JOHN A. ROEBLING'S SONS COMPANY,
KINKORA WORKS
(Roebling Steel Company)
(Colorado Fuel and Iron, Roebling Works)
(Roebling Steel Superfund Site)
(JARSCO)
2nd and Hornberger Ave
Roebling
Burlington County
New Jersey

HAER No. NJ-122

HAER
NJ
3-ROEBL,
1-

WRITTEN HISTORICAL AND DESCRIPTIVE DATA
REDUCED COPIES OF MEASURED AND INTERPRETIVE DRAWINGS
PHOTOGRAPHS

HISTORIC AMERICAN ENGINEERING RECORD
NATIONAL PARK SERVICE
DEPARTMENT OF THE INTERIOR
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HAER
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HAER No. NJ-122

Location: Roebling, Burlington County, New Jersey
USGS Quadrangles

Date of Construction: 1904

Fabricator: John A. Roebling's Sons Company

Present Owner: U.S. Environmental Protection Agency

Present Use: U.S. E.P.A. Superfund Site

Significance: In 1904, the John A. Roebling's Sons Company began construction of the Kinkora Works, a state of the art steel making, rod rolling, and wire drawing facility. During their ownership (1904-1953), the Roeblings implemented many of the significant developments in wire making at Kinkora while producing the wire used in some of America's most noted engineering achievements, including several prominent cable suspension bridges. The lasting family control over the Kinkora Works and nearby worker village offer a unique view of an independent steel and wire mill in an era and industry dominated by corporate conglomerations.

Historian: Matthew Sneddon, August 1997

Project Information: This project is part of the Historic American Engineering Record (HAER), a division of the National Park Service devoted to the documentation of the engineering and industrial heritage of the United States. Project co-sponsored by the U.S. Environmental Protection Agency under Remedial Project Manager Tamara Rossi and Cultural Resources Expert John Vetter.

Field work, measured drawings, photographs and a historical report were prepared under the general direction of Eric N. DeLony, Chief of HAER. The project was managed by Richard O'Connor, HAER Historian and Thomas M. Behrens, NCSHPO/HAER Architect. The field team consisted of field supervisor Dan Bonenberger (WVU Institute for the History of Technology and Industrial Archeology); architectural technicians Lee Clausen (Clemson University), Alivia Owens (University of Arkansas), Oliver Schreiber (ICOMOS/Technical University Vienna), Amy Wynne (Lehigh University); historian Matthew Sneddon (Lehigh University); and Photographer Joe Elliot.

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The John A. Roebling's Sons Company began a new phase of expansion in 1904 with the construction of the Kinkora Works near Florence Township in New Jersey. The facility designed by Charles G. Roebling was intended primarily to make wire for the company's rope making shops in Trenton. Aside from providing the means of increasing production, site plans added two significant dimensions to the Roebling enterprise: on-site steel making capabilities and a company village dedicated to housing the plant workforce. By 1952, the last year of ownership by the Roebling company, the Kinkora Works had produced the wire for the submarine nets and minefields used in two world wars; airplane control cables for the Spirit of St. Louis and C-74's that supplied Berlin; and the wire for the George Washington and Golden Gate bridges, adding to a legacy of wire making and bridge building that established the Roeblings in the ranks of great turn of the century industrial entrepreneurs.

The scope of a three month study of the John A. Roebling's Sons Company (JARSC) by the Historic American Engineering Record (HAER) is confined to a technological history of the processes and products manufactured at the Kinkora Works; yet underlying the technological developments that shaped wire making at Kinkora were fundamental changes – the mechanization of manufacturing, the increasing role of scientific research and development, and the displacement of skilled labor – that affected early twentieth-century American industry more broadly. Rather than emphasize, as past histories have, the remarkable personalities of the Roebling family, this study examines the system the Roeblings built around the technology of wire rope.[1] From a single, central invention – a method for stranding wire together – a technological system incorporating machinery, labor and

[1]An eccentric figure of firm convictions, company founder John A. Roebling has attracted most of the attention given the history of the Roebling enterprise. See Hamilton Schuyler, *The Roeblings: A Century of Engineers, Bridge-builders, and Industrialists* (Princeton: Princeton University Press, 1931); D.B. Steinman, *Builders of the Bridge* (New York: Harcourt, Brace and Company, 1945); John Mumford, *Outspinning the Spider* (New York: Robert L. Stillson Co., 1921).

management evolved to control both manufacturing from raw materials to finished product and engineering the application of wire and wire rope in bridges, buildings, and tramways.[2] The success of the product at Kinkora was tied to the efficacy of the system: the quality of wire and production capacity depended on efficient coordination of steel making, hot rolling and drawing processes, processes continually altered by technological change. During the era of Roebling ownership from 1905 to 1953, the Kinkora site witnessed three significant phases of development: (1) initial system design and construction; (2) implementation of continuous-type technologies; and (3) system ossification and obsolescence. A brief background history of the JARSC and the wire drawing industry sets the context for a discussion of the forces that governed the form, evolution, and decline of the technological system built at Kinkora.

## 1.0 ORIGINS OF WIRE ROPE AND THE JOHN A. ROEBLING'S SONS COMPANY

The early history of the wire rope industry is linked to the technologies that emerged from the nineteenth century industrial revolution. Wire rope provided an improved means of transmitting power and work that found application in new developments in transportation, mining, and communications. The superior durability and strength of wire based rope had a far reaching impact on engineering, permitting consideration of innovative designs previously limited by strength of materials and cost.

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[2]Thomas Hughes develops the concept of technological systems in *American Genesis* (New York: Penguin Books, 1990) and Bijker, Hughes, and Pinch, eds., *The Social Construction of Technological Systems* (Cambridge, MA: The MIT Press, 1987). "Systems" are a useful means of connecting both the physical and social elements of technologies by looking beyond individual inventors and inventions to examine the broader scope of technological development. The "essence of modern technology," Hughes argues, lies in the geographic and political context, organizational structures, and physical elements that have shaped the growth of large systems such as the generation and distribution of electricity, telegraphy and telephony, and transportation networks.

Many of the notable nineteenth and early twentieth century engineering achievements in the United States -- the Panama Canal, Empire State Building, Washington Monument, and massive federal dam projects, built with cable-based excavating apparatus, material conveyance systems or made feasible by cable supported elevators -- owed some debt to wire rope.

The development of long span bridge construction particularly benefitted from the high load bearing characteristics of iron and steel cables. Suspended bridges have an ancient history, but the earliest types built with iron chains or organically based (largely hemp or vines) suspenders had limited use on relatively small scale spans. Increased iron production in Great Britain as a result of the Industrial Revolution lowered the cost of ferrous materials such that a new generation of bridge builders began using iron more widely, initially in truss, tubular, or chain-suspension designs. Use of iron sparked the imagination of engineers who now believed new distances within the reach of long span bridges. The histories of both wire rope and long span suspension bridge building in the United States converge in the central figure of John A. Roebling.

## 1.1 John A. Roebling

Before emigrating to the United States in 1831, John Roebling received a technical training as an engineer at Berlin's Royal Polytechnic Institute and worked as a road builder for the Prussian civil service. He took special interest in bridges and visited the sites of innovative European designs, such as the chain-supported suspension bridge over the River Regnitz in Baumberg that provided a basic conceptual platform for later work in America.[3] Thus Roebling arrived in the U.S. with two advantages that would serve him well in the course of future events: a technical education difficult to obtain in a country with few engineering schools, and exposure to recent trends in European civil engineering.

Acknowledged as the first manufacturer of wire rope in America, John Roebling initially conceived of wire rope in 1840 as a superior substitute for hemp ropes used to pull canal barges

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[3]Schuyler, 14.

up inclined portages. Roebling later applied his training as an engineer and knowledge of wire rope making to bridges, pioneering several methods of construction and engineering many of the early suspension bridges in America, including the Niagara, Cincinnati, and Brooklyn bridges. After John's death in 1869, his sons greatly increased both the output and range of products manufactured in their Trenton, N.J. plant, but the history of the Roebling company remained closely tied to suspension bridge building. Establishment of a bridge division in the Roebling company set a precedent in the wire rope industry followed by other leading manufacturers, and several product, testing, and construction innovations resulted from their involvement in (the Bear Mountain, George Washington, Golden Gate, and La Paz) bridge projects. Maintaining a direct link between the manufactured product and its application proved an influential factor in distinguishing the Roebling company technologically and within the wire industry.

The inspiration behind the first manufacture of wire rope involved little of the "eureka" visions associated with future inventors such as Thomas Edison, Elmer Sperry, and Nikolas Tesla. Roebling's development of a method for stranding wire rope proceeded along empirical lines, marked by failure and success, and informed by investigations of American Charles Ellet Jr.'s work and European efforts in England and Hannover. The company history, *The Roebling Story,* reported that Roebling recalled from a scientific journal a previous attempt by a German engineer to make wire rope, and simply employed a traditional hemp rope walk to strand wire into rope.[4] Notwithstanding the relatively pedestrian origins of wire rope making, the torsion produced by twisting individual wires into strands required careful consideration of stranding techniques. John Roebling developed and patented a method to wind rope in a manner that maintained uniform tension in each wire, and later machinery he designed to strand without inducing internal torsion stress was so complex that his son Washington admitted that only his father and the

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[4]John A. Roebling's Sons Company, *The Roebling Story* (Trenton: John A. Roebling's Sons Company, 1941), 5 and Schuyler, 50.

superintendent Charles Swan understood its design and operation.[5]

Securing the contracts to replace hemp ropes with wire ones on the inclined portages of the Pennsylvania canal allowed Roebling to establish himself as a reputable independent engineer. By 1844, Roebling successfully executed his first suspension bridge to carry an aqueduct over the Allegheny River, but continued to face professional and popular resistance to suspension designs during his lifetime.

The practicality of suspension bridges rested partially on the reduction of towers needed to support the structure, thereby decreasing not only the amount and cost of materials, but its substantial appearance as well. Several failures of suspension bridges in America and Europe contributed to an inveterate skepticism of the stability of suspension designs. Roebling avoided the collapses that plagued his competitors with engineering acumen -- realizing vibrations caused by winds and uneven surface loading were the worst enemies of a suspension bridge, he devised a means of stiffening the structure with bottom trusses and cable guys from the towers.

For his early ropes, John Roebling depended largely on outside sources of wire, but as the increasing demands of his contracts began to overburden the capacity of the rope walk stretched out in a meadow on his Saxonburg farm east of Pittsburgh, Roebling realized expansion required relocating to a site with better access to supplies and markets. According to family historian Hamilton Schuyler, Peter Cooper, a noted iron maker in Trenton, N.J., recognized a potential customer in Roebling's wire rope business and recommended Trenton as site well-suited for industrial growth. Although the papers of John A. Roebling yield no evidence of any communications between Cooper and Roebling, Trenton had obvious advantages as a city in close proximity to New York and Philadelphia that possessed accessible canal and railroad lines, available labor from the nascent iron and steel industries, and the local supply of rods and wire. Roebling purchased a 25 acre farm across the Delaware

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[5]Clifford W. Zink and Dorothy White Hartman, *Spanning the Industrial Age* (Trenton: Trenton Roebling Community Development Corporation, 1992), 33.

Canal from Cooper & Hewitt's Trenton Iron works in 1848. The construction of a small wire drawing mill, rope walk, and boiler house to generate steam power marked the beginnings of a family-owned and managed business that would grow by 1953 into a multi-million dollar corporation.

**1.2 Roebling Wire Manufacturing in the Era of Steel**

Prior to the availability of inexpensive steel, the Roeblings primarily drew wire from iron using traditional methods that had remained relatively static over the preceding centuries. Except for its steam power source, the first wire drawing bench in Trenton differed little from seventeenth-century equipment used to draw wire. In essence, the basic process consisted of pulling a metal rod through a die, thus reducing the cross sectional area and correspondingly elongating the rod. The rods, or wire, were paid off from spools or "swifts" and pulled through a die and wound by a driven cylindrical "block." Until electric motors gained wider use after the turn of the century, a central steam engine typically powered the blocks through a set of belts, drive trains, and gears. The wire was stripped from the block by hand, and placed on a new swift feeding a smaller die if further drawing was necessary. Repetition of this procedure, commonly called "a draft," further reduced the cross sectional area to the desired size. The gage classification of wire sizes still in use today is roughly based on the nineteenth-century measurement of how many drafts a wire must pass through an iron die to obtain a given diameter.[6]

The era of steel initiated by the Bessemer converter in the early 1870s introduced a new world of complexities into wire making. Although substantially less expensive to produce or buy than older methods of steelmaking, the poorer quality of Bessemer steel caused many headaches for the Roeblings. First, the brittleness of the Bessemer steel exacerbated the substantial adjustments needed to make the transition from rolling and drawing iron to steel. Reducing a steel ingot to wire involved a multitude of intermediate processes, each greatly influenced by

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[6]A.O. Backert, ed., *The ABC of Steel* (Cleveland: The Penton Publishing Co., 1921), 195.

the quality and composition of the steel. The techniques and equipment used in rolling steel into rods, and cleaning, heat treating, and drawing the rods into wire had to be reevaluated and altered to fit the new material. Secondly, the consolidation of the steel industry that provided Bessemer steel to wire companies changed the corporate character of the wire industry.

Before Bessemer steel, little vertical integration existed in the early U.S. wire industry. Wire manufacturers either purchased rods or rolled them from billets, bars, or blooms provided by rolling mills. Independent rolling mills, or those integrated with steel manufacturers, reduced ingots cast by iron or steel mills to supply the rod mills. Because wire drawing was a function of the quality of the process that preceded it, the wire industry was particularly susceptible to tariffs or attempts to control the price of rods or billets. Steel magnates such as Andrew Carnegie, John Gates and Elbert Gary later exploited this vulnerability to bankrupt and purchase some competitors and force vertical integration in others. John Roebling drew the wire for his ropes from purchased iron rods, but his three sons, Washington, Ferdinand, and Charles, who managed the company after his death began to backwardly integrate the JARSC to ensure a more predictable and controllable supply of the raw materials.

While learning to draw wire from steel, the Roeblings concurrently developed different types of wire rope to best match the variegated uses surfacing in industrializing America. If intended for rope, a drawn and coiled wire was only one element of a machine "composed of a number of precise, moving parts, designed and manufactured to bear a very definite relation to one another."[7] Wire could be stranded in a bewildering assortment of patterns tailored for general or specific uses. By differing the quality and size of the steel wire, the "lay" of the wire, and the rope core, the flexibility, durability, and strength could be widely varied to suit applications from elevator cables to airplane control cords. The complexities of manufacturing quality wire rope tended to separate the field in nineteenth-century wire making, encouraging companies to distinguish their standard bearers by trademarking the name of their best wire

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[7]John A. Roebling's Sons Company, *Roebling Wire Rope Handbook*, unpublished engineering manual, 1944.

rope. The Roeblings dyed the hempen core of their best wire rope blue, differentiating their product visually and providing the origin for the label "Blue Center."

## 2.0 PHASE ONE - SYSTEM DESIGN AND CONSTRUCTION

A turning point in the history of the JARSC occurred in 1898 when the Roebling brothers declined a buyout offer from industrialists forming the American Steel & Wire Company (AS&WC). The consolidation of the wire industry, culminated by the AS&WC's acquisition of most of the wire production in the United States, was a precursor to the next great step in the genesis of the steel oligopoly, the formation of the United States Steel Corporation in 1901. Harvard Business School historian Alfred Chandler Jr. labeled the building wave of mergers and consolidations that had reshaped American industry since the 1880s "the most important single episode in the evolution of the modern industrial enterprise in the United States."[8] Resisting absorption by the AS&WC excluded the JARSC from trends such as the reduction of family control, the inclusion of financial institutions in the board of directors, and the nascent organization of managerial hierarchies taking form as a result of industrial consolidations.[9] By retaining family ownership of the company, the Roebling brothers faced an unusual business horizon in the new century with personal control over the direction and shape of the technological system of manufacturing wire products, and new competition from vertically integrated industrial giants. Their vision of success in the changing environment was manifested in the plans for Kinkora. The site layout, decision to include a steel mill and worker village, and choice of selection of certain technologies emphasized optimum flexibility, control and efficiency, reflecting the progressive rationalization of technological systems in early twentieth-century American industry.

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[8]Alfred D. Chandler Jr., *Scale and Scope: The Dynamics of Industrial Capitalism* (Cambridge, MA: The Belknap Press of Harvard University Press, 1990), 79.

[9]Chandler, 80, 85.

**2.1 Planning the Kinkora Works**

The farmland purchased for the new plant presented the Roebling system builders with a clean slate. Unimpinged by city growth, the experience of fifty years of manufacturing wire rope could be tangibly expressed in the Kinkora Works. Because the giant 30 ton and 80 ton rope machines built by Charles Roebling to strand wire into wire rope were too heavy and cumbersome to move from Trenton, the Roeblings dedicated the Kinkora facility to primarily making wire that would be sold in coils or finished as rope, insulated wire, or flat wire at Trenton. The river front property provided an easy access to barge traffic, and ensured a ready supply for the large quantities of water needed to make steel. Several outfalls spilled plant wastes into the river, and the Roeblings used their riparian rights to expand the property by dumping slag from the steel mill along the river front to provide foundations for future buildings.

Characteristic of many turn of the century industries, site layout emphasized process flow efficiency and future expansion. Considering the scale of Kinkora, the debt owed the principle engineer, Charles G. Roebling was substantial. Charles arranged the location of all buildings and equipment for the plant and the village, laid out plans for much of the machinery, and integrated a network of railroad tracks to facilitate the transfer of materials. Placement of the steel, blooming, rod, and wire mills in parallel reflected the trend toward continuous processing on a longitudinal axis -- process flow traveled roughly in a straight line from end to end, allowing anticipated growth to be met by lengthwise extensions.

In contrast, the arrangement of buildings at Trenton had impeded efficient flow between processes. Property purchased to supplement the original 1848 twenty-five acre plot afforded insufficient flexibility to accommodate the dynamic forces shaping the wire industry in the last half of the nineteenth century. New competition, unpredictable economic contingencies, and innovations in rolling technology were driving the industry toward vertical integration and corporate giantism. The explosive demand for wire brought by the invention of the telegraph attracted major manufacturers, including Washburn & Moen and the Trenton Iron Company to wire making. By the 1890s, the development of aerial tramways (used by the mining industry to carry excavated materials), elevator cables, log haulers, and urban cable car systems using wire rope prompted the installation of wire rope machinery at several wire makers, such as the American Steel & Wire Company and National Wire Company. The new competitors, combined with the expansion of the few established wire rope makers such as the Hazard Company and A. Leschen & Sons, eroded the John A. Roebling's Sons Company's sixty to seventy percent market share of the wire rope business in the 1880s.[10]

The market instabilities in the nineteenth-century wire market proved particularly difficult for smaller operations to weather, and persuaded the Roeblings to integrate vertically. Protective tariffs on iron bars or billets could require expensive solutions that put small wiremakers out of business. Responding to tariffs in the 1870s that affected the supply of Swedish iron bars, Charles Roebling invested large sums in a steam hammer to produce billets from domestically available ingots that was subsequently scrapped when the tariffs were dropped.[11] The fluctuating market for billets and rods encouraged backward integration into rolling and consolidation in the wire industry. The pursuit of greater output capacity in hot rolling steel led to mechanized, continuous rolling mills. Improvements in steam engines and roll casting enabled larger, more powerful and costly rolling machinery, elevating the capital requirements of maintaining a competitive position in the billet and rod rolling industry. As a result of experiments conducted by a class of innovative mechanical tinkerers including George Bedson, Charles Morgan, and William Garrett, improvements in rolling technologies in the 1880s and 1890s added to the capital costs of rolling. Adapting to the protean climate of the wire rope industry, JARSC integrated vertically, rolling its own billets and creating the Insulated Wire Division and New Jersey Wire Cloth Company to manufacture finished products. The construction of new rope houses, rolling mills, galvanizing, tempering, and annealing shops and the demolition of outdated structures to support this integration occurred ad hoc in available space,

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[10]Zink and Hartman, 75.

[11]Schuyler, 333.

complicating the logistics of manufacturing good wire and wire rope.

Much of Kinkora's design and construction drew on lessons learned from Trenton. Charles Roebling centrally situated a boiler and power house to provide steam and electricity for the entire plant, alleviating the waste and inefficiency of Trenton's scattered boilers.[12] The expansive site allowed for single story design of most buildings, avoiding the fire hazards and difficulties of transmitting power to multi-story structures that plagued the Trenton plant. While a combination of steel and timber supported the structure of many Trenton mills, at Kinkora Charles used only steel construction.[13] Steel as a structural material had several advantages over timber -- it allowed a wider building design and was thought to reduce the danger of fires.

Although Kinkora was considered a state-of-the-art facility, Trenton's shortcomings had not provided the only inspiration. In May 1902, the Grand Crossing Tack Company began ground breaking for a plant outside Chicago to manufacture wire, woven fence, nails, and staples. Although the original construction included only a steel mill, blooming mill, boiler house, and machine shop, the parallel layout of the buildings and placement of the rail lines anticipated the Kinkora design.[14] Similarly, Kinkora's arrangement of buildings and equipment loosely followed that of the American Steel & Wire Company's new Donora Works in Donora, PA, detailed in a December 1903 issue of Scientific American.[15] Although reports on new plant constructions in the *Iron Age*, *Iron Trades Review*, *Engineering*, and *Engineering News* often lagged a year or two behind erection dates, the trade magazines illustrate Kinkora's antecedents in the wire industry.

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[12]"Improving Flexibility and Cost of Power." *Iron Age* (April 17, 1924): 1141-1143.

[13]Zink and Hartman, p.111.

[14]"Steel Plant of the Grand Crossing Tack Company," *Iron Age* (August 4,1904):16.

[15]"Steel Wire and Nail Making," *Scientific American* (December 12, 1903)

Despite these general guides to the latest developments in steel and wire mill construction, Kinkora reflected a layout oriented around manufacturing bridge wire. In plants intended to draw low carbon wire, rod bundles generally traveled to the cleaning house before entering the wire mills. At Kinkora, an arterial railroad line delivered rod bundles directly to the Tempering Shop for a patenting treatment largely unique to processing high carbon wire. A large Galvanizing Shop accommodated several galvanizing rigs for applying a corrosion resistant coating of zinc to wire that became common practice in specifying bridge wire after the Brooklyn Bridge. Some forty years in the wire business had impressed upon the Roebling brothers the need to arrange the buildings and equipment toward a certain product. Attempting to enter into growing but unfamiliar markets could tax the profitability system designed for certain wire products. Washington Roebling recalled a venture into the wire-nail business in the late nineteenth century was abandoned, "not because it was intrinsically bad, but because it was necessary to make it one's principal line of production and arrange the entire plant with a view towards that one focus."[16]

**2.2 Influence of Product on System Design**

Foreseeing the direction of the wire rope industry in 1901, the Roebling brothers agreed that survival depended on the capacity to produce steel. The increasing number of steel mills in the wire industry stemmed from the introduction of open hearth furnaces in steelmaking, and the desire to control the quality and variety of the product. The JARSC had established its reputation drawing high carbon steel into high strength wire for their bridge cables, which necessitated importing superior grades of foreign steel. In addition to freeing a company from the vagaries of the global steel trade, the steel mill allowed for exacting control of the chemical composition so crucial to the hardness, toughness, strength, ductility and uniformity of the end product. With skilled supervision of the melting process, the carbon content of the molten iron could be manipulated to yield low, medium, and high carbon steels. Although strength,

[16]Schuyler, 335.

ductility, hardness, and corrosion resistance of steel varies widely with different chemical constituents, carbon content is the principle factor in classifying a steel by composition.[17] The easily drawn more pliable and ductile low carbon steels made useful tie wires and screen wire cloth. Having an outlet for low carbon steels dovetailed with early open hearth practices. Before metallurgical testing apparatus became available, carbon content of the steel relied largely on the skill and experience of the furnace foreman. If the carbon in a heat "dropped" too low, the time consuming process of raising carbon content was obviated; the heat could be tapped for a low carbon product.

Installation of an open hearth steel mill was hardly a trend started at Kinkora. In 1904, *The Directory to the Iron and Steel Works of the United States* listed thirty-two producers of wire-rods. Ten of these thirty-two mills had integrated open hearth furnaces, another twelve were owned by companies that produced their own open hearth steel at nearby steel mills, two were planning to add open hearth furnace facilities, and another two were idle, leaving only six companies, relatively minor members of the wire-rod industry, without iron or steel making capabilities or using older methods of making steel in 1904.[18] The ascendance of the open hearth steel mill in the wire industry reflected a general pattern emerging in the steel industry. Since 1880, open hearth furnaces had steadily gained acceptance

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[17]To a degree, a higher percentage of carbon roughly equates to a higher strength, less ductile steel. One classification of steel differentiates between low (0.10-0.30%), medium (0.30-0.60%) and high (0.60-0.90%) carbon content. Steel is often identified by the percentage of carbon, for example, a steel containing .80% carbons is referred to as "80" carbon steel. See George M. Enos and William E. Fontaine *Elements of Heat Treatment* (New York: John Wiley & Sons, Inc., 1953): 64. Classification of steel by composition varies somewhat in the steel industry, US Steels' *The Making, Shaping and Treating of Steel*, 4th ed. (Pittsburgh: United States Steel, 1951), 349, lists the ranges of steel as low (0.10-0.30%), medium (0.30-0.85%) and high (greater than 0.85) carbon.

[18]See Appendix A.

in the United States, surpassing the Bessemer converter in 1908 as the most favored method of processing steel.[19]

It is generally agreed among historians of the steel industry that open hearth furnaces and the Gilchrist-Thomas method changed the character of global steelmaking in the last half of the nineteenth century. In the open hearth process, a regenerative system of checkers preheats a mixture of air and gasified fuel before it is burned over the charged materials. This endothermic heating of the iron was a departure from the Bessemer process which relied on the exothermic heat generated from the oxidation of the metal when blown with air to reach sufficiently high melting temperatures.[20] The definitive manual of steelmaking in the U.S., *The Making, Shaping and Treating of Steel*, summarized the advantages of the open hearth process:

> (1) By the use of ore as an oxidizing agent and by the external application of heat, the temperature of the bath is made independent of the purifying reactions, and the elimination of the impurities can be made to take place gradually, so that both the temperature and the composition of the bath are under much better control than in the Bessemer process. (2) For the same reasons, a greater variety of raw materials can be used and a greater variety of products can be produced . . . (3) A very important advantage is due to the increased output of finished steel from the same amount of pig iron, which means that fewer blast furnaces are required to produce a given tonnage of steel.[21]

For companies not previously manufacturing steel, the open hearth

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[19]Bela Gold, William S. Pierce, Gerhard Rosegger, and Mark Perlman, *Technological Progress and Industrial Leadership* (Lexington, MA: Lexington Books, 1984), 531; and Backert, ed., *The ABC of Steel*, 133.

[20]Kenneth C. Barraclough, *Steelmaking, 1850-1900* (London: Institute of Metals, 1990), 13.

[21]Harold E. McGannon, ed., *The Making, Shaping and Treating of Steel*, 9th ed. (Pittsburgh: United States Steel, 1971), 28.

design did not require as costly or complex a step in backwards integration as the common practice in Bessemer steel production. In the early stages of open hearth steelmaking, operators charged the furnace with cold metal, usually some combination of pig iron and scrap, and heated it gradually to the proper temperature. Since Bessemer converters required a molten charge that could be more economically supplied by an integrated blast furnace facility, the choice of an open hearth steel mill involved a substantially less drastic undertaking.[22] The ability to use scrap as a portion of the charge in open hearth furnaces particularly benefitted the wire industry. Hot rolling ingots and rods and wire drawing generated substantial quantities of scrap steel, providing a local source of raw materials. Furthermore, the improved control of the chemical composition of the steel ingots offered by the open hearth furnaces was crucial for companies drawing wire for highly specialized purposes, such as bridge or heavy duty wire.

Any installation of open hearth furnaces posed a question of whether to build basic or acid types. When Henry Bessemer developed his famous converter in the 1850s, he fortuitously used a low phosphorous pig iron that minimized the deleterious effect of excessively high phosphorous content in iron that embrittles steel. The silica-based refractory bricks that lined early Bessemer containment vessels prevented the elimination of phosphorous. Low carbon steels tolerate higher percentages of phosphorous, but high carbon steels are sensitive to even 0.08 percent.[23] The acid character of the silica lining did not provide the free metal oxides needed to precipitate oxidized phosphorous, therefore allowing no removal of phosphorous from the molten iron. Thomas and Gilchrist's patent of a basic lining made from a mixture of lime and magnesia that made phosphorous removal possible solved the "phosphorous problem," ushering in an era of new possibilities for the use of high phosphorous ore in steelmaking. Open hearth furnaces also required refractory linings, so the decision to build either basic or acid furnaces generally depended on access to certain grades of pig iron, and

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[22]Gold, et al., 537.

[23]McGannon, 915.

the character of the end product. Although America possessed sizeable reserves of low phosphorous ore well into the twentieth century, adoption of basic linings in U.S. open hearth furnaces in 1892 added a flexibility with respect to raw materials.[24] While the basic process successfully reduced the ill effects of phosphorous, it encouraged the use of a lower quality ore or pig iron that generally did not result in a superior grade of steel. The quality of basic steel improved with later developments in metallurgy, however, during the early twentieth century, companies desiring to furnish quality high carbon products relied on acid Bessemer converters or open hearth furnaces.

The need to continue manufacturing high carbon bridge wire and extend the product line to offer a variety of low to medium carbon products dictated that both basic and acid open hearth furnaces be installed at Kinkora. The acid-basic type arrangement afforded a high degree of flexibility: the furnaces accepted either coal gas, natural gas or oil as a fuel, and a wide range of iron and scrap could be charged. Since many of the reheat furnaces, annealing pots and bakers, needed to manufacture wire from steel ingots fired coal gas, the desire to maintain a consistent fuel type and the cheap price of coal governed the widespread choice of coal gas in steel mills during the 1900s. After initially considering oil, the Roeblings followed industry convention, erecting several gas producers near the exhaust stacks along the lengthwise south wall to supply the furnaces with coal gas.[25] The low price of fuel oil encouraged a switch to firing gasified oil in the steel mill furnaces in 1917, presaging the eventual replacement of all coal gas fuel with oil and natural gas.

The Kinkora plans specified moderately sized furnaces of 30 ton capacity. Although companies were building 50 ton furnaces, unresolved problems with lining endurance, cooling, and crane lifting limits restrained the growth of furnace size.[26]

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[24]Barraclough, 239.

[25]"The New Roebling Works," *Iron Age* (April 26, 1906):1399.

[26]For example, Bethlehem Steel, Atlanta Steel Company, Colorado Fuel & Iron, and the American Steel & Wire Company built

Furthermore, the smaller furnaces facilitated control of the heat, an important concern for making steel of a precisely specified composition. Although solution of the salient technical limitations during the 1920s initiated a period of growth in furnace size, JARSC chose to increase capacity by adding new furnaces rather than greatly enlarge existing furnaces.[27] Even as furnace size exceeded 300 tons in 1930, the common experience in the wire industry held that heats intended for superior quality bridge wire should not exceed 100 tons.[28]

**2.3 Roebling Village - Cog in the System**

The pragmatism that influenced the selection of certain technologies and site design extended to attitudes toward labor as well. When the Roeblings decided to build a new facility, proximity to Trenton, good transportation networks, and water availability heavily influenced selection of a site. Ten miles south of Trenton, a farm abutting the Delaware River and bounded on one side by the tracks of the Pennsylvania Railroad fit many of the required criteria, yet its rural location ensured that labor would not be readily available. Undaunted, the Roeblings planned an entire community, complete with a general store, auditorium, inn, tavern, and recreational facilities to support their industrial enterprise.

The village represented an answer to troubling labor problems that interrupted the smooth flow of production. The technologies that made sense in terms of output, cost and

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50 ton open hearth furnaces prior to 1908. The American Iron and Steel Association, *Directory to the Iron and Steel Works of the United States* (Philadelphia: The American Iron and Steel Association, 1908)

[27]From 1910 to 1920, the company constructed three additional furnaces. By 1930, eight of the twelve open hearth furnaces had been modestly enlarged to a capacity of 40 tons, and a double spout 80 ton ladle was installed in 1941.

[28] "Bridge Wire Requires Fine Steel," *Iron Age* (April 17, 1930):1148.

efficiency had ramifications for the composition and skill of the workforce. Tending open hearth furnaces operating at three thousand degrees Fahrenheit or lifting heavy coils of wire was a demanding environment that became the domain of unskilled Eastern European immigrants arriving at the turn of the century. In the past, skilled English and German wire drawers and Swedish iron masters had constituted a vital component of the JARSC workforce, but the new scale of immigrant employment presented problematic social concerns -- how would workers from rural backgrounds adapt to the expectations of a modern industrial mill amidst a foreign culture? Attempts by employers to assimilate their foreign labor frequently followed a paradoxical course; reconciling the American concept of liberty with the desire to eliminate aspects of the worker's Old World heritage proved a difficult task. A balance was needed between liberty and social control, between personal freedoms and restriction.

Although born of necessity, the Roebling village was a form of social control that symbolized the rationalization of labor concerns and the desire to create a predictable workforce free of union influence. In several cases detailed by other studies -- the Pullman experiment, the stultifying financial stipulations that characterized some mining towns, and Ford's heavy-handed intrusion into the personal lives of his workforce -- the balance swung disproportionately to the advantage of the corporate employer.[29] The Roeblings made no attempt to mask the purpose of the town: Roebling village was "not designed in any sense as a Utopia, or built as the result of philanthropic ideals, but rather frankly contemplated as an industrial town which was designed to pay its own way."[30] Yet in its execution, the Roebling plan for the village managed to reasonably equalize the benefits sought by employer with those granted the employee. The provision of a hospital, considerable recreational facilities,

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[29]Stanley Buder, *Pullman: an Experiment in Industrial Order and Community Planning, 1880-1930* (New York: Oxford University Press, 1967); Stephen Meyer, *Five Dollar Day: Labor Management and Social Control in the Ford Motor Company, 1908-1921* (Albany: State University of New York. 1981)

[30]Schuyler, 372.

parks, and a home ownership association reflected a real concern for the quality of life of the Roebling workers. The construction of substantial brick houses equipped with "the usual conveniences" deviated from the small, shoddy clapboard houses of some company towns.[31] Maintenance crews repainted and wallpapered the homes every three years, made repairs, and landscaped the village free of charge.[32] The company built an elementary school, library, paid for town taxes, salaries of the police and firemen, and rented the houses at rates well below those of the surrounding area.[33] Even when the Depression revealed the deep inadequacies of corporate socialism, JARSC used the village to aid its workforce by extending credit in the general store and waiving rental fees for a number of years.[34]

Nevertheless, because the town provided housing for only 40 percent of the workforce, the low rates of rental and close proximity to work assured a waiting list that was filled by careful selection of reliable workers of long employment. Assessing the financial merit of the Roebling village, Iron Age voiced the intent behind the Roebling brothers' construction of a company town:

> Does it pay? Not in dollars and cents. As a matter of fact, the running expenses almost exactly balance the income -- in many years creating a deficit which the company has had to underwrite... But it most assuredly does pay in the larger sense. It pays in attracting men of the better kind. It pays in promoting permanence of employment. And hence avoiding costly labor turnover. It pays in promoting health of employees, and thus reducing absences and errors and

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[31] "Industrial Village on Sound Basis," *Iron Age* (January 1, 1924):9-14.

[32] Louis Borbi, interview by author, 18 June, 1997; and John Hodson, interview by author, 28 July, 1997.

[33] Zink and Hartman, 123.

[34] John Hodson, interview by author, 28 July, 1997.

accidents.[35]

The Roeblings hoped that a "Progressive Town" would ameliorate the labor discontent that disrupted productivity and secure a better workforce.

**2.4 Kinkora Equipment and Practices in the First Two Decades**

Although widespread acceptance of certain methods and equipment in the wire industry provided common ground for technology transfers, the diversity of turn of the century plant design reflected the ingenuity of individual engineers and different needs. Prior to the merger movement that reshaped the steel industry, a small class of mechanical innovators demonstrated that success in the wire business could rise dramatically based on the skill and experience of individuals.[36] This was born out at the JARSC in the figure of Charles Roebling. Charles' personal supervision of nearly all aspects of design and construction at Kinkora, notably in the rod and wire mills, provided a foundation well-suited for future growth. While the firm of McClintic-Marshall was usually contracted for the structural erection of the mill buildings, an onsite machine shop handled the casting and fabrication of all the components needed for Charles' customized blueprints that minimized reliance on outside vendors.

The initial design of the Kinkora plant reflected a mix of available technologies and practices with site specific

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[35]"Industrial Village on Sound Basis," *Iron Age* (January 3, 1924):14.

[36]Several prominent companies in the wire industry began as small ventures by mechanically inclined individuals or family combinations of brothers, sons and fathers. Theodore and Chester Wickwire founded the Wickwire Company by successfully building a machine to weave wire cloth, J. Wallace Page established the Page Woven Wire Company by patenting a method of weaving wire fence, and Charles Morgan left Washburn & Moen to organize the Morgan Construction Company to sell rod mills of his design.

adaptations. Although basic design of several mills at Kinkora was loosely governed by a choice between two rival systems, each final configuration represented a unique solution posed by variables such as cost, output, quality of product, flexibility, durability, and ease of repair. As the Roeblings expanded and modified production at Kinkora, adoption of new equipment and practices reflected three primary forces driving technological change in the wire industry: streamlining and mechanizing materials handling, increasing rod bundle size, and uniformity – that is, casting a more uniform steel ingot, and uniform treatment of the steel during all phases of wire making. Although increasing the efficiency of wire production at Kinkora partially depended on mechanization, in the first quarter of the twentieth century traditional skilled work in the steelmaking, hot rolling, heat treatment, cleaning, and cold working processes still played an integral role in manufacturing wire.

### 2.4.1 Steelmaking

As previously mentioned, the installation of open hearth furnaces at Kinkora followed a general trend in the steel industry. The specifics of furnace design, however, differed widely among plants. The variety of equipment types, steel mill layouts, and operating practices slowed the diffusion of open hearth technology with the result that experience gained in one situation was not readily transferable to others.[37] Attempting to wrest maximum output and quality from the furnaces, chemists and engineers kept the methods and equipment used in open hearth steelmaking in constant flux. In the 1890s, the work of Ernest Saniter, J.H. Darby, Benjamin Talbot, Bertrand and Thiel in desulphurization, recarburization and charging molten metal revealed that a standardized practice in steel making was not to be realized in the near future. Similarly, open hearth furnace design in America branched in the late 1880s when H.H. Campbell and S.T. Wellman introduced two types of tilting open-hearth furnaces that rotated the furnace on its longitudinal axis to ease slag removal and tapping operations. Perhaps deterred by the higher cost and complexity of the tilting furnace, Charles

[37]Gold, et al., 537.

Roebling hired Swedish furnace engineer J. Ecklund from American Steel & Wire Company's Worcester South Works to design stationary open hearths at Kinkora.[38] Ecklund brought several countrymen to assist in the construction and operation of the furnaces, thus the core of the first steel men at Kinkora were known as "the Swedes."

Steelmaking at the turn of the century was an extraordinarily complex and skilled endeavor. The critical control of bath temperature, slag composition, and metal composition were largely functions of the melter's skill. His position typically paid well; in one plant, ten times the day wage of a manual laborer. It is likely the role of Kinkora steel men mirrored that of the Phoenix Iron Company, "where the melters were at the juncture between labor and management; they reported to the steel plant's chemist, who also oversaw the gas producers and the testing department and who held a junior salaried position at $125 a month (a sum just barely above the melters' monthly pay)."[39] Kinkora melters also relied on a chemistry lab built adjacent to the steel mill to help evaluate the carbon content of steel heats and control the gas producers that initially fueled the open hearth furnaces.

In working a steel heat, the melter faced the formidable task of reducing the carbon content as rapidly but controllably as possible, and at the same time getting the metal heated up to a temperature that permitted the heat to be tapped and teemed satisfactorily. For the bulk of the steel made at Kinkora, "catching" or blocking the carbon content of the heat at the high level needed for bridge wire or Blue Center steel while maintaining proper steel chemistry was a particularly difficult process. Washington Roebling noted that it took over a year before the Kinkora steel mill yielded satisfactory heats; forcing the rod mill to use purchased steel ingots during its first year of operation.

### 2.4.2 Hot Rolling

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[38] "The New Roebling Works," *Iron Age* (April 26,1906)

[39] Thomas J. Misa, *A Nation of Steel* (Baltimore: The Johns Hopkins University Press, 1995), 55.

At the turn of the century, two competing rod mill arrangements, named after their inventors William Garrett and Charles Morgan, dominated rod rolling in the United States. Both methods represented improvements on older technologies – Garrett on the Belgian or looping mills and Morgan on George Bedson's straight line continuous mill – and each offered certain advantages and drawbacks. The existing Garrett-type mill and experienced operators at Trenton made duplication of this system an easy choice at Kinkora. Although the introduction of mechanical "repeaters" halved the number of men needed to catch and guide the rods through the stands of rollers in the Garrett-type mills, the first rod mill at Kinkora was semi-continuous and still employed some manual catchers. Aside from requiring strength and dexterity, one commentator observed that rod catching could be a dangerous occupation:

> The loops in a Garrett mill have a fatal habit of lassoing the unfortunate operators, and in spite of all safe-guards, occasionally catch and lop off a limb as they tighten. Rod points occasionally jump out of the repeaters and spear the operators or the innocent bystanders. The red hot point shoots through the limb or the body like a sword.[40]

Not one content with conventional technologies, Charles Roebling added a group of continuous roughing stands to the looping mill to gain the benefits offered by each type. This combination of looping and continuous mills in rod rolling, although replaced by a fully continuous arrangement in 1928, later proved a favored design in many modern rod mills.

Rolling in most blooming mills utilized either a two-high reversible or three-high mills. In deciding to adopt a less expensive three-high arrangement, Charles Roebling sacrificed some flexibility with respect to the size of the billet to gain a higher output rate. Because the three-high mill required a means of lowering and raising the ingot as it passed through the upper and lower sets of rollers, Charles patented a hydraulic tilting table with a system of guides that simultaneously turned and

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[40]Backert, ed., 187.

guided the ingot into the proper position between the rollers as it was lifted. With a commanding view from his control room near the roof of the mill, the blooming mill operator controlled the pace and the path needed to reduce the ingot to a billet, one of the most skilled operations in the plant. Too great a reduction of the ingot on one pass, an article in the Iron Age advised, would "injure the steel with telling effect later."[41] At the turn of the century, the practice of cutting production time by rolling steel without regard to cooling periods and proper temperature at too high a speed and too large a reduction resulted in a proliferation of rail failures. The ensuing "rail crisis" initiated an intense investigation of the relation of temperature and rolling practices to the structural integrity of rolled products.[42]

Because the blooming mill affected the first reduction of the steel ingot, the tremendous power and heat required to roll a structurally sound billet stimulated further development of engines, gearing, and roll casting that had limited the size of early blooming mills. In hot rolling, the life of a steel section passes through stages of reheating to a high, uniform temperature, reduction through a series of rollers, and cooling. The Roeblings designed hydraulic pushers to feed ingots into reheat furnaces to obtain a constant rate of heating, and a roller conveyor system to transport the hot ingots to the blooming mill. Charles' original 26" blooming mill rolled the cross-sectional area of a 12x12" ingot to a 4x4" billet well suited to the Garrett-type rod mill. The ability to roll a larger billet constituted a chief advantage of the Garrett rod mill over the Morgan mill, which could only roll a billet of much smaller cross-sectional area, necessitating an additional heating and reduction in a set of roughing stands. From a volumetric standpoint, however, use of billets weighing over 175 lbs. resulted in excessive cooling of the exposed rod loops in the Garrett system. Naturally, a weight limitation on billet size affected the length and weight of the rod bundle. Prior to the

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[41]Frederick Westphal, "Bridge Wire Requires Fine Steel." *Iron Age* (April 17, 1930): 1148.

[42]Misa, 148-150.

introduction of carbide dies in the 1920s, increasing the size of the rod bundle was not as crucial a concern because the amount of wire that could be drawn from a single rod bundle was governed by die wear rather than bundle size.

### 2.4.3 Heat Treatment

The heat treatment of wire and rods varied widely between products. Turn-of-the-century wire manufacturers recognized two primary divisions in heat treating metal: tempering and annealing. The label of "Tempering House" common to wire plants in the first decades of the twentieth century reflected the generalized understanding of heat treatment that lumped together several different forms of heat treatment. For example, the primary function of the Kinkora tempering house was patenting rather than tempering. Although future developments in metallography revealed the radical transformations that distinguished the various processes of heat treatment, the ingrained misnomer of the "tempering" house remained.

Methods of annealing metal after cold working to restore ductility had been in use for centuries, and were particularly useful in alleviating internal stresses generated by wire drawing. The annealing house used an established system of heating coils of wire in sealed pots to the desired temperature range (dependent on the desired properties — "full" anneal austentized the steel at higher than critical temperatures, "process" anneal involved sub-critical heating) followed by a period of slow cooling. Because annealing was primarily applied to low carbon steel, less attention was focused on innovating the process at Kinkora.

In contrast, the Roeblings' paid great attention to patenting, a form of heat treatment particular to high carbon wire. Patenting developed in a highly proprietary manner that reflected the influence a single technique could have on the quality and success of a product. During the first years of patenting wire in the second half of the nineteenth century, a noted consultant and historian of the wire industry, Kenneth Lewis, described the secrecy surrounding early efforts:

What I chiefly remember about patenting is that the

> earlier installations were surrounded by high board fences so others in the room could see nothing that went on inside. Entrance was through locked doors, wire was passed in through holes in the fence and the finished product passed out in the same manner, and the workers inside were confined to specific tasks so that practically nobody could know the whole process.[43]

Even well into the twentieth century, the Roeblings' guarded the details of their patenting process. Tours granted the New York branch of the Society of Electrical Engineers and visiting Japanese steel manufacturers in the 1930s excluded inspection of the patenting area.[44]

Patenting imparted both high strength and a measure of ductility to high carbon steel before drawing, thus permitting several drafts of the wire without prohibitive loss of the high strength needed for its use in bridges or superior wire ropes. Patenting roughly consisted of heating to a temperature well above the critical range to reform the microstructure of the steel, followed by a relatively rapid and controlled quench. In theory, detailed knowledge of the relation between time, temperature, quenching medium, grain size and the microstructure awaited the electron microscope and research in metallography that began to broaden understanding of material science after 1930.[45] The particularly empirical approach to developing an effective system of patenting in the early wire industry had two salient manifestations. First, the successful set-up and operation of heat treatment rigs generated a cadre of skilled engineers that, by force of reputation, could influence the

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[43]Kenneth Lewis, *Steel Wire in America* (Stamford, CT: The Wire Association, 1952), 194.

[44]Interview with John Hodson, "John A. Roebling's Sons Company's Vast Wire Plant Thrown Open to the New York Electrical Society: See Hudson River Bridge Cables Made and Tested," *Telephone and Telegraph Age* (May 16, 1929).

[45]W.H. Dennis, *A Hundred Years of Metallurgy* (Chicago: Aldin Publishing Company, 1964), 328-331.

marketability of the product. Years of experience in determining effective combinations of equipment and practice played a particularly crucial role in patenting innovation. Second, confusion marked discussion among experts in the wire industry, as late as 1932, regarding exactly what was happening to the wire as it passed through the stages of the patenting process. Without a comprehensive theoretical guide, practical experience and reasoned experiment fueled the progress of patenting technology. If the case of Kinkora can been taken as the likely state of wire plants in general, the design of patenting rigs was a protean endeavor, with many variants coexisting within the tempering house. Charles Roebling's first method of lead patenting had actually proved better than his subsequent attempts, to which Washington Roebling noted "why, no one knows."[46] Early patenting at Kinkora followed a method referred to as air patenting, with wire rods heated by furnaces from thirty to eighty feet in length and quenched in air, but later models experimented with other heating and quenching agents such as lead. The high reputation of Roebling bridge wire drawn from patented rods attested to the skillful process design in vital aspect of wire manufacturing.

### 2.4.4 Cleaning

An adage in the wire industry held that "a wire well cleaned is half drawn." Heating steel during hot rolling or annealing formed a hard, brittle oxide on the rod or wire known as mill scale. If improperly removed by cleaning, the scale scratched dies and resulted in off-gage wire. The rod cleaning operation at Kinkora followed an established sequence of immersion in an acid bath, a water rinse, a lime coating, and a period of baking. The original Kinkora cleaning house also employed the familiar technique of using a circle crane to raise and lower coils of rods in the various tanks of acid, water, and lime, which formed a semi-circular pattern about the crane. A quality clean depended on the foreman's control of the temperature and duration of the immersion of each step of the cleaning process, which varied between different products. Too long of soak in the acid

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[46]Schyuler, 345.

resulted in a condition known as acid brittleness that could be difficult to detect until the wire failed weeks or months later. Overbaking a rod reduced the effectiveness of the lime coating that aided lubrication during drawing. Perhaps most importantly for bridge wire, skillful application of a "sull" coat during cleaning provided an essential aid to lubrication.[47] While rods intended for dry drawing relied on the lime and sull coatings for lubrication, finer wire frequently employed a "wet" coating applied by a dip in copper or tin sulphates.[48]

The original number one cleaning house at Kinkora contained four cleaning stations, each one attended by a cleaning "gang." Most jobs in the plant had two shifts, but because the cleaned rods required an overnight baking, the cleaning gangs worked one shift from 8 am to 4 pm. The gang operated much like a team, comprised daily of the same personnel led by a gang foreman, with a numerical designation that identified its station, but had skill connotations as well. For example, the number one cleaning gang handled the most critical job of cleaning all the rods intended for Roebling bridge wire. After cleaning and coating, coils of rods were loaded on to baker trucks, and wheeled into a row of ovens for a ten to twelve hour bake. Roughly one million lbs. of rod coils were processed during the cleaning shift to provide wire mill number one with its next day's allotment of rod coils.

#### 2.4.5 Finishing

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[47]After the acid bath, a light spray of water allowed to dry on the rod formed a film of iron oxide that acted as a lubricant. A good rust coat, one steel manufacturing manual advised, permits rods to be given heavier drafts and to be drawn more drafts before being annealed. See Backert, ed., *The ABC of Steel*, 190. This "sull" coat was an essential part of lubricating bridge wire during drawing.

[48]The sulphate bath forms a metallic coating on the wire that facilitates drawing fine wire. To prevent exposure to atmospheric contaminants, the coated wire is usually kept in a mixture of water and lubricating soap. McGannon, ed., *Making Shaping, and Treating of Steel*, 831.

Like patenting, 'informed experimentation' guided the development of the galvanizing process to apply a corrosion-resistant zinc coating to iron or steel wire. When the Roeblings began to explore galvanizing for the booming telegraph wire market in the 1870s, methods of heating and cleaning the wire before a dip in molten zinc proceeded on a trial and error basis. Cost had to balance quality in applying the zinc coating – too thick could be excessively expensive, too thin resulted in an inferior product. Skilled galvanizers were vital to advancing the art of galvanizing that depended on intuition and experience. For certain wire that required extra corrosion resistance, the Roeblings developed a method of "double galvanizing," and marketed the product as "Extra Best Best Galvanized." Several of the original galvanizing rigs erected by Charles Roebling in the Kinkora Galvanizing Shop had double galvanizing capabilities.

### 2.4.6 Cold Working

The system that developed in the nineteenth century to pull a wire through a lubricated die with a power driven spool or "block" involved a relatively low-level of technology that had attracted only three patents up until 1889. At a diameter near 0.207 inches (No. 5 gage), it becomes more expedient to further reduce a rod by drawing it through a die than to continue rolling. Foremost among the few companies that manufactured drawing machines, the Vaughn Company equipped many of the wire mills built in the first decades of the twentieth century, but Charles Roebling designed and built nearly all the original wire drawing machines at Kinkora.

In 1911, the John A. Roebling's Sons Company could boast of operating the largest wire drawing facilities in the country. In the basements of Kinkora wire mills number one and two, a central steam engine powered a drive train geared to rows of wire drawing benches. Nearly all wire received an initial draft in wire mill number one. Higher carbon wire remained in the number one mill for further reduction to diameters between 0.500 and 0.060 inches. Wire mill number two drew wire into finer sizes, typically from 0.060 to 0.015 inches in diameter. Within each mill, bench design varied to fit specific product requirements. Drawing higher carbon wire required larger diameter blocks and greater power, while finer sizes were usually "wet drawn" on single draft or early continuous machines. Charles Roebling divided the parallel rows of benches into sections, each identified by alphabetic designators. Section C contained the specially built bridge bench that drew all the wire for Roebling bridges from 1907 until 1941. To accommodate increased demands, the Roeblings erected a third wire mill in 1914 to draw low carbon fine wire, and a fourth eventually called the Bridge Shop in 1923.[49] Aside from the switch to electrically powered benches in 1928, until WWII the bulk of the Kinkora wire mills utilized practices and machinery that had undergone few technological changes since the late nineteenth century.[50]

The simplicity of wire drawing on a fundamental level belied the complexity of manufacturing a quality finished product. The characterization of wire drawing as an art rather than a process by a popular 1921 manual of steel manufacturing reflected a recognition in the steel industry of wire drawers as craftsmen. The skill of threading and loading wire onto a block, controlling the speed and reduction of the draft, and monitoring die wear was acquired only with substantial experience. As in many crafts, wire drawers guarded trade secrets, such as their personal combination of lubricants used in the die boxes to mitigate the friction, and took pride in the ability to lift 150 to 250 lb. coils of wire prior to the mechanization of handling and stripping by overhead cranes. Because some wire required particularly skilled drafting, a measure of prestige was associated with certain benches, such as the bridge bench. The Kinkora wiremen also gained satisfaction knowing their workmanship made both lasting and vital contributions to the war efforts and bridge engineering.

### 2.5 Filling Orders: Wartime Production and the Bridge Division

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[49]Although some wire was drawn in the Bridge Shop, its primary purpose (and sole purpose at a later date) was to prepare reels of wire rope intended for bridge sites.

[50]Information in this paragraph from John A. Roebling's Sons Company, *The Roebling Story* (Trenton: John A. Roebling's Sons Company, 1941); and John Hodson, interview by the author, July 22 and July 28, 1997.

Despite efforts to effectively coordinate technology and labor, the viability of the technological system at Kinkora remained particularly sensitive to market forces. A system designed to optimize production of a specific product possessed an inherent vulnerability to sharp declines in demand. The wire market fluctuated greatly with rapid demand spurred by the introduction of dependent technologies such as the telegraph, telephone, elevator, and urban cable car systems, and varied in some cases with national economic cycles. For example, the number of large scale construction projects – skyscrapers, urban transit systems, dams or canals – that provided demand for wire rope tended to follow economic periods of prosperity and recession. Since its incorporation in the 1870s, the JARSC sought growth and protection from market instabilities through diversification: building a copper mill to produce copper wire, creating woven wire cloth, insulated wire, and flat wire products divisions and the Roebling Construction Company to apply its patented method of "fireproof" building construction. Diversification proved a rather ineffectual path to financial stability as several of these and subsequent attempts at broadening their manufacturing base became more of a liability than a profitable investment. The fortunes of Kinkora and the Roeblings, however, benefitted greatly from the demand created by World War I and their continued involvement in long span suspension bridge building.

### 2.5.1 The Great War

Although a myriad of needs arose for wire and wire rope during the war, most importantly for the JARSC, a major percentage of the demand consisted of high carbon products. Without major re-tooling, the JARSC could immediately contribute to the allied powers war effort. Two technologies that revolutionized warfare during World War I, the submarine and airplane, provided a nearly unlimited demand for high carbon wire and wire rope. To defend against the crippling threat of the submarine, the allies suspended steel nets across harbor entrances to prevent penetration by enemy U-boats and devised a vast North Sea minefield to block entry into vital shipping lanes. The large diameter, high carbon steel wire used in submarine nets required minimal reduction in Kinkora's wire mill number one before being woven into rectangular sections of various sizes. Wire mill number one also drew the bulk of the wire that made the JARSC the leading producer of wire rope for the North Sea minefields.[51] The North Sea mines were kept in place by high quality, high carbon steel wire rope to prevent a failure that would result in the surfacing of submerged mines and the potential to migrate into the path of allied ships. The struggle for control of the skies was viewed with increasingly importance as the war ground on, placing a premium on aircraft production that depended on high performance fine wire used in stays, guys, and controls. Orders for aircraft wire kept the fine wire mill number two at Kinkora in nearly constant operation, producing some five million feet by 1918. Additional demands, including both low carbon steel and copper telegraph and signal wire, generated work for nearly every department.

The burst of activity at Kinkora during the war years represented a local response to the nationwide demand for wire that posed a potential bottleneck for war production. Trenton and the JARSC became a focal point for the national organization of the wire industry. In 1917, the American Iron and Steel Institute appointed Karl Roebling chairman of a committee to manage production and distribution of wire in the United States and named the Roeblings' Trenton facilities national headquarters. Competitive rivalries were set aside, Washington Roebling recalled, as there was plenty of money to be made by all involved. The price of billets, rods, and wire soared during wartime, peaking from 1916 to 1917.[52] As a percentage of steel products, wire rod production also marked a high point in 1917, followed by a gradual decline into the nineteen sixties.[53] In the company records, a conspicuous gap exists for the profits earned during the war years, but enough capital was generated to finance

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[51]John A. Roebling's Sons Company. *Wire-Roping the German Submarine* (Trenton: JARSC, 1920), 37.

[52]American Iron and Steel Institute, *Annual Statistical Reports* (Washington D.C.: American Iron and Steel Institute, 1900-1996)

[53]Gold, et al., 574.

extensive new construction at Kinkora.[54] A flurry of building, including additions to the steel mill, blooming mill, three wire mills, galvanizing and tempering shops, doubled plant size at Kinkora. Although a period of great profitability for the JARSC, the WWI years did not pass without casualties. Washington Roebling attributed the deaths of company presidents Charles Roebling in 1918 and Karl Roebling in 1921 to the stress of contending with the tumultuous combination of the tremendous surge in demand with a series of disruptive strikes and fires that taxed production at the Roeblings' facilities.

### 2.5.2 Bridges and Research and Development

John and Washington's involvement in the building of the Brooklyn Bridge had associated the Roebling name with the foremost feats of engineering in the last half of the nineteenth century. As a new century approached, the Brooklyn legacy had overshadowed the fact that Roebling wire had not been used in the bridge, nor had the Roeblings engineered any other bridges since the Cincinnati-Covington Bridge in the late 1860s. By creating a Bridge Division, the Roeblings hoped the notoriety attached to long span suspension bridge engineering would establish their reputation as makers of superior bridge wire and provide some sizeable contracts for wire.[55] The contract for the Williamsburg Bridge in 1899 set a precedent for their participation in future bridge construction by restricting its engineering involvement to cable erection (instead of any involvement in structural work), and included manufacturing the bridge wire. Supplying the wire needed for the Williamsburg contract meant that the JARSC was heavily involved with making high carbon bridge wire during the period that US Steel began to consolidate the steel industry, making their dependence on high quality steel ingots more acute.

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[54]A rough indication of the profitability of the wartime market can be gained from the board of director's financial report that recorded a net profit for 1923 as $7,508,866.01, "the best in the history of the Company with the exception of 1917." Index of Minutes.

[55]Zink and Hartman, 89.

While the JARSC completed the Williamsburg Bridge a year before groundbreaking began at Kinkora, the new plant in part represented a response to the impact the steel mergers had on making bridge wire. As previously discussed, much of the plant design was oriented towards high carbon wire, of which the Roeblings anticipated bridge wire would comprise a sizeable portion. Compared to rope wire, bridge wire ultimately comprised a relatively low percentage of production.[56] Of the six sections in wire mill number one, only one was dedicated to drawing bridge wire or wire for bridge suspenders. Similarly, manufacturing bridge wire provided no work for wire mill number two nor for the annealing house, and only partially engaged the tempering and cleaning houses. The importance of the Bridge Division lay beyond its impact on overall sales, for this new means of generating orders for high carbon bridge wire provided needed boosts during wire market recessions, spurred research and development of wire making and bridge building, and erected tangible icons of engineering achievement that instilled pride in the workforce and solidified the Roebling reputation as manufacturers of high quality wire.

The bridge projects during the era of Roebling ownership of Kinkora had a twofold impact on the technological development of both plant equipment and methods of bridge construction. In company publications, the label "it's a Roebling Idea," was frequently invoked to signal a technique or innovation developed to improve bridge building. Many of the "Roebling Ideas" had old roots, as twentieth-century long span suspension bridges continued to use some of the basic aspects of structural design, engineering cable anchorages, and "spinning" suspension cables pioneered by John A. Roebling during the mid-nineteenth century. Some salient improvements since the Brooklyn bridge largely pertained to increasing the speed of cable erection through better spinning wheels, wire splices, and cable compression.[57]

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[56]Wire mill foreman John Hodson estimated bridge wire to comprise about 20% of Kinkora production during the late 1920s and 1930s.

[57]Specifically, several spinning wheel design modifications developed during construction of the Williamsburg, Manhattan, and

Problems specific to individual bridge projects led to some of the most notable innovations in Roebling bridge engineering. The unprecedented span lengths in the George Washington project sparked the development of a pre-stressing technique for use in constructing the footbridges needed to work on the main suspension cables. Accurate positioning of the footbridges, which were supported by wire ropes, was a vital concern for the engineers: a wire rope footbridge that deflected too low or too high could not fulfill its function to provide access to the main suspenders. When subjected to a constant load, the strands and individual wires in a wire rope tended to compress and induce inelastic stretch after extended service. The long length of the George Washington spans exacerbated the uncertainty of how much inelastic stretch would alter the length of the footbridge cables. Supervised by C.C. Sunderland, chief engineer of bridges, the JARSC developed a set of prestressing stations at the Kinkora site that applied carefully measured multiple high tension loads to remove the inelastic stretch that would occur at lesser tensions.[58] Although developed to meet the unique requirements of the George Washington Bridge, the JARSC immediately found use for prestressing in the contemporaneous St. John's and Grand' Mere projects, and the technique became useful for any wire rope intended for applications that demanded the

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George Washington bridges, a new wire coupling with nearly 100% of wire strength, a new cable wrapping machine, and a new cable compression technique used in the work on the Bear Mountain bridge were reported in two articles titled "George Washington Bridge Spinning — the Progressive Step," and "Bear Mountain Bridge," in John A. Roebling's Sons Company, *Suspension Bridges - A Century of Progress* (Trenton: John A. Roebling's Sons Company, n.d.).

[58]Spaced approximately 1875 feet apart, one station contained a 300 ton testing machine and a set of hydraulic jacks capable of applying the 300 ton load to the wire rope, the other a 150 ton tension testing machine attached to a sheave car that the wire rope wound around and returned to the first station. Thus wire rope of a maximum 3,750 feet could be prestressed in this system.

predictability of a linear stress-strain curve.

The Bridge Division engineers Sunderland, Blair Birdsall, and H. Kent Preston later carried their work on prestressing to applications in concrete bridge building. Drawing on their experience in bridge strand manufacturing, Roebling engineers developed an American variant of a European method of prestressed concrete construction. Since the 1920s, the Europeans had experimented with using a tensioned, ungalvanized wire to apply a compressive load to concrete sections that minimized concrete's poor tensile strength properties. In one method, a wire or group of wires were placed inside the concrete during casting, and tensioned externally after the concrete had set. The difficulty in gauging the quantity of concrete volume change and steel wire creep in the European method added a measure of uncertainty that complicated design. Roebling high strength, galvanized, and prestressed bridge wire strands and aircraft cord were ideally suited to use in compression loading concrete. The familiar Roebling prestressing technique removed the inelastic stretch that could eventually reduce the efficacy of the wire strand to maintain a constant tension. Experimental confirmation of the effectiveness of Roebling prestressed concrete that had endured two years of concentrated loads in the flooring of a company warehouse in Cicero, IL, led to a more notable application in 1949 when the Bridge Division successfully completed a long span suspension bridge with prestressed concrete floor system between the two countries of El Salvador and Guatemala. Prestressed concrete reduced the volume of concrete needed in bridge design, and facilitated construction because it could be cast elsewhere and transported to the site. The Bridge Division's work in pioneering American prestressed concrete later proved an attractive asset that influenced Colorado Fuel & Iron's decision to buy out the JARSC in 1953.

Even as bridge wire for the Manhattan Bridge rolled out of the Kinkora railyard, control over innovation in the steel and wire industry was shifting from the mechanical experimenters and inventive tinkerers to more scientifically trained engineers and scientists. Evidence of a more scientific approach to wiremaking at the JARSC was visibly manifested in a concentrated research laboratory and the emphasis placed on rationalizing production through increased controls and testing. The development of sophisticated testing and analytical equipment played a symbiotic role in improving the metallurgical and metallographical theories that began to elucidate the factors influencing metal hardness, strength, ductility, and toughness. Subsequently, plant engineers required more detailed information concerning the effect of temperature and time on the stress and strain properties of wire. From an early date the Roeblings had used tension testing machines to monitor wire performance, but since the 1920s, a proliferation of new testing apparatus and equipment controls in the plant reflected this intent to measure, record, and tightly control processing to provide a more uniform and consistent treatment. Between 1927 and 1928, engineering orders called for automatic controls connected to thermocouples for billet furnaces, pyrometers on annealing pots and open hearth furnace roofs, bending testers for wire mill number one, torsion testing machines in wire mill number two, and constant time-temperature recording instruments for the tempering shop. As part of the work on prestressing, in 1928 the Roeblings installed the world's largest tensioning apparatus, the Riehle Automatic Testing Machine, to apply the enormous loads needed to test bridge suspender wire ropes, and extensometers to measure yield point and ultimate elongation in wire.[59] 1928 also inaugurated a movement toward instrument control of steel chemistry when the Roebling chemical lab purchased an Enlund Carbon Apparatus. Later additions including the Laco Sulphur Determination Apparatus and a spectroscope chemical analyzer dubbed "Iron Mike," permitted a more precise and systematic control of steel composition that replaced earlier reliance on less accurate methods and the melter's skill.

Research was aided by the consolidation of the fragmented efforts of engineers connected with individual mills and departments under the aegis of a single laboratory.[60] Characteristic of industrial research labs emerging at many twentieth-century corporations, the lab represented a more coordinated and scientific approach to investigating manufacturing processes, especially in areas of steel making,

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[59] "World's Largest Testing Machine Breaks New York Bridge Cables," *Iron Trades Review* (May 9,1929):1263.

[60] *Blue Center* (August 1930): 14.

heat treatment, and material stresses. Although establishing a coordinated research program began in 1930, the drastic drop in demand for wire and wire rope precipitated by the Depression intensified the search for cost savings through rationalization and increasing the efficiency of existing processes rather than discovering ways to maximize production.

### 2.5.3 Impact of Bridge Building on Plant Technology

Although the Roeblings secured only two bridge contracts during the first two decades of wire making at Kinkora, the rapid expansion of automobile ownership brightened the prospects of bridge building in the 1920s. Indeed, the JARSC benefitted from this new source of bridge demand by successfully bidding for the Hudson River (1927), Maumee River (1929), St. John's (1929), Maysville (1930), Grand Mere (1930/1), Dome (1930/1), and Golden Gate (1932) Bridges in the late 1920s and early 1930s. Subsequently, the late 1920s became a period of adopting new technology and extensive modifications to existing equipment. Between 1927 and 1929, the JARSC replaced four of their twenty-one heat treatment rigs, nos. 18, 17, 15, 13, with new models, modified two galvanizing rigs and added another, converted the wire mills to electrical power, installed two batteries of four hole soaking pits in the blooming mill, constructed bridge wire reeling machines in the bridge shop, enlarged the no.5 and no.6 open hearth furnaces to a 40 ton capacity, and built a brand new continuous rod mill.[61] Bridge wire benefitted from the addition of the Chapman-Stein soaking pits that provided a more uniformly heated steel ingot, and consequently, a rolled billet of improved quality. Furthermore, the bridge contracts created a demand for rolling a standard high carbon rod and heightened the need for longer wire. The mill additions and purchases in late 1920s, in part spurred by bridge contracts, marked the emergence of continuous technologies at Kinkora.

## 3.0 PHASE TWO - THE IMPACT OF CONTINUOUS TECHNOLOGIES

After Charles' death in 1918, two roughly contemporaneous

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[61]Engineering Orders, JARSC, 1927-1928.

developments in the steel industry – standardized, continuous technologies and advances in metallurgy and metallography – initiated a replacement of the nuanced technologies at Kinkora with more universally used equipment and practices. The system of wire making became structured more by generic technology than by the design of an individual system builder. In particular, the construction of a new blooming mill and rod mill, and introduction of carbide dies, flash bakers, and straight line cleaning marked a period of transition during the decades between 1920 and 1940 to continuous modes of production.

**3.1 Continuous Rod Rolling**

During his last years as company president, Charles Roebling had continued to modify manufacturing at Kinkora with an eye towards future expansion. His plan to overhaul the blooming mill was carried out in 1920 by his nephew, company president Karl G. Roebling, who incorporated a new 36" mill to replace the existing 26" mill. The new system rolled harder steel more easily and quickly, and permitted future consideration of using larger ingots. Operation of the steam powered 36" blooming mill continued until the cessation of steel manufacturing in 1982.

Garrett mills faced an increasingly strong challenge from continuous mills that benefitted from improvements in electric motors and gearing that remedied timing problems. While the modified Garrett mill in rod mill number one offered certain advantages, the rods cooled non-uniformly on the looping floor, imparting a variation in temper that especially affected high carbon stock.[62] Moreover, the limitations on bundle size in the Garrett mills became more acute as improved dies of either chilled cast iron or hardened steel allowed longer lengths of wire to be drawn. Furthermore, as the Morgan Company led research and development efforts to refine continuous rod mill technology, it began to capture a larger share of the growing continuous rod mill market. Although purchase of a Morgan rod mill represented a substantial investment, it held the potential to roll larger bundles and increased output rates for similar products. Despite these trends, the first construction to supplement capacity at

[62]Backert, ed., 187.

Kinkora used a Belgian-type looping arrangement well-suited to rolling rods of various shapes and sizes. This smaller, second rod mill built in 1922 was likely added to maintain a level of flexibility for specialized rod production that was difficult to achieve in continuous mills, and to sustain rod rolling during the eventual alteration or replacement of rod mill number one.

Although the demand heightened the need for increased rod production, the record bridge spans encouraged adoption of a rod rolling technology that could produce larger rod bundles, and concomitantly, longer wire. In 1928, buoyed by orders for elevator cables and the 1927 contract for the Hudson River (George Washington) Bridge, the JARSC recorded its highest level of sales in an eighteen-year period. Subsequently, the board of directors allocated funds for a four-train 18" billet mill needed to roll a billet of a smaller cross sectional area and a Morgan rod mill in December of 1927. In contrast to Charles Roebling's personal design of the old mill, the new mill featured nearly all Morgan equipment, including a Morgan billet reheating furnace and rolling stands, installed by Morgan engineers. While the skilled catchers used in the old looping mill could still find work in rod mill number two, their role was substantially diminished and separated from production of the standard high carbon rod now rolled by the new number one rod mill.

### 3.2 Continuous Wire Drawing

Although single draft machines drew the bulk of the wire made until the 1930s, the idea of continuous or multiple die drawing had long been pursued by enterprising inventors and engineers aware of the obvious advantage of an increased rate of output. The author of a 1907 *Iron Age* article found that the desirability of multiple die system "had been recognized for many years, and various abortive attempts had been made in this country and in Europe, some of which had shown great financial courage and persistence on the part of the capitalists and inventors,"[63] to produce such a machine. Another wire industry consultant marveled after a visit to the Bethlehem Steel Works at

[63]W.W. Gibbs, "Wire Drawing: The Second Step in a Useful Art." *Iron Age* (January 3,1907): 18.

a process in which "a material of small and uniform cross-section in practically endless lengths subjected to a long series of identical operations would seem not merely to invite but to practically compel continuous treatment and yet it was treated non-continuously in a perfect bedlam of confusion."[64] The great power needed to dry draw rods and the difficulties encountered in aligning the speed of the revolving blocks to match the elongation of the wire proved an insurmountable hurdle for early attempts at continuous drawing. The intense generation of heat in drawing, die life, and means of lubrication provided further complications that prevented general use of multiple die machines in dry drawing. Because wet drawing fine wire mitigated the impact of these factors, some specialized multiple die machines successfully produced fine wire. Cognizant of the benefits this technology held for their limited production of fine wire, the JARSC ordered ten continuous machines from Robert Wetherill & Company in March, 1916 for wire mill number two.

Successful solution of the continuous drawing problem held the potential to revolutionize wire drawing. In 1907, W.W. Gibbs, general manager of the Shenandoah Steel Wire Company of Buffalo, N.Y., heralded the development of a multiple die machine by the Iroquois Machine Company capable of drawing all sizes of wire. He foresaw that the use of these machines in his model mill under construction would nearly abolish the use of skilled labor, boasting that "only five men in the new mill will have had any previous knowledge of wire, or the wire business," and that in the new system women would be employed to draw all wire finer than No. 21.5 gage. Gibbs stated that based on actual test data, a man who once produced 9600 lb. on single draft units in a 24 hour period could now produce 60,000 lbs using the multiple die machines.[65] Unfortunately, the actual performance of the Iroquois machines never lived up to Gibbs' praise, and the Shenandoah Steel Wire Company disappeared.

Although the conversion of the durable Roebling-designed wire drawing machines to electrical power in 1928 reflected the

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[64]Lewis, 218.

[65]W.W. Gibbs, "Wire Drawing: The Second Step in a Useful Art," 24-25.

satisfactory performance of the single draft system, the JARSC kept abreast of the slow progress toward practical multiple die machines. The small number of continuous machines had proved useful in wet drawing fine wire, and the company experimented with four Nullmeyer dual die machines in 1926. A 1929 engineering order to remove one of the Nullmeyers from storage and ship it to Trenton indicated the value of their contribution to production. In the same year, however, the purchase of three Type A Morgan-Connor continuous machines introduced a new wire drawing technology that signaled the eventual end of the prominence of single draft drawing at Kinkora.

The Morgan Company acquired a viable platform for continuous drawing from an English firm, the Connor-Singer Wire Company, after World War I and spent several years refining and marketing their new Morgan-Connor machine. Company representatives discovered that selling the new machines to traditional wire drawers proved a difficult task. Morgan engineer Kenneth Lewis felt that the continuous machines activated a worker's instinct, deeply ingrained, which warns him of impending revolution. Lewis remembered the tribulations of the demonstrator he hired to promote the Morgan-Connor machines:

> He was a genial cuss, a big man, a big tonnage producer in orthodox work, but the wiredrawers hazed him unmercifully with never a word from the foremen or superintendents. He had to clean the sand out of his soapbox every morning and after a trip to the latrine, and after running a while on rod bundles cleverly cut into about six pieces he had to adopt the practice of going into the baker and picking out his own rods, with one eye cocked toward his machines the while. If these machines hadn't been beautifully engineered, rugged, virtually foolproof, and soundly and thoroughly demonstrated and advertised, they would have flopped.[66]

Morgan's main competitor in the wire drawing machine business, the Vaughn Company, responded by developing a different continuous technology in their "Motoblox" benches. The two

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[66] Lewis, 229.

companies largely divided future sales of wire drawing machines between them. Prior to the introduction of tungsten carbide dies, however, continuous machines held little potential for drawing the bulk of high carbon, larger diameter wire at Kinkora.

The origins of the carbide die lay in the German Osram Company's work to find a substitute for the diamonds used in drawing light bulb filaments during the last stages of WWI. Because the superior hardness of the tungsten carbide greatly extended die life, generated less die heat and decreased the lubrication needed to draw wire, the carbide dies particularly benefitted dry drawing in continuous machines. As in the case of the early Morgan-Connor machines, the threat posed by the new dies to the tradition-bred skills of the wire drawers and diemen resulted in reported cases of misplaced shipments of carbide dies that later turned up under basement floors or in rivers.[67] Superior performance eventually overcame the initial resistence, and by the mid 1930s carbide dies had replaced virtually all older types of iron and steel dies. Contemporaneously, the JARSC won the contract to provide and erect the cables for what would be the longest-span suspension bridge in the world, the Golden Gate Bridge. The conditions appeared favorable for the conversion to continuous drawing at Kinkora with the new dies, yet this development was still several years away.

Despite a mild recovery from Depression-era losses in the mid 1930s, a sales slump following the completion of the Golden Gate Bridge in 1937 resulted in an operating loss of over one million dollars.[68] In 1938, the JARSC also faced a complaint filed by the National Labor Relations Board that the company had violated fair labor practices outlined in the Wagner Act.[69] It is likely the financial setbacks combined with the recognition that the still unproven continuous drawing technology would elicit a less than enthusiastic response from wire mill workers

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[67]Lewis, 241.

[68]John A. Roebling's Sons Company, *Financial Report of the Company*, Roebling Collection, Rutgers University, 163.

[69]Zink and Hartman p.159.

dissuaded the JARSC from immediately introducing the continuous machines on a widespread basis at Kinkora. In 1939, the JARSC first purchased Morgan-Connor machines intended for the number one wire mill, and in 1941 three type "BW" six-block machines replaced Charles Roebling's single draft benches in aisle A.[70]

Much as during the Great War, WWII created an almost unlimited demand for wire and wire rope products. To prepare for the expected surge in production, in July 1941 the JARSC ordered eleven new Vaughn Motoblox machines for wire mill number one. Although Vaughn and Morgan-Connor machines continued to supplant the older benches, a 1942 engineering order to construct twenty-four water-cooled blocks for conventional benches demonstrated that single draft drawing still had a place at Kinkora. Nevertheless, by the end of WWII, the pervasive use of carbide die-equipped, continuous drawing initiated an era of substantial changes that restructured the technological system of wire making at Kinkora.

First, several process changes resulted from the technologies related to continuous drawing. The superior hardness of the carbide dies obviated the need for the heavy sull coat so essential to lubrication in previous methods of drawing high carbon wire. Baking the rods after cleaning, which had formerly required heating to relatively low temperatures for a twelve hour period to avoid burning the lime and sull coating, could now be accomplished with five to fifteen minute exposures to temperatures between 450 and 600 F in "flash bakers." The increasing use of "inhibitors" during the cleaning process further contributed to the viability of this new technology by reducing the threat of acid brittleness that was normally alleviated by the longer baking time. Elimination of the twelve hour baking period radically altered the pattern of rod delivery to the wire mills. No longer did wiremen begin their day with an allotment of recently baked rods, as the flash bakers supplied rods nearly as fast as the cleaning house processing permitted. Consequently, a system of "straight line" cleaning houses emerged to clean rods more quickly. Constructed in 1943, a row of acid, water, and lime (or borax) tanks with rigid temperature and time controls and serviced by an overhead crane displaced the circular

[70]Engineering order #9484-A (Jan.16, 1941).

cleaning stations and cleaning house gangs. At the end of the cleaning line, several tank-like flash bakers handled the task of rod drying that was previously done in a row of fifteen alley-type drying ovens that ran the length of the north wall of wire mill number one. After lying idle for a few years, the company tore down the old drying ovens in 1947.

Second, many cleaning and wire mill workers found their skill and knowledge no longer applicable in the new environment. The displacement of the skilled wire workers occurred during a period of labor unrest in the steel industry and union militancy. In the early 1940s, union organizers penetrated the Roeblings' control of labor for the first time, and a strike followed in April, 1941. The connection between the disgruntled wiremen and the unionization of the Kinkora workers deserves further investigation, but additional factors related to the national labor climate of the early 1940s undoubtedly played a significant role.

Since its incorporation in 1876, the JARSC had resisted unionization of the workforce through various means: the company town of Roebling, profit sharing plans, pension plan, an employee association, and company publications. Prior to unionization, the JARSC's practice of weathering periods of poor sales by wage cuts precipitated several strikes, but the unwillingness of the executive board to negotiate with striking workers reflected the hardheaded, pro-business mentality of the first quarter of the twentieth century that placed a premium on financial stability. The end of the JARSC's ability to mitigate losses after unionization with wage reductions compounded the bleak market predictions of the late 1940s. Unionization had further ramifications for the traditional bond of community between management and the workforce. Company management of Roebling village no longer provided either an incentive to employment or an efficacious means of controlling labor. Now a financial liability, the JARSC sold the houses in the Roebling village, largely to its existing tenants, in 1947.

Third, the implementation of continuous technologies at Kinkora marked a growing reliance on vendors for equipment and the standardization of manufacturing processes. Since Charles Roebling's death, instead of relying on in-house design, the JARSC purchased much of the major equipment to update the Kinkora mills, notably the Morgan billet reheating furnace and rod mill, the Chapman-Stein soaking pits, Westinghouse bell-type and Lee-Wilson annealers, Morrison flash bakers, and Vaughn and Morgan-Connor continuous wire drawing machines. Naturally, this reflected the increasing difficulty in sustaining an internal capacity to research and develop each individual component in the increasingly sophisticated system of manufacturing wire – after WWI it became more practical and cost-effective to let specialized vendors concentrate research and development efforts on specific equipment. Practices that had once varied as a function of unique equipment designs assumed a more standardized form as certain technologies found universal use in the wire industry. The establishment of institutional vehicles for technology transfer within the wire industry, in the form of a journal dedicated to the wire industry, *Wire & Wire Products* (1926), and the founding of the Wire Association in 1930, cultivated this gradual and uneven standardization of practice and equipment.

In the late 1940s, company management still rested in the hands of directors with Roebling lineage, but their duties with respect to technological change at Kinkora no longer resembled Charles Roebling's model. Separated from component design, the engineering aspect of executive management focused on process efficiency and assessing the financial costs of adopting new technology. The development of the technological system of wire making at Kinkora evinced one element of a postwar corporate climate that increasingly viewed production and manufacturing from a financially oriented perspective.

## 4.0 PHASE THREE - SYSTEM OSSIFICATION AND OBSOLESCENCE

As in 1914, war in 1939 created an anomalous demand that affected the complete range of production at Kinkora – from high carbon steel for harbor nets, wire rope hoisting slings, and aircraft control cords to low carbon steel and copper for power and communications transmission wire and screen cloth. The war perpetuated the embedded technology of high carbon production at Kinkora that proved problematic in a peacetime market that did not offer the same constancy and diversity of demand. Unfavorable forecasts for the postwar bridge wire and wire rope market led the JARSC to consider other outlets for their high carbon capacity in manufacturing tire wire, spring wire, and developing prestressed concrete. In addition, market forces and new developments compelled the company to assess the upgrades needed in their primary steel making and rolling technologies to remain competitive in the industry.

After the frenetic pace of wartime production, the JARSC faced an uncertain future with an aging technological system. The pervasive electrification of plant machinery, coupled with the electrical demand from Roebling village, exceeded the generating capacity of the existing Kinkora power plant initially designed to support steam power. Furthermore, the continuous rolling technology lacked the flexibility of more modern mills for rolling a diverse range of steel products, and the open hearth steel mill could not accommodate the increasing use of alloyed and stainless steels.

Despite the bleak market outlook for some of their more traditional products, the JARSC committed substantial sums to addressing the most crucial deficiencies. From 1946 to 1948, the company spent 2.3 million dollars building a new power plant. They sought product diversification in conventional markets by installing a lead tempering rig for specialty wires and a tire bead wire rig, and invested in cutting edge developments by funding continued work in the prestressed concrete department and establishing the Roevar magnetic wire program in 1946 at the cost of 1.7 million dollars. In 1951, the board authorized the conversion of the 2-strand continuous rod mill to 3-strands to improve the flexibility of rod production. Some consideration was given to updating the forty-year-old open hearth furnaces, but the alternatives were limited.

The Roeblings had traditionally made bridge wire and Blue Center rope steel with a high pig iron content, but the growing use of scrap steel instead of pig iron in furnace charges encouraged the switch from open hearth furnaces to electric furnaces that melted a scrap charge more quickly and with greater quality control. Although in the postwar steel industry electric furnaces emerged as the favored method of making alloyed steel and stainless steels that could not be produced in open hearth furnaces, the installation cost was prohibitively expensive. By doubling the capacity of one open hearth furnace in 1950, the JARSC tried to compensate for the advantages of electric furnace steel production, but enlarging capacity proved only a temporary solution. Most steel plants found it better practice to charge larger capacity open hearth furnaces with molten pig iron from a blast furnace to reduce melting time and energy. Lacking the blast furnace facilities of the major steel companies, the JARSC could not obtain the same economies of scale by enlarging their existing open hearth furnace capacity.

Aside from its technological limitations, the integrated steel mill had troubling labor ramifications for the overall cost of production. As Clifford Zink points out, strikes in 1949 and 1950 that forced the company to raise wages to the level of the rest of the steel industry put the company at a disadvantage: "while regular steel production typically required 10 man-hours per ton, the labor-intensive wire rope production required roughly 25 hours per ton. The resulting high expense of the company's products weakened its competitiveness against other wire rope producers that operated under less expensive contracts with unions other than the United Steelworkers."[71] Zink and Hartman outlined several other influential factors that led to the sale of the company, including the crucial impact of union contracts, a declining potential for large scale wire and wire rope projects, and the company's reluctance to borrow to make necessary capital investment to restructure production at Kinkora.[72] The traditional tight family control of the business had made an uneven transition into the corporate climate of postwar America. Management continued a Roebling custom that eschewed borrowing to support expansion or plant improvements, but as the board became dominated by family members not actively involved in the daily operations, the character of company investment changed. "Demand for increased dividends was often satisfied through aggressive management of the investment account for profit rather than using it to promote the wire rope business or to serve as a source of company financing." Despite allocating some $13.4 million (much of it to Kinkora) for plant improvements in the late 1940s, the board decided the future held a decreasing likelihood that substantial re-investment in facility upgrades would produce sufficient profits. Without recourse to the past practice of adjusting wages to balance fluctuations in revenues,

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[71]Zink and Hartman, 167.

[72]Zink and Hartman, 165-170.

the JARSC began to view ownership of a plant best suited to producing a high volume, high carbon steel product with a waning market future as an untenable prospect. On January 1, 1953, the Roebling family sold the Company to Colorado Fuel & Iron for $23 million.

Since the 1920s, the system of wiremaking at Kinkora experienced a gradual uncoupling of executive management from system technology and labor control. New standardized technologies increased plant output and improved the uniformity of the products, but also separated ownership from engineering and imparted an increasingly financial focus. Threatened by deskilling and hoping to end cyclical wage policies, labor sought its own voice through unionization. A system once designed to operate in mutually supportive manner was now less viable in following the breakdown of traditional coordination between management, labor, and technology.

## 5.0 EPILOGUE

As one of the largest domestic steel companies, the Colorado Fuel & Iron Corporation (CF&I) brought the advantages of a fully integrated, broad based corporation and the potential capital resources needed to revitalize production at Kinkora. CF&I began as a consolidation of mining operations and iron making facilities in the early 1880s, expanding its holdings and diversifying production until it became the only fully integrated iron and steel manufacturer in the West, a distinction the company held until 1942. As a result of the prosperity restored to heavy industry by World War II, CF&I was in a position to embark on a period of acquisitions initiated by a merger with the Wickwire Spencer Steel Company, long time manufacturers of wire and wire rope. From 1945 to 1953, CF&I added several blast furnaces, steel and steel products mills (including facilities to manufacture insect wire screen, industrial wire cloth, carbon and stainless steel plates, and gas and oil transmission line pipes) that culminated with the purchase of the John A. Roebling's Sons

Company.[73]

The thorough modernization of Kinkora under CF&I's ownership ultimately failed not for lack of exploration of new technologies, but due in part to an inadequate financial commitment and increasing environmental requirements. Large investment did transform certain aspects of steel manufacturing. In 1964, the company replaced the Swedes' open hearth furnaces with three electric arc furnaces that still occupy the west end of the steel mill. Because CF&I retained Roebling management and employees, including several key engineers, a certain degree of continuity characterized the focus of further technological development at Kinkora. The new owners were particularly interested in expanding the capacity for making prestressed concrete that was finding wider use in short span highway bridges and parking structures. In 1966, Chief Product Engineer H. Kent Preston recommended applying English heat stressing techniques to enhance the relaxation properties of the prestressed concrete cables so the company could pursue building nuclear containment vessels more competitively.

Reports initiated in the early 1950s investigated the promising technologies of continuous casting, mechanical cleaning, and continuous rod patenting and cleaning. Updated reports that continued to surface during the era of CF&I ownership of Kinkora indicated a varying level of interest in developing these technologies. Continuous casting billets straight from molten steel presented a means of circumventing the casting of ingots and the related processes of reducing the ingot to a billet, thereby obviating the pressing need to modernize the aging blooming mill. Although in a 1953 assessment, Dartrey Lewis, head of Research & Development, found the economic benefits of continuous casting (since he found no quality advantage) did not justify further pursuit at that time, by 1969 refinement of the process that added in line rolling immediately following casting led CF&I to contract plans for the necessary construction and equipment. Yet the funds to actually implement continuous casting never materialized.

Some smaller scale projects were more successfully adopted.

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[73]H. Lee Scamehorn, *Pioneer Steelmaker in the West* (Boulder, CO: Pruett Publishing Company, 1976), 5, 169-177.

In the late fifties, an experimental installation of a mechanical descaling machine in conjunction with patenting and coating rig investigated the feasibility of by-passing the conventional cleaning process. Lewis noted "successful results from this equipment will not only save processing costs but will be a step toward solving our acid disposal problem."[74] This method satisfactorily cleaned rods for some applications, but did not displace straight line cleaning. Continuous patenting, cleaning, and coating rigs, with and without mechanical descaling, however, solidified a change in the traditional placement of equipment and flow of materials in the mills that had begun in 1952. The old path of a patented rod passed first through the tempering house, then through the cleaning house before proceeding to wire mill number one for drawing into wire. As the company began to install the continuous patenting, cleaning, and coating rigs directly in the wire mills, some rod coils traveled directly to the wire mill after rolling, substantially reducing handling and processing times. To this date, several rigs still occupy a sizeable area of wire mill number two.

In the 1960s, the state environmental enforcement agencies that grew from the new awareness of the industrial impact on soil, water, and air quality forced many companies like CF&I to face the environmental costs of past manufacturing practices. Part of the early attraction of the site for the Roeblings included the ability to expand the site acreage by dumping the solid slag byproduct of the steel mill into the Delaware River. Over the years, numerous additions including spent refractory brick, mill scale, and furnace scale to the slag pile had increased its toxicity. With no effluent restrictions, several outfalls had spilled the plant greywater, with acid wastes from the cleaning and galvanizing shops, directly into the Delaware for over sixty five years. Similarly, the emissions from the power plant, and steel and rolling mill stacks that once symbolized progress and good business had substantially contributed to the declining air quality of the region. By the early 1970s, the Crane Corporation had taken over CF&I and had

[74]Unpublished interoffice memorandum, *Process Development E.I. 196*, Box 107 Environmental Protection Agency, Edison Warehouse.

constructed a wastewater treatment facility and air pollution control equipment at the cost of $3.2 million and $1.5 million, respectively, needed to continue operations at Kinkora. Crane also allocated funds to install a new Morgan "No-Twist" rod mill to replace the 1928 rod mill, but the project was subsequently discontinued. Citing "inefficiency, rising raw materials costs, high pension and energy costs, and unrealistic union demands," Crane Corporation closed the Kinkora Works in 1974, ending substantial steel manufacturing and processing at the site.[75]

In October, 1971, an order placed to the Indiana Steel & Wire Company to supply the CF&I Wire Rope Division with wire for replacing Golden Gate Bride suspenders illustrated the distance that separated the current state of manufacturing at Kinkora from the days when enormous reels of bridge wire, emblematic of Roebling prestige and engineering, left the Works for destinations across the United States.

[75] Zink and Hartman, 173.

## 6.0 Appendix A

This table illustrates the high number of companies with access to open hearth furnace steel for the manufacture of wire-rods in 1904. Except where noted, Bessemer Converters are not included in the table.

| COMPANIES MANUFACTURING WIRE-RODS | ASSOCIATED STEEL WORKS WITH OPEN HEARTH FURNACES plant name, location, #, capacity (type) |
|---|---|

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|---|---|
| US Steel<br><br>American Steel and Wire Company<br>Allentown Works, Allentown, PA<br>American Works, Cleveland, OH<br>Anderson Works, Anderson, IN<br>Braddock Works, Braddock, PA<br>Consolidated Works, Cleveland, OH<br>Donora Works, Donora, PA<br>H.P. Works, Cleveland, OH<br>Newburgh Steel Works, Newburgh, OH<br>New Castle Works, New Castle, PA<br>Rankin Works, Rankin Station, PA<br>Sharon Works, Sharon, PA<br>Waukegan Works, Waukegan, IL<br>Worcester Works, Worcester, MA<br><br>Federal Steel Company -<br>Illinois Steel Company<br>Joliet Works, Joliet, IL | Newburgh Steel Works, Newburgh, OH<br>5-50 ton, (2 acid, 3 basic)<br><br>Worcester works, MA<br>8-various (5 acid, 3 basic)<br><br>South Works, South Chicago, IL<br>10-various (basic)<br><br>Other US Steel steel works:<br><br>Everett, Middlesex, MA<br>2-15 ton (acid)<br>Vandergrift Works, MA<br>8-30 ton (acid)<br>Wood's Works, McKeesport, PA<br>2-15 ton (acid)<br>Donora Steel Works, Donora, PA<br>12-15 ton (basic)<br>Duquesne Steel Works, Cochran, PA<br>14-50 ton (basic)<br>Homestead Steel Works, Munhall, PA<br>50-various (basic)<br>Sharon steel Works, Sharon, PA<br>6-40 ton (basic)<br>South Sharon Works, Sharon, PA<br>12-50 ton (basic) |
| Alabama Steel and Wire Company<br>Birmingham Works, Ensley, AL | Gadsden Works, Birmingham, AL<br>4-50 ton (basic) |
| Ashland Steel Company<br>Ashland works, Ashland, KY | Ashland works, Ashland, KY<br>2-5.5 ton Bessemer Converters |

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| Carpenter Steel Company<br>Reading works, Reading, PA | no open hearth facilities,<br>Reading works, Reading, PA<br>8 experimental crucible steel "melting holes" |
| Colorado Fuel and Iron Company<br>Minnequa Rolling Mills and Steel Works, Pueblo, CO | Minnequa Rolling Mills and Steel Works, Pueblo, CO<br>6-50 ton (1 acid, 5 basic) |
| Crucible Steel Company<br>Atha Steel Works | Aliquippa Steel Works, Aliquippa, PA<br>1-15 ton acid<br>Black Diamond Steel Works, Pittsburgh, PA<br>8-various (5 acid, 3 basic)<br>Crescent Steel Works, Pittsburgh, PA<br>2-15 ton (unknown)<br>Howe, Brown & Co., Pittsburgh, PA<br>1-15 ton (acid), 1-20 ton (basic)<br>La Belle Steel Works, Allegheny, PA<br>2-15 ton (acid)<br>Pittsburgh Steel Works, McKees Rocks, PA<br>1-20 ton (acid) |
| Cuyahoga Wire and Fence Company<br>Cuyahoga Falls Plant, Cuyahoga Falls, OH | no iron or steel making capabilities |
| Dillon-Griswold Wire Company<br>Sterling works, Sterling, IL | no iron or steel making capabilities, plant idle |
| Grand Crossing Tack Company<br>Grand Crossing Works, Grand Crossing, IL | Grand Crossing Works, Grand Crossing, IL<br>2-40 ton (basic) |
| John A. Roebling's Sons Company<br>Kinkora Works, Roebling, NJ | planning 6-30 ton open hearth furnaces (3 acid, 3 basic) |
| Kokomo Steel and Wire Company<br>Kokomo works, Kokomo, IN | no iron or steel making capabilities |
| McCoy-Linn Iron Company<br>Milesburg Iron Works, Milesburg, PA | no open hearth facilities,<br>3 single puddling furnaces |

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| National Steel and Wire Company<br>New Haven Works, New Haven, CT | National Steel Foundry Company, New Haven, CT<br>2-25 ton (acid) |
| Page Woven Wire Fence Company<br>Monessen works, Monessen, PA | Monnessen Plant, Monessen, PA<br>2-15 ton (basic) |
| Pittsburgh Steel Company<br>Monessen Works, Monessen, PA | planning to install basic open hearth furnaces |
| Trenton Iron Company<br>Trenton Works, Trenton, NJ | no iron or steel making capabilities |
| United States Wire and Nail Company<br>Shousetown works, Lewis Block, PA | no iron or steel making capabilities, idle and for sale |
| Washburn Wire Company<br>Phillipsdale Plant, Phillipsdale, RI | Phillipsdale Plant, Phillipsdale, RI<br>2-15 ton (1 acid, 1 basic), |
| Wickwire Brothers<br>Cortland Works, Cortland, NY | Cortland Works, Cortland, NY<br>2-30 ton (basic) |

Source: The American Iron and Steel Association, *Directory to the Iron and Steel Works of the United States* (Philadelphia: The American Iron and Steel Association, 1904)

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1931, 1945

*Trenton State Gazette*

**Interviews**

Louis Borbi, mill worker, John A. Roebling's Sons Company, former President Roebling Historic Society

Carl Friday, Electrician, John A. Roebling's Sons Company

John Hodson, Wire Foreman - Wire Mill No. One, John A. Roebling's Sons Company

Don Sayenga, former Manager, Bethlehem Steel Corporation; Cardon Group Consulting

Paul Varga, Railman, John A. Roebling's Sons Company

Conclusion? rapid mechanization impacts too many aspects of wire manufacturing to allow craft unions to form/exert any influence?

In many ways, the technological transformation of Kinkora in the late 1920s embodied the findings of a trade journal article that declared "Better Control Typifies Furnace and Mill Progress in 1928."[76]

Relying on bottom up innovation hurts U.S. industry?(Gold p.715)

Prior to the mergers of the 1890s, investment in American industrial enterprises had been far more personal than institutional.(Chandler, p.80) ...

Washington Roebling recalled the dissention created by the offer: "They made us an offer and Ferdinand insisted on taking it; even Charles favored it. But I am free to say that I violently opposed it, and the deal did not go through."(Schuyler, p.352)

"Fast running machines and so-called improvements, whose only justification is in a cheapening of cost at the expense of quality, have been studiously avoided." - Catalogue, price list 1898.

"We assume here that if an operation that is new to us but old in technology has always been done in a certain way, that way is wrong. That's the way Mr. Ford wishes us to approach new processes."(Lewis, p.226)

The carbide dies now in standard use precipitated a new technique of butt welding the ends of rod bundles together to radically increase wire length.

The Roeblings' manufactured bridge wire from higher carbon steels, typically "80" carbon (0.80%) steel for the main cables of the later large suspension bridges such as the George Washington and Golden Gate bridges.

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[76]"Better Control Typifies Furnace and Mill Progress in 1928," Iron Trades Review (January 3, 1929):21.

Roebling's concern for stability assumed a seemingly haphazard form in the Niagara Bridge, where he employed Even if they were required to do so at four miles per hour.

ADDENDUM TO: HAER NJ-122
JOHN A. ROEBLING'S SONS COMPANY, KINKORA WORKS *HAER NJ,3-ROEBL,1-*
(Roebling Steel Company)
(Colorado Fuel & Iron, Roebling Works)
(Roebling Steel Superfund Site)
(JARSCO)
Second & Hornberger Avenues
Roebling
Burlington County
New Jersey

FIELD RECORDS

HISTORIC AMERICAN ENGINEERING RECORD
National Park Service
U.S. Department of the Interior
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Washington, DC 20240-0001