1912 and 1913. That short lived effort, which raised some opposition among shipyard workers, had little effect on the chain shop in Building 40 or the smithy in Building 105 except perhaps to encourage the keeping of more detailed records.[49] More significant for the chain makers were continuing steps to consolidate operations in the yard. Combining of chain and anchor production in an enlarged Building 40 had been one such step. Next came the centralizing of all forging operations in Building 105 in 1913. After that move, the pace of mechanization increased and the special status of chain makers came under fire.[50]

There were eight chain makers and twenty-five helpers in Building 105 in 1914, when the helpers asked for a higher wage. Because no commercial companies made chains near Boston (and since piece rates were typical in such firms elsewhere), it had been difficult to establish a comparative basis for daily wages at the shipyard. When the helpers walked out in July, 1914, to protest inaction on their latest wage demand, the skilled chain makers joined them in an apparent example of shop floor solidarity. All but one stayed out during ensuing negotiations, and striking chain makers were discharged along with the helpers. The shipyard's Commandant and a young Assistant Secretary of the Navy, a Democrat named Franklin Delano Roosevelt, took a hard line against the strikers. At the same time, the manager in charge of chain making in the yard proposed a major shift to mechanical processes, with an emphasis on the use of drop hammers.[51] As discussed below, chain making was evidently entirely mechanized by late 1914.[52]

The strike by chain makers and their helpers failed. The striking workers almost lost their jobs permanently, but were allowed to re-register for employment in a conciliatory gesture in January of the following year. However, those who returned lost the status associated with the separate rating of chain maker, which was abolished. They became smiths and smiths' assistants, part of the larger workforce in a rapidly mechanizing Building 105.[53] Powered machinery, not for the first nor the last time, was helping managers exert control over the shop floor.

Drop hammers, now powered by compressed air, were replacing many of the sledge hammers, anvils, and small forge fires in Building 105 as World War I began in Europe. It seems likely that even the relatively new Bradley helve hammer had quickly given way to more versatile drop hammers. Welding large chain with hand sledges may not have ended immediately, but the shift to powered hammers was clearly gaining momentum in

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46 U.S. Navy Correspondence, Record Group 181, Box 79, December 9, 1910; National Archives and Records Administration (NARA), Waltham, MA, quoted in Carolan *et al*. 2012: 35; boxes have been renumbered and may be hard to locate (personal communication, Justine Christianson)..
47 Lucas, 1910: 448-50; Black 1988, I: 274.
48 U.S. Navy Correspondence, Record Group 181, Box 79, April 4, 1911 (NARA), quoted in Carolan *et al*. 2012: 35; see Note 46.
49 Black 1988, I: 270-272
50 Christianson 2013: 6
51 Black 1988, I: 272-74
52 Lutts 1920.
53 Ibid.: 277-79.

1914. The need for stronger chains had been obvious since construction of the super dreadnought *USS Pennsylvania* began in 1913.

A battleship as heavy as the *Pennsylvania* required exceptionally large and well-made anchor chains. The proposed size of the *Pennsylvania* also affected the design of locks for the canal that the United States was building in Panama. The width of the locks was increased to 110 feet, to meet the needs of the U. S. Navy, which was planning to give its new battleship a beam of almost 98 feet – 4 feet wider than the *Titanic*, the biggest passenger ship at the time. General George Goethals, who was in charge of the canal project, wanted to be sure not only that ships would fit in the locks but also that they would not damage the lock gates.[54] There were numerous cases of ships losing control as they approached canal gates and ramming them. Water had rushed through lock gates damaged by a runaway ship on the Soo Canal in Michigan, and only the manual use of an emergency bridge/dam had halted the disastrous flow. The Panama Canal was uniquely threatened, since rupture of certain lock gates could theoretically lower the level of the enormous Gatun Lake, which formed the summit of the canal and provided water for lock operation.[55]

The British had started using chain fenders to protect threatened locks late in the 19th century. Goethals and his engineering staff decided to make chains the first line of defense for their most vulnerable gates. They relied on the forge in Boston to produce those wrought iron chains. As a ship approached, a large chain was stretched across the lock. The chain fenders at Panama were more complex than earlier British designs. They would (if necessary) bring an uncontrolled ship to a gradual halt using hydraulic cylinders, valves, and other resistance. Normally, ships slowed promptly, wire cables linked them to locomotives along the canal walls, and operators then released the tension on the fender chain, which dropped out of the way, into a slot at the bottom of the lock. The fender chain would contact a ship only in an exceptional situation, but it had to be strong enough to handle the stress of a collision. Ira Bennett said that the "huge chain, whose links are fashioned out of three-inch iron" could stop a 10,000 ton ship, moving five miles per hour, in only seventy feet. Claims in Goethals's official report were a little more modest. There were twenty four of the heavy, wrought iron chains at the canal. On average, they were 427 feet long and weighed 85 pounds per foot. [56]

An article on the Panama Canal chains in *The Advance* in the summer of 1914, noted that "considerable difficulty is being experienced at the Boston Navy Yard making links of the required strength." All were tested to 275,000 pounds "and the weaknesses found so far have been mostly at the welds."[57] The problems were occurring just as the chain makers and their helpers were about to go on strike and just before management proposed increasing the level of mechanization in the Chain Forge. By the end of the year, and before completion of the Panama Canal chains, two more hammers had been installed with which all welding was mechanized. Also in place was a machine for bending chain rods. The Chain Forge acquired additional powered machinery in 1916 that gave it the capability to make chains of a larger (3 3/8") size, and installed an annealing furnace to address problems of link strength.[58]

There were at least eight reasons for the surge in mechanization in the Chain Forge after 1913:

1) A general emphasis on efficiency growing out of Scientific Management;
2) The consolidation of all forging operations in Building 105;
3) Technical problems encountered in making large wrought iron chains for battleships and for the Panama Canal locks;
4) Efforts to reduce the power of chain makers;
5) The absence for six months of both chain makers and their helpers after the strike of 1914;
6) Successful experiments with powered machinery by commercial chain makers and also by managers and workers at the shipyard;
7) The urgency of national involvement in an international war in 1917;
8) Expectation of increasing demand for naval anchor chains and anticipated competition from other facilities.

[54] McCullough 1977: 539, 599-600.
[55] Ibid; Bennett 1915: 152-154; Christianson 2013: 14, 39; Goethals, ed. 1916, II: 119, 132.
[56] Bennett 1915: 152; Goethals, ed. 1916, II: 118-126; Anonymous 1914.
[57] Anonymous, 1914..
[58] Lutts 1920; Christianson 2013: 6.

Mechanization alone, however, could not solve all the problems associated with wrought iron chains. Even if welding with compressed air hammers had been perfected (and we have no evidence that it was), the limitations of wrought iron as a material were still troubling. The Navy needed to make ship's anchor chains from a stronger metal. World War I had created a sudden increase in demand for anchor chain that could not be met with established chain-making methods. To meet the increased demand, commercial manufacturers developed a technique for fabricating chain from low-carbon (0.3 percent) steel by casting the interconnected links in sand moulds. This eliminated the need for welding and permitted use of a stronger material than wrought iron. However, high-strength, alloy steel could not be made into chain by the casting process.

To address the problem of making chain of heat-treatable alloy steel, the Navy Yard's master blacksmith James Reid and leadingman blacksmith Albert M. Leahy devised the detachable-link chain design described in their U. S. patent 1,386,732 issued 9 August 1921. The chain links were forged from alloy steel that could be heat treated for maximum strength. Alternate links in the chain were made with an open side that was closed with a fitted cap once the detachable link was passed through its adjoining links. This link was "C" shaped. The ends of the "C" were made with projecting studs that engaged recesses in the cap that closed the link. The cap was locked in place by a screw or by a tapered pin driven through the cap and link (Figure 11). The Navy Yard put the new, detachable-link chain into production, and it was successfully used on navy vessels through the 1920s. Some refinements and improvements in the design were made as experience was gained in the manufacture of the detachable links. Leahy and Carlton Lutts incorporated these improvements in the modified detachable link described in their patent 1,776,515 filed in 1929 and issued in 1930. Section VII of this report provides additional detail.

These inventors realized that chain could be made both stronger and more rapidly if the links could be closed by forging instead of being closed with an insert that had to be precisely formed and pinned in place. This led them to the development of the die-lock process.

B. Die-Lock Chain Patents

The concept of the die-lock chain is spelled out in patent 1,753,941filed with the Patent Office in 1926 by James Reid, Albert Leahy and Carlton Lutts, and issued in 1930. Leahy and Lutts are identified by Kenneth Mitchell in his 1979 interview with Arsen Charles as employees at the navy yard. Leahy [1883-1952], originally hired as a blacksmith, was master mechanic at the time of his retirement. Lutts [1891-1957] began work as a physical metallurgist and was head of the materials laboratory at his retirement. At the time this patent was issued Reid had died.

The patent specifies that each chain link is to be made from a pair of half-links. One half-link, the "stem member," is to have its ends formed into tapered stems containing a set of bosses or collars designed to fit into recesses in the mating half-link, the "socket member." Under a forge hammer the recesses in the socket half-link are closed around the collars of the stem half-link, thereby joining the links without the need for welding. The links are to be made of "high grade steel" and heat treated to develop high strength. With this design a chain that is stronger than one with welded or cast links could be made. A companion patent, 1,753,942, enlarges the process description in the first patent, and adds an expanded description of the forging dies to be used. In patent 1,974,827 issued in 1934 Lutts and Leahy expand the description of the desired shape of the stems and sockets that are to be formed during the forging of the links. They explain that while the stem member is to be heat treated by quenching and tempering so as to attain the full strength possible in the alloy steel used, this is not possible in the socket member since it must be heated to forging temperature for the joining process. They suggest that the rapid cooling of the socket member when placed in contact with the stem member when the two are joined will sufficiently strengthen the stem member (Figures 12-13).

Patent 2,693,673 filed in 1950 and issued in 1954 to C. G. Lutts and A. M. Leahy describes an improvement in the design of the die-lock links intended to prevent kinking of the chain. The middle part of the link is to be thickened relative to the ends, which retain the diameter of the metal stock used to make the links. This required changes in the dimensions of the stems and collars on the stem half-link and the recesses in the socket half-links. This patent contains a more detailed description of the manufacturing process and the specifications for the steel than the earlier patents (see discussion below). Lutts and Leahy assert in this patent that failure of a link, if it were to occur, is to be in the socket end of the completed link. To attain this they specify use of steel with lower carbon content and hardenability for socket half-link than for the stem half-link.

Additional patents obtained by staff at the Boston Navy Yard describe modifications of the die-lock chain link shape, and are for other chain products that do not use the die-lock process. These include patent 1,974,827 (1930 – 1934) for a variant on the chain link shape initially described in patent 1,753,941, and patent 2,304,938 (1941 – 1942) for welded chain that is not a die-lock product.

C. Manufacturing Process

After the 1926 patent explained the principle of the die-lock joint, development of the actual manufacturing process became the task of men with diverse skills on the staff of the navy yard. Design of tools and equipment for forming and joining the stem and socket half-links was needed. The 1926 patent also presented a metallurgical challenge if the full strength of the steel used was to be realized. The die-locks had to be closed at the forging temperature of the steel, typically 2,200^{o}F (1,200^{o}C). Since the chain was made link-by-link until it reached 90-feet long, there was no way to heat treat the entire chain by quenching from high temperature followed by tempering at a lower temperature in order to attain the maximum strength of the steel. The completed chain was too large to be successfully heated, quenched and tempered. As Ivas described it the idea of heat treating a whole shot "…was one of those things that was a dream idea that couldn't be physically worked with." [59] Metallurgical processing had to be fitted into the mechanical processes used in making the chain as best it could.

1. Forging and Joining Chain Links

The interviews with Ken Mitchell, the last master of the forge shop, conducted in 1979 as he viewed pictures of the die-lock manufacturing process, show how the forge shop staff took the concept presented in the patents to actual production. His descriptions and equipment designations match well with the 1950s floor plans of the shop. The chains with sizes less than 3 ½ inch were made on the lines of machines and furnaces in area M; the larger chains were made in area J; equipment in areas H and N was used to make some components for both the large and smaller chain sizes (Figure 4). In all cases the following basic steps were used.

For the socket half-link:
1 Cut bar stock with the diameter of the desired links to the required length cold with mechanical shears or power saw.
2 Heat the cut bar to forging temperature, 2200^{o}F.
3. Bend bar to "U" shape in a mechanical press fitted with appropriate tooling to make a half link.
4. Reheat the bent bar to forging temperature.
5. Transfer the U-shaped bar to a punch and upsetting machine to punch the recesses in the ends of the half-link. This machine eliminated the need to drill out the recesses that had been used in the initial manufacturing process.
6. Return the work piece to the reheat furnace.

For the stem half-link
7. Cut bar stock with the diameter of the desired links to the required length cold with mechanical shears or power saw.
8. Heat the cut bar to forging temperature, 2200^{o}F.
9. Form stems on each end of the straight bar by rotating it between strokes of a forging hammer fitted with dies containing stem-shape cavities (the process designated "rolling").
10. Reheat the bar to forging temperature.
11. Bend the bar to "U" shape in a mechanical press fitted with appropriate tooling to make a half link.
12. Heat treat the half-link to the desired hardness via heating and quenching.

[59] Ivas 1978: 40-41.

Making the chain:
13. Place a cold stem half-link through the last link of the chain being made and insert it in the bottom die block of a forging hammer. Remove a hot socket member from the reheat furnace and place it in the die block with the stems of the cold stem-half-link inserted in the socket openings. Forge the joints together with successive hammer strokes.
14. Trim the flash from the assembled link with a mechanical press.
15. Repeat until a complete shot of chain is made.
16. Place the completed shot of chain in the annealing furnace and heat to the temperature required for stress relief.
17. Clean the chain with a Wheelabrator, (which projects fine steel shot at the chain within an enclosed cabinet to clean it).
18. Paint the chain.

D. Required Tooling

The process description shows that while the patent gives the overall concept used in uniting the half-links without welding, a maker of this kind of chain would have to design the actual sequence of operations to be used, and design and make the forming dies required. At the navy yard the die shop, which was not in the forge shop, was an essential component of the chain-making process; it had to make the dies and repair or re-make them as they were worn in use. The work of the die sinkers would have been among the most highly skilled work required for the entire process. Heat treating the dies was also a challenging task because of their large size. Most of the dies would be used in generic forging presses and hammers, but bending the half-links and punching the socket half-links required either purpose-built machines or standard tools modified for these particular tasks.

Because of the temperature gradients and high stresses they are exposed to, the chain-making dies required reworking or replacement on a regular basis. The closing dies used in the hammer when mating the two sections of each link were exposed to particularly challenging conditions since a cold stem half-link would be placed in the die and the socket member heated to 2200^{o}F placed over it. The large temperature gradient combined with the high stress applied to close the link would accelerate die deterioration. This was one reason it was impractical to have both stem and socket members made elsewhere and shipped to the navy yard for closing, as explained by Kenneth Mitchell. The length of the bar used to make a socket had to be adjusted by as much as 3/16th of an inch to compensate for wear of the closing dies.[60]

E. Safety Issues

Shipyards that build, outfit, and repair naval vessels are inherently dangerous places to work. The Navy made strenuous efforts to avoid on-the-job accidents. Posters, signs, and illustrations in the *Boston Navy Yard News* during World War II show that safety was a high priority. The television production of “Let’s Take a Trip” shows shop master Paul Ivas emphasizing safety in the chain forge, but it also reveals a frightening combination of powerful machinery, hammers and anvils, hot steel, blazing furnaces, and moving equipment. There were also impact and tensile tests of chains, sometimes to their breaking point. Obviously, workers had to be very careful in this environment, and veteran managers such as Ivas were trying hard to prevent injuries or deaths. Review of the *Boston Navy Yard News* from 1936 to 1973 yielded little if any evidence of serious accidents in Building 105, so safety efforts must have had considerable success unless the newsletter failed to discuss accidents. Nevertheless, it is sobering to see a poetic 1942 warning about forging, in the form of an epitaph:

“A Blacksmith’s bones lie moldering here
He bent his head so he could peer
His helper swung - twas quite a blow
Now he’s forging down below.
- Nuf Sed.[61]

[60] Mitchell 1979b: 5.
[61] *Boston Navy Yard News* 1942.

F. Metallurgy

A problem with the process description in the die-lock patents is the specification that the part of the socket half-link beyond the recesses is to be heat treated for high strength, before assembly. Any heat treating accomplished before assembly would be erased when the half-link was heated to forging temperature for the joining with the stem half-link. Hence the chain-making process presented a metallurgical conundrum. Attaining the full strength of the steel used for the links required heat treating that involved quenching from high temperature followed by tempering. This could not be done on a shot of chain unless the forge shop had access to extraordinarily large furnaces and quenching tanks, and was willing to use expensive, high-alloy steel that had a high hardenability. So, a compromise method was used. The stem half-links would be heat treated for high strength. The socket half-link would have whatever strength could be attained through the temperature changes it sustained during and after its attachment to the stem half-link.

The die-lock patent specifies use of "high grade" steel. Kenneth Mitchell described using steel in the 8615, 8627, 8630, and 8632 range for the 4¾ inch chain. The 8600-series alloys contain approximately 0.5% Ni, 0.4% Cr, 0.2% Mo, and 0.7% Mn in addition to the carbon indicated by the last two digits of the designation. These are described as low nickel-chrome-moly steels; their alloy content gives them higher strength than plain carbon steel and so could fit the patent's specification of "high grade steel." However, these steels have a relatively low hardenability. Only the smallest links – for chain made from one-inch or smaller stock -- could be heat treated by the conventional quench and temper process for greatest strength, as described in the Mitchell interview. (It is unclear what size links the quenching and tempering process Mitchell described earlier applied to.)[62]

According to the 1950 patent the stem half-links were to be heat treated to attain a tensile strength of about 150,000 psi by heating to 1550°F, quenching, and tempering at 850°F. This strength could be attained if the half-link was fully hardened throughout during the quench. There appears to be a problem here because of the limited hardenability of the 8400 series steels. The TTT diagram[63] for these steels indicates that it would be difficult to cool the large-size half-links fast enough to fully harden them throughout; instead the metal structure of the quenched half-link probably would have been a mixture of ferrite and fine pearlite. Its strength would be less than that attainable in a smaller half-link, but nevertheless well above that of the steel in the annealed condition.

The cooling history of the socket half-links was complex because the links that had been heated to forging temperature were placed in large steel die blocks with the hot sockets in contact with the cold stems of the mating link. One consequence of this is that the socket half-links could not be heat treated to attain the same strength as the stem half-links. The 1950 patent asserts that it was desirable that the socket member fail before stem member. (Perhaps this assertion was added when it was realized that the earlier failure of the socket member was an inevitable result of the fabrication process.) Unequal cooling rates in the socket links would have resulted in a heterogeneous, and therefore weaker, metallurgical structure probably with undesirable stress gradients at the joint with the collars on the stems. The stress-relief heating of the completed shot of chain (at about 750°F,[64] somewhat lower than the specified tempering temperature of the stem member) was intended to remove these residual internal stresses. Nevertheless, the heating-cooling cycle of the socket members left them with a lower strength than the stem members. Another consequence of the joining process was that the scale formed on the inside surfaces of the sockets when heated to forging temperature would be incorporated in the resulting joint, where it would prevent formation of any welding between the members. The joint was a purely mechanical one that depended on the strength of the metal interlocked between the collars and sockets. Samples of broken chain retained in the forge shop show that failure was always in the socket half-link.

[62] Mitchell 1979a: 6, 18, 56.
[63] Time-temperature-transformation (TTT) diagrams are plots of temperature versus time, used to understand the transformations of an alloy steel that is cooled.
[64] Mitchell 1979a; 27.

G. Testing and Inspection

Each shot of chain was placed in the pit of the Tinius Olsen testing machine[65] (Figure 2: M26-M29) and proofed. For 4 ¾ inch chain the proof load of 1,750,000 pounds force stressed the links to nominal 50,000 psi (see below), which would be somewhat below the elastic limit for the steel and its thermal treatment as practiced in the chain-making process. Failure of a chain in proof was very rare. Occasionally short lengths of chain were pulled to failure in order to determine the actual strength attained, or to test variants in the manufacturing process. In all this work the testing machine was used only as a device for applying force to the chain. The applied force was measured with a load cell (an electronic device and therefore a later addition to the original instrumentation on the 1917 machine). Use of the machine to measure displacement as a function of applied load so as to create a force-displacement diagram is not mentioned in the process descriptions.

In addition to the Tinius Olsen testing machine the chain forge had rather only sparse testing equipment. A Brinell hardness tester, mentioned in the Mitchell interview, could have been used on small parts such as components of detachable links or other products that the shop made. The shop had a Magnaflux machine that could detect cracks by perturbations in the magnetic field formed when an electric current is passed through the specimen under test. A tensile impact tester (033) allowed weights to be dropped on a test length of chain. The broken chain links shown on one of the display boards were probably tested on this equipment. A "chain end crush testing machine" offered an alternative test method, but was not used in production testing. The latter two testers were built at the Navy Yard in 1938, almost certainly for the comparative tests between die-lock and cast-steel chains discussed above. They may have been rarely used after this contest.

H. Strength of Die-Lock Chain

At the time cast steel chain was being developed, comparative tests were made by the General Electric Company on cast steel and wrought iron chain.[66] (General Electric did the tests because it made the electric furnaces that melted the steel for casting chain.) Navy Yard tests to failure on samples of 2-inch die-lock chain are shown on a display board (Figure 15). The measured breaking forces on 2" chain were as follows:

Wrought iron	225,792 lb.	Ratio 1.0	Nominal tensile strength 35,950 psi
Cast steel	329,750 lb.	Ratio 1.5	Nominal tensile strength 52,510 psi
Die-lock	488,000 lb.	Ratio 2.2	Nominal tensile strength 77,710 psi

The nominal tensile strength of the metal in each chain is the breaking strength divided by twice the cross sectional area of the bar used to make the chain. These results show that the cast steel chain was 50 percent stronger than the wrought iron chain then in common use, and that the die-lock chain was about 50 percent stronger than the cast steel chain.

True tensile strength is measured by applying a pure tensile load to a cylindrical specimen pulled in a testing machine. When a chain link is pulled the stresses developed in the link are more complex than pure tension, and highest in the curved part of the link. Consequently the nominal tensile strength will be lower than the actual tensile strength of the metal. We do not have data on the magnitude of the stress concentration in the chain link. An estimate of a correction for this factor can be made from A. L. Holley's data on the strength of wrought iron bar used for chain making. He found the average strength was 53,000 psi.[67] The strength of the cast steel can be estimated from its Brinell hardness, 260.[68] By the rule of thumb conversion of hardness to strength this steel should have a tensile strength of 128,000 psi. These data indicate that the nominal tensile strength estimated from the breaking strength of the chain is about half of the actual tensile strength of the metal. Thus the goal of 150,000 psi tensile strength in the die-lock was attained.

[65] Tinius Olsen Testing Machine Company 1919, c1955

[66] Cox 1918.

[67] Holley 1877-1878: 101-24

[68] Camp and Davis 1919.

A tag attached to a sample of broken 1¼ inch die-lock chain at the Navy Yard shows these test results:

Die-lock breaking strength 212,000 lb/ft. Nominal tensile strength 86,380 psi[69]

Direct comparison with the data on the 2-inch chain data cannot be made since the actual stress developed in the different size links is not known. However the nominal tensile strength again shows the superior properties attained with the die-lock process.

I. Process Sequence for Small Chain

With reference to work areas shown on Figure 4 and discussed below, Area M was used to make socket half-links and assemble all chain that was smaller than 4 3/4th or 3 ½ inch. The sequence of operations at the production line at the west end of area "M" made the socket member half-links and assembled the chain. The stem members were made in area "H." Equipment reference numbers are from the key on Figure 2.

1. Operations in Area M

1. Cut bar stock cut to required length cold in shears M11 or M12.
2. Heat bar to forging temperature in furnace F4, described as "controlled atmosphere, no doors, 2 Hauck 780 burners."
3. Bend bar to "U" shape in machine P17, described as "pneumatic press vertical; C-frame; capacity: 11,000 lb, 7" stroke."
4. Reheat in furnace F42, described as "capacity: 600 lbs/hour; inside of steel, 1 Hauck #780 burner; burns 8 gallons/hour at 2100 degrees F." The temperature specified is the standard forging temperature (1150^{o}C). Atmosphere control would not ordinarily be needed for this. It's unclear why it was specified for furnace 100 and not for furnace F42.
5. Transfer to the punch and upsetting machine P18, described as made by "the Ajax Mfg Co, Cleveland, OH; capacity of a 2,000 lb blow, 36" stroke; steam or air operated, double frame with extra piston." The extra piston would have been needed to clamp the work while the sockets were being punched. Tooling for the job would have been required. We don't know if the dies and other tools were made at the yard, by the press maker to yard specifications or the press was a standard machine made for this kind of work.
6. Return the work piece to the reheat furnace F42.
7. Place a stem member, cold, from area "H" in the bottom die block of hammer H6. Remove a hot socket member from furnace F42 and place it in the die block with the stems inserted in the sockets. Hammer the joints together with hammer H6, made by "Chambersburg Engineering Co., Chambersburg, PA; capacity: 1500 lb blow, 44" stroke; Model E, steam or air operated; double frame." This is a generic hammer, but the dies had to be custom made for the work in the yard's die shop by specialist die sinkers.
8. The flash on the assembled link was then trimmed on press P19, a "mechanical press made by the E.W. Bliss Co, Canton, OH, capacity: 93 ton, 6" stroke; vertical, straight sided, single action, 1 point, single crank; Model 205; powered by a belt drive and an electric motor, 7.5 HP, 220/440 VAC, 3 phase, 50/60 cycle, 865/715 RPM." The trimming dies used in this machine would have been made at the die shop.

2. Operations in Area H

Here stem half-links were made for the smaller chain sizes.
1. Heat the bars cut by the shears M11 or M12 in furnace F47. The bars were placed on to a rotating platform in the furnace. They were heated to forging temperature as they moved through the furnace, and were removed individually for rolling.
2. Remove a hot bar from furnace and form the stems with the 3,500 pound-blow forging hammer H18 by rotating each end of the bar in succession in the stem-size recesses in the die blocks fitted to the hammer.
3. Bend the bar to "U" shape in the 161-lb. capacity mechanical press P32.
4. Forge the half-link with the 3,000 pound capacity drop hammer H17.
5. Reheat the forged half-link in furnace F45 and quench.

[69] BOSTS 12754

6. Temper the hardened half-link in furnace F46.

J. Process Sequence for Large Chain (generally greater than 2")

Most of this process was carried out on the production line in area J.

1. Cut bar stock to the required length with shears M11 or M12, or with power saw M10.
2. Heat bar for the socket member in furnace F22 to forging temperature.
3. Remove the heated bar from the furnace and with tongs thrust it into the horizontal bender. In this machine the bar is forced between rolls into "U" shape. This machine is not identified from the 1950 floor plan and is missing from the later plans.
4. Reheat the bent bar to forging temperature in furnace F23.
5. Remove the heated bar from the furnace and insert it into the upsetting machine P9, the 113 ton-capacity mechanical press made by E. W. Bliss Co. This machine punches the recesses in each end of the bent bar simultaneously expanding the metal that will form the stud in the center of the finished link.
6. Heat a bar for the stem member to forging temperature (not sure where this was done)
7. Form stems on each end of the bar by rotating ("rolling") the bar under dies in 10,000 lb. capacity forging hammer H13 located in area N.
8. Bend the bar to "U" shape in the 161-capacity mechanical press P32.
9. Reheat the bent bar in furnace F24.
10. Forge the reheated bent bar under the 25,000 lb.-capacity hammer H7 to form the collars on the stems.
11. Trim the flash from the forged stem half-link with press 230286 (Navy number; not extant)
12. Heat the completed half-link in furnace F51 to 1600^{o}F and quench.
13. Draw temper by reheating the half-link in the electric tempering furnace F36 to 840^{o}F.
14. Closing the link: The end link of the chain already made is inserted in the stem half-link, which is then placed in a forming die cold. The socket half-link is heated in furnace F24 to forging temperature, grasped by tongs and placed in the closing die in the 25,000 lb. hammer H7 so that the stems enter the sockets. Up to nine hammer strokes are used to close the socket around the collars. Given the weight of these links. maneuverability was a challenge and suggests the skill of the workers in this hot and dangerous work.
15. Trim the flash formed as the joint between the two half-members was closed in press 230286 (Navy numbr, not extant).
16. When a shot of chain is completed, place it in furnace F36 for the stress-relief anneal at a temperature of about 750^{o}F.
17. Clean the shot of chain in the Wheelabrator (Navy number 230355; not extant)
18. Proof test the shot of chain in the testing machine M26-M29.

VII. DETACHABLE CHAIN LINK

One of the most important inventions from the chain forge is often overlooked or given much less attention than the famous die-lock chain. As discussed above, the first significant patent resulting from research and development at the forge was for a detachable chain link, pre-dating and in some ways foreshadowing die-lock chain. Navy Yard blacksmiths James Reid and Albert Leahy submitted a patent application for "a new and useful Improvement in Detachable Chain-Links" in 1920. Their shop floor innovation was "especially adapted for use in ship cables" (a broad term including chains for mooring and anchors). This was not the first effort to make a detachable chain link, but it was distinguished by an ingenious mechanical design and by its success in creating a very strong link from forged alloy steel, without the need for a welded scarf joint (overlapping angled surfaces joined by welding). The difficulty of welding a scarf joint in a steel chain link was a major factor in the retention of wrought iron chain until this time. With the advent of cast steel chain and the likely loss of jobs in Boston, discussed above, the two talented blacksmiths came up with a new product. One has to assume that part of their motivation was to save their jobs, or the jobs of many of their fellow workmen in the forge. Were they also looking ahead to an entirely new type of chain, one that could mean long term survival of their forge and even expansion of its workforce?

Marine cables or chains were made up of fifteen fathom (90 feet) shots. These sections were “united by shackles to form a continuous cable.” The shackles, however, could “interfere with the movement of the cable over the windlass or through the hawser pipe.” And if any link in a chain proved defective, an entire 90 foot shot had to be “transferred to the repair shop.” What Reid and Leahy were proposing in their 1921 patent was that “all the links of the cable” should be “forged from an alloy steel.” They claimed that this would increase tensile strength, reduce corrosion and abrasion, and much simplify repairs. They did not specify how the solid (non-detachable) links were to be made as forgings from alloy steel, but they must have been thinking of practical ways to do that. By 1926, when they submitted their next patent application for chain improvements with shipyard metallurgist Carlton Lutts, they had a revolutionary design for a forged die-lock link, made from alloy steel.

In their patent description for the detachable chain link, Reid and Leahy called for every other link in a shot to be detachable. That way any defective link (either solid or detachable) could be replaced without difficulty. They seriously underestimated the cost of producing a chain with so many detachable members, each of which would require careful hand fitting, some machining (drilling a tapered hole and machining a locking pin), and assembly in a shop production process. Workers numbered detachable link parts, heated treated them, set up temporary chains of detachable links for proof testing (requiring more assembly and disassembly operations), and painted them before sending them to users.

In 1927, the forge did make large (3”) chains of forged alloy steel (the first ever produced) using alternating detachable and solid links. These chains replaced older (c1914) wrought iron chains that protected lock gates at the Panama Canal.[70] They were a very important step toward the adoption of the forged die-lock chain that Reid and Leahy were developing. We do not know what type of solid links were used in 1927, but it seems likely (since this was a forged chain) that some form of die-lock design (then under development and with a patent application pending) was applied. The fender chains have been removed (along with several other pieces of original safety equipment) from the current Panama Canal.[71]

It seems doubtful that many other chains were made with the alternating solid and detachable links. The standard practice has been to connect 90 foot shots of die-lock chain with detachable links and to replace (with additional detachable links) only those links that proved defective in use. As it turned out, failure of die-lock links was rare, so detachable links became a very important, but secondary product of the chain forge. There were, however, elements of the 1920 detachable design (forged alloy steel, smooth outer surfaces, and collared stems interlocking mechanically with socket members) that foreshadowed the later die-lock patents.

The Navy instruction manuals used by generations of boatswain’s mates and deck officers provide an interesting clue about one important aspect of the detachable links made here at Charlestown. The manuals warned against taking apart more than one detachable link at a time: the parts were “not interchangeable” and could get mixed up (although numbers stamped on fitted parts helped to prevent that). Despite the military obsession with interchangeability, this particular item was hand fitted and assembled by artisans in the chain forge. Kenneth Mitchell, the last master mechanic of the shop, confirmed that the detachable links were not interchangeable. Workers carefully filed the forged parts so that they fit tightly together. Mitchell also noted that assembling detachable chain links was one of the jobs done by women in the forge during WWII.[72]

[70] Ivas et al: 14.
[71] Patrick M. Malone 2014 observations while on Panama Canal tour.
[72] Mitchell 1979a: 59-61; 1979b: 1-2.

VIII. WORK AREAS

Chain forge managers defined a number of work areas for general oversight or planning, most of which were likely in place by c1930 although some evolved as larger chain sizes and additional anchor-production tasks were introduced. For World War II and later, the following areas were noted (Figure 4; equipment key numbers as per Figure 2):

A Blacksmith shop for handmade items, with small furnaces, three 1500-lb flat die forging hammers, and other smaller hammers for forging chisels and other tooling.

B Bench area for filing detachable link couplings and C-links drilled in Building 42. C-links are the main part of a detachable link, to which the couplings are attached.

C Anchor shank production on hydraulic press [P25] and hammer [H11]; "heavy fires" work for blocking out (cutting) material on 10,000-lb flat die forging hammer #22 [H11], for processing in areas N or J; also made large swedges and hand tongs

D Heat treatment area and magnetic particle inspection tester [053/M32]; in east end of central and south bays. Car bottom furnace [103/F34] in central bay used for very heavy forgings like anchor shackles. Larger chain stems put in automatic rotary furnace [045/F51] in south bay; smaller stems put in small furnaces to east [049, 050, 055/F52-54]. In-ground quench tanks for oil and water remain; fires and anvil for hand-welded chain have been removed.

E Test pit and test area. Included area to flake out chain, with spool [removed] to wrap chain using a crane which also seems to be removed. Crane dropped an end of wrapped chain into pit near test trench, to facilitate attachment of chain ends to testing machine. "Draw back" final stress annealing for most or all chain sizes in pit furnace 109/F36. The 100-cubic-inch Wheelabrator [removed] cleaned stems and completed shots of 4-3/4 inch chain, much faster than former sandblasting of chain extended along floor, and less noisy than use of removed tumbling barrel. All chain painted in pit M6.

F Shearing and sawing – 3 saws and 2 shears; also assigned to storage areas for dies and tools in connecting structure between original powerhouse and main forge.

G Socket production and final assembly of 3" to 3-3/8" die-lock chain, and 3½" "heavy duty" mooring chain – largest sizes prior to 4 ¾" line; rolled stems for 4 ¾" chain.

H Rolling, bending, and forging of stems for larger chain sizes other than 4¾".

J Bending of half links [machine removed], forging of stems on 25,000-lb hammer #30/H7, socket production, and assembly of 4 ¾" chain; also finishing of stems members on removed trim press. Monorail used to handle each half of link, beginning at furnace #26/F22 to heat stem or socket, then to bender [removed], to furnace [293/F23], to 8-inch upsetter to punch socket [302/P21], to furnace [294/F24], and to hammer #30 for assembly. After assembly, boomed to removed trim press (no longer on site). Process repeated until shot completed. Furnace at east end of monorail [131/F25] for ball end of anchor shank and other large items. Area J also used for 3-1/2 inch "heavy duty" chain.

K Small drop forge plant with mechanical forging press #29/P23 – little used.

L 1000 – 2000 lb hammers for detachable link and couplings, drop bolts, wing nuts, other hardware, and stems for chain up to 1-5/8."

M 6 assembly lines for ¾" to 2" chain, with size increasing from west to east. #8 plant, probably the 3rd from east, had 2 booms on a single post and could handle 2 chains at once; also made non-magnetic chain for mine sweepers. Most operations other than ¾" chain were limited by c1960 due to commercial manufacture of other small sizes.

N Drop forge work for chain assembly on 12,000 lb hammer #21/H12; other items also made here. It appears this area made some of the larger sizes prior to 4¾"; two adjacent trim presses P26-P27.

P 1½" upsetting machine [removed] for rivets.

IX. HAMMER, UPSETTER, AND FURNACE EQUIPMENT

Figure 2 and Table 1 show existing equipment, based on April 2014 inspection and mapping. In addition to the mechanical equipment and furnaces, the die stowage area between the main forge and the blacksmith shop contains a large number of dies used for the numerous smaller items discussed above. There are also several gripper dies used to make die-lock sockets, for chain of about 2", on the floor next to furnace F26. This section summarizes available context information on many of the equipment pieces.

C. Hammers and Equipment Personalization

The 27 power hammers at the Chain Forge are very basic machines, with relatively limited differences from the earliest examples of this technology. The steam- or air-driven drop hammer is the ultimate extension of the blacksmith's arm and hammer, which for centuries was amplified by power trip or helve hammers usually driven by water power. Early power hammers of this type could perform repetitive motions without tiring, but were limited improvements on the human arm and hammer in terms of delivered force. Large-scale trip or helve hammers were not terribly effective on items such as large shafts or anchors.

The modern power hammer, initially operated by steam, was designed by two engineers working independently at about the same time in 1839, Englishman James Nasmyth (1808-1890) and Frenchman Francois Bourdon (1797-1865). Bourdon's model was built first, based at least in part on Nasmyth's work. Nasmyth, who created his model to make a large shaft for a steamship, realized the almost unlimited potential size of the hammer, workpiece, or force which could be applied. The original steam hammers used steam only to lift the hammer, which was then allowed to fall freely under the force of gravity. The earliest examples closely resembled mid 20th century models in appearance. About 1843 Nasmyth realized that he could also use the steam pressure to enhance the force of gravity, adding on the order of several thousand pounds of force to a moderately large hammer. About this same time he apparently developed the closed die or impression die technique, later used to assemble die-lock chain as described below. Large steam hammers were also used to make anchors with open die forging early in the history of this technology in Europe, where it quickly spread in the 1840s. A steam hammer design was first licensed in the United States by 1860, and American designers including Frederick Miles improved valve mechanisms.[73]

Forging hammers were made in several basic styles: single frame, used for medium-sized flat work; double frame, used for large open-die work such as shafts and anchor shanks; and drop hammers (also in double or single frame configurations) used for closed-die work. Drop hammers have narrower areas under the hammer, and probably characterize most of the pieces in the Chain Forge.[74] Some models have self-contained air compressors, including at least one of the smaller Chain Forge examples (Figure 2: H27). There is also a board drop type of hammer much used in light forging work, but not represented at the Chain Forge; this type is a purely mechanical device using a friction drive to lift the hammer.

None of the earlier hammers installed in the Chain Forge or other facilities at the shipyard survive. As discussed above, all steam-operated equipment in the Chain Forge was converted to compressed air in 1908, and the extant examples in this shop, installed 1936-1953 during three periods of expanding operations, were all operated with compressed air. They were built by Erie Foundry (established 1895, now Erie Press Systems, Erie, PA), Chambersburg Engineering of Chambersburg, PA (founded 1897, out of business c2002 with assets later purchased by Ajax Manufacturing Company, Cleveland, OH which is now Ajax-Ceco Manufacturing Company), and Alliance Machine Company (founded 1901 in Alliance, OH). These hammers show the great

[73] Anonymous 1885; Nasmyth 1913; Roe 1916.

[74] Personal communication, George Currie.

range of sizes available in the mid 20th century, with piston/rod/hammer assemblies ranging from 300 to 25,000 pounds (Table 1). They are all composed of a rigid single- or double-leg frame, a base called the anvil (often topped by anvil covers or sow blocks for attaching dies), a steam/air cylinder, a double-acting piston fitting the cylinder with a rod protruding from the bottom, steam/air valving to control the motion of the piston, and a hammer or ram connected to the bottom of the piston rod (Figure 16). Most components of the examples in the Chain Forge are likely made of steel castings, with some use of cast iron in lighter components. Overall heights of the hammers at the shop range from about 10 to 25 feet.

The air pressure is used both to raise the hammer and to add its force to the force of gravity on the downward or working stroke. The force can be very precisely controlled through either a foot treadle or hand lever. Operators often boasted of being able to crack a hard-boiled egg with the hammers, without damaging the rest of the egg. All these hammers were intended to manipulate iron or steel in a high temperature, nearly plastic state, referred to as hot forging. The shop contained over 40 oil-fired furnaces, at least one near every hammer, to heat the metal before forming it. Shop managers reported some customized hand controls mimicking ale and beer taps to distinguish different actions, though none of these controls were observed in 2014.[75]

Hammer forging is performed in two basic ways: open die and closed die. With open die forging, the die attached to the hammer and the die on the anvil (or on the intermediate sow block, if so equipped) are flat surfaces. This type of forging is typically for comparatively large work and for approximate rather than finished dimensions. The anchor shanks produced at the Chain Forge were done this way, most recently using the American Steel Foundries hydraulic press (Figure 2: P25) for the largest shanks. Closed die forging is used to produce a finished or nearly finished product. An accurately cut or milled concave pair of dies, produced by craftsmen called die sinkers, are fitted to the hammer and anvil, the heated steel is placed on the lower die, and the hammer descends to force the metal into the cavities. This process produced the die-lock chain stems from round stock, and was then used to "lock" the two segments into a chain link. Most of the Chain Forge work on other products requiring power forging, including a huge range of ship's hardware, hooks, tools, etc., was apparently closed die work. Closed die work produced considerable excess material (flash) on forged products, which was removed using trimming presses. Thirteen trimming presses, most of them motor-driven mechanical machines produced by E.W. Bliss Company during World War II, survive in the shop. Two contemporary hydraulic presses made by Bliss and by the A.B. Farquhar Company trimmed larger-sized chain and hardware forged at the largest hammer installed prior to the Korean War (Figure 2: H12, P26, P27).

For closed-die forgings, a system of dovetail joints was used to hold the intermediate piece called the sow block in place on the anvil. Details appear to have varied slightly by manufacturer. A metal piece called a key locked the sow block in place. The bottom die had a stem which fit into the sow block, held with a second key. The upper die also had a stem that fit into the ram, held by a key. Lateral adjustment is accomplished by screw-controlled wedges that move the upper structure (Figure 17).

The hammers in the Chain Forge are the culmination of over 100 years of gradual design evolution. Forging hammers continue to have an important place in 21st-century metal working. The rise of the automotive industry in the early 20th century was a great impetus for forging hammer development, as many parts of early cars were closed-die forgings. Steam/air hammers continue to be the usual tool of choice for forging steel, especially open or flat die work, although much steel is also closed-die forged on hammers. Powerful hydraulic presses have advantages in the forging of very large steel objects, but they are much slower in operation than hammers and cannot match their productivity. There are probably several hundred hammers similar to those in the Chain Forge still in use today in North America.[76]

The hammers in the shop were also the most dramatic examples of how workers left their personal stamp on the workplace. There were numerous instances of employees using welding rods to put their names and sometimes a date on metal floor plates; at least one still survives. Occupational graffiti on lockers used for clothing and personal effects is common in many workplaces, and the Chain Forge was no exception. One worker left a

[75] Ivas 1978: 61-3.
[76] Personal communications, Charles Crout, George Currie.

tabulation inside his locker of the number of times he was angered or lost his temper.[77] Forge operators also treated some machines as individuals, giving them distinctive names or the names of their operators. The large hammers were imposing machines, even to the men who worked with them on a daily basis. There is a good account of how "Big Barney," an Erie Foundry Co hammer with a piston/rod/hammer weight of 10,000 pounds, got its name. The forge acquired this powerful hammer (Figure 2: H13; Figures 32, 33, 57, 58) in 1936 for "the manufacture of heavy die-lock chain for battleships." At 175 tons, it was then the largest hammer in the forge. There was an elaborate ceremonial christening of the hammer, named for one of the workers, probably the man who was to put it to daily use: "Big Barney Monagle swung a hefty right hand holding a bottle of champagne (the real goods too) against the ram of the hammer… Good luck to both Big Barneys."[78]

Paul Ivas, a new apprentice when Big Barney arrived, said this was the first in a series of names given to hammers throughout the shop, including 12,000-pound hammer "Little Andy" (Figure 2: H12) and 10,000-pound "Old Harry" (Figure 2: H11). Ivas seemed more deferential when he pointed out the "Mighty Monarch," a 25,000-pound hammer (Figure 2: H7) he installed as part of the 4¾" line in the early 1950s. All these giant double-frame hammers were Erie Foundry Co products. The "Monarch," complete with its anvil, weighed over 600,000 pounds, resting on a 35-foot-deep foundation of almost 1.7 million pounds designed to dampen vibrations from the shock of hammer blows and prevent damage to nearby structures and machines.[79]

B. Upsetters

When Reid, Leahy, and Lutz submitted their first application for a die-lock chain patent in 1926 (patent # 1,753,9410, 1, Figs. 1-3), they included drawings showing forged stem collars and socket recesses drilled to accept those collars. The text of the application says that the stepped recesses are "formed either by punching, while the metal is hot, or by drilling, when the metal is cold." In fact, they had begun their experimentation on the die-lock concept by machining the collars on the stem members and then drilling the sockets. Workers had to take the U shaped sockets to a shipyard machine shop for that drilling step and then return them to the forge for re-heating and hot forging in the final assembly with the cold stems members. Because the collar design of the forged stems got more complicated over time, the drilling of the corresponding sockets began to adversely affect the rate of production. An historical report by forge shop workers said that this "bottle-neck lasted until 1929, when dies were made for the forging machines" to punch the recesses.[80] The punching operation, done with a forging machine called an upsetter, also formed a stud across the socket member with the hot steel displaced from the recesses, as discussed below. The use of the upsetter eliminated both the cost and delay of drilling the sockets. The forge was on its way to the mass production of die lock chains. Soon there were lines of machines and furnaces for making chains of various sizes.

The upsetters now in place were made by the Ajax Manufacturing Company of Cleveland, Ohio. Most date from the World War II period, and none date to the introduction of socket punching at the forge in 1929 (Hay and Christenson inventories). They are, however, probably similar to the earlier upsetters which they replaced, and there is evidence to suggest that Ajax worked with forge employees to design special dies and customized tooling for the original socket operations. Upsetters may have their origins in powered machinery for making the heads of nails, spikes, and bolts in the early 19th century. They grip work tightly in one set of dies and then apply great force against its end(s) with another set of dies or a header tool.[81] For forming the socket member of a chain link, the other set of dies were pointed punches.

An upsetter used for this purpose had two sets of gripping dies and two sets of punches (a roughing set of two and a finishing set of two). First, the operator used tongs to position a heated socket member in the correct vertical position in the stationary (right hand) die. Next, a helper activated the moving gripper (left hand) die, which closed against the U shaped piece with ends pointing into the machine. That die moved horizontally to grip this vertical piece in the upper cavity or impression (there were two separate cavities). The two rougher

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[77] Ivas 1978: 45-6, 45; Patrick M. Malone site inspection, January 1976.
[78] Boston Navy Yard News 1936.
[79] Anonymous c1952: 4-6; Ivas 1978: 60-2.
[80] Ivas *et al*. c. 1950
[81] Bathe and Bathe, 1943; Najoks and Fabel, 1929: 39-43; Ajax Manufacturing Company, n.d,: 1.

punches then moved forward to begin the socket holes and start the formation of the stud (with hot, flowing steel). This was not a violent hammering, but a relatively gradual punching and expansion of the ends of the bent bar. After that “first pass,” the operator shifted the work piece down to a second die cavity with slightly different contours for the final shaping of the socket member. The finisher punches then moved forward to complete the socket holes and the stud.[82] The hottest parts of the heated work piece were the receiving ends of the U, with forging temperature of about 2200F when first inserted in the upsetter. The tongs held the other end at the bend, and both gripper dies had a slot to allow the tongs to fit between them without being crushed.[83] The Park Service has gripper dies (both stationary and movable) for several sizes of chain.

An upsetter, particularly one of #8 size used for the 4 ¾” chain, is an extremely heavy machine, but it contains and absorbs its own dynamic forces – in a horizontal plane. It does not require a massive foundation, as large hammers do, and it sends no violent shock waves that would be damaging to the building or nearby equipment. The #8 upsetter frame was “the largest single piece of equipment handled” during the creation of the 4 ¾” chain production line in the early 1950s. It required shipment on a railway flat car, the use of a craneship to turn it upright, and elaborate rigging efforts to move it into the chain forge.[84]

The two passes in the upsetter had to be completed quickly before the steel cooled too much for effective forging. Machine operators doing such time-sensitive work needed to judge approximate temperature by the color of the hot metal, a skill they shared with blacksmiths. For large size chains, three men worked in close coordination at the upsetter, with one man responsible for the accurate placement of the work in the gripper dies. Ajax claimed that after clutch improvements in 1932, its upsetters produced alloy steel forgings “at the maximum rate that skilled operators could handle the hot stock.”[85] Film of chain shop processes in 1956 shows a team of men working smoothly and rapidly to form the recesses and the stud in stem members.[86] Paul Ivas said that no time-motion studies were necessary in managing this “team work.” He let his employees determine the most productive way to do a job. Although he believed that hand blacksmiths (he was one) were more skilled and versatile than machine operators who relied on dies, he was clearly proud of the organizational ability, dexterity, and work ethic of the men using furnaces and powered machinery such as upsetters to make die lock chains.[87]

C. Furnaces

There was a wide variety of furnaces installed in the Chain Forge for heating and heat treating. They comprise the largest category of equipment in the building, with fifty-seven extant examples. Forge furnaces may be classified according to the method of loading as batch type, rotary, and continuous furnaces.[88] The batch type is charged with a single load, most commonly from the front into a steel-framed box-like hearth with one or more chambers lined with refractory brick and furnished with sliding vertical steel doors. Most of the Chain Forge oil-fired heating furnaces of this type, sometimes referred to as slot furnaces, were built by Navy Yard personnel with the majority installed during World War II. Some of the larger examples were installed earlier, associated with expanded die-lock chain production during the 1930s (Figure 2: F29, F31, F32). The largest slot furnace, built at the Navy Yard in 1919, was most likely used for anchor shanks, a task to which it probably remained dedicated throughout the shop’s history (Figure 2: F28).

During World War II and the later build-up to production of 4¾” chain, some electric rotary furnaces were purchased from a number of suppliers to speed up heating of stems (Figure : F13, F30, F46). This furnace type has a steel-framed refractory hearth rotating on a horizontal axis, on which work is charged and removed after one rotation at the same door. It is well suited to mass production of relatively small items.[89] The largest rotary furnace, installed in 1953 in Area H for larger stems other than 4¾”, was probably far less typical of this

[82] Ivas 1978: 28-33.
[83] Mitchell 1979a: 9, 13.
[84] Ajax Manufacturing Company n.d.; 3-4, 6; Anonymous c.1952.
[85] Ajax Manufacturing Company n.d.; 3.
[86] “Let’s Take a Trip,” 1956.
[87] Ivas 1978: 56, 1979: 5,8.
[88] E.g., Naujoks and Fabel 1939: 245.
[89] Ibid; United States Steel 1957: 417.

general class (Figure 2: F47). This gas-fired furnace, purchased from The Lithium Company, was used with lithium salts which removed many oxidizing, corrosive properties of the furnace atmosphere, and which were relatively self-sustaining so that large quantities of this highly-reactive metal were not needed.[90] More typically used for heat treating, the example at the Chain Forge appears to have been used only to heat for rolling, bending, and forging of stems prior to heat treating. As contemporary metallurgy reference books do not mention this type of rotary furnace, it is likely that its use was not extensive. The use of lithium may have been in part a promotional means of differentiating The Lithium Company's products from those of its competitors. This firm supplied more conventional furnaces, such as the two oil-fired slot furnaces used on the 4¾" chain production line in Area J (Figure 2: F23, F24).

Heat treating furnaces were first used at Building 105 during the era of wrought iron chain, to strengthen the larger links made during the first period of fully-mechanized chain production. The earliest heat treating furnace was the large oil-fired car-bottom type purchased from The Quigley Annealing Furnace Company in 1915. Classified as a continuous or a batch furnace type, depending on the author, this furnace was essentially a refractory-lined steel tunnel with tracks running into the open end. The work was placed on a car-supported hearth which moved through the tunnel on tracks, with a tight fit between the car and the refractory walls.[91] Initially located adjacent to the test trench, this furnace was moved by World War II to what later became Area J, and moved again to its present location in the central bay section of Area D c1953. The shots of 4¾" chain were too large for the furnace, which at or by that time was used instead to anneal anchor shanks (Figure 2: F34).[92] Other early heat treating facilities included two small oil-fired batch furnaces built at the Navy Yard in 1917 and 1919, probably at their present locations along the south wall in Area D (Figure 2: F52, F53).

Beginning with the maturation of die-lock chain production c1929, and expanded considerably during World War II, approximately eight electric resistance heat treating furnaces were installed in areas D and E – so many that only two small additional furnaces was needed during the era of 4¾" chain. The earliest and largest heat treating furnace in this period, installed in 1930 by the Electric Furnace Company to heat treat stems, was a rotary furnace equipped with a hydraulic lift to transfer stems from the hearth to a conveyor, from which a trolley was used to move the stems to a rectangular quench tank (Figure 2: F51). During World War II, pit-style batch furnaces 7-9 feet deep were installed by Lindberg Engineering Company, loaded with steel buckets from bridge or jib cranes (Figure 2: F36-F38, F48, F49). One continuous furnace, also supplied by Lindberg, included an endless belt hearth which discharged stems to a conveyor, from which a small traveling crane transferred them to oil and water quench tanks. In 1952, Lindberg installed one additional small electric pit furnace, and Ajax installed a small salt bath furnace probably used for small forged pieces other than chains (Figure 2: F50, F60)[93]

[90] The Lithium Company 1944.
[91] Naujoks and Fabel 1939: 245-6; United States Steel 1957: 415-16.
[92] Lutts 1920; Boston Naval Shipyard 1952, c1953, 1965-1973; Mitchell 1979a: 49-50.
[93] Ibid; Ivas 1978: 37-8, 43-4; Mitchell 1979a: 55-6; Christianson 2013: 24.

X. SIGNIFICANCE AND DISPOSITION RECOMMENDATIONS

A. Discussion of Equipment Significance

Assessment of significance, developed in part from criteria for inclusion on the National Register of Historic Places,[94] was based on a variety of factors associated with periods of innovation in wrought iron and steel alloy chainmaking c1914-1930 and c1949-1953, and with periods of expansion of American naval forces c1914-18, c1935-44, and c1949-1959. Within each of these periods the Chain Forge, the people who worked there, and the equipment they used played nationally significant roles in American history. Criteria utilized to evaluate each piece of equipment are:

1. Rarity, uniqueness, and age relative to known examples in industrial or museum settings. Equipment of unusual scale, innovative pieces built on site by Navy Yard personnel and special-purpose commercial equipment associated with master designers would all fit within this criterion.

2. Distinctive pieces or assemblages of equipment associated with important forge products and significant periods of innovation or American naval history, even if individual pieces in such an assemblage may have been typical of contemporary technology.

3. Examples of once-typical commercial equipment associated with distinctive shop-floor innovation or management techniques for production of important forge products, including atypical, innovative equipment applications.

Review of historic equipment catalogs, and ongoing discussions with manufacturers and historians of technology, have addressed many though not all issues of equipment rarity. Industrial contacts, some very interested in this project, include representatives or officers of the Forging Defense Manufacturing Consortium, the Forging Industry Association (trade association for American forging industry), the Association for Manufacturing Technologies (umbrella organization for metalworking technologies), and the presidents of Erie Forging Systems, Erie, PA and Apex/Ceco, Cleveland, OH – companies which in earlier corporate identities built many hammers and upsetter machines for the chain forge.

At present, it appears that most commercially-purchased equipment in the Chain Forge is typical of contemporary forging operations elsewhere, and that similar upsetters and 10,000-to-12,000-lb hammers built c1940-1955 remain in common use. While we are informed that hundreds of such machines may exist in operating shops, however, most of the specific examples we have identified are smaller than those in the Chain Forge, suggesting the possibility that the larger hammers in the shop may now be relatively rare. Specific examples of operating equipment include:

Divisions of IMT, Clifford-Jacobs, Illinois: 1 c1940 20,000 lb. Chambersburg hammer, 4 c1940-1950 6-8,000 lb Erie hammers;

Welland Forge, Welland Ontario: 2 1944-45 Erie 5,000 lb hammers;

P.C Forge, Ontario: 5 pre-1960 Erie 2-8,000 lb hammers.

Just as buildings or engineering structures may be deemed historically significant as the work of a master designer, so may machines used in production or testing be recognized for significance when noted engineers or master craftsmen were responsible for their designs. At least three figures involved in the work of the Chain Forge can be considered masters in their fields. Perhaps the best known was Tinius Olsen (1845-1932), a noted inventor, mechanical engineer, and materials testing specialist. The enormous 2,000,000 pound chain tester that he designed for the U. S. Navy, and which still survives in the Chain Forge with associated trench, jib cranes, and pumps, was one of the largest such facilities ever installed in the United States (Figure 2: M26-29, M35, C7-

[94] 36 CFR Part 63, Determinations of Eligibility for Inclusion in the National Register of Historic Places

8), is one obvious example of his genius. It was by far the largest in the world (and one of only two of its type ever built). He also made a record-setting general testing device for the U. S. Bureau of Standards and was one of the founders of the American Society for Testing Materials. The Norwegian immigrant earned international acclaim and numerous awards for his achievements in materials testing. The Franklin Institute gave him its prestigious Elliott Cresson medal for the "great ingenuity" displayed in his design of an autographic testing machine which recorded test data. His testing equipment won prizes at a number of international expositions, including the Panama Pacific Exposition in San Francisco in 1915 and the Paris Exposition of 1900. The King of Norway made him a Knight of St. Olav, and his hometown of Kongsberg erected a monument with a sculpted bust in his honor.[95]

This report has already documented the highly significant innovations by Albert Leahy and Carlton Lutz in chain design (with numerous patents, discussed above) and their improvements in machine processes and heat treating that made die lock chains world famous for strength and uniformity. Both were master inventors, widely respected in their fields, and well known. Lutz was a noted metallurgist whose publications in professional journals such as the *American Society for Testing and Materials Proceedings* drew much attention to the achievements at the Chain Forge.[96] Lutz was likely involved with the purchase or design of the earliest heat treating furnaces in the shop during or just prior to World War I, including small furnaces built by Navy Yard personnel (Figure 2: F52, F53), and the car-bottom annealing furnace which survives with its associated tracks in shop area D (Figure 2: F34). The latter piece was moved several times, and later used to treat large anchor shanks.

These and most other furnaces in the shop are probably typical of contemporary examples elsewhere, but have significance for their associations with important phases of Chain Forge history or manufacturing practice. Navy Yard personnel built almost all the slot-type heating furnaces, including some very large ones for anchor and larger-size chain production (Figure 2: F28). The heat treating furnaces, most purchased, represent an excellent sample of forging industry equipment for small steel products c1915-1945. At least one larger example, the first heat treating furnace installed after all die-lock chain production steps were developed, may be an unusual example of rotary and conveyor furnace design, including a furnace hearth which could be raised as well as rotated (Figure 2: F51). The Lithium Company rotary furnace used to heat die-lock chain stems may have been typical in design, but this seems to be an atypical technology for controlling furnace atmosphere.

The two Navy-Yard-built chain testing devices, built in 1938 near the main south door for the tests between die-lock and cast-steel chain, are probably the most innovative and unusual pieces of equipment built at the Chain Forge (Figure 2: M5, M31). Most likely built for a series of tests with cast-steel chain which firmly established die-lock chain as the strongest the Navy could hope to use, these machines are probably very atypical of most chain production shops, and are associated with the Navy's expansion before and during World War II.

In addition to examples of innovative equipment, historians of technology now recognize the significance of incremental innovations, particularly those made on the shop floor by artisans and managers. As shown in works by some authors of this report, the cumulative impact of small improvements often contribute more to the success of an industry than major inventions.[97] Minor modifications of machinery, for instance, can have a dramatic effect on production efficiency. Incremental improvements were seldom patented and may not appear in the documentary records of an industrial establishment. One of the best ways to look for them is by examining actual machinery and tooling.[98] Material evidence of in-house alterations and innovative process improvements may be as obvious as a custom-made fixture on a standard machine or as hard to see as changes in the metal grain structure of a chain link because of an improved heat treating process. In the Chain Forge, perhaps the best examples of incremental improvements associated with equipment are some commercially-purchased pieces used to streamline work flow in ways now rarely seen. The use of jib cranes to move forged chain links to trim presses may have once been common in American chain-making shops, but is now unusual. Several surviving jib cranes in the shop pre-date the die-lock chain era, suggesting possible deployment of such

95 Tinius Olsen Testing Machine Company 1919, c1955.
96 Lutz 1920; Leahy 1936. See also patents by Lutz and/or Leahy (including two with Reid).
97 Malone 1988; Gordon and Malone 1994.
98 Gross 1981.

equipment during the early years of mechanized wrought-iron chain production (e.g., Figure 2: C4). Large bridge cranes in the central and north bay, while typical of many large forges and machine shops, not only moved equipment and large anchor shanks when necessary, but evidently supported hanging chains used to hold and manipulate the large tongs needed to move chains at furnace, hammer, and press work stations (e.g. Figure 2: M21, M36).[99]

Some assemblages of forge shop equipment appear significant as intact remains of die-lock chain and anchor-shank manufacturing methods. These pieces include some well-preserved examples in shop area M of equipment used to make smaller chain sizes, with furnaces and small bending presses built by the Navy Yard between the mid-1930s and World War II, along with intact purchased upsetter machines, hammers, and trim presses. There are intact assemblages of larger purchased hammers, trim presses, and jib cranes used for larger chain sizes during the same period in shop areas G and N. The manufacturing line for 4¾" chain in shop area J is incomplete because of some equipment removal (the bending press and the trim press), but retains some large individual pieces which along with available associated artifacts could be developed into interpretative displays about the shop's largest anchor chain product. Most of the shear and cut-off machines critical to initial chain manufacture steps remain in shop area F. Large anchor shank shaping of the early 1950s and later remain well represented by furnace and press equipment in shop area C, and by the already-noted large car-bottom heat treatment furnace in shop area D (Figure 2: F34).

The blacksmith operations in shop areas A and B so critical to forge shop output remain well reflected in small hammers used with the surviving dies noted above, as well as in small tools, anvils, and chains retained in current National Park Service collections elsewhere in the Charlestown Navy Yard.

B. Recommended Retention Options and Issues

We identified 162 pieces of mechanical equipment (Table 1). Figure 2 and Table 2 identify 18 significant pieces including some in groups or assemblages which should remain together, recommended for retention in place or as close to original position as possible, and 20 significant pieces including some in groups or assemblages which should remain together, recommended for retention in new locations which could include areas beyond Building 105. For enhanced clarity, Figure 2A shows only the items recommended for retention in place or nearly in place. Figures 19-55 show current conditions of most pieces identified as significant. Although all equipment associated with the Tinius Olsen testing machine is recommended for retention in place, the enclosure around the principal pieces of equipment does not appear significant and could be removed. Items recommended for retention in non-original locations within the chain forge include the largest shear and cut-off machines, a small heat treating furnace & quench tank, one or two small blacksmith shop hammers along with associated tools and dies, and an assemblage of equipment used to make smaller-sized chain in shop area M based on identification of the best preserved examples of equipment typical of production of ¾" die-lock chain, for which the National Park Service retains sets of dies. The latter assemblage could be re-positioned in the central bay to show a complete production line for small die-lock chain. Development of blacksmith shop interpretation could include borrowing of some items from National Park Service collections.

To provide reasonable, functional space for adaptive re-use of the building, retention of any of the larger pieces used to make 4¾" chain may require re-installation in adjacent exterior space. As discussed below, it is recommended that interpretative development for this production line include dies from National Park Service collections, as well as complete examples of chain currently not accessioned but under National Park Service control. Similarly situated examples of other die-lock chain sizes could be used inside Building 105 for interpretation of other production lines.

There are several unresolved issues in retaining any of these machines. Metal conservation practice suitable for long-term artifact display has never been fully developed for this site. Although all paint on machines at the time of Chain Forge closure was removed during remediation c2002, there was no final determination of post-remediation coatings best suited to inhibit corrosion.[100] Our 2014 inspection indicated corrosion on a large

[99] E.g., "Let's Take a Trip" 1956.

[100] Hay 2000; personal communications, Duncan Hay, Stephen Carlson, Martin Blatt

number of machines, most notably on sheet metal or steel plate components. Furnaces will present particularly difficult conservation issues, as corrosion of interior components would require their cleaning and painting after temporary removal of exterior shells or of interior refractories. There was no inspection of furnace interiors during remediation efforts, and it is also possible that some deposits within the furnaces could be identified as toxic. A thorough program of equipment cleaning and conservation will be required to meet long-term objectives of retaining and displaying significant pieces.

We recognize that in some cases artifact conditions, size or weight may make on-site retention extremely costly. If the agencies and other stakeholders responsible for project planning and development determine that on-site retention of some significant pieces is not feasible, we recommend that additional mitigatory documentation be conducted for any such piece which cannot be retained or moved, prior to any scrapping or other disposition. The pieces for which we think such an option may be necessary are identified in Table 2. Documentation should include additional research in naval correspondence or purchase records to address questions such as why such pieces were purchased, and whether they presented any special problems or opportunities for Chain Forge managers. Documentation should also address possibilities of finding detailed equipment plans in further catalog research or surviving records of equipment manufacturers, and should include detailed photography of each machine.

C. Disposition of Equipment Not Recommended for Retention

Contacts with professional/preservation groups, including published descriptions of the project in newsletters of the Society for Industrial Archeology and the Association of Tourist Railroads and Railway Museums, have not yet yielded expressions of interest in inspecting or acquiring equipment. However, representatives of the Forging Defense Manufacturing Consortium and the Forging Industry Alliance have expressed considerable interest in inspecting the shop and evaluating potential re-use of many hammers and perhaps other equipment. It is recommended that NPS coordinate a site inspection with these groups to explore responsible disposition possibilities.[101] Publicity generated by such an event might also encourage museums and similar preservation entities to consider taking some of the shop equipment.

XI. PRELIMINARY INTERPRETATIVE RECOMMENDATIONS

Although hotel development will alter the interior of the Chain Forge dramatically, much of the earlier intent of the NPS and the BRA to make the building a museum can be realized through:

- Preservation of the central bay of the mains shop (which retains the look of a "Cathedral of Industry"), and dedication of much of this space to interpretative display;

- Retention of the equipment noted above including development of adjacent outdoor displays;

- Use of other artifacts in NPS collections as long term loans;

- Interpretation of the shop's significance and operations through a variety of media which can enhance the experience of hotel guests and visitors, broaden the publicly-accessible resources of the BNHP, and create a positive synergy between the public and private stakeholders. Public interaction with historical collections in such a setting is sometimes more engaging than in a specialty museum. The suggestions below are presented by theme and shop area where possible, and will in some most cases require further research as well as the participation of skilled exhibit designers, fabricators, and animators.

[101] Tirpak 2014.

A. Interior Spaces

1. Central Bay West Section

With limited movement of some equipment, the large hammers, presses, furnaces and at least one jib crane in this section can be retained in conditions fairly close to those in effect when the Chain Forge closed. Interpretation here can focus on production of anchors and some components of larger die-lock chain sizes. In addition to interpretative signage including historic views of workers and post-1974 views taken by HAER photographers Jack Boucher and Jet Lowe, there are opportunities for more dramatic displays such as:

- use of audio and video sections from the 1956 television footage at the press used for anchor shank production and at one or more of the hammers;
- interior lighting of furnaces to simulate heating conditions;
- fabrication of long tongs used for production work, and suspension of the tongs at work sites to simulate some operations;
- enlargements of two dramatic paintings of work at the "Big Barney" hammer, one produced for an Erie Foundry Company catalog by an as-yet unidentified artist, and the other (owned by NPS) by noted combat artist, William F. Draper (Figures 57-58);
- figures simulating male and female forge workers near these large pieces of equipment, using mannequins near the equipment, or perhaps scrim displays on the edges of this space using historic or newly-created images painted or printed on lighted transparent/translucent fabric.[102]
- original commissioned artwork by experienced illustrators of industrial environments, such as David Weitzman or David Macaulay.[103]

2. Central Bay East Section and South Entrance

Aside from the components of the Tinius Olsen Testing Machine facilities and the car-bottom annealing furnace, no pieces of equipment are recommended for in-place preservation in the east section of the central bay, leaving this area and some adjacent space available for interpretation of several major themes.

a. Complete Die-Lock Chain Fabrication and Assembly

As discussed above, there are well-preserved examples in shop area M of equipment used to make smaller chain sizes. An assemblage of this equipment can be relocated to the central bay, and interpreted to show all steps needed to fabricate and assemble chain. The availability of ¾" chain dies and the well-preserved nature of many pieces associated with this assembly line suggest a focus on this size chain for interpretation. In addition to interpretative signage explaining the process and illustrating chain components, the fabrication and assembly display can be enhanced by:

- use of original dies;
- animated three-dimensional explanation, perhaps the best way to explain steps including stem production, upsetter operation with gripper dies and punches, and link assembly and trimming;
- cut-away sections of actual or replicated die-lock links.

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[102] Scrims are theater drops with scenes that appear opaque lit from the front and transparent or translucent lit from the back.

[103] Weitzman 1987; Macaulay 1988.

b. Heat Treating

The rather dramatic appearance of the car-bottom furnace and its tracks, along with the top of at least one stress-relief furnace and relocated heat treating furnaces used for die-lock stems from the south shop bay, can be used to illustrate the basics of heat treating Chain Forge practices. To enhance simple signage explanations, displays here could include interior lighting of furnaces and workpieces to simulate heating conditions, with actual or replicated anchor shanks in the car-bottom furnace, stems in the heat treating furnaces, and shots (lengths) of chain in the stress-relief furnace suspended from an overhead crane.

c. Testing and Inspection

With removal of its shed enclosure, the entire assemblage associated with the unique two million pound Tinius Olsen Testing Machine can be exposed and interpreted as a critical part of chain testing beginning in World War I. Two-dimensional displays here can include historic images of display boards highlighting the strength of die-lock chain. A dramatic enhancement of the testing machine display would be installation of a complete 90-foot-long shot of smaller chain in the testing trench. NPS holdings appear to include at least one shot of suitable size.

Near the present south entrance, the two vertical testing machines built at the Navy yard in 1938 can tell an important story of how the Chain Forge secured command over Navy chain work for another generation, in the tests conducted against NACO steel chain. Interpretative displays can include at least one historic image of a display board highlighting this test.

3. Other Interior Displays and Interpretation

Other interpretative programs or components are less tied to specific interior locations, but can include:

- display focused on the production and output of the blacksmith shop, including a small power hammer, anvil, forge fire, original dies and swedges, hand tools, and available NPS holdings of the many smaller items made in the Chain Forge with collection of more information on the functions of these items;

- preparation of a written and illustrated summary on Chain Forge history which can be given to visitors and hotel guests;

- a cross-section display of structural changes in the main shop from World War II through hotel development using HAER drawings and historical plans, to provide visitors and guests with information on original spaces.

- a small display on the detachable link including a disassembled or replicated artifact with “exploded” parts to suggest the way each link is assembled and disassembled, and coverage of the importance and non-interchangeable nature of these links;

- video exhibit showing anchors and chains at work on large Navy vessels, requiring some research in military film archives;

- use of surplus original die-lock chain and anchors as components of hotel interior design, including support for lobby tables.

- graphics for advertising, logos, letterheads, menus, signs in the hotel, etc.

B. Exterior Displays

If some of the larger pieces recommended for retention in non-original locations cannot be kept inside the building for reasons related to proposed redevelopment, another viable option is display and interpretation of some pieces in sheltered areas adjacent to the northwest corner of the Chain Forge. This location can offer valuable exhibits to site visitors who do not plan to enter the hotel, and may invite some of them to sample the interior exhibits.

Aside from very large metal artifacts such as the hammers discussed below, much smaller or lighter-weight pieces such as turbine runners and metal waterwheels have withstood exterior conditions well for extended periods. Examples include components of the Kinne Water Turbine Collection at the Jefferson County Historical Society in Watertown, NY, and several turbines at Scribner's Mill in Harrison, ME. A more recent example is the waterwheel at the Ames Shovel Works in Easton, MA, now painted with a highly durable, long-lasting epoxy coating. Successful exterior display at the Chain Forge will require proper conservation and treatment, and a permanent, sufficiently-funded program for long-term maintenance and upkeep. The study team is familiar with successful treatment options, but specifications for object treatment(s) are beyond the scope of this study and the expertise of its authors. The National Park Service and site developers must obtain the services of an object conservator intimately familiar and experienced with treatment and maintenance of metal objects outside. Such an expert can provide guidance not only on coatings and other such treatments but also on mounting, drainage, and other considerations to ensure the longevity of this equipment.

Exterior Chain Forge displays can focus on the 4-3/4" die-lock chain and final production of Navy anchors. Components can include:

- the 25,000-pound hammer, its associated jib crane, a heating furnace if feasible, and perhaps the large upsetter, displayed in association with panels of historical and HAER photographs, and a production flow diagram based on a HAER drawing;

- replicated or original sample(s) of 4-3/4" chain or chain components, perhaps with the replicas lit to suggest heating during production;

- an original or replicated anchor with chain, as it would have looked when completed at the Chain Forge.

1. Current Status of Hammers on Public Outdoor Display or in Museums

Large steam hammers are impressive objects that evoke the drama of industrial production at its most spectacular. Although drop hammers driven by compressed air are still in widespread use for forging operations, those rated at 10,000 pounds or more (combined weight of piston, rod, and ram) are no longer common. A 25,000 pound hammer, such as the 24-foot-high "Mighty Monarch" in the Boston Chain Forge stands out as a giant machine. If put on display in an outdoor setting, it would be the largest hammer open for public viewing in America. Most visitors to the Boston Naval Shipyard would never have seen anything like it.

During its very successful "1876" show, the National Museum of History and Technology (part of the Smithsonian Institution) exhibited a c1856 Nasmyth steam hammer that was rated at about 6,000 pounds and stood more than 19 feet high. One conservative estimate of the weight of the entire hammer (without anvil or foundation) was 28,000 pounds, much less than the taller and more substantial "Mighty Monarch" whose upper works weighed 130,000 pounds. Still, it was one of the most significant artifacts in the Smithsonian's Arts and Industries Building, an 1881 structure with very high ceilings. No one who toured the exhibit, which opened in 1976, a hundred years after the original Centennial Exposition in Philadelphia, could miss that enormous machine or fail to appreciate its capacity for shaping iron. Visitors would stand in awe, imagining the sound of the striking hammer and the heat of iron at forging temperature.[104]

[104] Post, ed. 1976

Once the 1876 exhibition ended, museum staff and contractors disassembled the Nasmyth steam hammer and shipped it to Bethlehem, PA, with plans for erection in a planned National Museum of Industrial History that would be affiliated with the Smithsonian. The steam hammer was to be the highlight of a major exhibition and an important drawing card for Bethlehem's new museum. Unfortunately, the management of the new museum failed to carry out plans for renovating a building to house its industrial exhibits. The Smithsonian Institution has apparently lost faith in the project, and a grand jury has been investigating the financial operations overseen by the CEO. The non-profit has spent more than $17 million dollars over seventeen years, with little accomplished to date.[105] The Nasmyth hammer, although blameless in this debacle, remains in pieces and in storage out of the public eye.[106]

There are much more successful displays of steam hammers in overseas museums such as The Sheffield Industrial History Museum on Kelham Island[107] and Ironbridge Gorge Museum in Shropshire, both in the United Kingdom. The latter is a museum complex which actually operates a large steam hammer in demonstrations.[108] Obviously, visitors have to stand back for safety, but the sights and sounds of hot metal forging are memorable.

No existing hammer, either preserved as an historic artifact or still in use, compares with the one now standing in a public square at Le Creusot, France. This truly gigantic hammer, built in 1876 and moved in 1969 from the nearby Schneider works, is rated at between 75 and 100 tons (just the moving piston, rod, and ram, with dies of varying sizes). The hammer has become a major tourist attraction. The American Society of Mechanical Engineers designated it an International Historic Mechanical Engineering Landmark in 1981.[109] So important to French national pride was the Le Creusot/Schneider steam hammer that a full-size wooden model of it was part of the 1878 Exposition Universelle in Paris. Much attention was paid to the fact that Germany's Krupp works had only a 50 ton hammer at that time.[110] American engineers and metal workers eventually won the 19th century race for supremacy in steam hammer size when Bethlehem Steel in 1893 fabricated the largest hammer ever made, a monster standing 90 feet above the ground and rated at 125 tons. Like the Le Creusot hammer, a wooden model of this one was a jaw-dropping feature of an international exposition, in this case the Columbian Exposition in Chicago in 1893. When *Engineering News* wrote an article about "The End of the Great Bethlehem Steam Hammer," during its demolition in 1902, the reporter said that the hammer had been "the heaviest in the world when built by far" and expressed confidence that the record had never been surpassed.[111]

There are a number of steam hammers now on outdoor display in the world. Some are in a set of photos of "Ten Massive Steam Hammers" (not all clearly identified) on a website called OObject.com.[112] There can be seen United Kingdom examples at Wigan Pier and in Wales. A separate online search identifies a hammer at a Telford service station (complete with sign panels certified by Ironbridge Gorge Museum).[113] Another hammer in the photo set is notable for its size and antiquity: the Sandvik Hammer (made by Kirkstall Forge Co. of Leeds, United Kingdom, with an 1863 patent date). It is now in a park in Sandviken, Sweden. The Society for Industrial Archeology visited that hammer on a study tour in 2002. It appears to be comparable in height to the tallest hammer at the Chain Forge.[114]

In the United States, there are relatively few hammers on display, and none that are as large as the four 10,000-25,000 pound hammers in the Chain Forge. The biggest appears to be an 8,000 lb steam hammer outside A. Finkl and Sons, a forging shop currently at 93rd St. North Chicago. It is due to be moved to a new plant in South Chicago in the near future. There is also a single frame steam hammer in Shelby County, AL and a mechanical drop hammer in Chula Vista, CA, both much smaller than the Chicago example.

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[105] http://www.lehighvalleylive.com/bethlehem/index.ssf/2014/06/3_million_donation_in_the_work.html
[106] http://www.lehighvalleylive.com/bethlehem/index.ssf/2014/06/3_million_donation_in_the_work.html
[107] Anonymous n.d.
[108] http://www.ironbridge.org.uk/collections/our-collections/engineering/steam-machines/steam-hammer/
[109] http://en.wikipedia.org/wiki/Creusot_steam_hammer; ttp://files.asme.org/asmeorg/Communities/History/Landmarks/10265.pdf
[110] Ibid.
[111] *Engineering News* 1902; *Scientific American* 1895.
[112] http://www.oobject.com/category/10-massive-steam-hammers/
[113] http://www.waymarking.com/waymarks/WM844W_Nasmyth_Steam_Hammer_Telford_Shropshire_UK
[114] See SIA photos by Greg Galer and Robert Vogel, sent to the authors.

Overseas sites have made more effective use of hammers and have found them to be highly valuable as urban amenities, cultural attractions, and educational assets. The American hammers we are suggesting for retention in the Chain Forge, both large and relatively small models, have great interpretive potential and would be fascinating objects for hotel visitors to examine. With appropriate signage, including graphics (or even sound and video), they would be highly informative artifacts – direct links to the dynamic action and sensory overload that made the Chain Forge such an exciting place to work. We are not suggesting operating any of these hammers[115] (as Ironbridge Gorge Museum does), but recommend retaining them in positions where the public could appreciate them, either inside or outside Building 105. The one hammer that truly belongs in the open, where more people would see it, is the 25,000 pound hammer, the "Mighty Monarch" made by the Erie Foundry Company. It would be very difficult to create a hotel within the former Chain Forge without moving that towering machine. It may be possible to move this hammer without its approximately 500,000-pound anvil, reducing rigging costs, with the anvil top replicated in other material. We strongly suggest putting it outside on a solid foundation and letting everyone who passes by marvel at its scale and its visual power. It is a perfect symbol for a hotel at this site and for the industrialized shipyard that made the strongest chains and anchors in the world.

[115] Pousson *et al*. 1991; Hagley Museum & Library Papers 1981.

Table 1. EXTANT EQUIPMENT, CHAIN FORGE (BUILDING 105) AS OF 2014
Data organized by period of installation, keyed to Figure 2

EQUIPMENT, MAKER, BOSTS NUMBER(S)	1900-1906	1915-1919	1920-1933	1934-1941	1941-1944	1951-1953	UNDATED	TOTAL
FURNACES								
A. HEATING								
Oil-Fired, smaller chain & hardware, BNS 17965 17924 17915, 17927, 17929, 17914, 17926, 17933, 17913, 17938, 17937, 17935, 17944, 17946, 17970, 17969, 17974, 17899, 17867, 17869, 17979, 17981, 17868			1 [F40]		19 [F2-F10, F12, F14, F20-F22, F26, F39, F41-F42, F44]		3 [F1, F11, F43]	**23**
Oil-Fired, smaller chain & hard- ware, non-BNS, 17932, 17966, 1740, 17909	2 [F19, 27]						2 [F16, F18]	**4**
Oil-Fired, larger chain, BNS, 17964 17969, 17956 17953 17945, 17854		2 [F28-F29]		2 [F31-F32]	2 [F25, F45]			**6**
Oil-Fired, slot, 4-3/4" chain, Lithium Co. 17952, 17948						2 [F23-F24]		**2**
Oil-Fired, Rotary, Gas Machinery Co. 17961					1[F30]			**1**
Oil-Fired, Smithy, BNS [no BOSTS numbers]							5 [F55-F59]	**5**
Electric Rotary, chain, General Electric Co. 17934, 17853						2 [F13, 46]		**2**
Gas, stems, Lithium Co.17852						1 [F47]		**1**
B. HEAT TREAT								
Oil-Fired, stems, BNS, 17875, 17876		2 [F52-F53]						**2**
Electric, Pit, chains, Lindberg Engineering Co.17886, 17887, 17888					3 [F36-F38]			**3**
Electric, stems Lindberg Engineering Co. 17878					1 [F54]			**1**
Oil-Fired, chains & anchors, Quigley Annealing Furnace Co. 17885		1 [F34]						**1**
Electric, stems, Electric Furnace Co. 17874			1 [F51]					**1**
Electric, Pit, Hevi-Duty Electric Co. 17884						1 [F33]		**1**
Electric, Pit, Lindberg Engineering Co. 17871, 17872				2 [F48-F49]				**2**
Electric, Pit, 17873						1 [F50]		**1**
Electric, salt bath, Ajax Mfg. Co. 17879						1 [F60]		
TOTAL FURNACES	**2**	**5**	**2**	**4**	**26**	**8**	**10**	**57**
HAMMERS								
A. 300-lb								
Chambersburg Eng. Co. [no BOSTS numbers]							2 [H26-H27]	**2**
B. 1000-2000 lb								
Erie Foundry Co. 17859, 17856, [no BOSTS numbers for H23-H25], 17917, 17916, 17911, 17967				5 [H19, H22-H25]	4 [H1-H2, H4, H9]			**9**
Chambersburg Eng. Co. 17971, 17862, 17908, 17907, 17858, 17857					2 [H8, H14]	4 [H5-H6, H20-H21]		**6**
Alliance Machine Co, 17863, 17865				2 [H15-H16]				**2**
C. 2500-3500 lb								
Chambersburg Eng. Co. 17912, 17851						2 [H3, H17]		**2**
Erie Foundry Co. 17963, 17849				1 [H10]	1 [H18]			**2**
D. 10,000-12,000 lb								
Erie Foundry Co. 17840, 17842, 17844				3 [H11-H13]				**3**
E. 25,000 lb								
Erie Foundry Co. 17947						1 [H7]		**1**
TOTAL HAMMERS				**11**	**7**	**7**	**2**	**27**

Table 1. EXTANT EQUIPMENT, CHAIN FORGE (BUILDING 105) AS OF 2014 (cont.)

EQUIPMENT, MAKER, BOSTS NUMBER(S)	1900-1906	1915-1919	1920-1933	1934-1941	1941-1944	1951-1953	UNDATED	TOTAL
BENDING PRESSES								
Pneumatic, smaller chain, BNS, 17925, 17928, 17931, 17936, 17941, 17943					6 [P1, P4, P7, P10, P14, P17]			**6**
UPSETTERS								
Ajax Mfg. Co. Model 2, 17918, 17919, 17921, 17922, 17923					5 [P2, P5, P11, P15, P18]			**5**
Ajax Mfg Co. Model 4, 17920				1 [P8]				**1**
Ajax Mfg Co. Model 6, 17951				1 [P20]				**1**
Ajax Mfg Co. Model 8, 17950						1 [P21]		**1**
TOTAL UPSETTERS				**2**	**5**	**1**		**8**
TRIM PRESSES								
Mechanical, E.W. Bliss Co. Model 205, 17900, 17901, 17903, 17910, 17906, 17968, 17864, 17860					8 [P3. P6, P12, P13, P19, P22, P30, P33]			**8**
Mechanical, E.W. Bliss Co. Model 208, 17845					1 [P28]			**1**
Mechanical, E.W. Bliss Co. 17902						1 [P9]		**1**
Mechanical, Erie Foundry Co. 17855				1 [P34]				**1**
Hydraulic, E.W. Bliss Co. Model HS-200-H, 17843					1 [P27]			**1**
Hydraulic, A.B. Farquhar Co. 17841					1 [P26]			**1**
Unidentified, 17904					1 [P16]			**1**
TOTAL TRIM PRESSES				**1**	**12**	**1**		**14**
OTHER PRESSES								
Hydraulic,American Steel Foundries anchor shanks, 17839						1 [P25]		**1**
Mechanical, E.W. Bliss Co. 17866, 17864					1 [P32]		1 [P31	**2**
Mechanical, Erie Foundry Co. 17861				1 [P29]				**1**
Mechanical, Erie Foundry Co. Model 10, 17972				1 [P24]				**1**
Mechanical, Ajax Mfg Co. Model 10, 17972				1 [P24]				**1**
TOTAL OTHER PRESSES				**3**	**1**	**1**	**1**	**6**
CRANES								
15-to-25 ton bridge cranes, 17955, [no BOSTS numbers for M21 and M36]							3 [M2, M21, M36]	**3**
Jib cranes, various suppliers/BNS, 17905, 17846, 17949,17898, [no BOSTS number for C6], 17976	1 [C5]	1 [C4]				1 [C1]	3 [C3, C6, C7]	**6**
Mono-rails/conveyors, 17957, [no BOSTS number for C9]						1 [C2]	1 [C9]	**2**
Traveling crane, Shepard Niles Crane & Hoist, 17877					1 [C11]			**1**
Booms/trolleys/hoists 17882, [no BOSTS numbers for C10, C12]							3 [C8, C10, C12]	**3**
TOTAL CRANES	**1**	**1**			**1**	**2**	**10**	**15**

Table 1. EXTANT EQUIPMENT, CHAIN FORGE (BUILDING 105) AS OF 2014 (cont.)								
EQUIPMENT, MAKER, BOSTS NUMBER(S)	**1900-1906**	**1915-1919**	**1920-1933**	**1934-1941**	**1941-1944**	**1951-1953**	**UNDATED**	**TOTAL**
SHEARS & SAWS								
Shearing machines, Buffalo Forge Co. 17978, 17898				2 [M11, M12]				**2**
Cut-off machine, Armstrong-Blum Mfg. Co. 17977					1 [M10]			**1**
Band saw, Coall Co. 17975						1 [M8]		**1**
TOTAL SHEARS & SAWS				**2**	**1**	**1**		**4**
TESTING EQUIPMENT								
Chain testing machine, Tinius Olsen Testing Machine Co. 17881 [one BOSTS number for M26-M29]		1 [M26-M29]						**1**
Chain end test crushing machine, BNS, 17848				1 [M5]				**1**
Tensile impact testing machine, BNS, 17847				1 [M31]				**1**
Magnetic particle inspection machine, Magna Flux Corp., 17870					1 [M32]			**1**
TOTAL TESTING EQUIPMENT		**1**		**2**	**1**			**4**
PUMPS, COMPRESSORS								
Pumps for Olsen testing machine, Worthington Pump Machine Co.,17880				2 [M35]				**2**
Worthington vertical pump, air compressor, 4 motors for hydraulic press P25, [no BOSTS numbers]						6 [M15-M20]		**6**
Unidentified pump, [no BOSTS number]							1 [M13]	**1**
TOTAL PUMPS, COMPRESSORS				**2**		**6**	**1**	**9**
QUENCH TANKS, 17883 [no BOSTS numbers for M34, M38]							3 [M33, M34, M38]	**3**
FURNACE BASKETS/ STEEL TANKS, 17893-17894, 17891-17892, 17889, 17890							6 [M3, M4, M24, M25]	**6**
MISCELLANEOUS								
Forging roll machine, Ajax Manufacturing Co. Model 2 [no BOSTS number]							1 [M1]	**1**
Paint pit, [no BOSTS number]							1 [M6]	**1**
small generator, [no BOSTS number]							1 [M14]	**1**
TOTAL MISCELLANEOUS							**3**	**3**
TOTAL EQUIPMENT	**3**	**7**	**2**	**27**	**60**	**26**	**37**	**162**

Table 2. SIGNIFICANT EQUIPMENT AND RECOMMENDED OPTIONS

EQUIPMENT/ ASSEMBLAGE; BOSTS NUMBERS	FIG. 2 KEY NO(S).	LEAVE IN PLACE OR CLOSE TO ORIGINAL LOCATION	LEAVE ON SITE IN NON-ORIGINAL LOCATION	DOCUMENT IF RETENTION ON SITE NOT FEASIBLE	SIGNIFICANCE CRITERIA NUMBER(S)	COMMENTS
HYDRAULIC PRESS/ HEATING FURNACE, 17919, 17964	P25, F28	X			2 (both)	Large anchor shank shaping of the early 1950s, for all large Navy anchors, with largest heating furnace in shop
10,000 LB ERIE HAMMER, 17840	H11	X			1, 2	Key piece used for anchor shafts, large tools & other pieces, World War II & later; central location may enhance interpretative display
15- AND 25-TON TRAVELING CRANES [no BOSTS numbers]	M21, M36	X			3	Typical of many large forges and machine shops, but used here to streamline floor operations
12,000 LB ERIE HAMMER/ 2 HYDRAULIC TRIM PRESSES 17842, 17841, 17843	H12, P26, P27	X			1 (H12) 2 (all)	Key piece including 2 hydraulic trim presses, used for large-size chain production and other items World War II and later; central location may enhance interpretative display
10,000 LB ERIE HAMMER/ DOUBLE HEATING FURNACE/TRIM PRESS/JIB CRANE 17844, 17956, 17845, 17846	H13,F31 P28, C4	X			1 (H13, C4) 2 (all) 3 (C4)	Centrally-located intact equipment assemblage for large-size chain production c1930s-World War II, including heating furnace, trim press, and rare survival of jib crane use with hammer
QUIGLEY CAR-BOTTOM ANNEALING FURNACE [no BOSTS number]	F34	X			2	Heat treatment furnace with associated tracks, earliest such furnace in shop; used for chains c1915-World War II & for shanks used for all large Navy anchors by World War I
TINIUS OLSEN TESTING MACHINE & TRENCH/JIB CRANES/PUMPS, 17880, 17881, 17882, 17976	M26-29, M35, C7-8	X			1 (all)	One of the largest such facilities ever installed in the United States
TENSILE IMPACT TESTING MACHINE, 17847	M31	X			1	Built by Navy Yard for significant strength tests of cast vs. die-lock chains
CHAIN END TEST CRUSHING MACHINE, 17848	M5	X			1	Built by Navy Yard for significant strength tests of cast vs. die-lock chains
CHAMBERSBURG ENG. CO. 300 LB HAMMER/ SMITHY FURNACE [no BOSTS numbers]	H26, F58		X		2	Typical power equipment associated with blacksmith operations critical to forge shop output
BUFFALO FORGE CO. SHEARING MACHINE 17898	M12		X		2	Critical equipment for cutting bar stock used to make die-lock chain
ARMSTRONG-BLUM CUT-OFF MACHINE 17977	M10		X		2	Critical equipment for cutting bar stock used to make die-lock chain
CHAMBERSBURG ENG. CO. 300 LB HAMMER, BUILT-IN COMPRESSOR [no BOSTS number]	H27		X		2	Typical forge equipment with possible unusual power fitting, for small forge products
LITHIUM CO. GAS-FIRED ROTARY FURNACE 17852	F47		X	X	2	Rotary furnace with typical design but rare use of lithium to control heating environment for large stems.
AJAX MODEL 8 UPSETTER 17950	P21		X	X	2	Associated with 4¾ " chain production; other examples likely in use
25,000 LB ERIE HAMMER/JIB CRANE/ LITHIUM CO. OIL-FIRED DOUBLE FURNACE 17947, 17949, 17948	H7, C1, F24		X	X (F24)	1 (H7) 2 (F24) 3 (C1)	Key components associated with 4¾ " chain production; rare survival of jib crane use with hammer for chain production
2 NAVY YARD HEATING FURNACES/NAVY YARD BENDING PRESS/AJAX MODEL 2 UPSETTER/ CHAMBERSBURG 1500 LB HAMMER/TRIM PRESS 17942, 17935, 17931, 17922, 17908, 17904	F17, F14, P7, P15, H5, P16		X		2	Assemblage of pieces representing typical manufacturing line for smaller-sized chain, based on identification of best preserved examples of equipment with focus on those used for ¾" size
LINDBERG ELECTRIC HEAT TREAT PIT FURNACE 17886	F36		X		2	Used for "Draw back" final stress annealing for most or all chain sizes, a critical production step
ELECTRIC FURNACE CO. ROTARY FURNACE 17874	F51		X	X	2	Earliest heat treating furnace for mature die-lock chain production process; probably typical of industry heat treating practice, but combination of liftable rotary hearth and conveyor may be rare
NAVY YARD HEAT TREAT FURNACE/2 QUENCH, TANKS, 17876, 17883, [no BOSTS number for M34]	F53, M33, M34		X		2	Early examples of heat treating equipment built for chain forge by Navy Yard

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PERSONAL COMMUNICATIONS

Dr. Martin Blatt, Chief of Cultural Resources, Charlestown Navy Yard, Boston National Historical Park

Stephen P.Carlson, Preservation Specialist, Charlestown Navy Yard, Boston National Historical Park

Maurice Caskey, Former Shipbuilding Executive, Ingalls Shipbuilding and NASSCO-General Dynamics

Justine Christianson, Historian, Historic American Engineering Record

Charles Crout, President, Ajax-Ceco Manufacturing Co. (successor to Ajax Manufacturing Co. and Chambersburg Engineering Company)

George Currie, Vice President, Erie Press Systems (successor to Erie Foundry Company)

John Hattendorf, Professor, U. S. Naval War College and Director, U. S. War College Museum

Duncan Hay, Northeast Regional Office, National Park Service

Peter Liebhold, Curator, National Museum of American History, Smithsonian Institution

Steven Lubar, Professor of American Studies, Brown University

Jon Tirpak, Executive Director, Forging Defense Manufacturing Consortium

David J. Vecchioli, Museum Curator, Charlestown Navy Yard, Boston National Historical Park

Arnold Visser, Chairman, Forging Industry Alliance

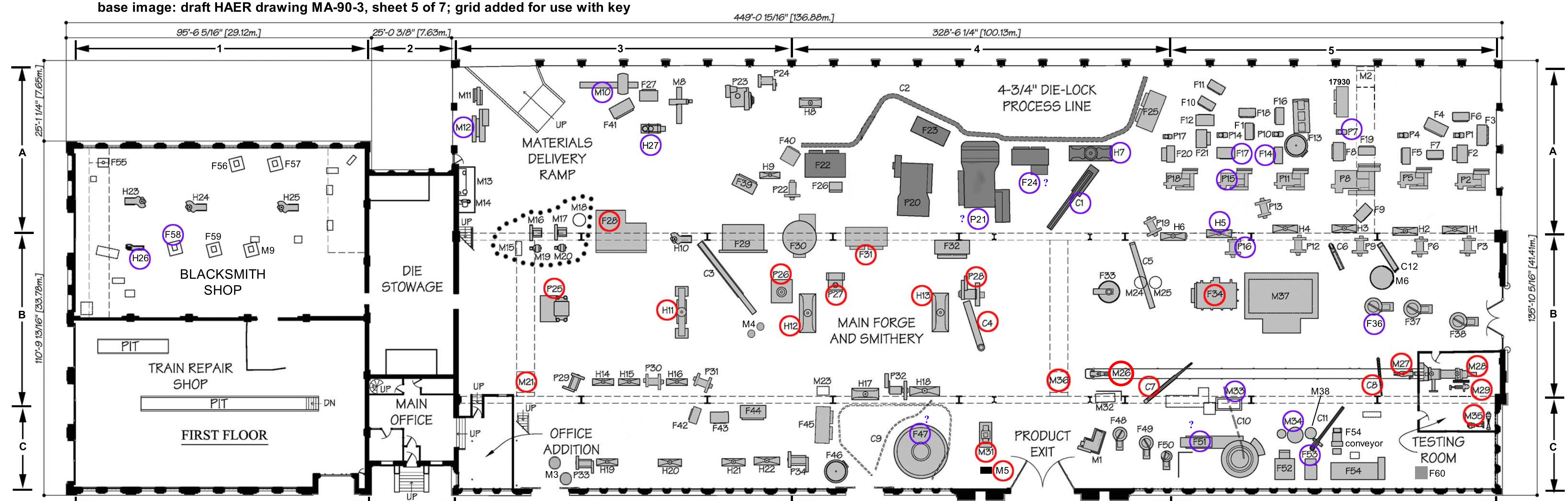
Robert Vogel, Curator Emeritus, National Museum of American History, Smithsonian Institution

Charles Wilde, Retired Naval Officer (Supply and Submarine Duty)

Figure 1. CHAIN FORGE LOCATION AT PRESENT CHARLESTOWN NAVY YARD
base map: National Park Service

Figure 2. 2014 CONDITIONS: EQUIPMENT IDENTIFICATION AND SIGNIFICANCE

base image: draft HAER drawing MA-90-3, sheet 5 of 7; grid added for use with key



EQUIPMENT KEY (NPS NUMBER/NAVY NUMBER, DATE & FUNCTION IF KNOWN, GRID LOCATION

Not all key numbers on HAER drawing used; most pieces without manufacturer name were made at Navy Yard

SIGNIFICANT: RETAIN IN PLACE OR CLOSE TO ORIGINAL LOCATION

SIGNIFICANT: RETAIN IN NON-ORIGINAL INTERIOR OR EXTERIOR LOCATION
? = CONDUCT MITIGATORY DOCUMENTATION IF RETENTION NOT FEASIBLE

0 10 20 30 40 50 FEET
0 5 10 15 METERS

F FURNACES

F1	Oil-Fired, 17979/230153	A5
F2	17924/230181, 1944	
F3	Oil-Fired, 17915/230020, 1942	
F4	Oil-Fired, 17927/230100, 1941	
F5	Oil-Fired, 17929/230168, 1944	
F6	Oil-Fired, 17914/230128, 1944	
F7	Oil-Fired, 17926/230169, 1944	
F8	Oil-Fired, 17933/230167, 1943	
F9	Oil-Fired, 17913/230129, 1944	
F10	Oil-Fired, 17938/230127, 1944	
F11	Oil-Fired, 17981/???	
F12	Oil-Fired, 17937/230165, 1944	
F13	Electric, 17934/230329, 1952 (with 3 transformers)	
F14	Oil-Fired, 17935/230164, 1944	
F16	17940/230178	
F17	17942/230180	
F18	17909/230187	
F19	Oil-Fired, Rockwell Engineering Co., 17932/230150, 1900	
F20	Oil-Fired, 17944/230166, 1944	
F21	Oil-Fired, 17946/230177, 1944	A5
F22	Oil-Fired, 17970/230159, 1943	A4
F23	Slot, Oil-Fired, The Lithium Co., 17952/230293, 1953	
F24	Slot, Oil-Fired, The Lithium Co., 17948/230294, 1953	
F25	Oil-Fired, 17945/230131, 1944 for anchors	
F26	Oil-Fired, 17969/230162, 1944	A4
F27	Oil-Fired, Rockwell Engineering Co., 17966/230151, 1906	A3
F28	Oil-Fired, 17964/230067, 1919 for anchors	A/B3
F29	Oil-Fired, 17962/230080, 1919	A/B3
F30	Oil-Fired, Gas Machinery Co., 17961/230083, 1942	A/B4
F31	Oil-Fired, 17956/230087, 1936	A/B4
F32	Oil-Fired, 17953/230090, 1941	B4
F33	Electric, Hevi-Duty Electric Co., 17884/230290, 1952	B4
F34	Oil-Fired, Quigley Annealing Furnace Co., 17885/230103, 1915	B5
F36	Electric, Lindberg Engineering Co., 17886/230109, 1942 Heat Treat	B5
F37	Electric, Lindberg Engineering Co., 17887/230110, 1942 Heat Treat	B5
F38	Electric, Lindberg Engineering Co., 17888/230111, 1943 Heat Treat	B5
F39	Oil-Fired, 17974/230176, 1944	A3
F40	Oil-Fired, 17965/230017, 1921	A3
F41	Oil-Fired, 17899/230023, 1942	A3
F42	Oil-Fired, 17867/230132, 1944	C3
F43	17868/230331	C3
F44	Oil-Fired, 17869/230018, 1939	C3
F45	Oil-Fired, 17854/230024, 1942	C4
F46	Electric, General Electric Co., 17853/230328, 1952	
F47	Gas-Fired, Lithium Co., 17852/230287, 1953 Heat Treat	
F48	Electric, Lindberg Engineering Co., 17871/230040, 1940	
F49	Electric, Lindberg Engineering Co., 17872/230042, 1938	
F50	Electric, Lindberg Engineering Co., 17873/230407, 1952 Heat Treat	C4
F51	Electric, Electric Furnace Co., 17874/230045, 1930 Heat Treat	C5
F52	Oil-Fired, 17875/230049, 1917 Heat Treat	
F53	Oil-Fired, 17876/230050, 1919 Heat Treat	
F54	Electric, Lindberg Engineering Co., 17878/230055, 1942 Heat Treat	C5
F55-		
F59	Oil-Fired, 230059, 230205-230206, 230210-230211 Smith Fires	A/B1
F60	Electric, The Ajax Mfg. Co., 17879/230301, 1952 Salt Bath	C5

P PRESSES

P1	Pneumatic, 17925/230170, 1943 Bender	A5
P2	Forge, The Ajax Mfg Co., 17918/230133, 1943 Model 2 Upsetter	A5
P3	Mechanical, E.W. Bliss Co., 17900/230155, 1943 Model 205 Trim	B5
P4	Pneumatic, 17928/230171, 1943 Bender	A5
P5	Forge, The Ajax Mfg Co., 17919/230134, 1943 Model 2 Upsetter	A5
P6	Mechanical, E.W. Bliss Co., 17901/230118, 1943 Model 205 Trim	B5
P7	Pneumatic, 17931/230172, 1944 Bender	A5
P8	Forge, The Ajax Mfg Co., 17920/230135, 1939 Model 4 Upsetter	A5
P9	Mechanical, E.W. Bliss Co., 17902/230283, 1952	B5
P10	Pneumatic, 17936/230173, 1943 Bender	A5
P11	Forge, The Ajax Mfg Co., 17921/230136, 1943 Model 2 Upsetter	A5
P12	Mechanical, E.W. Bliss Co., 17903/230115, 1941 Model 205 Trim	B5
P13	Mechanical, E.W. Bliss Co., 17910/230117, 1943 Model 205 Trim	A5
P14	Pneumatic, 17941/230174, 1944 Bender	A5
P15	Forge, The Ajax Mfg Co., 17922/230137, 1943 Model 2 Upsetter	A5
P16	17904/230119, 1941 Trim	B5
P17	Pneumatic, 17943/230175, 1943 Bender	A5
P18	Forge, The Ajax Mfg Co., 17923/230138, 1943 Model 2 Upsetter	A5
P19	Mechanical, E.W. Bliss Co., 17906/230140, 1943 Model 205 Trim	A4
P20	Forge, The Ajax Mfg Co., 17951/230093, 1936 Model 6 Upsetter	A4
P21	Forge, The Ajax Mfg Co., 17950/230302, c1950,Model 8 Upsetter	A4
P22	Mechanical, E.W. Bliss Co., 17968/230120, 1942 Model 205 Trim	A4
P23	Mechanical, The Ajax Mfg Co., 17973/230152, 1943 Model 7C	A3
P24	Mechanical, Erie Foundry Co., 17972/230001, 1937 Model 10	A3
P25	Hydraulic, American Steel Foundries, 17839/230300, 1951 Model 8006	B3
P26	Hydraulic, A.B. Farquhar Co., 17841/230081, 1941 Trim	B3
P27	Hydraulic, E.W. Bliss Co., 17843/230085, 1943 Model HS-200-H Trim	B4
P28	Mechanical, E.W. Bliss Co., 17845/230091, 1942 Model 208 Trim	B4
P29	Mechanical, Erie Foundry Co., 17861/230158, 1933	B3
P30	Mechanical, E.W. Bliss Co., 17864/230010, 1941 Model 205 Trim	B3
P31	E.W. Bliss Co., 17866/230116	B3
P32	Mechanical, E.W. Bliss Co., 17850/230030, 1944	B4
P33	Mechanical, E.W. Bliss Co., 17860/230008, 1942 Model 205 Trim	C3
P34	Mechanical, Erie Foundry Co., 17855/230014, 1937 Trim	C4

H HAMMERS

H1	2,000 lb, Erie Foundry Co., 17917/230126, 1943	A5
H2	2,000 lb, Erie Foundry Co., 17916/230139, 1943	A5
H3	3,000 lb, Chambersburg Engineering Co., 17912/230291, 1951	A5
H4	2,000 lb, Erie Foundry Co., 17911/230123, 1943	A5
H5	1,500 lb, Chambersburg Eng. Co, 17908/230296, 1952 Model E	B5
H6	1,500 lb, Chambersburg Eng. Co, 17907/230297, 1952 Model E	B5
H7	25,000 lb, Erie Foundry Co., 17947/230292, 1951	A4
H8	1,500 lb, Chambersburg Engineering Co., 17971/230154, 1942	A4
H9	1,000 lb, Erie Foundry Co., 17967/230098, 1942	A3
H10	2,500 lb, Erie Foundry Co., 17963/230073, 1941	B3
H11	10,000 lb, Erie Foundry Co., 17840/230078, 1941	B3
H12	12,000 lb, Erie Foundry Co., 17842/230082, 1941	B4
H13	10,000 lb, Erie Foundry Co., 17844/230089, 1936	B4
H14	1,000 lb, Chambersburg Engineering Co., 17862/230002, 1943	B3
H15	1,500 lb, Alliance Machine Co., 17863/230004, 1939	B3
H16	1,500 lb, Alliance Machine Co., 17865/230003, 1939	B3
H17	3,000 lb, Chambersburg Engineering Co., 17851/230285, 1951	B4
H18	3,500 lb, Erie Foundry Co., 17849/230029, 1943	B4
H19	1,500 lb, Erie Foundry Co., 17859/230009, 1941	C3
H20	2,000 lb, Chambersburg Engineering Co., 17858/230299, 1952	C3
H21	2,000 lb, Chambersburg Engineering Co., 17857/230298, 1952	C3
H22	2,000 lb, Erie Foundry Co., 17856/230015, 1936	C3
H23	1,500 lb, Erie Foundry Co., ?/230189, 1941	A1
H24	1,500 lb, Erie Foundry Co., ?/230201, 1941	A1
H25	1,500 lb, Erie Foundry Co., ?/230188, 1941	A1
H26	300 lb, Chambersburg Eng. Co, ?/230191, Model 1700	B1
H27	300 lb, Chambersburg Eng. Co, ?/665012327, Model 10165-1 with built-in compressor	A3

C JIB CRANES AND HOISTS

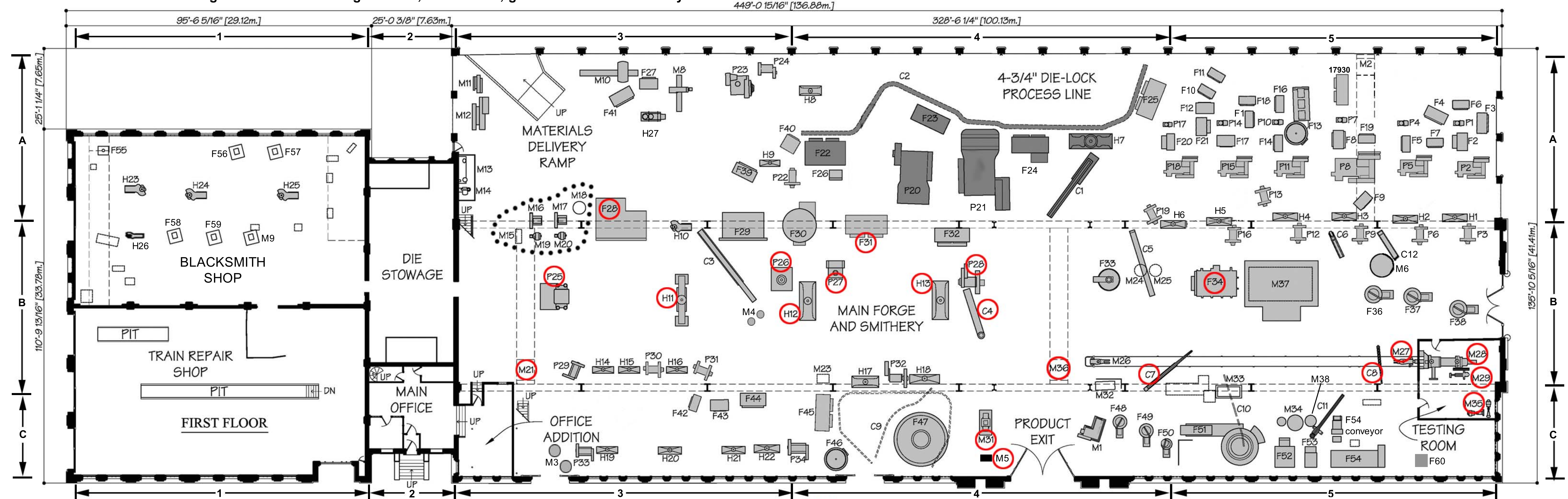
C1	Jib, 17949/230304, 1954	A4
C2	Mono-Rail, 17957/230314, 1953	A4
C3	Jib, Cleveland Crane & Engine Co., 17897/230076	B3
C4	Jib, 17846/230092, 1917	B4
C5	Jib, Shephard Electric Crane Co., 17905/230107, 1904	B4
C6	Jib, ?/230235	B5
C7	Jib, Niles, Bement & Pond Co., 17976/230044	B4
C8	Boom, 17882/230056	B5
C9	Monorail/Conveyor	C4
C10	Trolley/Hoist	C5
C11	Traveling, Shepard Niles Crane and Hoist, 17877/316795, 1941	C5
C12	Crane/Hoist	B5

M MISCELLANEOUS

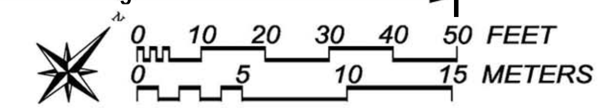
M1	Forging Roll Machine, Ajax Model 2	C4
M2	15-Ton, Traveling Crane, 17955/230229	A5
M3	2 7.5'-high steel tanks, 17893-17894/??, 1961	C3
M4	2 30-" dia. furnace baskets, 17891-17892/230351-230352	B3
M5	Chain End Test Crushing Machine, 17848/230032, 1938	C4
M6	Paint Pit, ?/230113	B5
M8	Band Saw, Coall Co., 17975/230323, 1958	A3
M9	Base of removed furnace, 230209	B1
M10	Cut-Off Machine, Armstrong-Blum Mfg Co., 17977/313117, 1941	A3
M11	Shearing Machine, Buffalo Forge Co., 17978/230147, 1935	
M12	Shearing Machine, Buffalo Forge Co., 17898/230148, 1935	
M13	Pump, ?/230072	
M14	Small generator, ?/230071	A3
M15-M20	Compressor, Pump, Motors for P25, 1951	A/B3
M21	15-Ton, Traveling Crane, ?/230108	B3
M23	Electrical power box?, ?/230281	B4
M24-M25	2 24-" dia. furnace baskets, 17889-90/230347-48	B4
M26-M29	Chain Testing Machine, Tinius Olsen Testing Machine Co., 17881/230060, 1918	B4/5
M31	Tensile Impact Testing Machine, 17847/230033, 1938	C4
M32	Magnetic Particle Inspection Machine, Magna Flux Corp., 17870/230053, 1945	C4
M33	Quenching Tanks, 17883/230047	C5
M34	5'-dia. steel quench tank, ?/230052	C5
M35	Pumps, Worthington Pump Machine Co., 17880/313086, 1940	C5
M36	25-Ton Traveling Crane , ?/230108?	B4
M37	Wheelabrator, American Foundry Equipment Co., ?/230355 [removed - depression in floor]	B5
M38	3.5'-dia. steel quench tank with water pipes, ?/230051?	C5

Figure 2a. 2014 CONDITIONS AND EQUIPMENT RECOMMENDED FOR RETENTION IN PLACE

base image: draft HAER drawing MA-90-3, sheet 5 of 7; grid added for use with key



SIGNIFICANT: RETAIN IN PLACE OR CLOSE TO ORIGINAL LOCATION



EQUIPMENT KEY (NPS NUMBER/NAVY NUMBER, DATE & FUNCTION IF KNOWN, GRID LOCATION

Not all key numbers on HAER drawing used; most pieces without manufacturer name were made at Navy Yard

F FURNACES

F1	Oil-Fired, 17979/230153	A5
F2	17924/230181, 1944	
F3	Oil-Fired, 17915/230020, 1942	
F4	Oil-Fired, 17927/230100, 1941	
F5	Oil-Fired, 17929/230168, 1944	
F6	Oil-Fired, 17914/230128, 1944	
F7	Oil-Fired, 17926/230169, 1944	
F8	Oil-Fired, 17933/230167, 1943	
F9	Oil-Fired, 17913/230129, 1944	
F10	Oil-Fired, 17938/230127, 1944	
F11	Oil-Fired, 17981/???	
F12	Oil-Fired, 17937/230165, 1944	
F13	Electric,17934/230329, 1952 (with 3 transformers)	
F14	Oil-Fired, 17935/230164, 1944	
F16	17940/230178	
F17	17942/230180	
F18	17909/230187	
F19	Oil-Fired, Rockwell Engineering Co., 17932/230150, 1900	
F20	Oil-Fired, 17944/230166, 1944	
F21	Oil-Fired, 17946/230177, 1944	A5
F22	Oil-Fired, 17970/230159, 1943	A4
F23	Slot, Oil-Fired, The Lithium Co., 17952/230293, 1953	
F24	Slot, Oil-Fired, The Lithium Co., 17948/230294, 1953	
F25	Oil-Fired, 17945/230131, 1944 for anchors	
F26	Oil-Fired, 17969/230162, 1944	A4
F27	Oil-Fired, Rockwell Engineering Co., 17966/230151, 1906	A3
F28	Oil-Fired, 17964/230067, 1919 for anchors	A/B3
F29	Oil-Fired, 17962/230080, 1919	A/B3
F30	Oil-Fired, Gas Machinery Co., 17961/230083, 1942	A/B4
F31	Oil-Fired, 17956/230087, 1936	A/B4
F32	Oil-Fired, 17953/230090, 1941	B4
F33	Electric, Hevi-Duty Electric Co., 17884/230290, 1952	B4
F34	Oil-Fired, Quigley Annealing Furnace Co., 17885/230103, 1915	B5
F36	Electric, Lindberg Engineering Co., 17886/230109, 1942 Heat Treat	B5
F37	Electric, Lindberg Engineering Co., 17887/230110, 1942 Heat Treat	B5
F38	Electric, Lindberg Engineering Co., 17888/230111, 1943 Heat Treat	B5
F39	Oil-Fired, 17974/230176, 1944	A3
F40	Oil-Fired, 17965/230017, 1921	A3
F41	Oil-Fired, 17899/230023, 1942	A3
F42	Oil-Fired, 17867/230132, 1944	C3
F43	17868/230331	C3
F44	Oil-Fired, 17869/230018, 1939	C3
F45	Oil-Fired, 17854/230024, 1942	C4
F46	Electric, General Electric Co., 17853/230328, 1952	
F47	Gas-Fired, Lithium Co., 17852/230287, 1953 Heat Treat	
F48	Electric, Lindberg Engineering Co., 17871/230040, 1940	
F49	Electric, Lindberg Engineering Co., 17872/230042, 1938	
F50	Electric, Lindberg Engineering Co., 17873/230407, 1952 Heat Treat	C4
F51	Electric, Electric Furnace Co., 17874/230045, 1930 Heat Treat	C5
F52	Oil-Fired, 17875/230049, 1917 Heat Treat	
F53	Oil-Fired, 17876/230050, 1919 Heat Treat	
F54	Electric, Lindberg Engineering Co., 17878/230055, 1942 Heat Treat	C5
F55-		
F59	Oil-Fired, 230059, 230205-230206, 230210-230211 Smith Fires	A/B1
F60	Electric, The Ajax Mfg. Co., 17879/230301, 1952 Salt Bath	C5

P PRESSES

P1	Pneumatic, 17925/230170, 1943 Bender	A5
P2	Forge, The Ajax Mfg Co., 17918/230133, 1943 Model 2 Upsetter	A5
P3	Mechanical, E.W. Bliss Co., 17900/230155, 1943 Model 205 Trim	B5
P4	Pneumatic, 17928/230171, 1943 Bender	A5
P5	Forge, The Ajax Mfg Co., 17919/230134, 1943 Model 2 Upsetter	A5
P6	Mechanical, E.W. Bliss Co., 17901/230118, 1943 Model 205 Trim	B5
P7	Pneumatic, 17931/230172, 1944 Bender	A5
P8	Forge, The Ajax Mfg Co., 17920/230135, 1939 Model 4 Upsetter	A5
P9	Mechanical, E.W. Bliss Co., 17902/230283, 1952	B5
P10	Pneumatic, 17936/230173, 1943 Bender	A5
P11	Forge, The Ajax Mfg Co., 17921/230136, 1943 Model 2 Upsetter	A5
P12	Mechanical, E.W. Bliss Co., 17903/230115, 1941 Model 205 Trim	B5
P13	Mechanical, E.W. Bliss Co., 17910/230117, 1943 Model 205 Trim	A5
P14	Pneumatic, 17941/230174, 1944 Bender	A5
P15	Forge, The Ajax Mfg Co., 17922/230137, 1943 Model 2 Upsetter	A5
P16	17904/230119, 1941 Trim	B5
P17	Pneumatic, 17943/230175, 1943 Bender	A5
P18	Forge, The Ajax Mfg Co., 17923/230138, 1943 Model 2 Upsetter	A5
P19	Mechanical, E.W. Bliss Co., 17906/230140, 1943 Model 205 Trim	A4
P20	Forge, The Ajax Mfg Co., 17951/230093, 1936 Model 6 Upsetter	A4
P21	Forge, The Ajax Mfg Co., 17950/230302, c1950,Model 8 Upsetter	A4
P22	Mechanical, E.W. Bliss Co., 17968/230120, 1942 Model 205 Trim	A4
P23	Mechanical, The Ajax Mfg Co., 17973/230152, 1943 Model 7C	A3
P24	Mechanical, Erie Foundry Co., 17972/230001, 1937 Model 10	A3
P25	Hydraulic, American Steel Foundries, 17839/230300, 1951 Model 8006	B3
P26	Hydraulic, A.B. Farquhar Co., 17841/230081, 1941 Trim	B3
P27	Hydraulic, E.W. Bliss Co., 17843/230085, 1943 Model HS-200-H Trim	B4
P28	Mechanical, E.W. Bliss Co., 17845/230091, 1942 Model 208 Trim	B4
P29	Mechanical, Erie Foundry Co., 17861/230158, 1933	B3
P30	Mechanical, E.W. Bliss Co., 17864/230010, 1941 Model 205 Trim	B3
P31	E.W. Bliss Co., 17866/230116	B3
P32	Mechanical, E.W. Bliss Co., 17850/230030, 1944	B4
P33	Mechanical, E.W. Bliss Co., 17860/230008, 1942 Model 205 Trim	C3
P34	Mechanical, Erie Foundry Co., 17855/230014, 1937 Trim	C4

H HAMMERS

H1	2,000 lb, Erie Foundry Co., 17917/230126, 1943	A5
H2	2,000 lb, Erie Foundry Co., 17916/230139, 1943	A5
H3	3,000 lb, Chambersburg Engineering Co., 17912/230291, 1951	A5
H4	2,000 lb, Erie Foundry Co., 17911/230123, 1943	A5
H5	1,500 lb, Chambersburg Eng. Co, 17908/230296, 1952 Model E	B5
H6	1,500 lb, Chambersburg Eng. Co, 17907/230297, 1952 Model E	B5
H7	25,000 lb, Erie Foundry Co., 17947/230292, 1951	A4
H8	1,500 lb, Chambersburg Engineering Co., 17971/230154, 1942	A4
H9	1,000 lb, Erie Foundry Co., 17967/230098, 1942	A3
H10	2,500 lb, Erie Foundry Co., 17963/230073, 1941	B3
H11	10,000 lb, Erie Foundry Co., 17840/230078, 1941	B3
H12	12,000 lb, Erie Foundry Co., 17842/230082, 1941	B4
H13	10,000 lb, Erie Foundry Co., 17844/230089, 1936	B4
H14	1,000 lb, Chambersburg Engineering Co., 17862/230002, 1943	B3
H15	1,500 lb, Alliance Machine Co., 17863/230004, 1939	B3
H16	1,500 lb, Alliance Machine Co., 17865/230003, 1939	B3
H17	3,000 lb, Chambersburg Engineering Co., 17851/230285, 1951	B4
H18	3,500 lb, Erie Foundry Co., 17849/230029, 1943	B4
H19	1,500 lb, Erie Foundry Co., 17859/230009, 1941	C3
H20	2,000 lb, Chambersburg Engineering Co., 17858/230299, 1952	C3
H21	2,000 lb, Chambersburg Engineering Co., 17857/230298, 1952	C3
H22	2,000 lb, Erie Foundry Co., 17856/230015, 1936	C3
H23	1,500 lb, Erie Foundry Co., ?/230189, 1941	A1
H24	1,500 lb, Erie Foundry Co., ?/230201, 1941	A1
H25	1,500 lb, Erie Foundry Co., ?/230188, 1941	A1
H26	300 lb, Chambersburg Eng. Co, ?/230191, Model 1700	B1
H27	300 lb, Chambersburg Eng. Co, ?/665012327, Model 10165-1 with built-in compressor	A3

C JIB CRANES AND HOISTS

C1	Jib, 17949/230304, 1954	A4
C2	Mono-Rail, 17957/230314, 1953	A4
C3	Jib, Cleveland Crane & Engine Co., 17897/230076	B3
C4	Jib, 17846/230092, 1917	B4
C5	Jib, Shephard Electric Crane Co., 17905/230107, 1904	B4
C6	Jib, ?/230235	B5
C7	Jib, Niles, Bement & Pond Co., 17976/230044	B4
C8	Boom, 17882/230056	B5
C9	Monorail/Conveyor	C4
C10	Trolley/Hoist	C5
C11	Traveling, Shepard Niles Crane and Hoist, 17877/316795, 1941	C5
C12	Crane/Hoist	B5

M MISCELLANEOUS

M1	Forging Roll Machine, Ajax Model 2	C4
M2	15-Ton, Traveling Crane, 17955/230229	A5
M3	2 7.5'-high steel tanks, 17893-17894/??, 1961	C3
M4	2 30-" dia. furnace baskets, 17891-17892/230351-230352	B3
M5	Chain End Test Crushing Machine, 17848/230032, 1938	C4
M6	Paint Pit, ?/230113	B5
M8	Band Saw, Coall Co., 17975/230323, 1958	A3
M9	Base of removed furnace, 230209	B1
M10	Cut-Off Machine, Armstrong-Blum Mfg Co., 17977/313117. 1941	A3
M11	Shearing Machine, Buffalo Forge Co., 17978/230147, 1935	
M12	Shearing Machine, Buffalo Forge Co., 17898/230148, 1935	
M13	Pump, ?/230072	
M14	Small generator, ?/230071	A3
M15-M20	Compressor, Pump, Motors for P25, 1951	A/B3
M21	15-Ton, Traveling Crane, ?/230108	B3
M23	Electrical power box?, ?/230281	B4
M24-M25	2 24-" dia. furnace baskets, 17889-90/230347-48	B4
M26-M29	Chain Testing Machine, Tinius Olsen Testing Machine Co., 17881/230060, 1918	B4/5
M31	Tensile Impact Testing Machine, 17847/230033, 1938	C4
M32	Magnetic Particle Inspection Machine, Magna Flux Corp., 17870/230053, 1945	C4
M33	Quenching Tanks, 17883/230047	C5
M34	5'-dia. steel quench tank, ?/230052	C5
M35	Pumps, Worthington Pump Machine Co., 17880/313086, 1940	C5
M36	25-Ton Traveling Crane , ?/230108?	B4
M37	Wheelabrator, American Foundry Equipment Co., ?/230355 [removed - depression in floor]	B5
M38	3.5'-dia. steel quench tank with water pipes, ?/230051?	C5

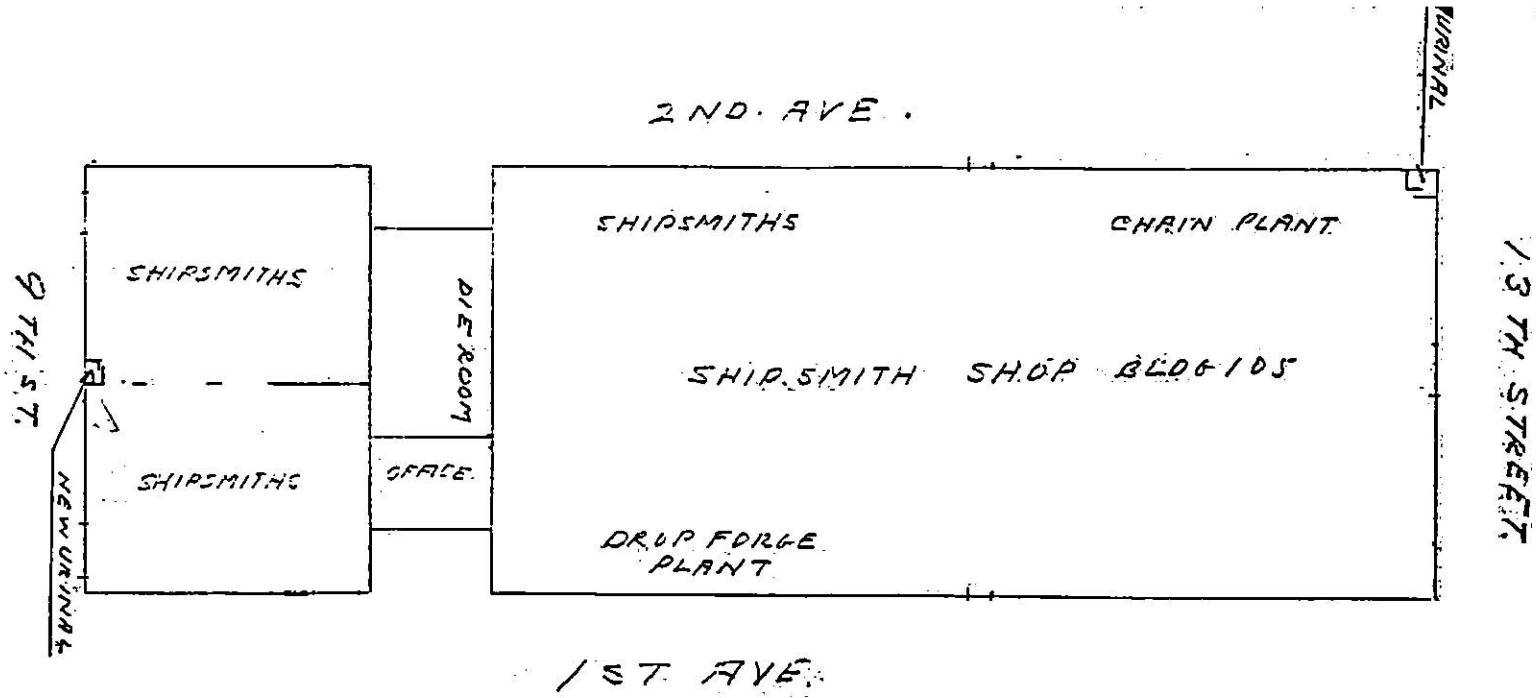


Figure 3. Plan for Light of Smithery, September 20, 1915. Drawing No. PW105-109. BOSTS

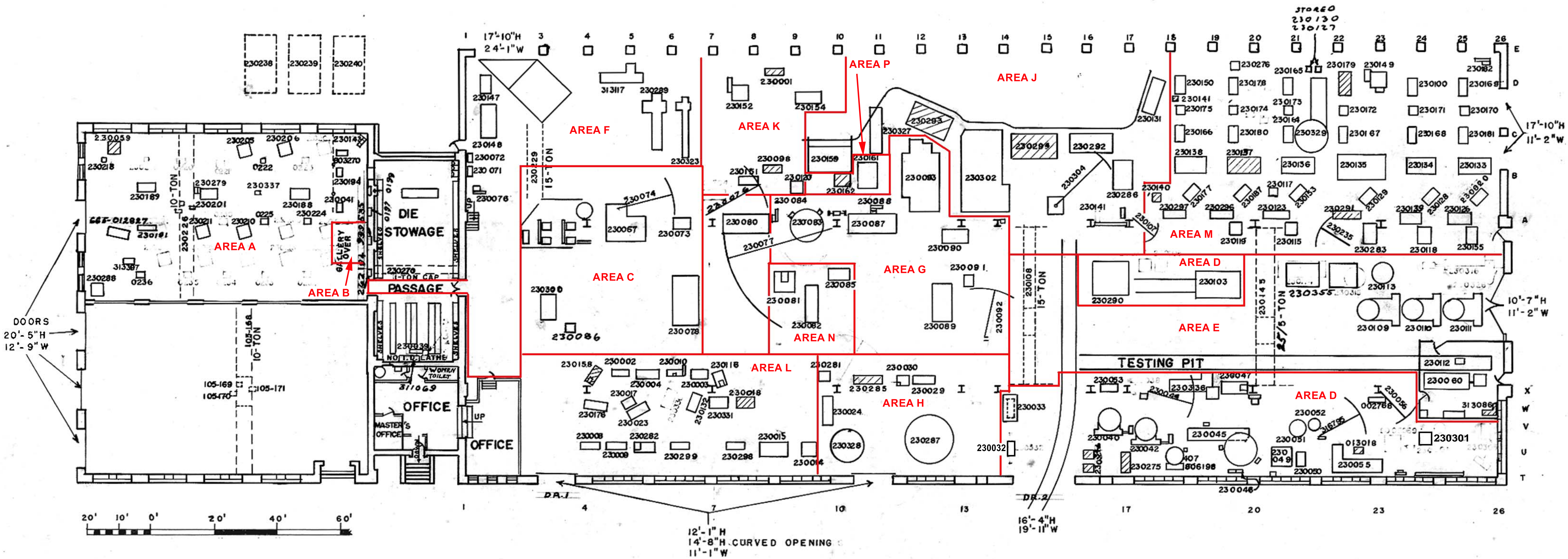


Figure 4. APPROXIMATE CHAIN FORGE WORK AREAS c1953 - 1974

base image: Boston Naval Shipyard, 1965-1973 Forge Shop/Building Number 105/Arrangement of Equipment;
work areas shown on Boston Naval Shipyard, c1953 Forge & Chain Shop/Arrangement of Shop Equipment and emergency shut-offs and switches.

Figure 5. 2012 VIEW EAST OF 10,000-12,000 LB. HAMMERS IN CENTRAL BAY [see Figure 2: H11-H13] source: HAER No.MA-90-3-64 (Jet Lowe)

Figure 6. 2012 VIEW SOUTHEAST OF CENTRAL BAY EAST END INCLUDING TEST TRENCH & CAR-BOTTOM FURNACE[see Figure 2: F34, M26-27] source: HAER No.MA-90-3-62 (Jet Lowe)

Figure 7. 2012 VIEW SOUTH OF 15-TON TRAVELING AT WEST END OF CENTRAL BAY [see Figure 2: M21] source: HAER No.MA-90-3-63 (Jet Lowe)

Figure 8. 1976 VIEW EAST OF 440-TON TRIM PRESS USED TO MAKE 4-3/4” CHAIN [later removed] source: HAER No.MA-90-3-25 (Jack Boucher)

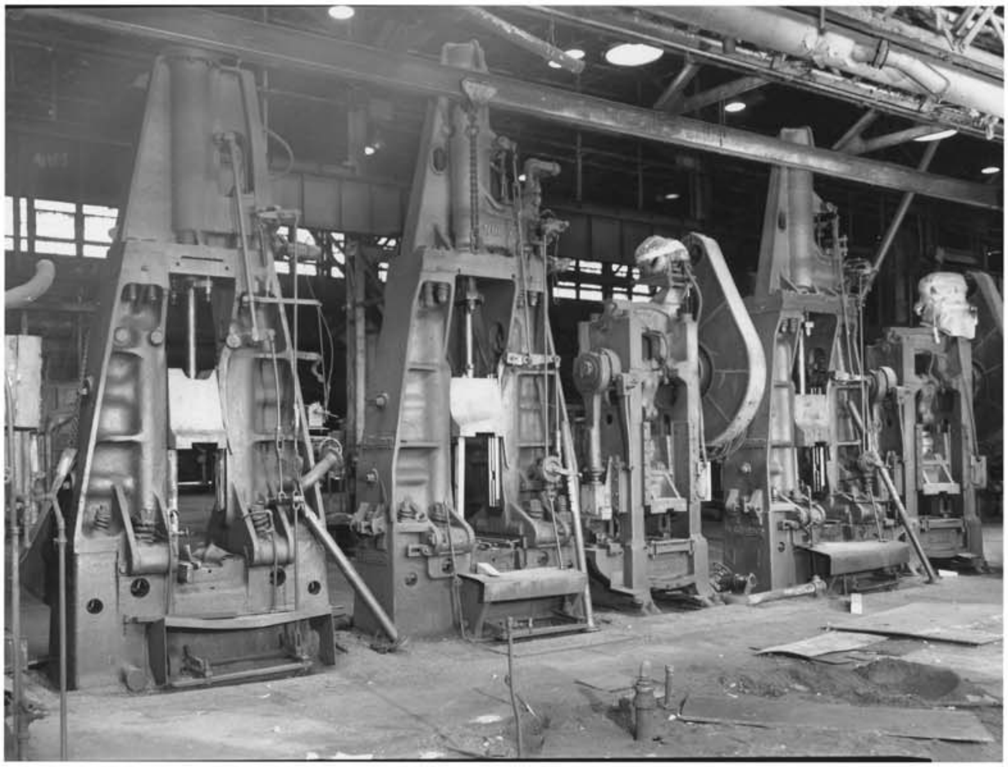


Figure 9. 1976 VIEW SOUTHEAST OF HAMMERS AND MECHANICAL PRESSES NEAR SOUTHWEST END OF CENTRAL BAY [see Figure 2: H14, H15, P30, H16, P31]
source: HAER No.MA-90-3-8(Jack Boucher)

Figure 10. 1976 VIEW SOUTHEAST OF CONVEYOR AND EQUIPMENT USED TO MAKE 4-3/4" CHAIN [see Figure 2: F23, P21, F24, HH7, F25]
source: HAER No.MA-90-3-13 (Jack Boucher)

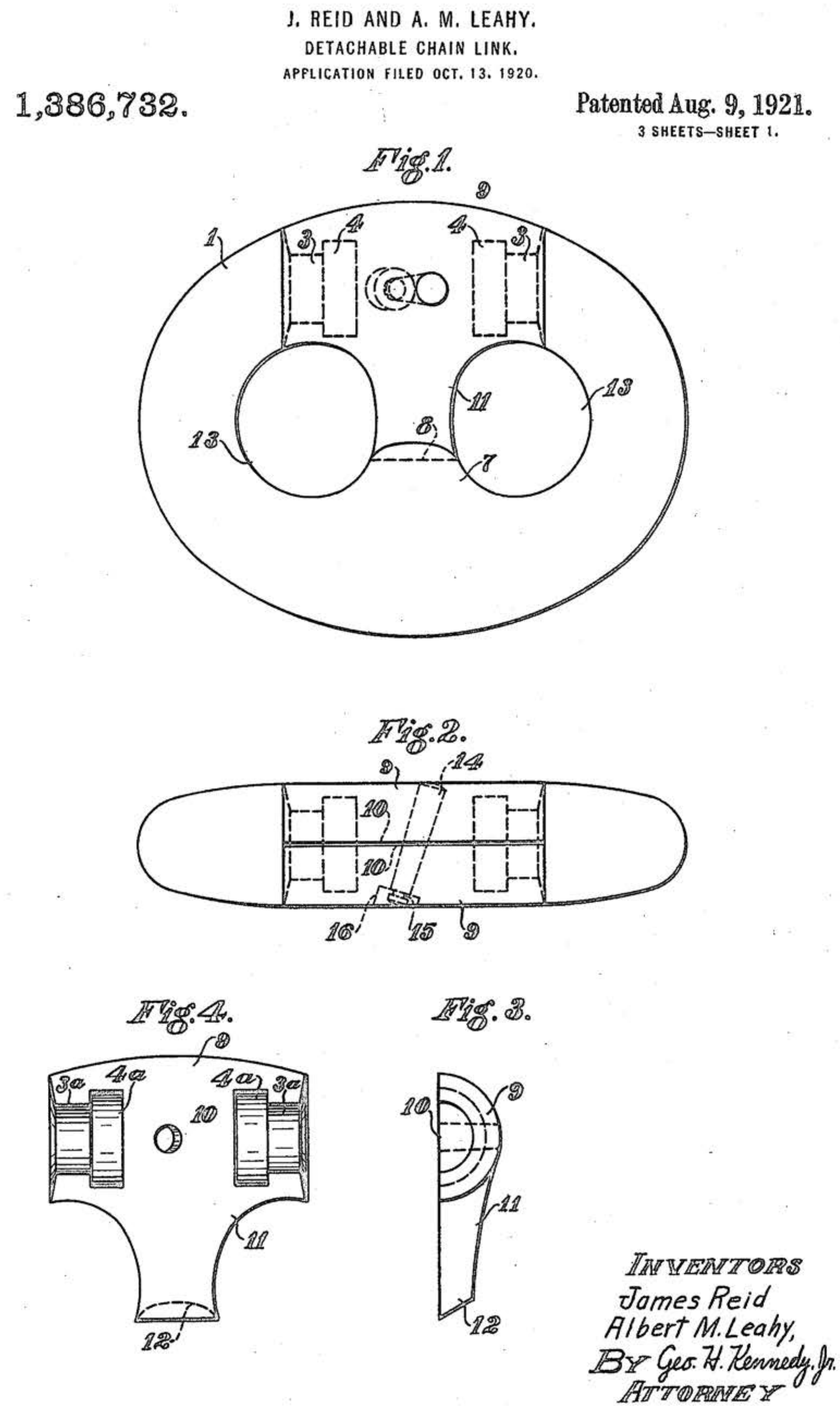


Figure 11. PATENT DRAWING FOR DETACHABLE-LINK CHAIN
source: Reid and Leahy 1921

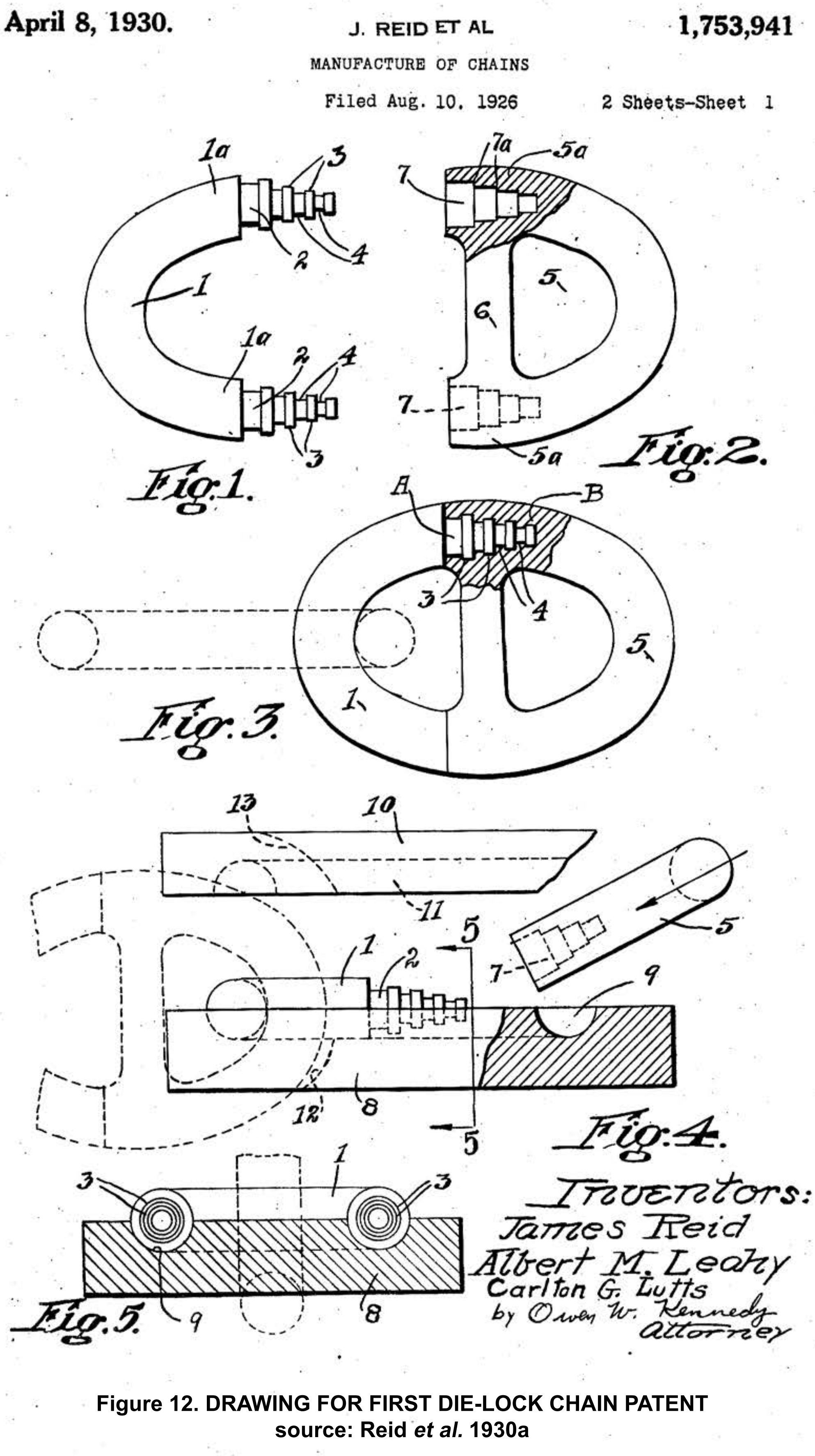


Figure 12. DRAWING FOR FIRST DIE-LOCK CHAIN PATENT
source: Reid *et al.* 1930a

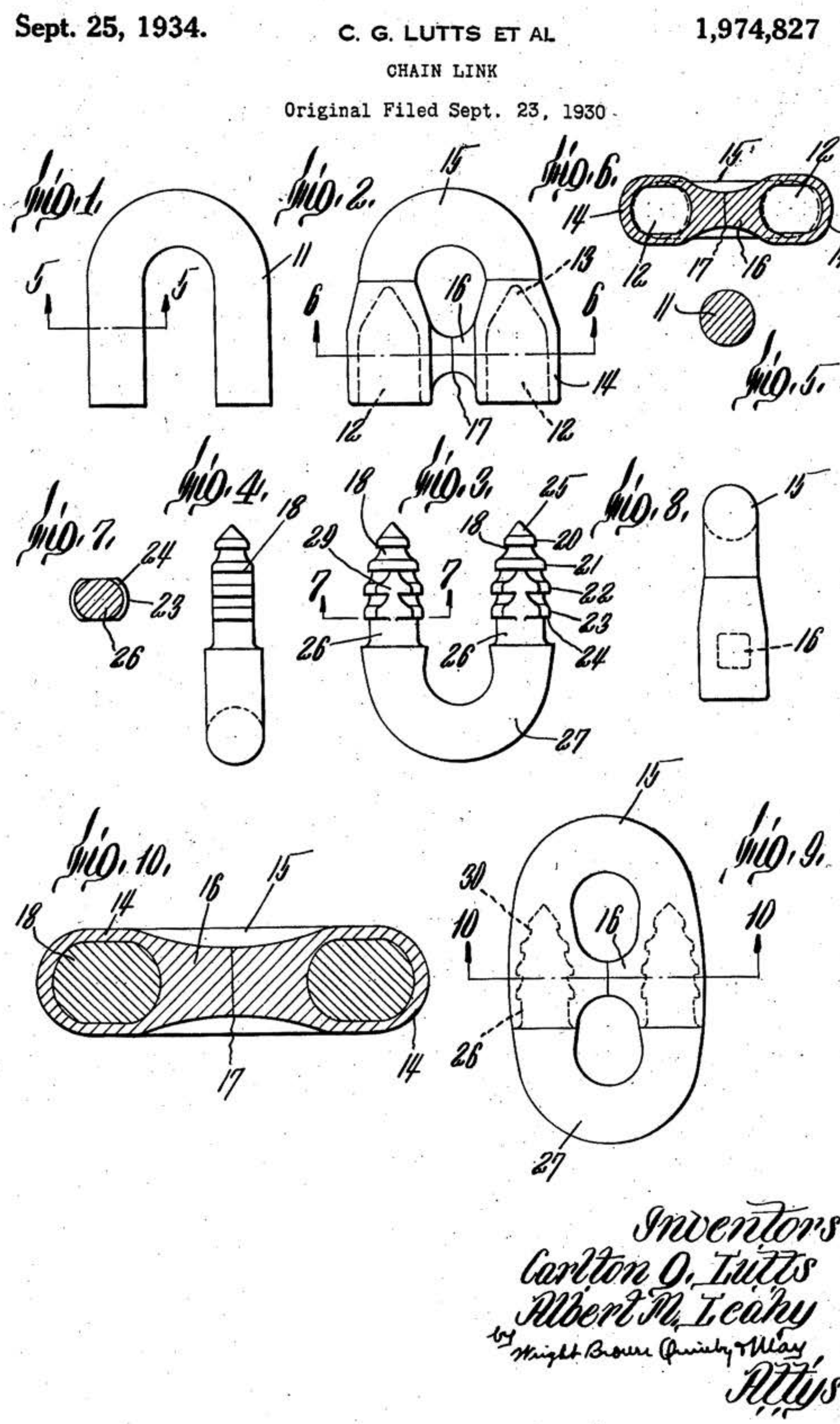


Figure 13. DRAWING FOR ENHANCED DIE-LOCK CHAIN PATENT
source: Lutts and Leahy 1934

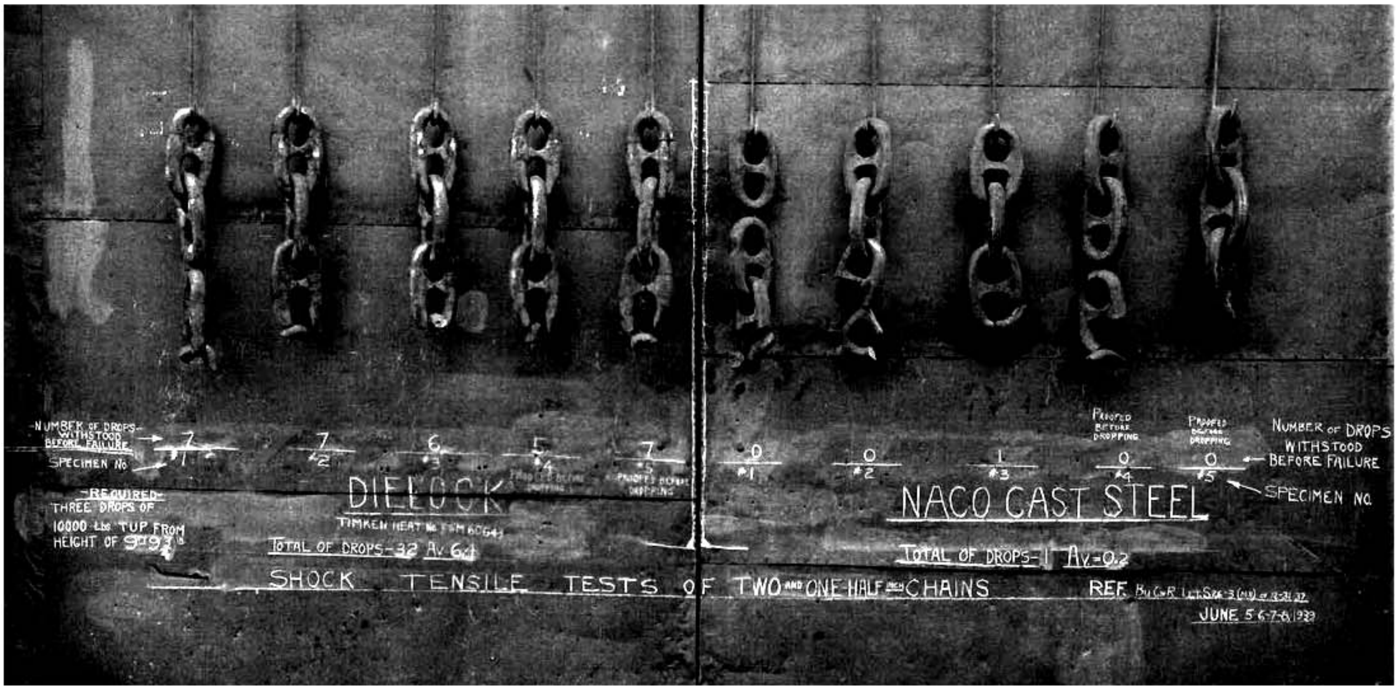


Figure 14. PHOTOGRAPH OF DISPLAY BOARD WITH 1939 TESTS RESULTS OF DIE-LOCK VS. CAST STEEL CHAIN
BOSTS 9684

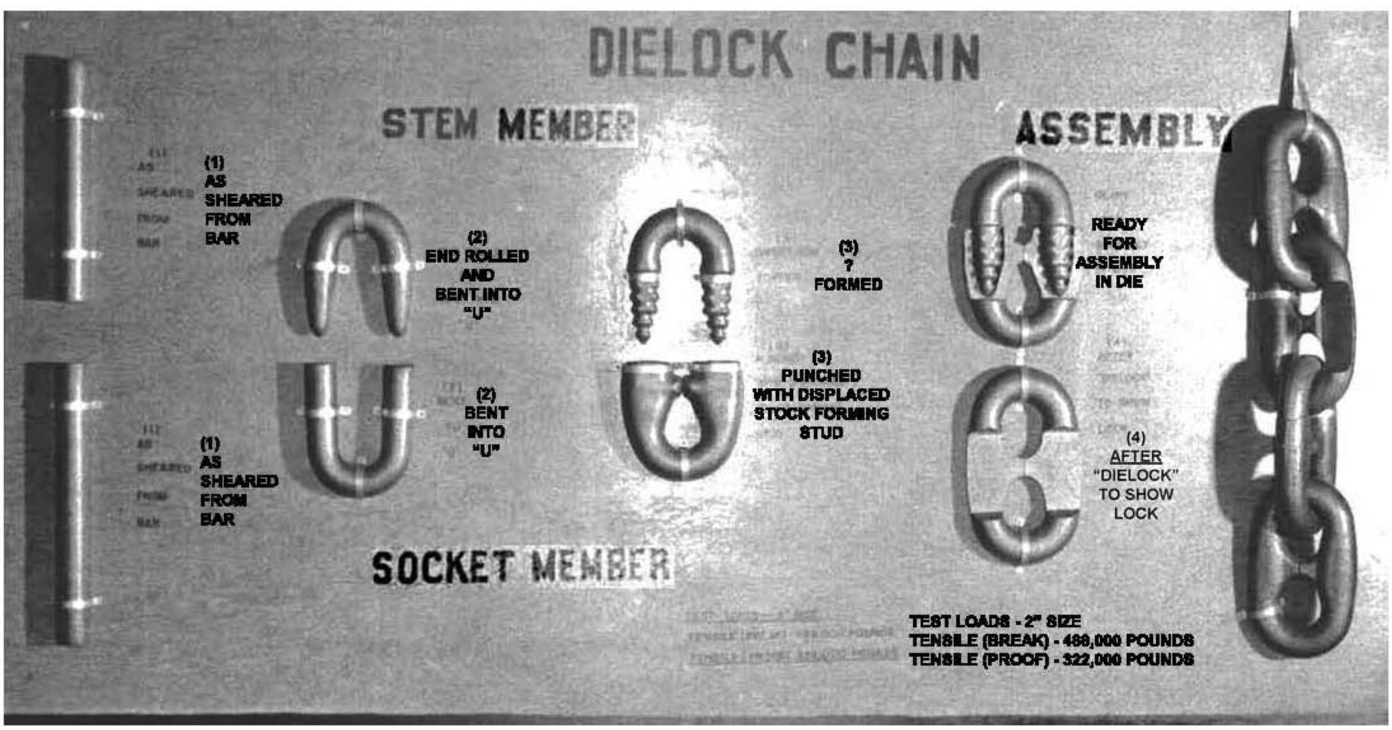


Figure 15. PHOTOGRAPH OF DISPLAY BOARD INCLUDING TEST DATA ON 2-INCH DIE-LOCK CHAIN
BOSTS 9684

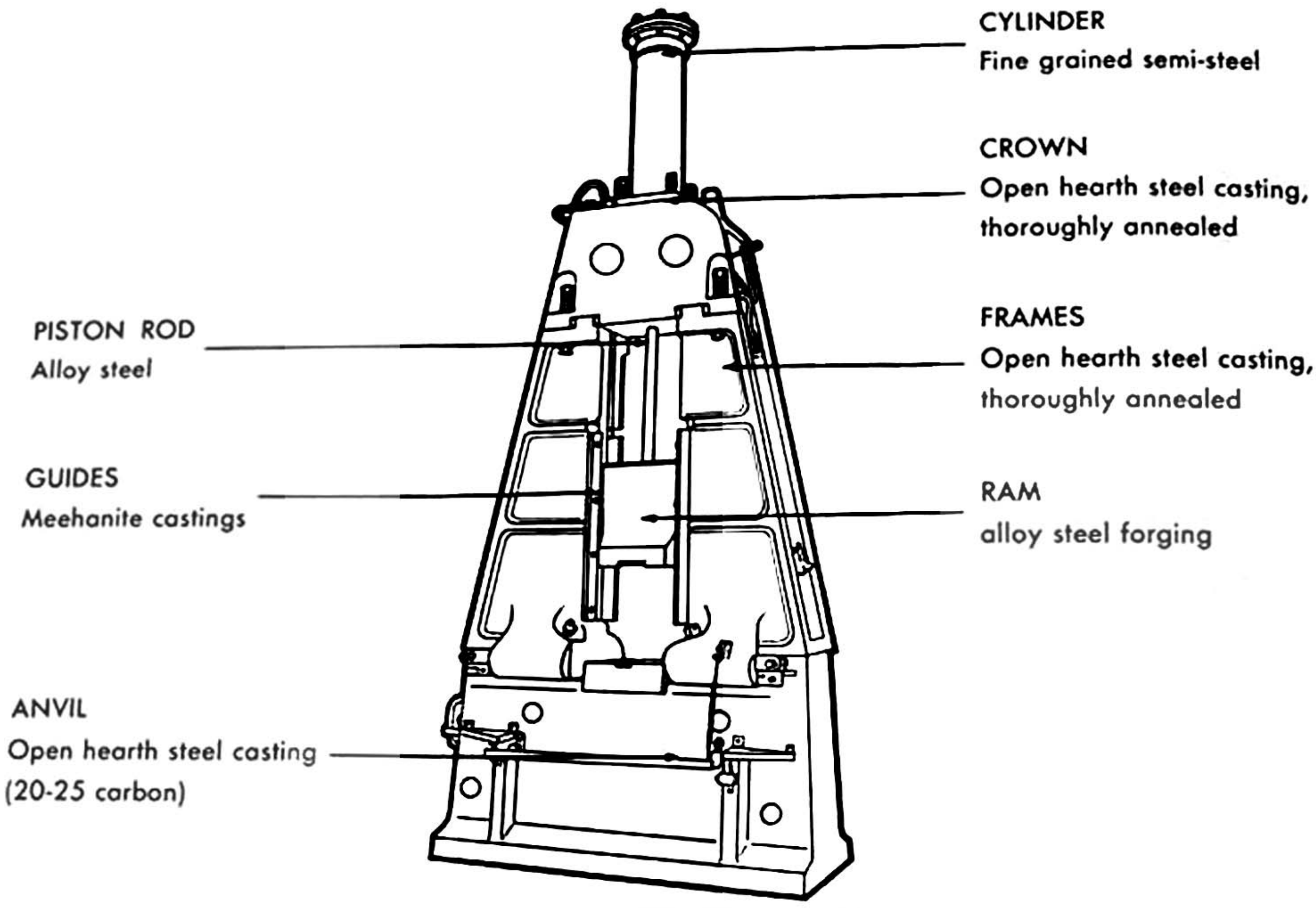


Figure 16. MAJOR COMPONENTS OF TYPICAL DROP HAMMER
source: Erie Foundry Company n.d.

2. DEFINITIONS (as shown on figure 1).

2.1 Anvil. - The anvil is the base of a hammer into which the sow block and die are set.

2.2 Sow block. - The sow block is a block of heat-treated steel placed between the anvil and the forging die.

2.3 Shank. - The shank is the portion of the die by which the die is held in position in the forging unit or press.

2.4 Dowel. - The dowel is a tapered metal wedge a portion of which is inserted into each of two related notches, one in the die shank and the other in the ram or sow block to prevent front to rear shift of either die.

2.5 Ram. - The ram is the moving part between the guides of a drop hammer or press, to which the top die is fastened.

2.6 Key. - The key is a retaining wedge for locking the dies in position in the ram and sow block.

2.7 Die notch. - The die notch is a female dovetailed channel machined into the horizontal face of the ram or sow block into which the die shank is secured by a dowel and a tapered key.

2.8 Dowel notches. - The dowel notches are a pair of related notches, one in the die shank and the other in the ram or sow block, into which a common dowel is inserted to eliminate front to rear die movement.

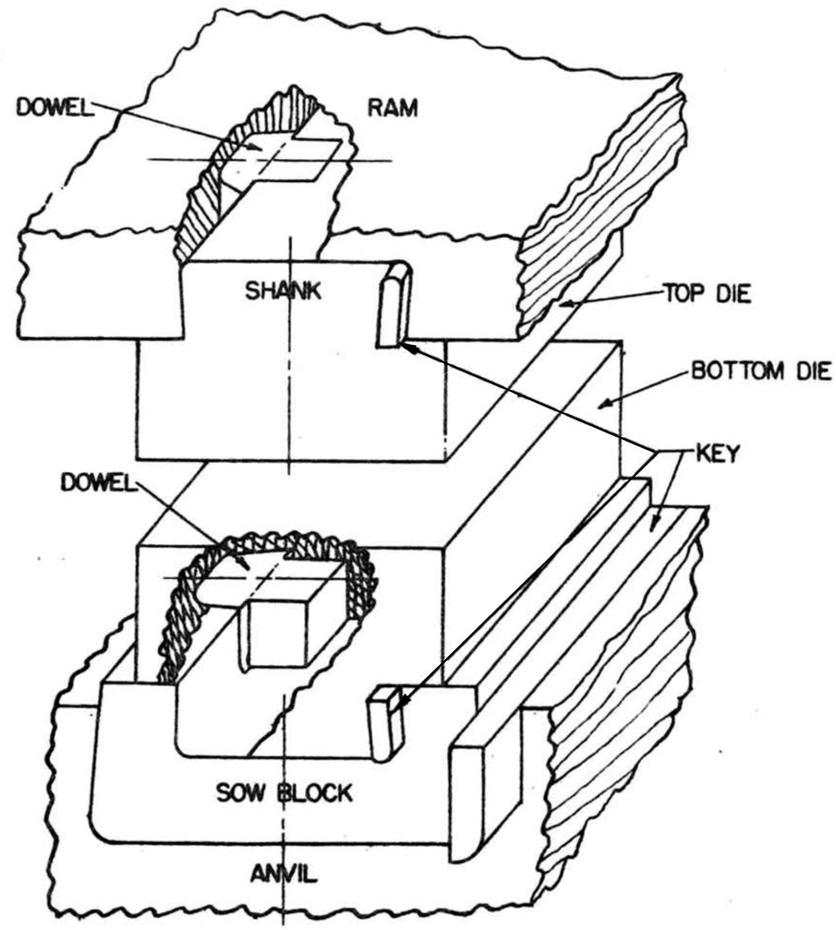
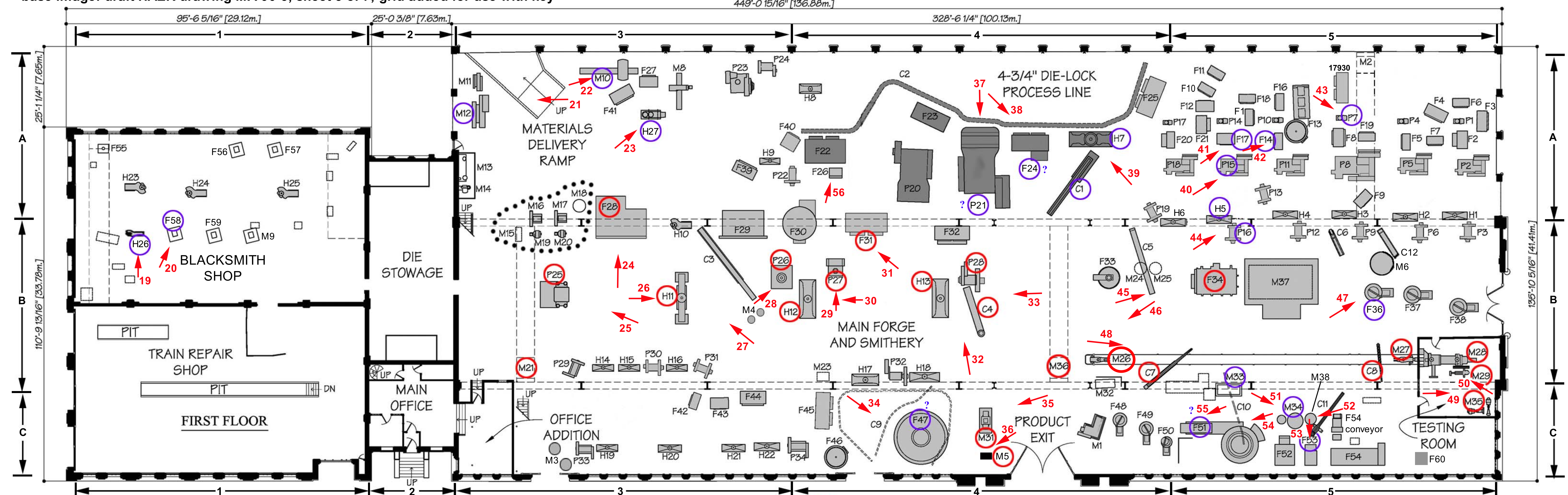


Figure 17. SCHEMATIC DIAGRAM OF TYPICAL CLOSED-DIE FORGING COMPONENTS
source: Department of the Navy 1968

Figure 18. KEY TO FIGURES 19-56: 2014 PHOTOGRAPHS OF SIGNIFICANT EQUIPMENT

base image: draft HAER drawing MA-90-3, sheet 5 of 7; grid added for use with key



SIGNIFICANT: RETAIN IN PLACE OR CLOSE TO ORIGINAL LOCATION

SIGNIFICANT: RETAIN IN NON-ORIGINAL INTERIOR OR EXTERIOR LOCATION
? = CONDUCT MITIGATORY DOCUMENTATION IF RETENTION NOT FEASIBLE

0 10 20 30 40 50 FEET
0 5 10 15 METERS

EQUIPMENT KEY (NPS NUMBER/NAVY NUMBER, DATE & FUNCTION IF KNOWN, GRID LOCATION

Not all key numbers on HAER drawing used; most pieces without manufacturer name were made at Navy Yard

F FURNACES

F1 Oil-Fired, 17979/230153 — A5
F2 17924/230181, 1944
F3 Oil-Fired, 17915/230020, 1942
F4 Oil-Fired, 17927/230100, 1941
F5 Oil-Fired, 17929/230168, 1944
F6 Oil-Fired, 17914/230128, 1944
F7 Oil-Fired, 17926/230169, 1944
F8 Oil-Fired, 17933/230167, 1943
F9 Oil-Fired, 17913/230129, 1944
F10 Oil-Fired, 17938/230127, 1944
F11 Oil-Fired, 17981/???
F12 Oil-Fired, 17937/230165, 1944
F13 Electric, 17934/230329, 1952 (with 3 transformers)
F14 Oil-Fired, 17935/230164, 1944
F16 17940/230178
F17 17942/230180
F18 17909/230187
F19 Oil-Fired, Rockwell Engineering Co., 17932/230150, 1900
F20 Oil-Fired, 17944/230166, 1944
F21 Oil-Fired, 17946/230177, 1944 — A5
F22 Oil-Fired, 17970/230159, 1943 — A4
F23 Slot, Oil-Fired, The Lithium Co., 17952/230293, 1953
F24 Slot, Oil-Fired, The Lithium Co., 17948/230294, 1953
F25 Oil-Fired, 17945/230131, 1944 for anchors
F26 Oil-Fired, 17969/230162, 1944 — A4
F27 Oil-Fired, Rockwell Engineering Co., 17966/230151, 1906 — A3
F28 Oil-Fired, 17964/230067, 1919 for anchors — A/B3
F29 Oil-Fired, 17962/230080, 1919 — A/B3
F30 Oil-Fired, Gas Machinery Co., 17961/230083, 1942 — A/B4
F31 Oil-Fired, 17956/230087, 1936 — A/B4
F32 Oil-Fired, 17953/230090, 1941 — B4
F33 Electric, Hevi-Duty Electric Co., 17884/230290, 1952 — B4
F34 Oil-Fired, Quigley Annealing Furnace Co., 17885/230103, 1915 — B5
F36 Electric, Lindberg Engineering Co., 17886/230109, 1942 Heat Treat — B5
F37 Electric, Lindberg Engineering Co., 17887/230110, 1942 Heat Treat — B5
F38 Electric, Lindberg Engineering Co., 17888/230111, 1943 Heat Treat — B5
F39 Oil-Fired, 17974/230176, 1944 — A3
F40 Oil-Fired, 17965/230017, 1921 — A3
F41 Oil-Fired, 17899/230023, 1942 — A3
F42 Oil-Fired, 17867/230132, 1944 — C3
F43 17868/230331 — C3
F44 Oil-Fired, 17869/230018, 1939 — C3
F45 Oil-Fired, 17854/230024, 1942 — C4
F46 Electric, General Electric Co., 17853/230328, 1952
F47 Gas-Fired, Lithium Co., 17852/230287, 1953 Heat Treat
F48 Electric, Lindberg Engineering Co., 17871/230040, 1940
F49 Electric, Lindberg Engineering Co., 17872/230042, 1938
F50 Electric, Lindberg Engineering Co., 17873/230407, 1952 Heat Treat — C4
F51 Electric, Electric Furnace Co., 17874/230045, 1930 Heat Treat — C5
F52 Oil-Fired, 17875/230049, 1917 Heat Treat
F53 Oil-Fired, 17876/230050, 1919 Heat Treat
F54 Electric, Lindberg Engineering Co., 17878/230055, 1942 Heat Treat — C5
F55-F59 Oil-Fired, 230059, 230205-230206, 230210-230211 Smith Fires — A/B1
F60 Electric, The Ajax Mfg. Co., 17879/230301, 1952 Salt Bath — C5

P PRESSES

P1 Pneumatic, 17925/230170, 1943 Bender — A5
P2 Forge, The Ajax Mfg Co., 17918/230133, 1943 Model 2 Upsetter — A5
P3 Mechanical, E.W. Bliss Co., 17900/230155, 1943 Model 205 Trim — B5
P4 Pneumatic, 17928/230171, 1943 Bender — A5
P5 Forge, The Ajax Mfg Co., 17919/230134, 1943 Model 2 Upsetter — A5
P6 Mechanical, E.W. Bliss Co., 17901/230118, 1943 Model 205 Trim — B5
P7 Pneumatic, 17931/230172, 1944 Bender — A5
P8 Forge, The Ajax Mfg Co., 17920/230135, 1939 Model 4 Upsetter — A5
P9 Mechanical, E.W. Bliss Co., 17902/230283, 1952 — B5
P10 Pneumatic, 17936/230173, 1943 Bender — A5
P11 Forge, The Ajax Mfg Co., 17921/230136, 1943 Model 2 Upsetter — A5
P12 Mechanical, E.W. Bliss Co., 17903/230115, 1941 Model 205 Trim — B5
P13 Mechanical, E.W. Bliss Co., 17910/230117, 1943 Model 205 Trim — A5
P14 Pneumatic, 17941/230174, 1944 Bender — A5
P15 Forge, The Ajax Mfg Co., 17922/230137, 1943 Model 2 Upsetter — A5
P16 17904/230119, 1941 Trim — B5
P17 Pneumatic, 17943/230175, 1943 Bender — A5
P18 Forge, The Ajax Mfg Co., 17923/230138, 1943 Model 2 Upsetter — A5
P19 Mechanical, E.W. Bliss Co., 17906/230140, 1943 Model 205 Trim — A4
P20 Forge, The Ajax Mfg Co., 17951/230093, 1936 Model 6 Upsetter — A4
P21 Forge, The Ajax Mfg Co., 17950/230302, c1950,Model 8 Upsetter — A4
P22 Mechanical, E.W. Bliss Co., 17968/230120, 1942 Model 205 Trim — A4
P23 Mechanical, The Ajax Mfg Co., 17973/230152, 1943 Model 7C — A3
P24 Mechanical, Erie Foundry Co., 17972/230001, 1937 Model 10 — A3
P25 Hydraulic, American Steel Foundries, 17839/230300, 1951 Model 8006 — B3
P26 Hydraulic, A.B. Farquhar Co., 17841/230081, 1941 Trim — B3
P27 Hydraulic, E.W. Bliss Co., 17843/230085, 1943 Model HS-200-H Trim — B4
P28 Mechanical, E.W. Bliss Co., 17845/230091, 1942 Model 208 Trim — B4
P29 Mechanical, Erie Foundry Co., 17861/230158, 1933 — B3
P30 Mechanical, E.W. Bliss Co., 17864/230010, 1941 Model 205 Trim — B3
P31 E.W. Bliss Co., 17866/230116 — B3
P32 Mechanical, E.W. Bliss Co., 17850/230030, 1944 — B4
P33 Mechanical, E.W. Bliss Co., 17860/230008, 1942 Model 205 Trim — C3
P34 Mechanical, Erie Foundry Co., 17855/230014, 1937 Trim — C4

H HAMMERS

H1 2,000 lb, Erie Foundry Co., 17917/230126, 1943 — A5
H2 2,000 lb, Erie Foundry Co., 17916/230139, 1943 — A5
H3 3,000 lb, Chambersburg Engineering Co., 17912/230291, 1951 — A5
H4 2,000 lb, Erie Foundry Co., 17911/230123, 1943 — A5
H5 1,500 lb, Chambersburg Eng. Co, 17908/230296, 1952 Model E — B5
H6 1,500 lb, Chambersburg Eng. Co, 17907/230297, 1952 Model E — B5
H7 25,000 lb, Erie Foundry Co., 17947/230292, 1951 — A4
H8 1,500 lb, Chambersburg Engineering Co., 17971/230154, 1942 — A4
H9 1,000 lb, Erie Foundry Co., 17967/230098, 1942 — A3
H10 2,500 lb, Erie Foundry Co., 17963/230073, 1941 — B3
H11 10,000 lb, Erie Foundry Co., 17840/230078, 1941 — B3
H12 12,000 lb, Erie Foundry Co., 17842/230083, 1941 — B4
H13 10,000 lb, Erie Foundry Co., 17844/230089, 1936 — B4
H14 1,000 lb, Chambersburg Engineering Co., 17862/230002, 1943 — B3
H15 1,500 lb, Alliance Machine Co., 17863/230004, 1939 — B3
H16 1,500 lb, Alliance Machine Co., 17865/230003, 1939 — B3
H17 3,000 lb, Chambersburg Engineering Co., 17851/230285, 1951 — B4
H18 3,500 lb, Erie Foundry Co., 17849/230029, 1943 — B4
H19 1,500 lb, Erie Foundry Co., 17859/230009, 1941 — C3
H20 2,000 lb, Chambersburg Engineering Co., 17858/230299, 1952 — C3
H21 2,000 lb, Chambersburg Engineering Co., 17857/230298, 1952 — C3
H22 2,000 lb, Erie Foundry Co., 17856/230015, 1936 — C3
H23 1,500 lb, Erie Foundry Co., ?/230189, 1941 — A1
H24 1,500 lb, Erie Foundry Co., ?/230201, 1941 — A1
H25 1,500 lb, Erie Foundry Co., ?/230188, 1941 — A1
H26 300 lb, Chambersburg Eng. Co., ?/230191, Model 1700 — B1
H27 300 lb, Chambersburg Eng. Co, ?/665012327, Model 10165-1 with built-in compressor — A3

C JIB CRANES AND HOISTS

C1 Jib, 17949/230304, 1954 — A4
C2 Mono-Rail, 17957/230314, 1953 — A4
C3 Jib, Cleveland Crane & Engine Co., 17897/230076 — B3
C4 Jib, 17846/230092, 1917 — B4
C5 Jib, Shephard Electric Crane Co., 17905/230107, 1904 — B4
C6 Jib, 17949?/230235 — B5
C7 Jib, Niles, Bement & Pond Co., 17976/230044 — B4
C8 Boom, 17882/230056 — B5
C9 Monorail/Conveyor — C4
C10 Trolley/Hoist — C5
C11 Traveling, Shepard Niles Crane and Hoist, 17877/316795, 1941 — C5
C12 Crane/Hoist — B5

M MISCELLANEOUS

M1 Forging Roll Machine, Ajax Model 2 — C4
M2 15-Ton, Traveling Crane, 17955/230229 — A5
M3 2 7.5'-high steel tanks, 17893-17894/??, 1961 — C3
M4 2 30-" dia. furnace baskets, 17891-17892/230351-230352 — B3
M5 Chain End Test Crushing Machine, 17848/230032, 1938 — C4
M6 Paint Pit, ?/230113 — B5
M8 Band Saw, Coall Co., 17975/230323, 1958 — A3
M9 Base of removed furnace, 230209 — B1
M10 Cut-Off Machine, Armstrong-Blum Mfg Co., 17977/313117, 1941 — A3
M11 Shearing Machine, Buffalo Forge Co., 17978/230147, 1935
M12 Shearing Machine, Buffalo Forge Co., 17898/230148, 1935
M13 Pump, ?/230072
M14 Small generator, ?/230071 — A3
M15-M20 Compressor, Pump, Motors for P25, 1951 — A/B3
M21 15-Ton, Traveling Crane, ?/230108 — B3
M23 Electrical power box?, ?/230281 — B4
M24-M25 2 24-" dia. furnace baskets, 17889-90/230347-48 — B4
M26-M29 Chain Testing Machine, Tinius Olsen Testing Machine Co., 17881/230060, 1918 — B4/5
M31 Tensile Impact Testing Machine, 177847/230033,1938 — C4
M32 Magnetic Particle Inspection Machine, Magna Flux Corp., 17870/230053, 1945 — C4
M33 Quenching Tanks, 17883/230047 — C5
M34 5'-dia. steel quench tank, ?/230052 — C5
M35 Pumps, Worthington Pump Machine Co., 17880/313086, 1940 — C5
M36 25-Ton Traveling Crane , ?/230108? — B4
M37 Wheelabrator, American Foundry Equipment Co., ?/230355 [removed - depression in floor] — B5
M38 3.5'-dia. steel quench tank with water pipes, ?/230051? — C5

Figure 19. 2014 VIEW NORTH OF CHAMBERSBURG 300-LB HAMMER (Figure18: H26)

Figure 20. 2014 VIEW NORTH OF TYPICAL FIRE IN BLACKSMITH SHOP (Figure18: F58)

Figure 21. 2014 VIEW WEST OF BUFFALO FORGE COMPANY SHEARS, WITH WILLIAM JOHNSON (Figure 18: M11, M12)

Figure 22. 2014 VIEW NORTHEAST OF ARMSTRONG-BLUM CUT-OFF MACHINE (Figure 18: M10)

Figure 23. 2014 VIEW NORTHEAST OF CHAMBERSBURG 300-LB HAMMER WITH BUILT IN COMPRESSOR (Figure 18: H27)

Figure 24. 2014 VIEW NORTH OF OIL-FIRED FURNACE FOR ANCHOR SHANKS (Figure 18: F28)

Figure 25. 2014 VIEW NORTHWEST OF AMERICAN STEEL FOUNDRIES HYDRAULIC PRESS, USED FOR ANCHOR SHANKS (Figure 18: P25)

Figure 26. 2014 VIEW EAST OF 10,000-LB ERIE HAMMER (Figure 18: H11)

Figure 27. 2014 VIEW NORTHWEST OF 10,000-LB ERIE HAMMER (Figure 18: H11)

Figure 28. 2014 VIEW NORTHEAST A. B. FARQUHAR HYDRAULIC PRESS (Figure 18: P26)

Figure 29. 2014 VIEW NORTH OF E. W. BLISS COMPANY HYDRAULIC PRESS (Figure 18: P27)

Figure 30. 2014 VIEW WEST OF 12,000-LB ERIE HAMMER (Figure 18: H12)

Figure 31. 2014 VIEW NORTHWEST OF OIL-FIRED HEATING FURNACE (Figure 18: F31)

Figure 32. 2014 VIEW NORTH OF 10,000-LB ERIE HAMMER (LEFT), JIB CRANE (RIGHT), AND E. W. BLISS MECHANICAL TRIM PRESS (CENTER BACKGROUND) (FIGURE 18: H13, C4, P28)

Figure 33. 2014 VIEW WEST OF 10,000-LB ERIE HAMMER (BACKGROUND), JIB CRANE (LEFT), AND E. W. BLISS MECHANICAL TRIM PRESS (RIGHT) (Figure 18: H13, C4, P28)

Figure 34. 2014 VIEW SOUTHEAST OF GAS-FIRED LIITHIUM COMPANY ROTARY FURNACE (Figure 18: F47)

Figure 35. 2014 VIEW SOUTHWEST OF TENSILE IMPACT TESTING MACHINE (CENTER), CHAIN END TEST CRUSHING MACHINE (LEFT) AND LITHIUM COMPANY ROTARY FURNACE (RIGHT BACKGROUND
(Figure 18: M31, M5, F47)

Figure 36. 2014 DETAIL VIEW SOUTHWEST OF CHAIN END TEST CRUSHING MACHINE
(Figure 18: M5)

Figure 37. 2014 VIEW SOUTH OF AJAX MODEL 8 UPSETTER, WITH WILLIAM JOHNSON (Figure 18: P21)

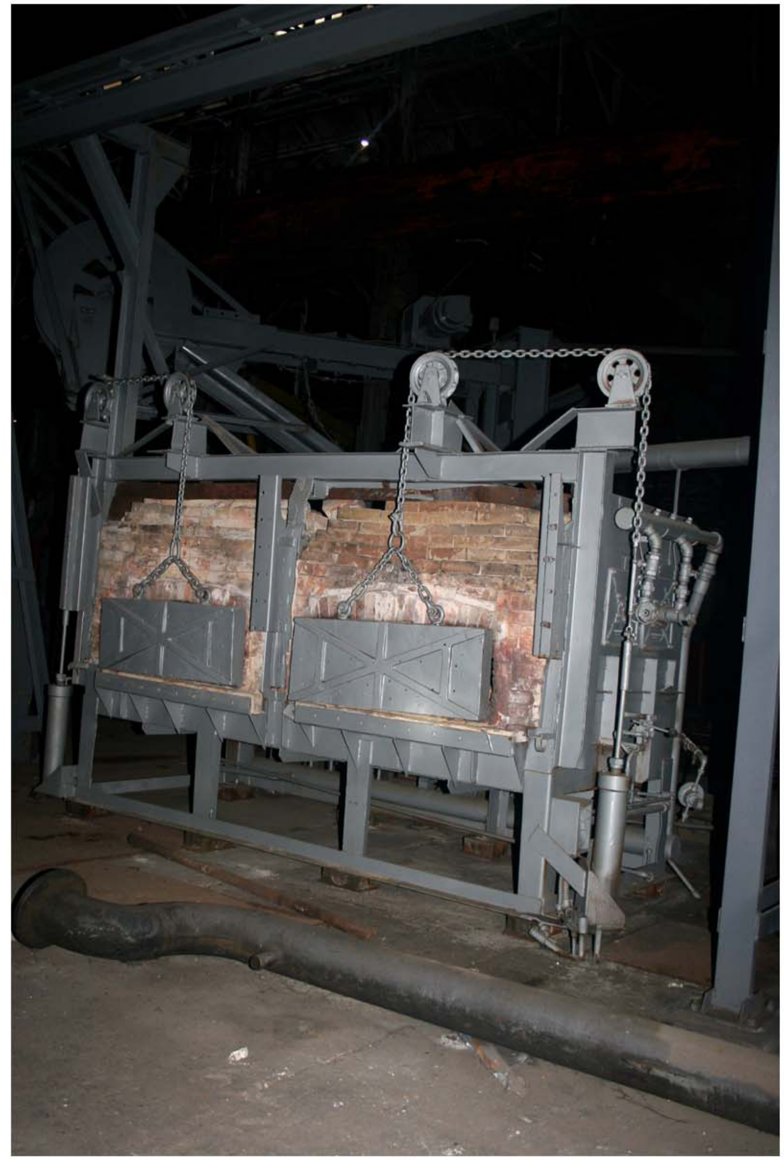


Figure 38. 2014 DETAIL VIEW SOUTHEAST OF OIL-FIRED LITHIUM COMPANY FURNACE (Figure 18: F24)

Figure 39. 2014 VIEW NORTHWEST OF 25,000-LB ERIE HAMMER (Figure 18: H7)

Figure 40. 2014 VIEW NORTHEAST OF AJAX MODEL 2 UPSETTER (Figure 18: P15)

Figure 41. 2014 VIEW NORTHEAST OF OIL-FIRED FURNACE
(Figure 18: F17)

Figure 42. 2014 VIEW EAST OF OIL-FIREDFURNACE
(Figure 18: F14)

Figure 43. 2014 VIEW SOUTHEAST OF PNEUMATIC BENDER (Figure 18: P7)

Figure 44. 2014 VIEW NORTHEAST OF 1500-LB CHAMBERSBURG HAMMER (LEFT) AND TRIM PRESS (RIGHT) (Figure 18: H5, P16)

Figure 45. 2014 VIEW EAST OF OIL-FIRED QUIGLEY CAR-BOTTOM ANNEALING FURNACE (Figure 18: F34)

Figure 46. 2014 VIEW SOUTHWEST OF 25-TON TRAVELING CRANE (Figure 18: M36)

Figure 47. 2014 VIEW NORTHEAST OF ELECTRIC LINDBERG HEAT TREAT FURNACE (Figure 18: F36)

Figure 48. 2014 VIEW EAST OF CHAIN TESTING TRENCH, BOOM (RIGHT) AND JIB CRANE (CENTER) (Figure 18: M26, C7, C8)

Figure 49. 2014 VIEW EAST OF TINIUS OLSEN TESTING MACHINE (LEFT) AND ASSOCIATED PUMPS (RIGHT) (Figure 18: M28-29, M35)

Figure 50. 2014 VIEW NORTHWEST OF TINIUS OLSEN TESTING MACHINE (Figure 18: M28-29)

Figure 51. 2014 VIEW SOUTHEAST OF QUENCH TANKS, STEEL BASKET, AND TRAVELING CRANE (CENTER), OIL-FIRED HEAT TREAT FURNACES (RIGHT & CENTER BACKGROUND) (Figure 18: M34, MM38, C11, F52, F53)

Figure 52. 2014 VIEW WEST OF OIL (REAR) AND WATER-PIPE-FITTED QUENCH TANKS (Figure 18: M38, M34)

Figure 53. 2014 VIEW SOUTH OF 1917 OIL-FIRED HEAT TREAT FURNACE (Figure 18: F53)

Figure 54. 2014 VIEW SOUTHWEST OF 1930 OIL-FIRED GAS MACHINERY COMPANY ROTARY HEAT TREAT FURNACE WITH CONVEYOR (Figure 18: F51)

Figure 55. 2014 DETAIL VIEW SOUTHWEST OF CONVEYOR ON 1930 OIL-FIRED GAS MACHINERY COMPANY ROTARY HEAT TREAT FURNACE (Figure 18: F51)

Figure 56. 2014 DETAIL VIEW NORTH OF UPSETTER GRIPPER DIES FOR DIE-LOCK CHAIN SOCKETS, IN FRONT OF OIL-FIRED HEATING FURNACE(Figure 18: F26)

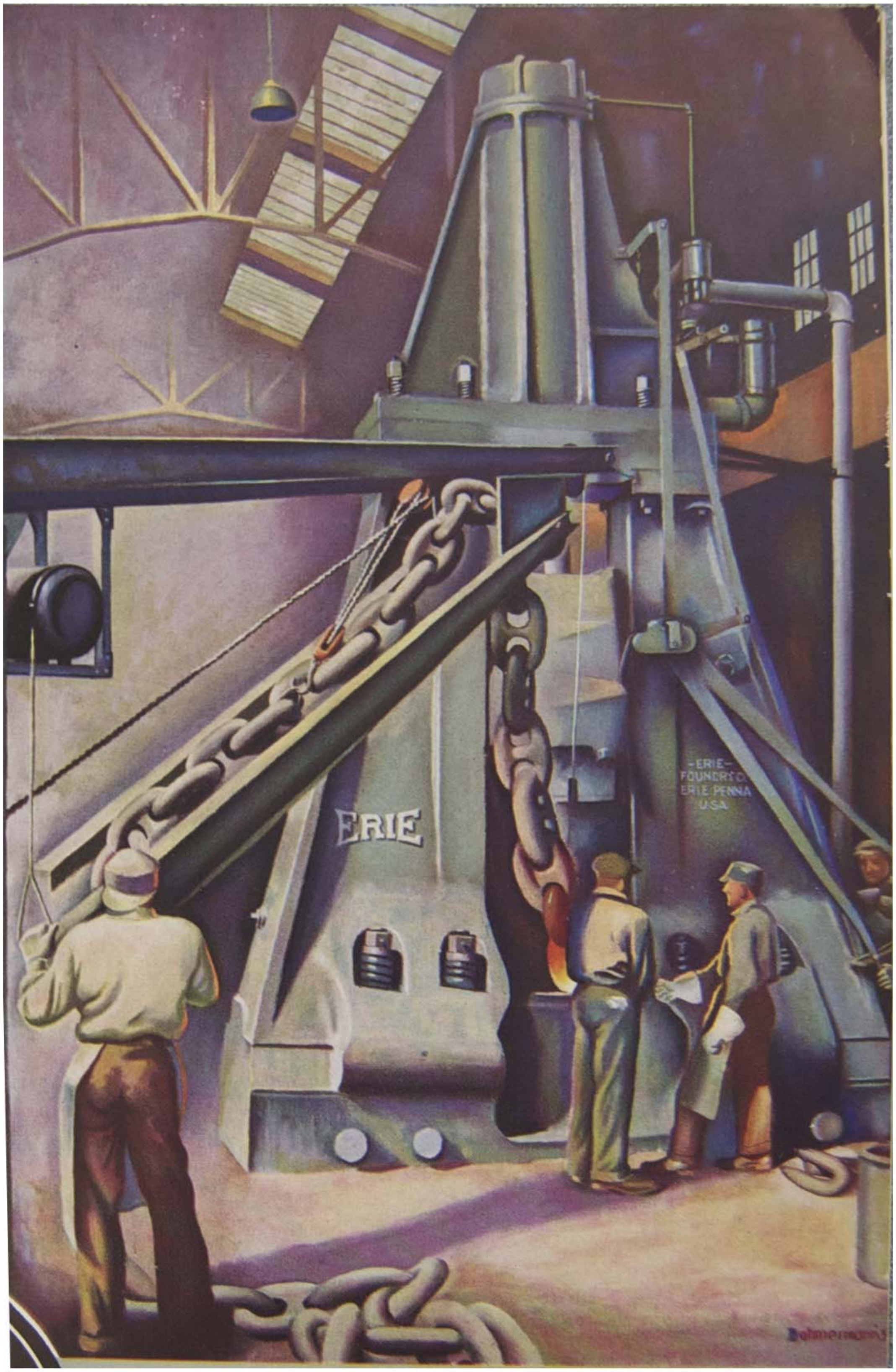


Figure 57. c1938 CATALOG PAINTING OF CHAIN ASSEMBLY AT HAMMER "BIG BARNEY"
View is to northwest, with hammer and jib crane (Figure 2: H13, C4)
source: Erie Foundry Company 1938

Figure 58. 1942 PAINTING OF CHAIN ASSEMBLY AT HAMMER "BIG BARNEY"
Walter Draper
View is to northeast, with hammer, jib crane, and trim press replaced in 1942
(Figure 2: H13, C4; see Figure 33)
source: BOSTS 7000