BRIDGES THE CELEBRATION
OF PASSAGE

by

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Thesis submitted to the Faculty of
Virginia Polytechnic Institute and State University
in partial fulfillment of the requirements for the degree of
MASTER OF ARCHITECTURE
in
Architecture

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March, 1985

Blacksburg, Virginia

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(ABSTRACT)

The purpose of this paper was to investigate the architectural appearance and the evolution of bridges. It is to show the intentions and consequent symbols of civilizations who built bridges. The paper also investigates bridge types, foundations and falsework.

BRIDGES
THE
CELEBRATION
OF
PASSAGE

Passages within a lifetime take many forms. Within intervals of space and time our perceptions pass from one place to another, from one moment to another, from one level of thinking to a higher understanding, and from life to death. In the physical world, the bridge allows passage of rivers and valleys and carries the burden of humanity over its shoulder. Wind and water are temporarily obstructed by the bridge but pass back into an even flow. Internal and external forces are distributed back to the earth. The bridge fuses the city, ocean, earth, river and the heavens into one image. It is the celebration of the distribution of forces, the unifying of city and nature and the welcoming gateway of introduction or the final boundary of departure which the bridge represents. In the intangible world of thoughts and feeling, the bridge serves as a link for continuation.

* * *

The character of a bridge changes with the atmosphere. On a clear sunny day the bridge reflects upon the water, releasing images of itself in moving undulations. On a clear night with a full moon, the bridge may leave a picturesque silhouette. The mood of the bridge sways with sunlight and clouds, moonlight and shadow, wind and waves, tides and flow, terrain and weather, seasons and age. The bridge is artificial to natural scenery and alters an environment bringing about new meaning. This can be done eloquently if care is taken with proportion, material, economy, and location of the crossing.

* * *

Martin Heidegger, in his essay, "Building, Dwelling and Thinking" states:

> The location is not already there before the bridge is. Before the bridge stands, there are of course many spots along the stream that can be occupied by something. One of them proves to be the location, and does so because of the bridge. Thus the bridge does not first come to location to stand in it; rather a location comes into existence only by virtue of the bridge. [1]

The location is found for the bridge for convenience of the public and strength of the structure. The presence of the bridge brings dependence upon it. The river bed must be uncovered to find solid ground. The place where the soil has built strength since the beginning of time, to bear the piers, will be selected. The river's shores must be held in place to provide a base for anchorage and the abutments, with provisions for different currents. The intersection of ways, one of road and the other of navigable channel, will determine the height of the bridge. When the steady elevation of the road does not allow passage for navigation, only one way will be able to operate at a time. The bridge becomes an obstacle and brings a journey to a pause. The bridge makes way for movement.

* * *

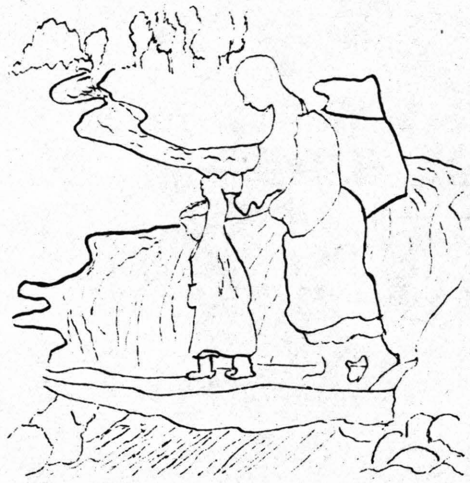
INTRODUCTION

Bridges evolved from primitive form to today's modern cable stayed. The thoughts and feelings that a bridge evokes have also evolved. The bridge becomes a symbol of the beliefs a particular society thought to be true at the time. The type of construction and form of the bridge reveal the period it was built. The building of a bridge becomes a fascinating subject. Imagine building a bridge which is considered an evil act, or a reward to go to heaven. What emotion would possess the builders: fear, devotion to a god, or the saving of humanity? The form, the spirit of the time, and the method of construction all contribute to an intriguing history.

THE INTENTIONS

PRIMITIVE MAN

When man first came to a river he had the choice of wading or floating across. The first bridge represents man ascending natural boundaries to hasten and simplify his journey. To primitive man nature knew best. All things of nature were simply manifestations of his gods.



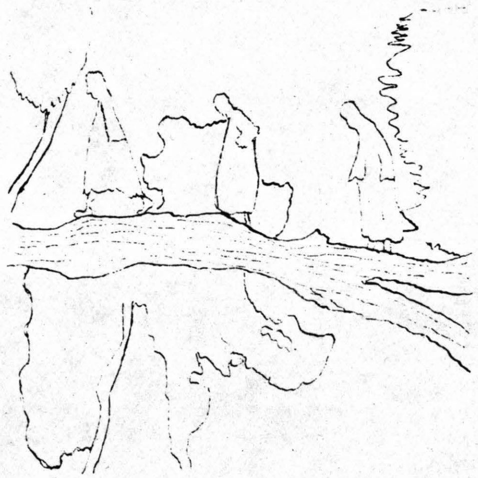
Spirit and Sacrifice

The physical danger of crossing a river or valley was also a spiritual violation. Rivers, valleys, and streams were looked upon as a divine intention to separate groups of people into regions defined by the contour of the land. The idea of building a bridge to shatter these pantheistical boundaries would go against divine intention. Retribution had to be made in the form of sacrifice, sometimes human.

Sacrifice for building a bridge, although less ceremonial, is a recurring theme throughout the ages. Loss of human life, through accident or miscalculation, is still looked upon as a mystical penance for breaching the laws of nature.

According to Dr. Paul Friedman,

> It seems that man's uneasiness in spanning nature's barriers, in defiance of the implied prohibition, was his sense of guilt which has remained buried in the unconscious, ready to be projected into the outer world in situations of psychic torment. This inescapably leads to the conjecture that the symbol of the bridge may indeed be an archaic acquisition of mankind."[2]



THE ROMANS

The Romans were more interested in spreading their power than bridge building. Permanent fords or ships were often used to cross a body of water instead of a bridge. This might have been done to hasten troop movement or to lessen the wrath of the river spirit. Once the conquered land was settled, permanent aquaduct and road bridges were built.

The Romans still believed the superstition that the river had magical powers, a belief left over from primitive cultures. During the Roman era, human sacrifice was substituted with the tossing of coins or dolls made of rush into the river. The crossing of the river was treated with the utmost caution. To the Roman mind, permanent structures were much more offensive to the river god than temporary ones. Tools and materials were categorized by the nature of their permanence and therefore the degree of offense to the river spirit. The story of a bridge across the Tiber river serves as an example.

For many years only one bridge crossed the Tiber river. According to tradition the bridge was made entirely of timber, because of its temporary character. A wooden bridge might be more tolerated by the river god than a permanent stone bridge. The use of iron was not permitted in the construction of the bridge. It seems the reason for this is the Romans still lived morally in the bronze age and had the feeling of repulsion for the new material.[3]

THE DARK AGES

During the Dark Ages or Medieval times, the Catholic Church of Rome was responsible for providing money, incentive, and for retaining the knowledge of the Romans in bridge construction. The arch was still the predominant form of constructing bridges.

The Roman Catholic Church reigned throughout Europe. During that time, the primitive belief in

river gods was transformed into a more omnipresent spirit, the devil. Legends and stories are told of bridge builders who, after repeated failures, enter into a contract with the devil. The agreement states that in exchange for the first living soul who crosses the bridge, the devil will insure the bridge is completed. The devil is then tricked when an animal instead of a human crosses and he must take its soul.

<u>The Symbol of the Bridge Transcends</u>

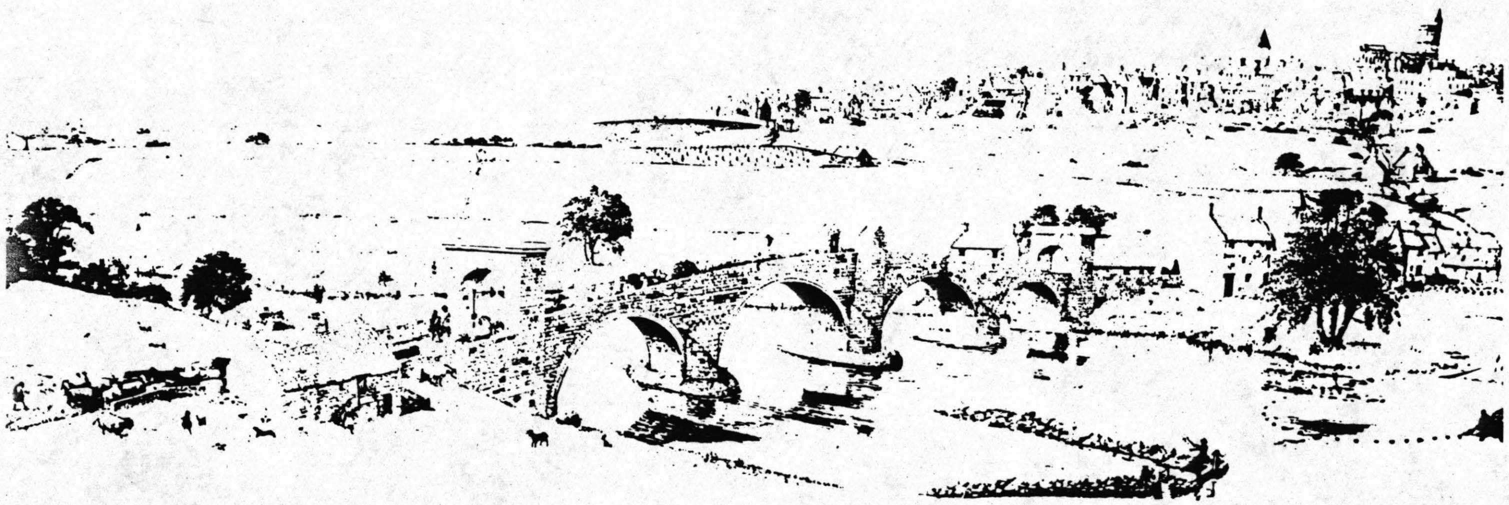
The dominance of Christianity changed the symbolic view of the bridge. The bridge was no longer seen as a violation of nature, but as protected by God.

The bridge actually became a work of charity and any contribution towards its construction would be rewarded in heaven. There was no longer a need to appease a river god through sacrifice. "To build a bridge was a good deed aiding the soul in purgatory."[4]

During this time the bridge was held in powerful symbolic reverence. The word for leader of the Roman Catholic Church, Pontifex, meaning priest or pope, is rooted in the word 'bridge'. 'Pontifex' is derived from the latin term 'Pontis' or 'Pons', which means bridge. 'Pontis', when added to the word 'facere', means bridge maker, or the bridge between heaven and earth.

Building bridges became a church enterprise. The bridge was a work of charity, which according to the church, was to be "anti-militaristic, forbidding the fortification of bridges. It also provided for the poor; demanding passage across a bridge should be gratuitous for all, not merely local residents. Any money donated should be for the love of God."[5]

In the 11th and 12th centuries the motivation for building bridges began to change. No longer was the bridge to be a work of charity. The immaterial reward of the promise of heaven changed to the more immediate, tangible world of



profit. The location of the bridge would be determined by military advantage and convenience for the public. Tolls were paid for floating under or crossing over the bridge.

THE RENAISSANCE

The Renaissance was a time when people devoted themselves to Christianity, art, science, and the growth of the individual. Knowledge was the pathway to heaven.

The fascination with geometry and renewed interest in art and science brought Renaissance bridges above the shadow of the Roman Empire.

THE 18th CENTURY

The 18th century was a period of transition between the Renaissance and the Modern period. It provided bridge forms made of natural materials which would later be the examples for man-made materials of the modern period.

Experimentation with new forms and the development of machinery hastened bridge construction. Power sources were still limited to human, animal, and flowing water but were used more efficiently.

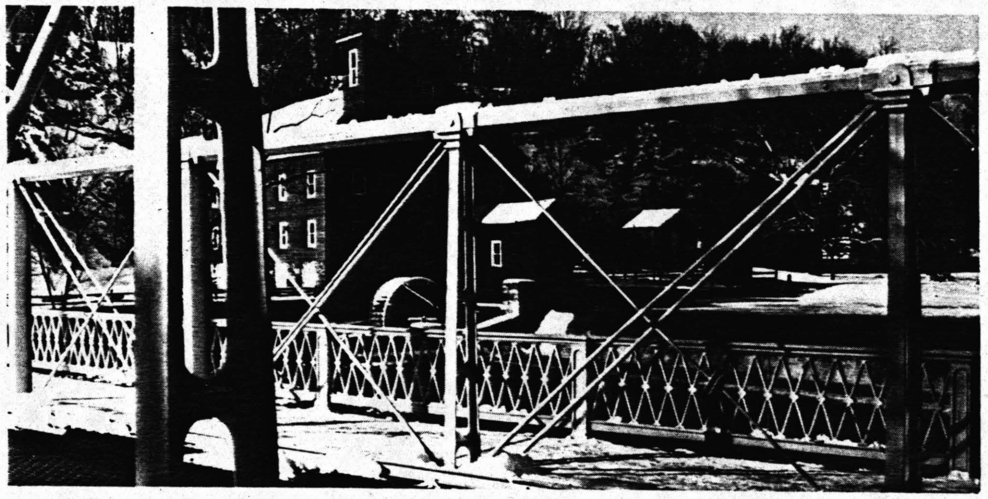
The transition from the 18th century to the modern period was the search for a better life through mechanization.

THE MODERN PERIOD

Throughout the industrial revolution the sparsely populated agrarian society was becoming a densely populated urban , industrial society. Improvements in health care led to rapid population growth. Institutionalized religion still had important social value but, intellectually, theology was devalued. Science and technology became more important.

The world was becoming smaller, first by the railroad and later by the automobile. Space and time shrank as vehicles' speed increased.

Mechanization of factories led to mass productions. It was thought that through material progress civilized behavior would occur. This philosophy is evident in John Roebling's quote:

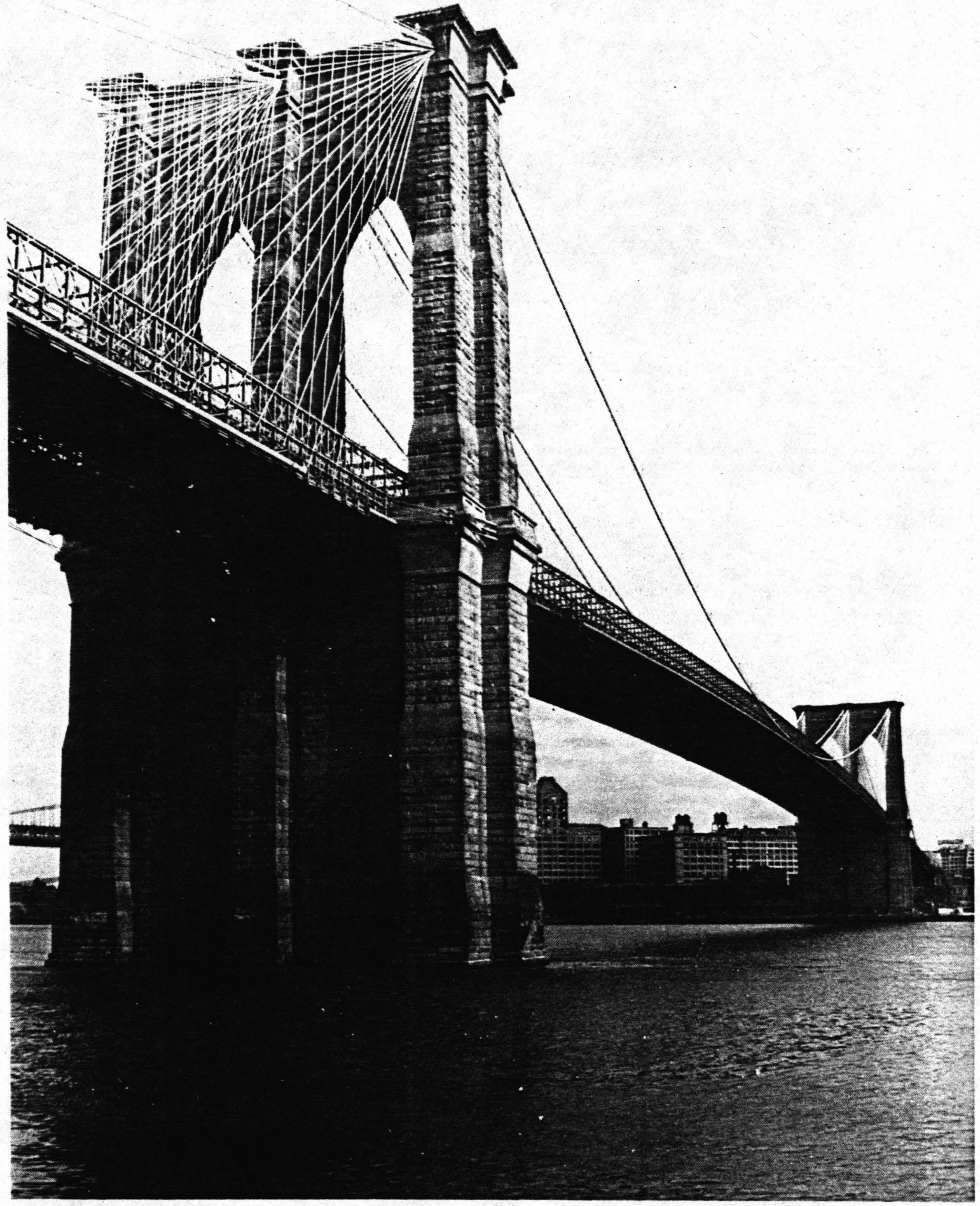


The present age is emphatically an age of usefulness. The useful goes before the ornamental. No matter what may be charged against the material tendencies of the present age, it is through material advancement alone that a higher spiritual culture of the masses can be obtained. The rich gifts of nature must first be rendered subservient to man before he can hope to comprehend her true spirit. In this sense the advancement of the sciences and various arts of life may well be hailed as the harbingers of good; its laborers are friends, not our enemies. The work of industry will be sown broadcast over the surface of the earth, and want will disappear.

The role of the bridge was to carry the products of mass production to and from the city and relieve the pressure of densely populated cities.

The bridge was a way not only to escape the city into rural areas but also to provide transportation to build more or larger cities. Proposals for major bridges acted in two ways. First, they created real estate speculation and increased property value. Second, they acted as a representation of a city. An example of this is the St. Louis Bridge built by James Eads in 1874. To reestablish economic dominance in the Mid West, the city of St. Louis set out to build a bridge to act as a nexus of railroad systems to connect with the Northeast. The intention was to build "for all ages, of a material that shall defy time and of a style that will be equally a triumph of art and contribution to industrial development."[6]
When a major bridge was built, it was a city's statement. Cities competing for commerce enticed business with their bridges, a statement of civic pride such as the Brooklyn Bridge of New York City and the Eads bridge of St. Louis. These bridges were statements of easy, fast and available transportation systems. Bridges became the joints of expanding transportation fingers.

The bridge is a dichotomy. It dares to push forward and provide for a better world and by doing so violates tradition. The primitive belief that the bridge is a violation of divine intention is an archetypical spectre. The haunting beauty of the bridge is its form which speaks of a former time when men were of earth, heaven or machine. It is the skeleton of forgotten tongues that gave way to April.



INTERPRETATIONS

When encountering a bridge certain emotions are aroused. The feeling can be from a simple set of logs crossing a stream or a suspension bridge vaulting across a large river. Both caputure an eclipse of time and have broader meaning than the space they occupy. They echo the desires of a particular people and become symbols of that desire. Poets and artists often use a particular type of bridge to portray a particular set of feelin or beliefs.

Crossing

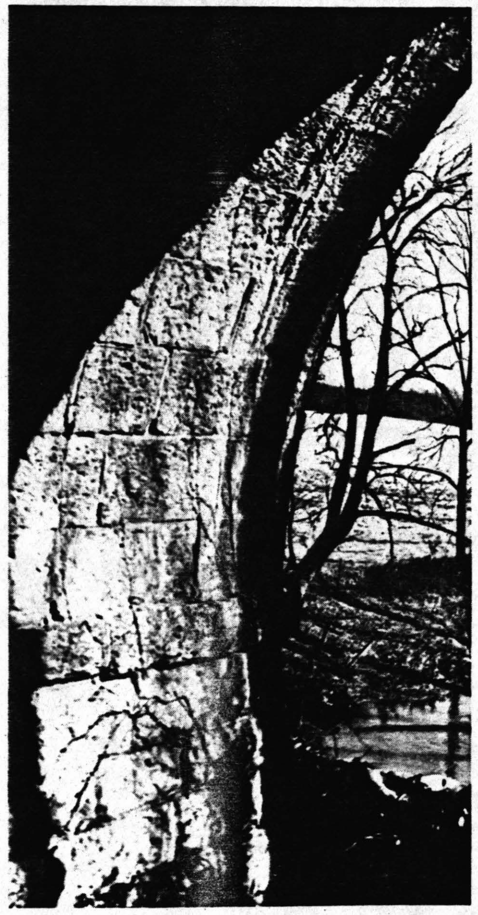
The first means of man ascending natural boundaries was probably by felling a tree, crossing a beaver dam or swinging on a vine. Man the hunter/gatherer did not have time to build elaborate bridges while he was in pursuit of prey.

The simple laying of logs across a stream gives the most pleasure knowing it was easy to build and even though it was a short span it kept your feet dry. It also reminds us of our primitive ancestors.

STONE ARCHED BRIDGES

Stone weathers the vicissitudes of time better than any other material. The Romans were the first to use stone in arch form. When the Romans did build bridges that became a permanent means of crossing, they used stone. The stone arch is a symbol of long lasting strength.

Some Roman bridges remain standing today as a reminder of this strength.



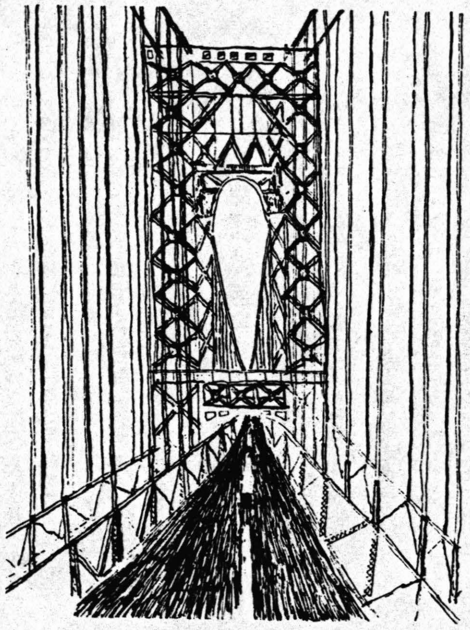
COVERED BRIDGES

The wooden covered bridge is a symbol of temporary shelter and the transition from agrarian to industrial society. The wooden covered bridges remaining today, looking like barns, preserve part of an older transportation system, and link us to our agrarian past. They perpetuate the feeling that living off the land is healthier, which is so much a part of today's psyche.

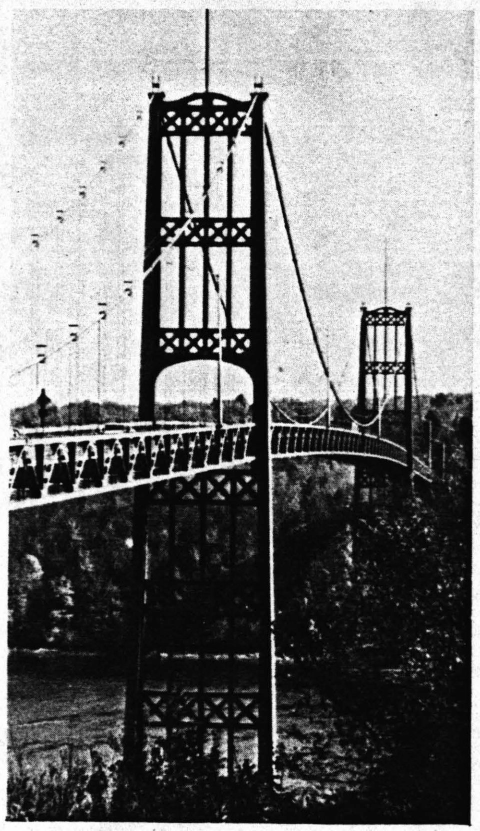
Covered wooden bridges shelter the structure from the elements. When passing through a covered bridge, the traveler experiences a widening aperture of light. Intervals of space and time are defined when the traveler enters darkness and departs from the light. Once through the bridge a new light and space appear.

The grave itself is but a
covered bridge. Leading
from light to light,
through a brief darkness.
A Covered Bridge at Lucerne
Longfellow

SUSPENSION BRIDGES



The suspension bridge has a beauty and lightness no other bridge can express. Reversing the arch into a slender cable, it uses tower, arch and truss into one. Floating in air, capable of breaching huge spans, the suspension a bridge comes close to perfect form. It tries to defy gravity. Encapsulated by towers and cables the suspension bridge gives changing perspectives of its surroundings. The suspension bridge is uniquely American.



An Emerging Symbol

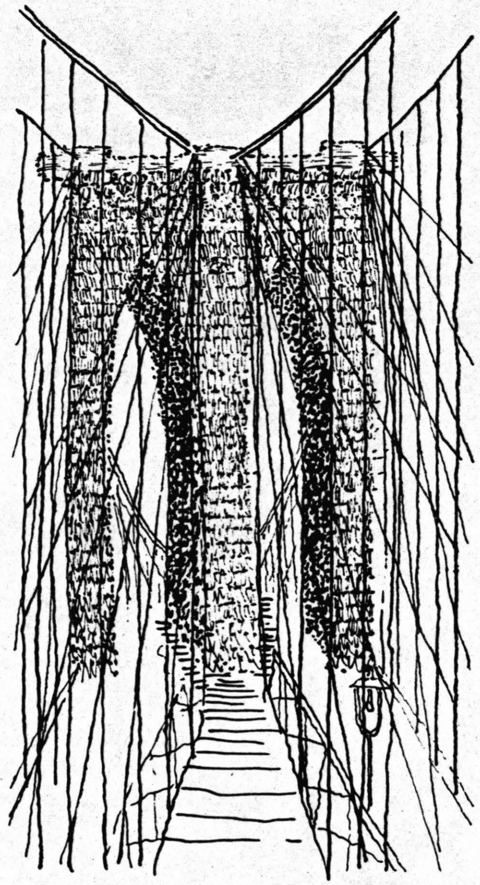
The suspension bridge became a symbol deeply entrenched in the emerging American spirit. The Brooklyn Bridge was the most celebrated suspension bridge. Artists such as Joseph Stella and John Marin thought of the bridge as an icon of the industrial age.

Stella wrote: "The bridge arises imperturbably with the dark inexorable frame among the delirious raging all around of the temerarious heights of the sky scrapers, emerges victorious with the majestic sovereignty sealed on his arches upon the subjugated fluvial abyss roaring below with the moaning of appeal of the tug-boats."[7]

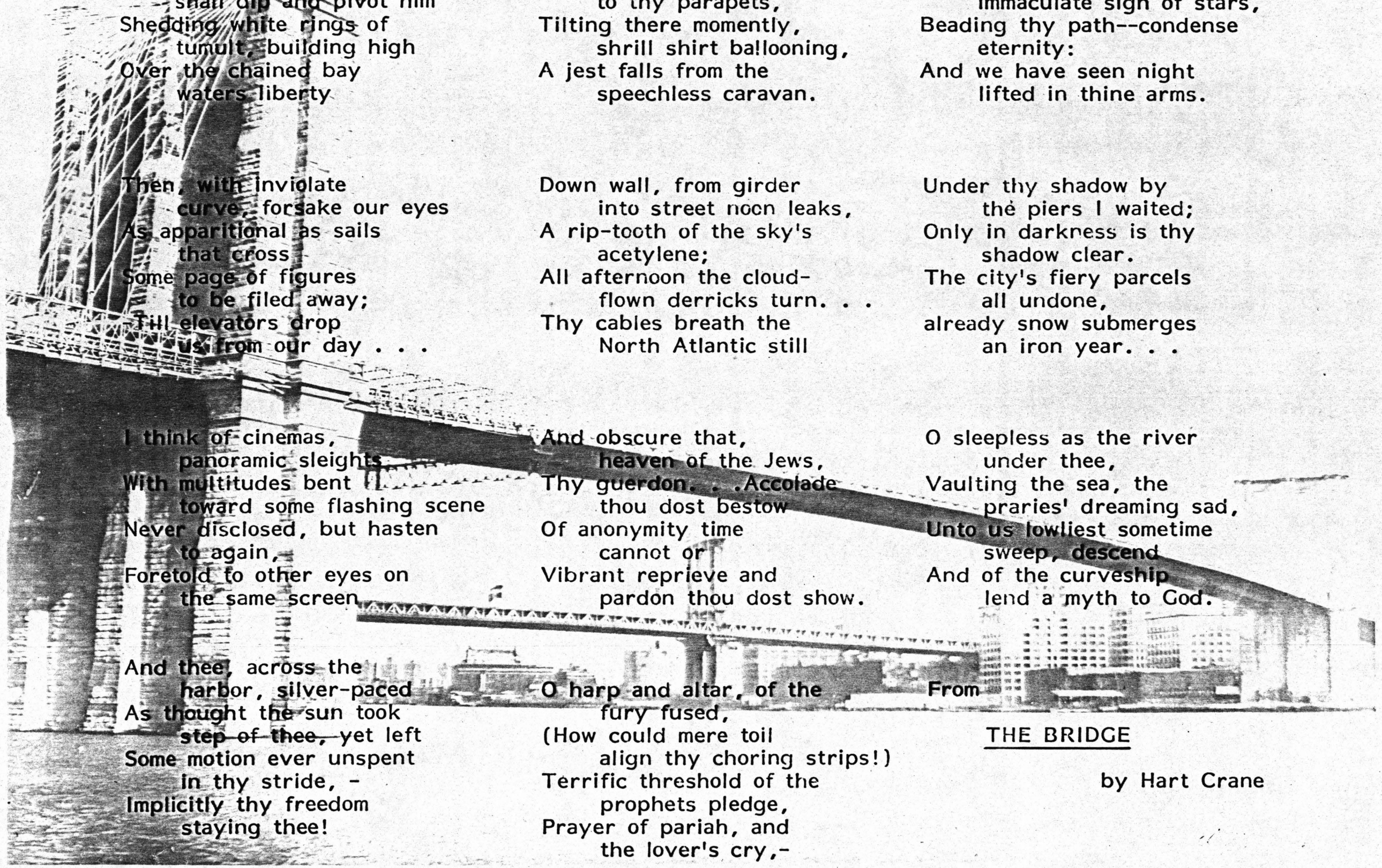
The Brooklyn Bridge was seen as a synthesis of city and country, and a reconciliation between industrialism and humane organic growth. This synthesis anticipated a healthy coexistance between machine and man.

The poet Hart Crane became the voice of this philosophy with his poem, The Bridge. Renouncing T. S. Eliot's symbol in The Wasteland of London Bridge as a passage way for the dead, Crane used the Brooklyn Bridge as a prophecy of promise. Crane wrote his poem in the same apartment and room from which Washington Roebling observed the construction of the bridge. The poem was based on the archaic myth of return. History was used in abstract form. "History was to be overcome by abolishing time, and the autonomy of events, and show that all meaningful events partake of an archetype: the quest for a new world." [8]

Crane wrote of his poem,"It concerns a mystical synthesis of America...The initial impulses of our people will have to be gathered up toward the climax of the bridge, symbol of our constructive future, our unique identity, in which is also our scientific hopes and achievements of the future." The bridge is meant to synthesize the temporal world of chaos and bring man to the state of order which his soul craves; the machinery itself is the benevolent instrument for the expanding consciousness of man, the thrust into an absolute and eternal, beyond space and time."[9]



Proem: To Brooklyn Bridge



How many dawns, chill
from his rippling rest
The seagull's wings
shall dip and pivot him
Shedding white rings of
tumult, building high
Over the chained bay
waters liberty

Then, with inviolate
curve, forsake our eyes
As apparitional as sails
that cross
Some page of figures
to be filed away;
Till elevators drop
us from our day . . .

I think of cinemas,
panoramic sleights
With multitudes bent
toward some flashing scene
Never disclosed, but hasten
to again,
Foretold to other eyes on
the same screen

And thee, across the
harbor, silver-paced
As thought the sun took
step of thee, yet left
Some motion ever unspent
in thy stride, -
Implicitly thy freedom
staying thee!

Out of some subway
scuttle, cell or loft
A bedlamite speeds
to thy parapets,
Tilting there momently,
shrill shirt ballooning,
A jest falls from the
speechless caravan.

Down wall, from girder
into street noon leaks,
A rip-tooth of the sky's
acetylene;
All afternoon the cloud-
flown derricks turn. . .
Thy cables breath the
North Atlantic still

And obscure that,
heaven of the Jews,
Thy guerdon. . .Accolade
thou dost bestow
Of anonymity time
cannot or
Vibrant reprieve and
pardon thou dost show.

O harp and altar, of the
fury fused,
(How could mere toil
align thy choring strips!)
Terrific threshold of the
prophets pledge,
Prayer of pariah, and
the lover's cry,-

Again thy traffic lights
skip thy swift
Unfractioned idiom,
immaculate sign of stars,
Beading thy path--condense
eternity:
And we have seen night
lifted in thine arms.

Under thy shadow by
the piers I waited;
Only in darkness is thy
shadow clear.
The city's fiery parcels
all undone,
already snow submerges
an iron year. . .

O sleepless as the river
under thee,
Vaulting the sea, the
praries' dreaming sad,
Unto us lowliest sometime
sweep, descend
And of the curveship
lend a myth to God.

From

THE BRIDGE

by Hart Crane

MOVABLE BRIDGES

Movable bridges separating themselves from land to allow passage by water give more meaning by motion than by form. It is the separation and reunification to land that gives one the most pleasure when viewing a movable bridge. It gives flexibility to an inflexible rail or water transportation system, the movable joint.

Synthesizing machine and bridge into one they move rapidly to allow land or water vehicles minimal pause in their journey.

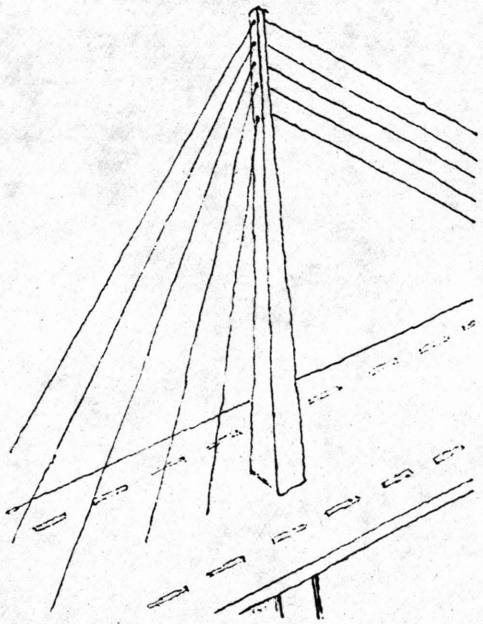
The bascule bridge's beauty comes from the movement of a horizontal position of bearing to a lofty ascending column. The abrupt yielding of a man made system to provide an opening for a natural one, acts as an alternating synapse which synchronizes the pulse rate of each transportation network.

Ending one passage for another to continue can be used symbolically in a variety of ways. An example of this is the idea of life after death. The ending brings opening.

Sounds of the sea washing
The whistle of a train to
a whisper
The bascule bridge
waits to bear its load
Flexing its muscle
Allowing passage
Reversing strength
Doing handstands
For the waves
From ships
In a river
That is never the same
Only, the meek
Float by unobstructed
Cold salty air, wind & water
Wait
To relieve the bridge
From the heavy burden

CABLE STAYED BRIDGES

The cable stayed bridge is the most advanced form in bridge building today. With light towers and cables appearing as magnetised laser beams, the cable stayed bridge dematerializes into the lightest of forms. It follows the tradition of simple form piercing into the future. It is the new horizon, the human quest for a better tomorrow.



CONSTRUCTION

FOUNDATIONS

In the built environment the bridge reaches out and pushes technology forward for a society to follow. It represents not only a need, but the daring and the expense a society is willing to risk to allow passage. In any given time period the bridge is part of a network that keeps the vital resources of a society flowing. Palladio, the 16th century architect, stated:

> The convenience of bridges was first thought upon because many rivers are not fordable by reason of their largeness, depth, and rapidity: upon which account it may well be said that bridges are a principal part of the way; and are nothing else but a street or way continued over water. Bridges therefore ought to have the self-same qualifications that are judged requisite in all fabrics; which are that they shall be convenient, beautiful and durable.[10]

To make bridges more convenient, beautiful and durable, advances were made by building stronger foundations, improving false work, using new and stronger materials and the manipulation of form.

Man searched for firm support of his bridges. When crossing over water the earth was not always firm enough to withstand the weight of the bridge. The answer was to either build somewhere else or dig deeper until solid ground was found.

The Romans first developed the cofferdam for the construction of foundations and piers beneath the water's surface. It accomplished the task of creating a void in a liquid which suffused anything with which it came in contact. The cofferdam opened enough space in the water to dredge soft materials, drive piles, set a foundation and build a pier.

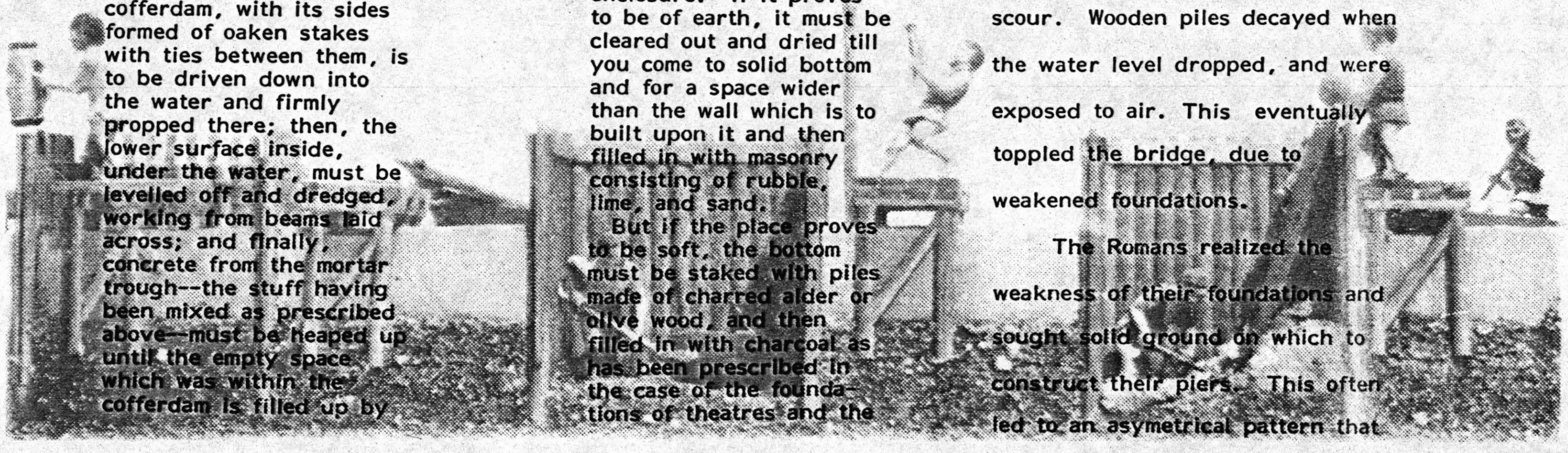
Vitruvius describes the method the Romans used:

> "Then, in the place previously determined, a cofferdam, with its sides formed of oaken stakes with ties between them, is to be driven down into the water and firmly propped there; then, the lower surface inside, under the water, must be levelled off and dredged, working from beams laid across; and finally, concrete from the mortar trough--the stuff having been mixed as prescribed above--must be heaped up until the empty space which was within the cofferdam is filled up by the wall. This, however, is possessed as a gift of nature by such places as have been described above. ...
>
> Then, on the water's edge and at the sides of the platform, let marginal walls be constructed, about one and one half feet thick and brought up to a level with the surface above mentioned; next, let the sloping part be filled in with sand and levelled off with the marginal wall and the surface of the platform. Then, upon this level surface construct a block ... But in places where this powder is not found, the following method must be employed. A cofferdam with double sides, composed of charred stakes fastened together with ties, should be constructed in the appointed place, and clay in wicker baskets made of swamp rushes should be packed in among the props. After this has been well packed down and filled in as closely as possible, set up your water-screws, wheels, and drums, and let the space now bounded by the enclosure be emptied and dried. Then, dig out the bottom within the enclosure. If it proves to be of earth, it must be cleared out and dried till you come to solid bottom and for a space wider than the wall which is to built upon it and then filled in with masonry consisting of rubble, lime, and sand.
>
> But if the place proves to be soft, the bottom must be staked with piles made of charred alder or olive wood, and then filled in with charcoal as has been prescribed in the case of the foundations of theatres and the city wall. Finally, build the wall of dimension stone, with the bond stones as long as possible, so that particularly the stones in the middle may be held together by the joints. Then, fill the inside of the wall with broken stone or masonry. It will thus be possible for even a tower to be built upon it."[11]

The arched bridge, which thrusts outward at the piers, needs a very strong foundation. Vitruvius' description did not protect the foundation from scour. Scour occurs when the river current undermines the foundation.

The habit of designing the pier in a V shape, known as a cutwater, on only the upstream side increased scour downstream. Roman bridges failed because the piles were not driven deep enough and were susceptable to scour. Wooden piles decayed when the water level dropped, and were exposed to air. This eventually toppled the bridge, due to weakened foundations.

The Romans realized the weakness of their foundations and sought solid ground on which to construct their piers. This often led to an asymetrical pattern that



weakened the bridges continuity.

The Roman contribution to the construction of bridge foundations through the use of the cofferdam and the driving of piles for the foundation of piers is today the basis for construction.

The Dark Ages

During the Dark Ages foundations for piers were built in a very primitive way. Stones were placed in a basket and lowered into the water to form a foundation. Piers were then built upon this pile of stone. This method resisted so much water flow that in some cases the upstream water level was higher than the downstream side.

Pointing the piers on both upstream and downstream side reduced scour, improving the Roman tendency to point only the upstream side.

Between the Renaissance and the Modern period major improvements took place in excavation methods.

In 1538, the first diving bell, or a large inverted kettle, was used. This was the first time air pressure was used to displace water.

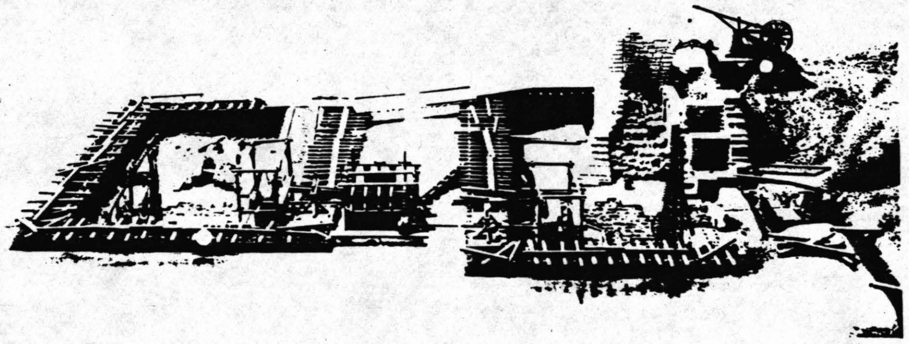
In 1685, an architect named Romain, who was a teaching brother from Holland, proposed the first caisson for the construction of piers for Pont Royal in Paris. Great timber boxes filled with the masonry of the pier were assembled on land, floated out, and sunk on previously driven piles.

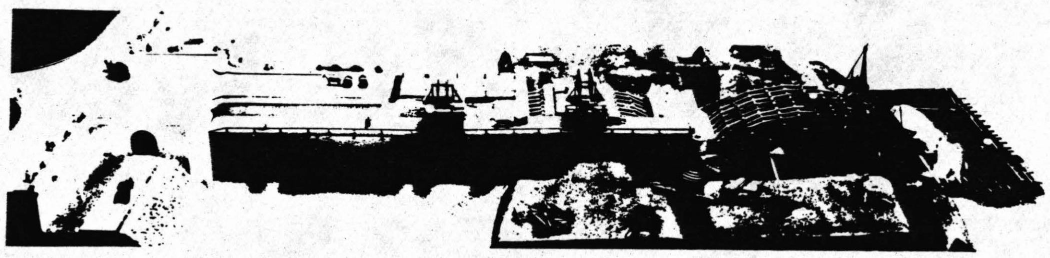
Improvements in removal and displacement of water to excavate sand and soil helped to establish stronger foundations.

Labelye, a Swiss engineer, invented the first reusable caisson. Constructed on shore, it was floated out to the foundation site, which had already been dredged. Stone ballast was placed to form a working mat before the caisson was sunk. The caisson was sunk and pumped out. The masonry for the foundation and pier was placed. When the appropriate height was reached the caisson was floated up, dismantled, and used on the next pier foundation.

Improvements in the pile driving machine were achieved, through work of James Valove' and Charles Labelye. Powered by horses, it included a releasing clutch, a 1700 lb. hammer and a raising height of 20 feet. Heretofore, the pile driver hammer was lifted by humans with a maximum weight of 800 lbs. and a height of 10 feet.

Chain pumps, piston pumps, and water wheel pumps replaced archaic methods of water removal such as bailing, scooping, water troughs, and the archimedian screw.



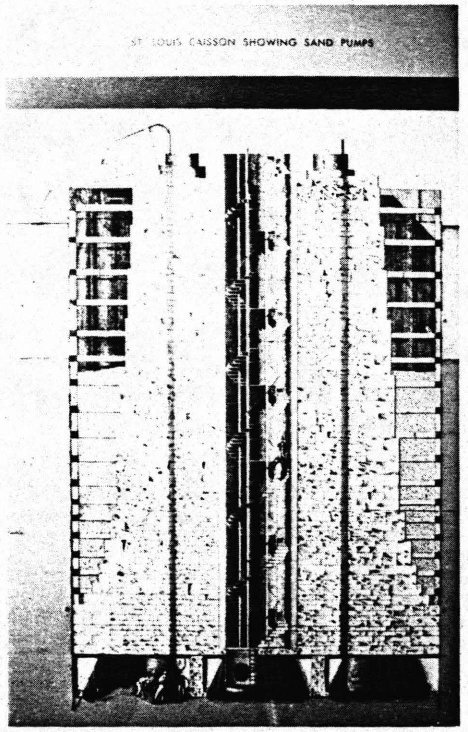


FALSEWORK

During the Modern period great advances in the construction of foundations took place. The single most important invention in the construction of underwater foundations was the pneumatic caisson. This mechanical mole displaced water, enabling workers to excavate on the river bed. The pneumatic caisson consists of a giant box, opened on the bottom. Filled with compressed air, with enough pressure to keep water from entering, men were able to work inside it on the river's bottom. As they excavated, masonry was placed on top of the caisson to sink it down further. The foundation is an inverted tower underwater to provide strength for the structure above.

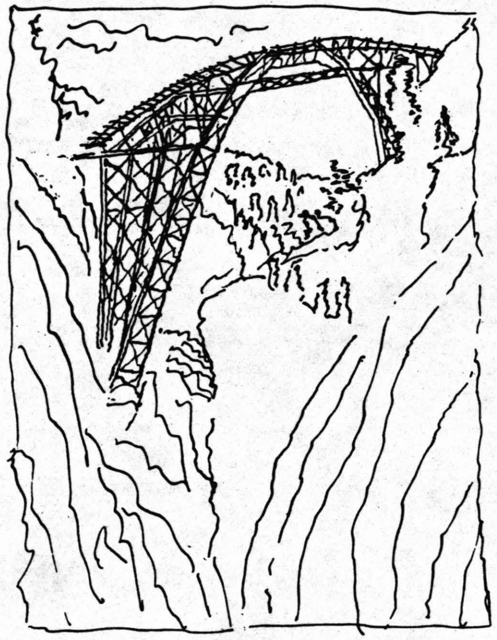
The first pneumatic caisson was invented by William Cubitt and John Wright. It was first used in the Medway river for a bridge in Rochester, England in 1851. It was later perfected by James Eads and John Roebling. A caisson for James Eads' bridge in St. Louis reached a depth of 136 feet.

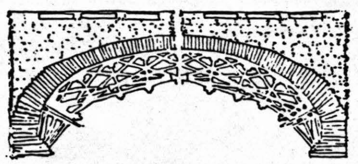
There were problems, however, with the effect of compressed air on the workers in the caisson. If decompression takes place too quickly, the human body's nitrogen supply in the blood comes out of solution, blocking circulation. Known as the bends, or caisson disease, many workers were killed or crippled. Fifteen men died of this disease during construction of the foundation for the Eads bridge in St. Louis. Improvements in the decompression method eliminated this problem.

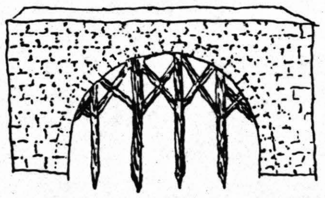


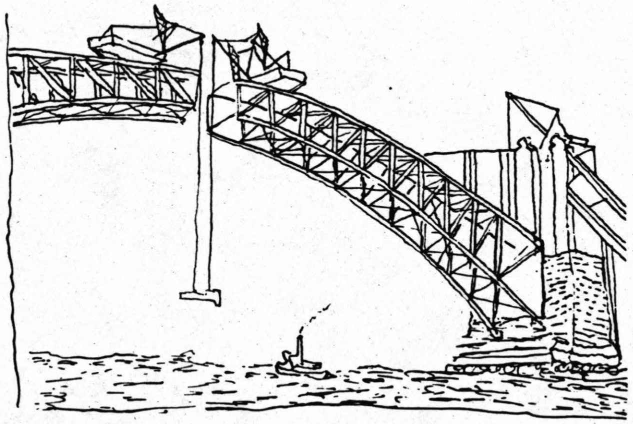
The Romans were the first to use removable and reusable wooden framing and scaffolding to construct stone bridges. Using a temporary structure to build a more permanent one minimized the amount of material needed for the final product. Piers were built thickly, almost acting as abutments. Timber piles were driven between the piers and a web of wooden falsework was used to lay wedge-shaped stone "voussoirs" in place.

Advances took place in false work with the understanding of the truss. In the modern period Malliart's and Freysinett's falsework was as elegant as their bridges. Cantilever suspension and cable stayed bridges eliminate most falsework. The temporary is permanent.



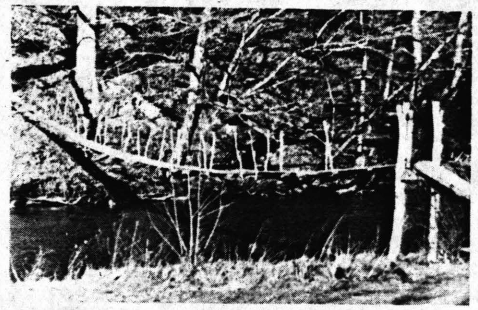






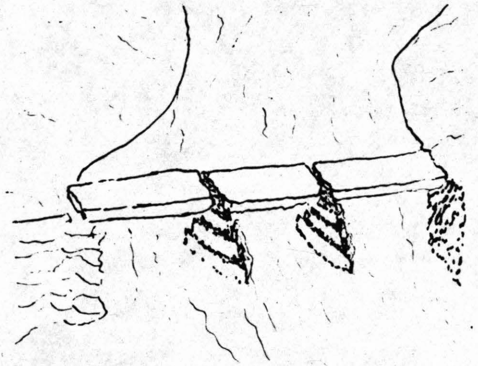
FORM

The manipulation of material and form enables man to overcome the barriers of nature. Each form comes from an archetype and advances with new materials and connections that is a metaphor of the original archetypical form.



BEAM BRIDGES

The most primitive beam was a log or stone slab placed across a stream. An example of this is the ancient clapper bridges of England.

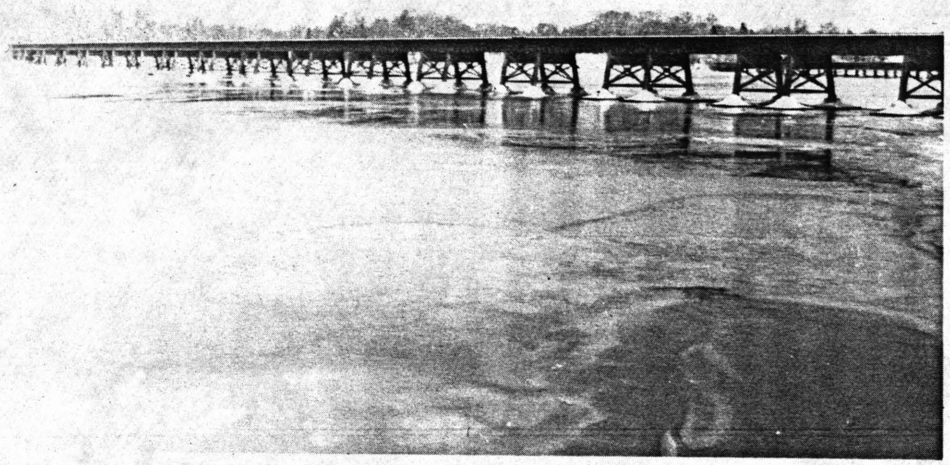


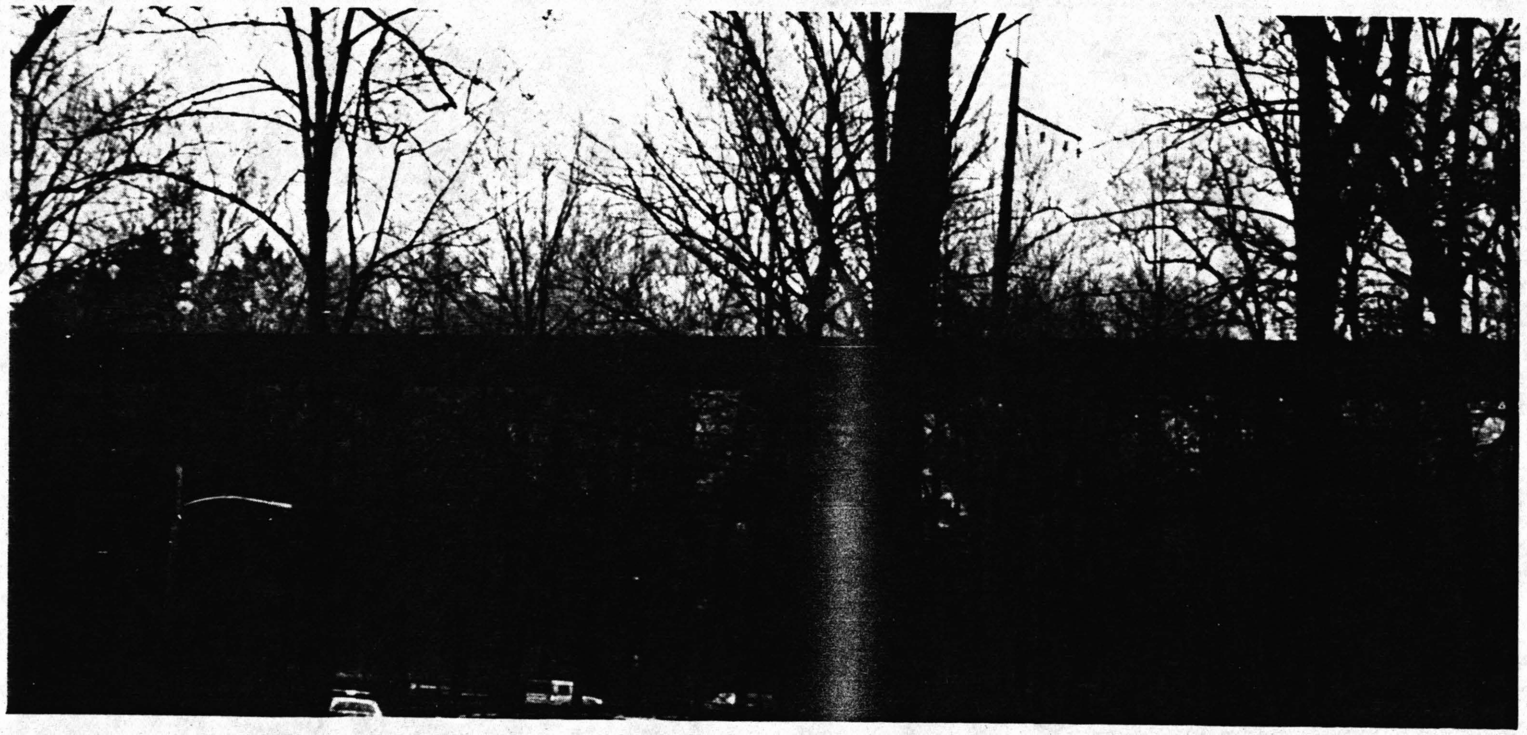
Man did not develop elaborate piers or connections until he settled.

As early as 200 B.C., according to Anijot Diodorous of Silicy, "a bridge was built with piers 12 feet apart and stone fastened together by iron bars anchored in holes filled with lead."[12]

Often the beam was stiffened and layered to provide more strength in the middle. Riveted together, some girders appeared massive. The rolled steel beam eliminated some of the massive quality and the box beam relieved torsion.

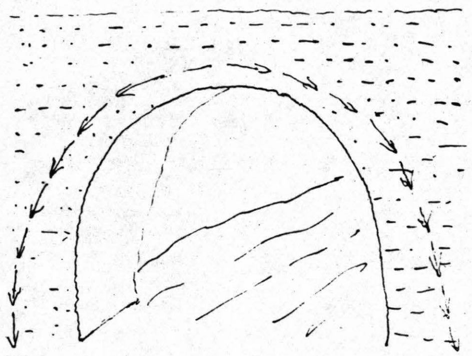
The beam bridge can appear thin and elegant when expressed in reinforced concrete or steel.





ARCHED BRIDGES

The development of the arch was as important for bridge construction as the containment of fire for heating and the invention of the wheel for transportation. By using compression, smaller components were connected together to form an arch. Gravity was used as a friend instead of an obstacle.



This allowed greater distances between spans. Bridges were no longer restricted in size by the length of a material. Although the Egyptians and Greeks had knowledge of the arch, it was not used exclusively until the Roman Empire.

During construction the two half arches are relieved by the insertion of the keystone. The keystone, the uppermost closing wedge of the arch, provides unity and equal distribution of force between the two half arches. Once the keystone is placed, all falsework can be removed.

THE DARK AGES

During the Dark Ages the form of the arch and cut waters changed subtly. The remaining Roman bridges were structurally superior and lighter. Form would provide the way to continue improvement in arched bridges.

The Romans used the semi-circular arch only. The semi-circular arch was also used during the Medieval period and ogival or pointed and segmental arches were introduced.

> Each of these arches has its advantages and disadvantages. The semi-circular arch is relatively stable and easy to build; but in floodtime the higher the water level, the less the space available for navigation. The segmental arch exerts more pressure against the piers, but when properly balanced it allows the use of small piers and involves little blocking of the freeway. However, the chief advantages of the segmental arch were difficult to realize in the Middle Ages, for in an age which could not calculate thrusts and strains, large piers were almost inevitable. The pointed or ogival arch is very stable, exerting less pressure on the piers and in floodtime there is less question of decreasing the area of the freeway as the waters rise; but the use of pointed arches calls for a greater number of piers in the river than does the semi-circular or segmental arch.[13]

THE RENAISSANCE

Before this time the achievements of the Roman Empire in bridge construction remained superior to any other development. During the Renaissance improvements occurred.

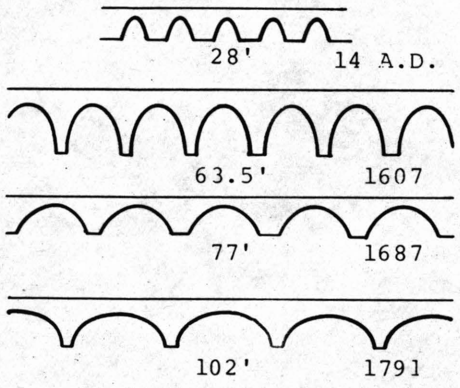
Arches still remained the dominant form for constructing bridges. The idea of attenuation and simplicity began to take place. Arched bridges became more elliptical, flat and slender.

Palladio, writing on arched bridges, also had a profound influence on bridge construction.

> The place...for building bridges ought to be...where the river has a direct course, and its bed equal, perpetual, and shallow. The pilasters (i.e. piers)...ought to be in number even; as well because we see that nature has produced all those things of this number, which being more than one, are to support any weight, as the legs of men, and all other animals can justify; as also because this same compartment is more agreeable to be looked at, and renders the work more firm; because the course of the river in the middle, (in which place it is naturally more rapid, as being farther from the banks) is free, and doth not damage the pilasters by continually shaking them...
>
> The pilasters ought not to be thinner than the sixth part of the breadth of the arch; nor ordinarily thicker than the fourth. They must be made with large stones, which are to be joined together with cramps, and with iron or metal nails, that by such concatenations they may come to be all of one piece. the fronts of the pilaster's are commonly made angular, that is, that they have in their extremity a rectangle (i.e. a pointed end of 90° angle); and some are also made sometimes semicircular, that they may cut the water, and that those things which are carried down by the impetuoisty of the river, may, by striking against them, be thrown off from the pilasters, and pass through the middle of the arch.
>
> The arches ought to be made firm and strong, and with large stones, which must be well joined together. Those arches are very firm that are made semicircular, because they bear upon the pilasters, and do not shock (thrust?) one another. But if...the semicircle should offend by reason of the too great height, making the ascent of the bridge difficult, the diminished must be made use of, by making arches, that have but the third part of their diameter in height (Designs in the book show that a ratio of height to span of one-third is meant); and, in such case, the foundations in the banks must be made very strong.[14]

18th CENTURY

During the transitional period of the 18th century, the French engineer Perronet, masonry bridges came to a grande finale. He economized on the use of materials and brought a lightness to his bridges. He theorized that each arch could carry the horizontal forces next to it, transporting the load into the abutments. The size of the piers were reduced to half the previous size, since only vertical forces had to be accounted for. Thinning and eliminating the number of piers reduced resistance to water flow. The thin piers and flattened arches gave the appearance of continuous structure.



THE MODERN PERIOD

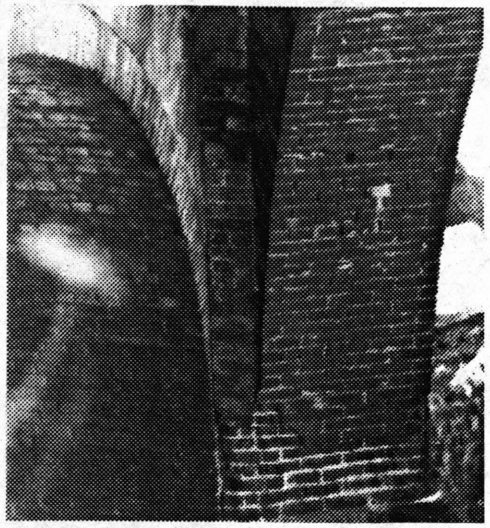
With the industrial revolution man-made materials were used to build arches. Eiffel built crescent shaped bridges made of iron members.

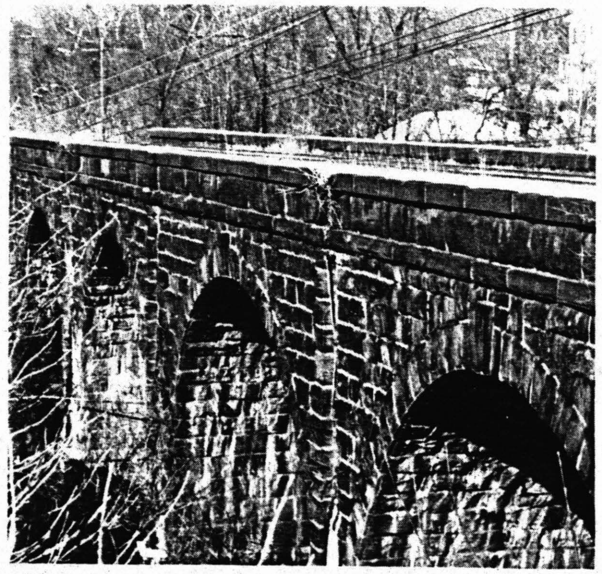
Eiffel specialized in the trussed arch form. To permit flexibility in the event of expansion or contraction, or movement of the foundation, he used hinges at each end of the arch. Hinges facilitated design by making the arch statically determinate and eliminating problems due to temperature change.

<u>Slender and Simple</u>

The idea of a sleek bridge started with Palladio. Economy of materials would lead to monetary savings. Perronet, by transferring loads into abutments and thinning piers, achieved this ideal in stone. Maillart must be given the most credit for achieving this ideal in the new artificial stone.

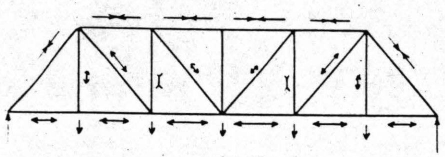
Maillart, like Eiffel, also used hinges but used reinforced concrete to build his arched bridges. His bridges are the highlight of what an arch can be.





TRUSSED BRIDGES

The truss, like the arch uses connections to let a bridge span a greater distance, that could not be achieved by an individual member. Combining members in a triangular form the truss provides the truss provided additional strength that a single member could not.



A

UNIFORM LOAD

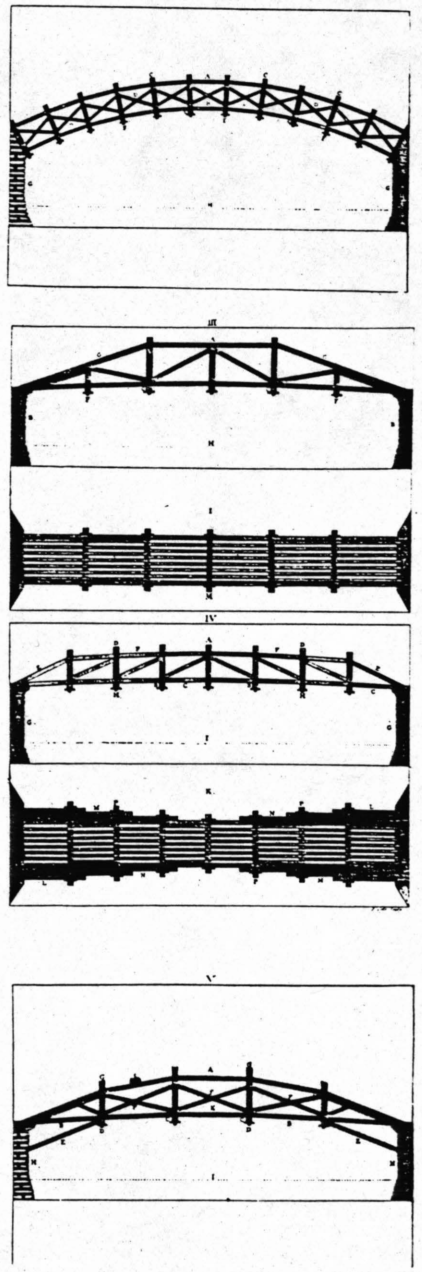
Temporary Structure Becoming Permanent

The Roman use of the parapet to differentiate the bridge from the road and to protect travelers from falling was taken one step further by Palladio. Through the use of the truss, he was the first to abstract the parapet into part of the structural support of the bridge. His trusses minimized falsework. Made of wood, the bridges looked like the falsework for stone arches. Although the truss was in use in roof construction as far back as Greek civilization, it was Palladio who first proposed various trusses for bridge design.

> The invention of this bridge is in my opinion, very worthy of attention, as it may serve upon all occasions, in which the said difficulties shall occur; and because that bridges thus made, are strong, beautiful, and commodious: strong, because all their parts mutually support each other; beautiful, because the texture of the timbers is very agreeable and commodious, being even and in the same line with the remaining part of the street. The river where this bridge was ordered, is one hundred foot wide; the breadth is divided into six equal parts; and at the end of each part (excepting at the banks, which are strengthened with pilasters of stone) the beams are placed, that form the bed, and breadth of the bridge; upon which, a little space being left at their ends, were placed other beams lengthways, which form the sides. Over these, directly upon the first, the colonelli on each side were disposed (so we call those beams vulgarly, that in such works are placed directly upright.) These colonelli are bound with the beams (which, as was said, formed the breadth of the bridge) with irons which we call cramps, passing through a hole, made for that purpose in the heads of the said beams, in that part which advances beyond the beams that form the sides. These cramps, because they are in the upper part along the said upright and plain colonelli, are perforated in several places. And in the under part, near the said thick beams, by one hole only, sufficiently large, they were driven into the colonello, and fastened afterwards underneath with iron bolts, made for that purpose; they therefore made the whole work to be in a manner united. The beams that form the breadth, and those of the sides being as it were, of one piece with the colonelli, support the beams that form the breadth of the bridge; and those are also supported by the arms that go from one colonello to the others, whereby all the parts are supported the one by the other; and their nature is such, that the greater the weight upon the bridge, so much the more they bind together, and increase the strength of the work. All the said arms, and the other beams that form the texture of the bridge, are but one foot broad, and but three quarters thick. But those beams that form the bed of the bridge, that is, those that are laid long ways, are a great deal smaller.[15]

Palladio, however, was naive to the fact that trusses eliminated bending forces on individual structural members and that stresses increased toward the center. Although very few trussed bridges were constructed at this time, they would become prevalent some 200 years later.

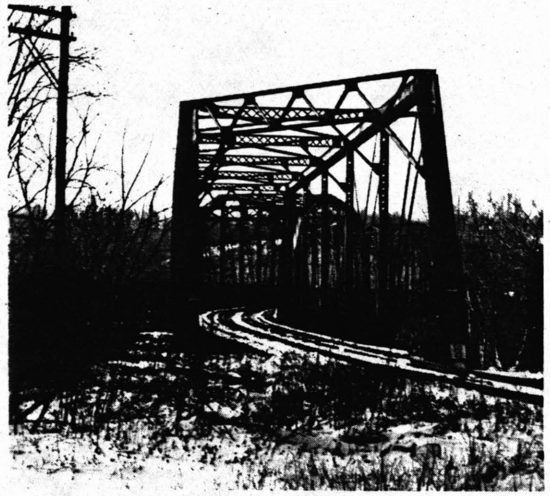
The truss like the arch has been used in a great variety of formations.

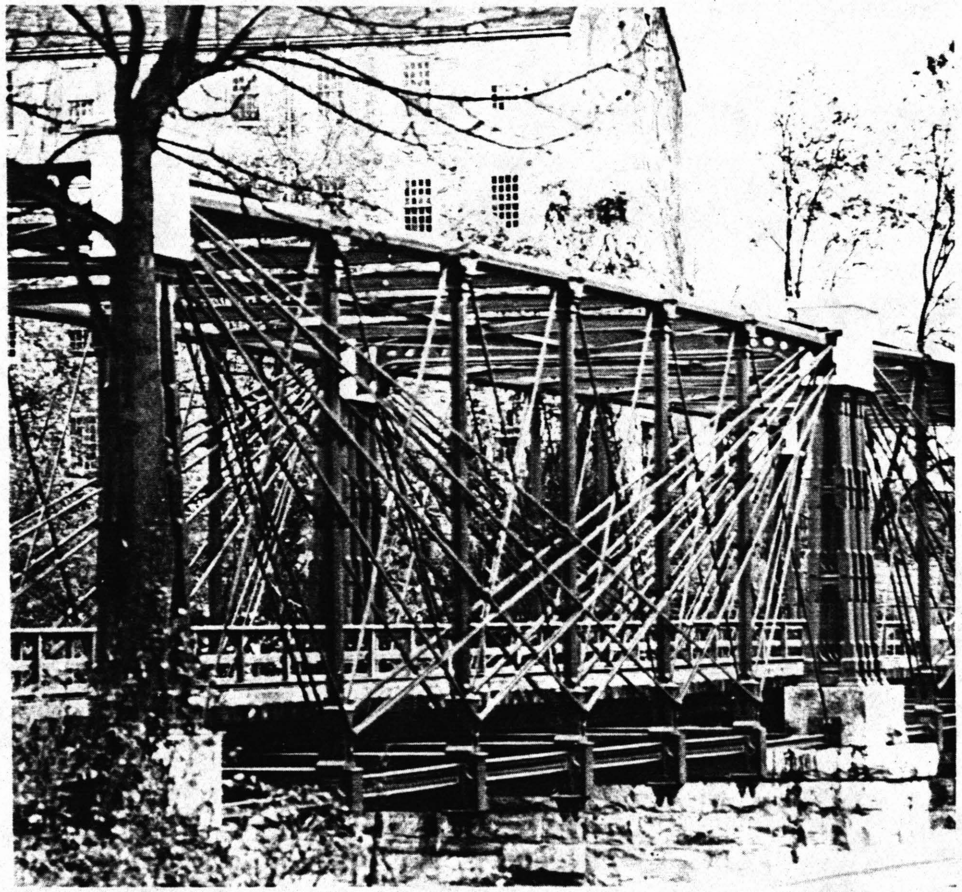


Palladio's "Draughts" of Wooden Trusses

In America the development of railroads and canal systems led to a wide variety of iron trussed bridges. The Whipple, Fink, Bollman, Town, Pratt, and Warren Truss are an example of this variety. Squire Whipple originally built bridges for the Erie canal. He was the first to use scientific analytical calculations to determine the size of members needed in an iron trussed arch bridge. Whipple published A Work on Bridge Building in 1847, showing methods of bridge designing through calculation. Until new materials emerged, empiricism began to give way to scientific method.

American bridges were characteristically through or deck trusses. They had the appearance of a cobweb flung across a river or valley. Some spanned great distances. It would not be long before these gossamers were turned vertically to form sky scrapers.





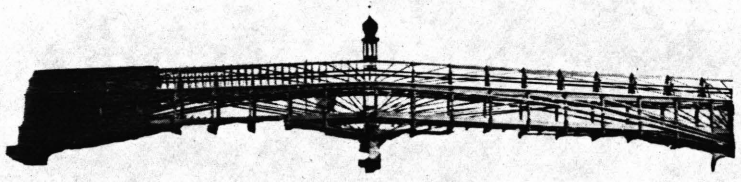
COVERED BRIDGES

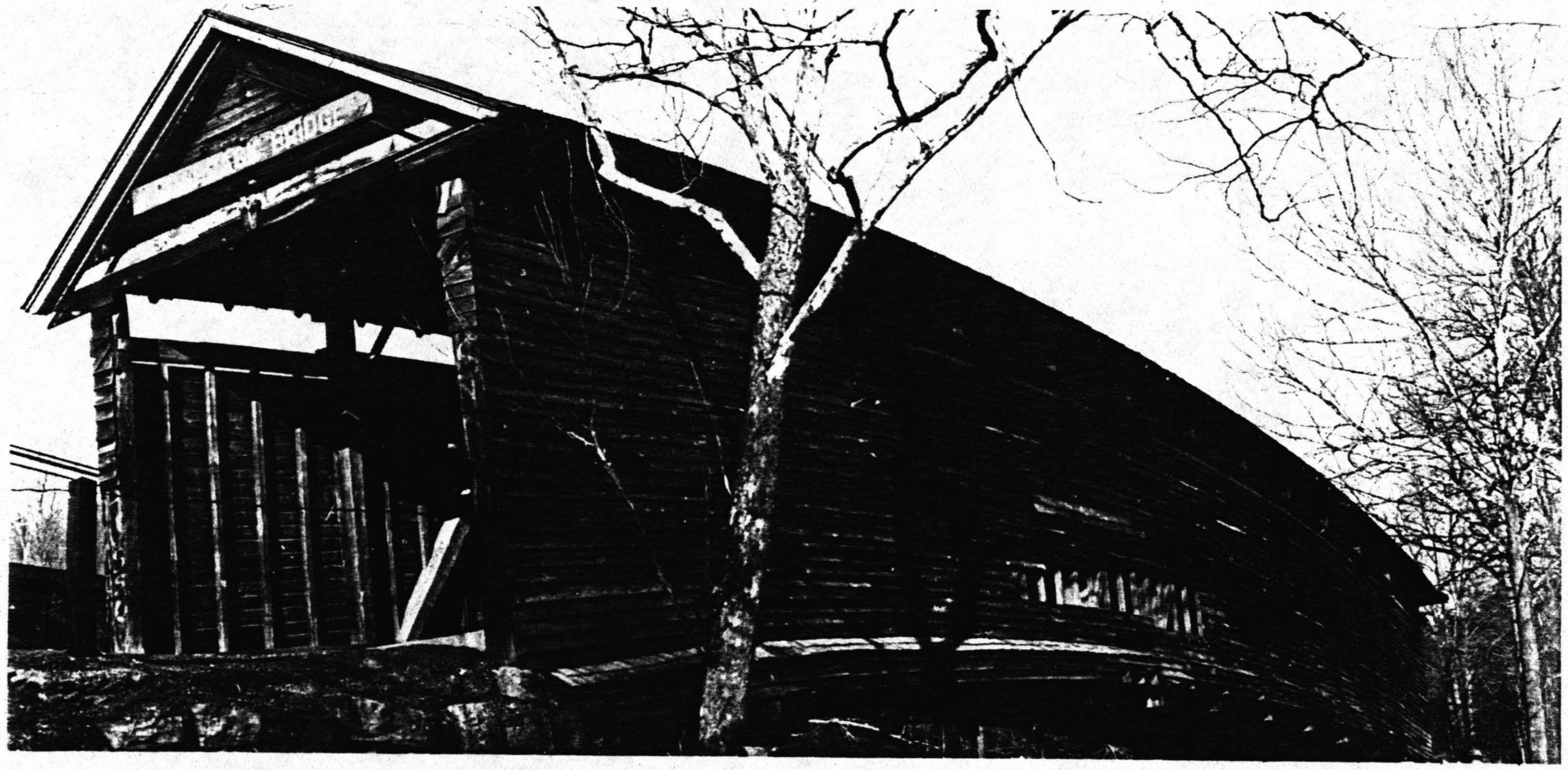
Wooden covered bridges were the first through trusses. The upper room members are usually part of the structural integrity bringing rigidity to the side trusses and floor.

Often wooden covered bridges were made of laminated arches. Gautier was the first to propose a laminated arch to cross the Seine in Paris in 1714.

Lamination works by the layering of pieces of wood which are held together by clamps or bolts to make a structural member larger in cross section.

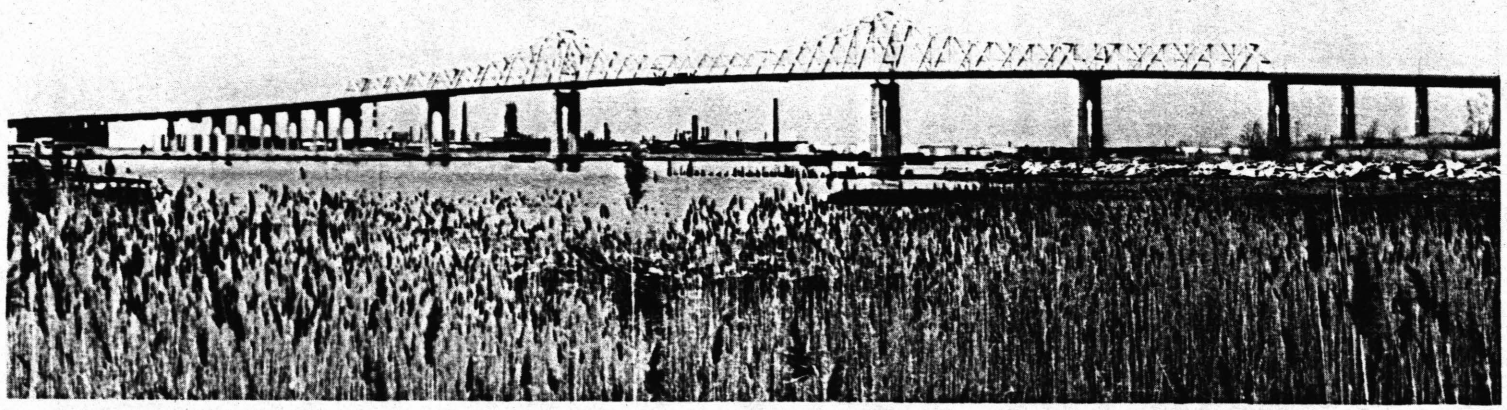
Although not covered it was the forerunner of the most famous bridge of this time, which crossed the Rhine at Schoffhausen and was designed by Ulrich Grubenman. Consisting of laminated arches, it was clamped by iron connections and was covered.

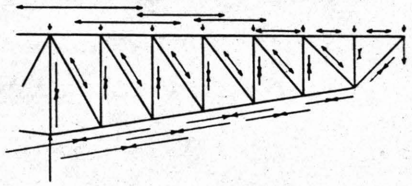




CANTILEVER BRIDGES

The cantilever method of construction was used as early as 1670 by the Chinese. It was James Eads who improved the method and use of materials. James Fowler and Benjamin Baker employed this method on the Firth of Forth in Scotland. Gustav Lindenthal improved the cantilever bridge with the use of creeper cranes on the Hells Gate and Queensboro bridges in New York City.

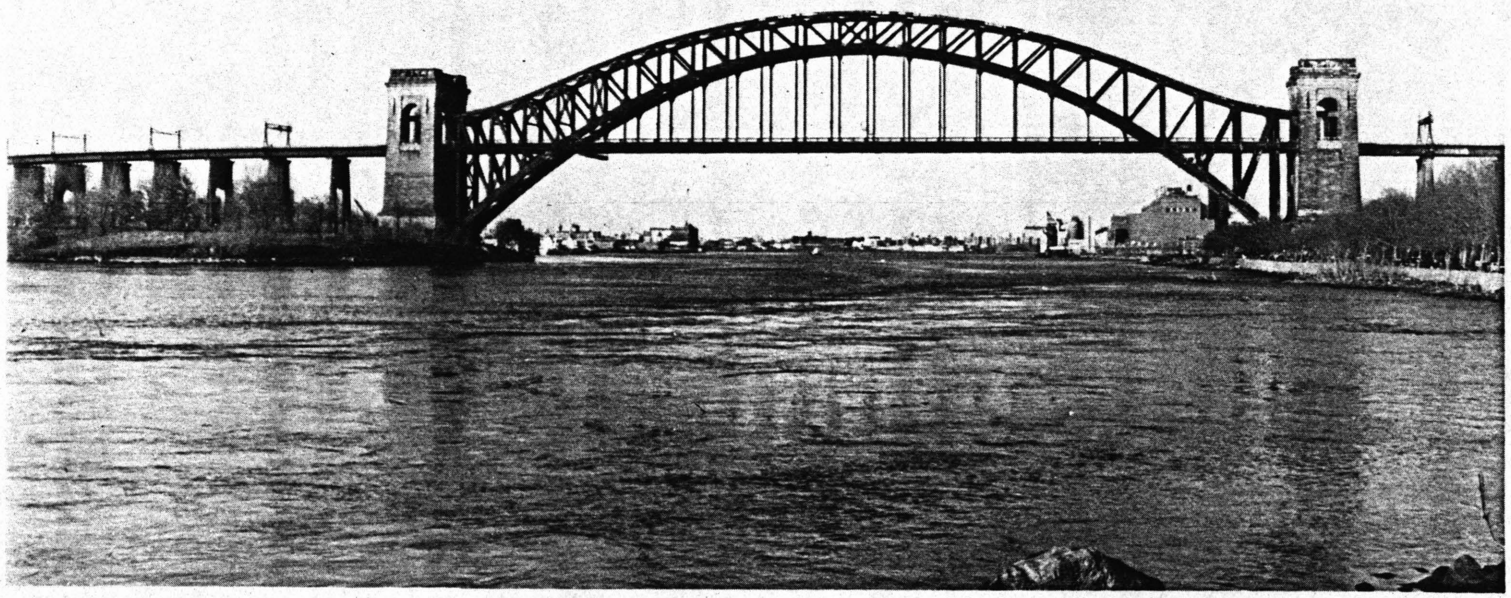




Temporary Falsework and Structure Become One

The idea of a cantilever is to counterbalance each side of the structure from the pier in given stages. This requires little if any falsework.

The cantilever feeds itself structural parts and reaches out for unity.



Stupendous plan! which none
  before e'er found
That half arch should
  stand upon ground
Like half a rainbow
  rising on shore
While its twin partner spans
  the semi o'er
And makes a perfect whole
  that need no part
Till time has furnished us
  a nobler art.

Thomas Pope
A Treatise on Bridge
Architecture, 1811

SUSPENSION BRIDGES

John Roebling and Otmar Ammann refined the heavy iron suspension bridges of Telford. Suspension bridges were originally made of rope. As early as 56 A.D. the Chinese used iron chain suspension bridges. The first modern suspension bridge was made by James Finley in Pennsylvania in 1801.

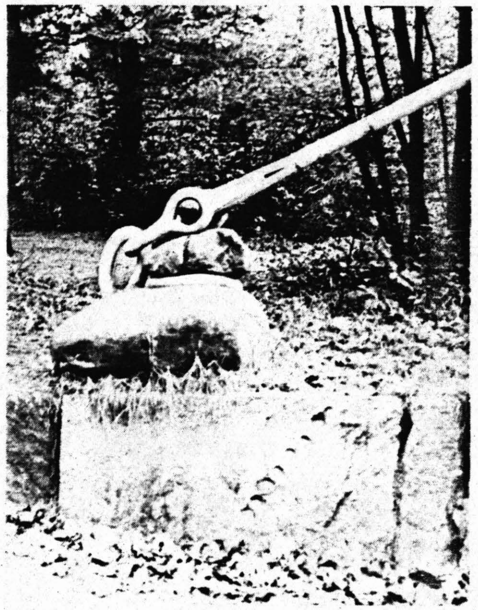
The bridge consisted of eye bars connected in a series to form an inverted arch suspended from two towers. Suspended from the eye bars were solid wrought iron bars to support the superstructure.

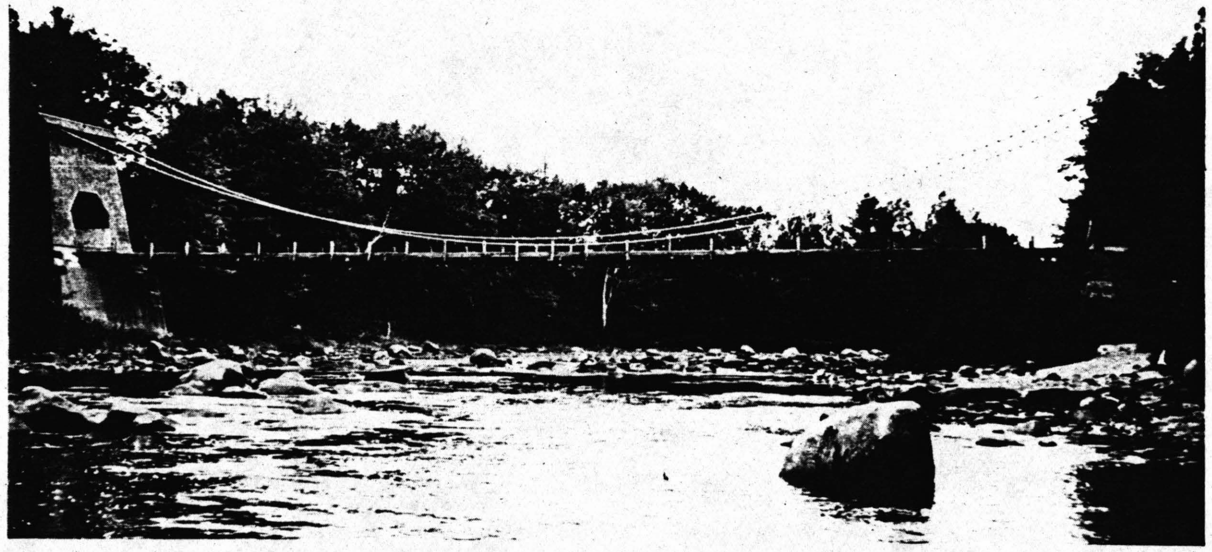
Telford built many of these bridges in England, but it was John Roebling who changed the character of the bridge with the introduction of steel. Spinning wires together in a helix formation gave his product great strength. Many canal systems used this wire rope instead of hemp to pull barges.

Eliminating eye bars Roebling used iron and later steel cables to support suspension bridges for aquaducts. He refined a spinning process for the main suspension cables. He invented a machine that wove a single strand of wire at a time. Bobbing from tower to tower the main cables slowly materialized. The helixed ropes were hung from the main cables to support the superstructure. Roebling used steel cables for the Brooklyn Bridge.

The suspension bridge climaxed with Otmar Ammann; his design of the steel towers of the George Washington bridge expressed the structure forces and added lightness and flexibility making the Brooklyn Bridge seem much heavier.

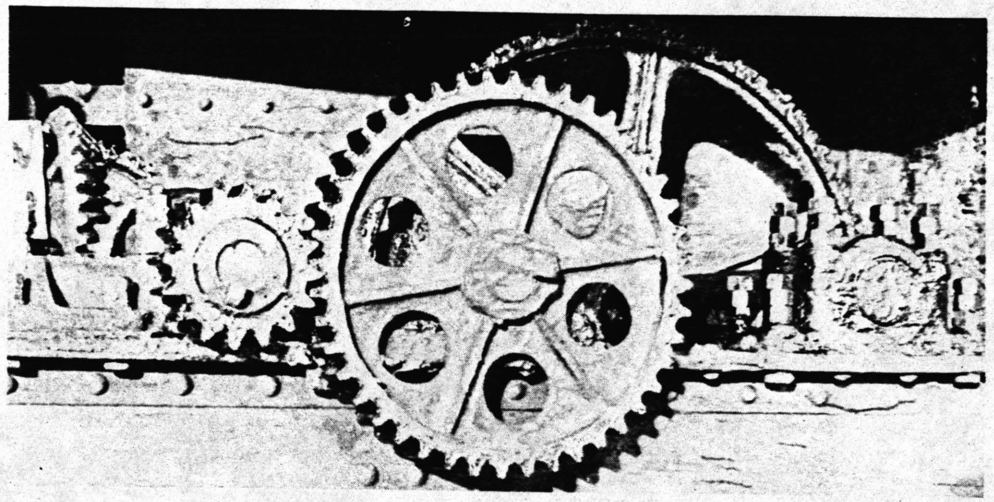
The suspension bridge only appears to defy gravity. The movable bridge actually does defy gravity through the use of machines.

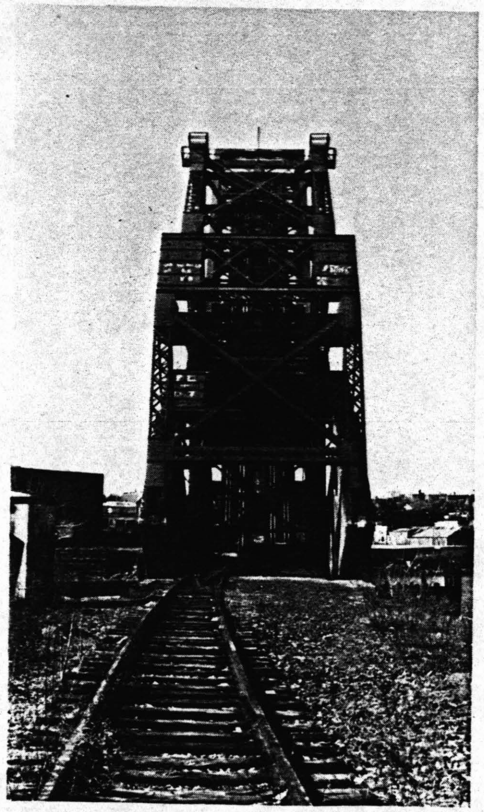




MOVABLE BRIDGES

Movable bridges have many forms. The earliest and most primitive was the bascule. It was used to keep enemies from crossing moats into the opposition's castle. There were variations of movable bridges. The most popular were the bascule, swing and lift.



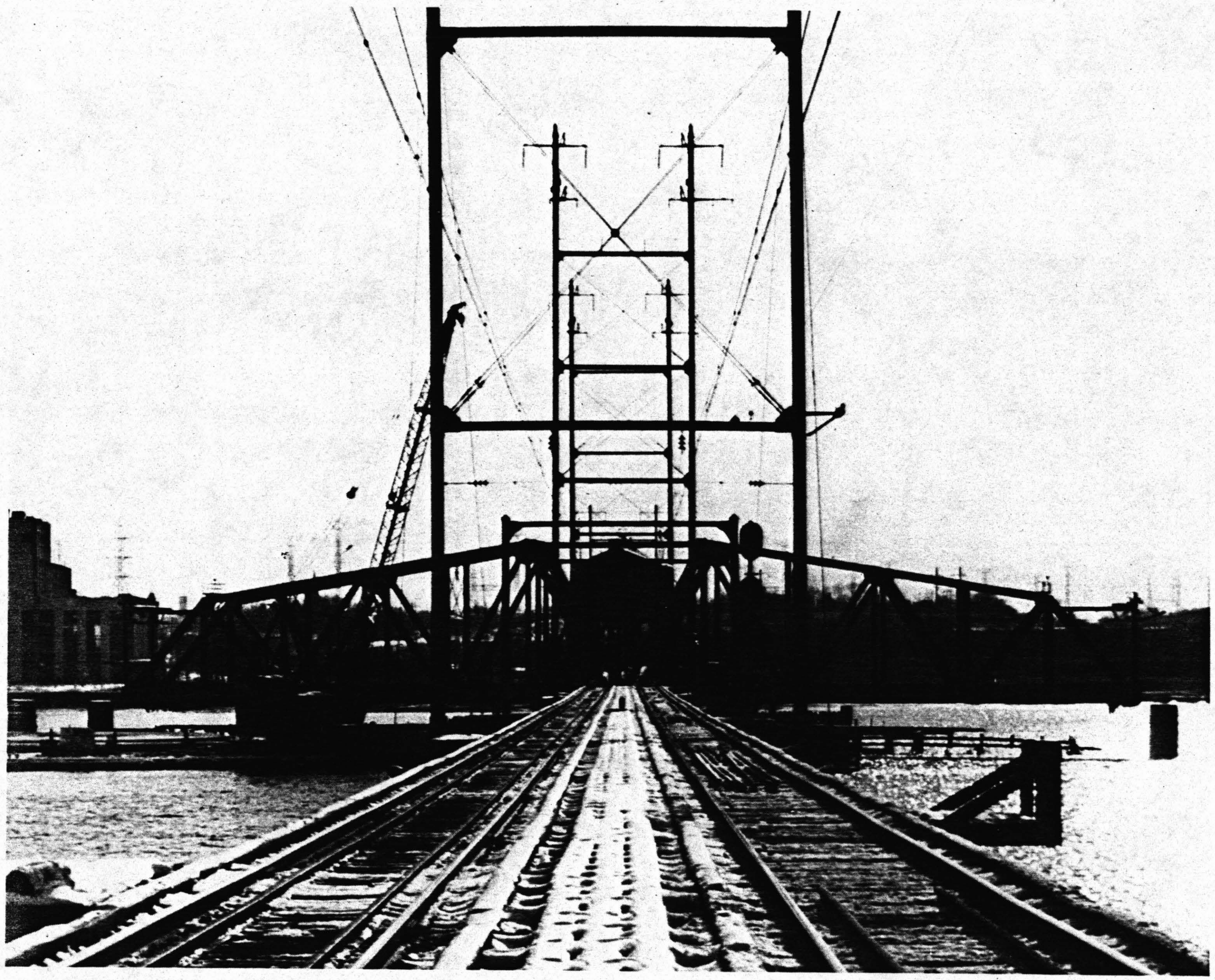


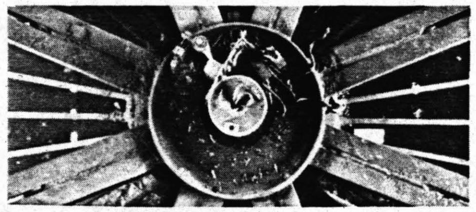
Bascule

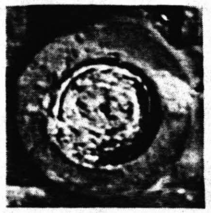
A modern bascule bridge lifts in three ways: it lifts the bridge with cables or uses a counterweight and a pin hinge connection called a trunnion. The other means is a rolling lift bascule which rolls on a cogged track and is lifted by a counterweight. The roller lift bridge not only swings up but also moves back. All have a beauty as they raise towards the sky and fall back to earth.

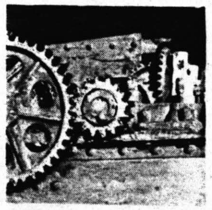
Swing

Swing bridges usually rest on a turntable. They rotate in a horizontal plane around one or more vertical axes. The axis is usually at the center but there are exceptions. In motion they appear as mechanical wings in flight.



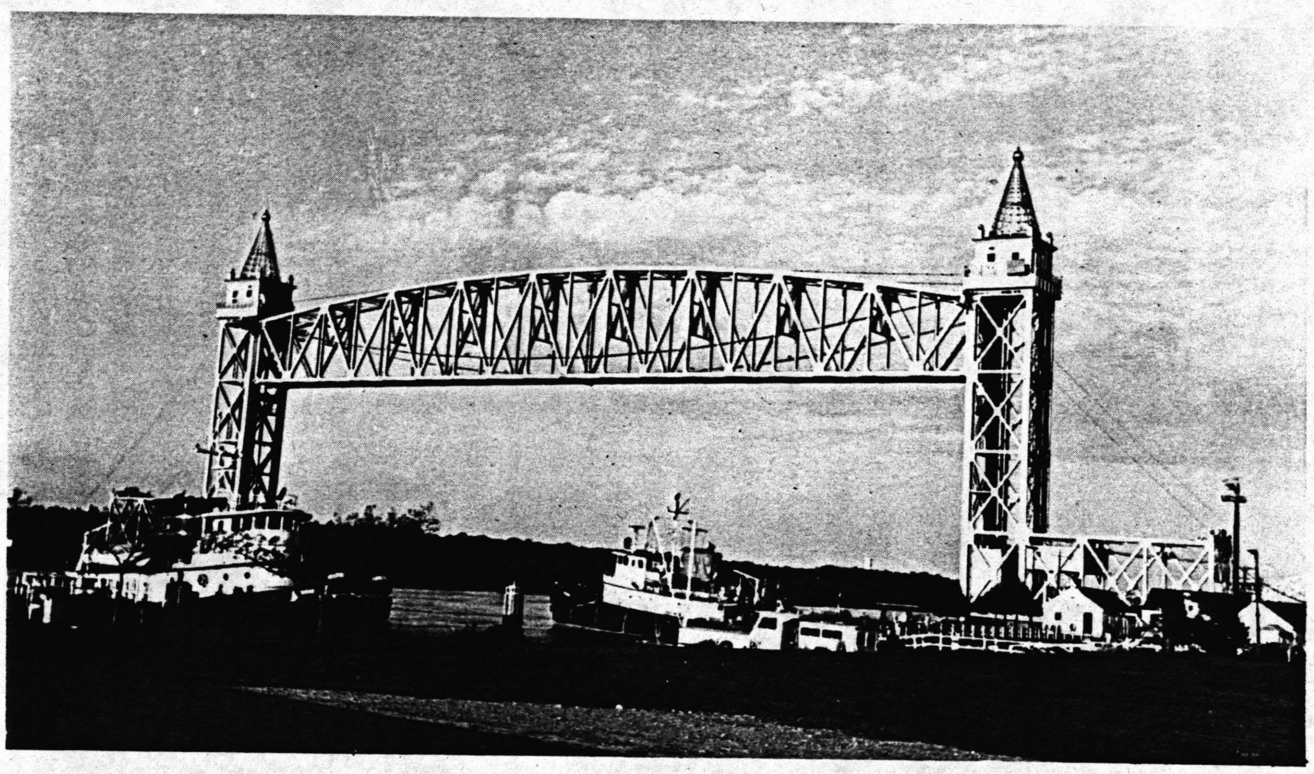


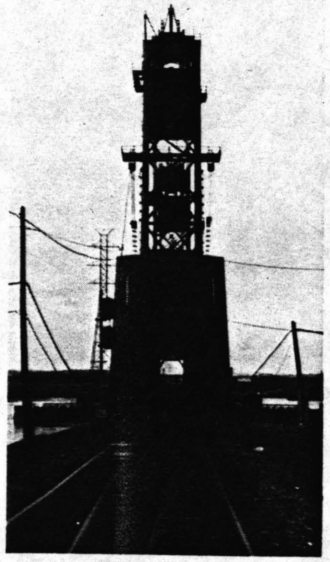


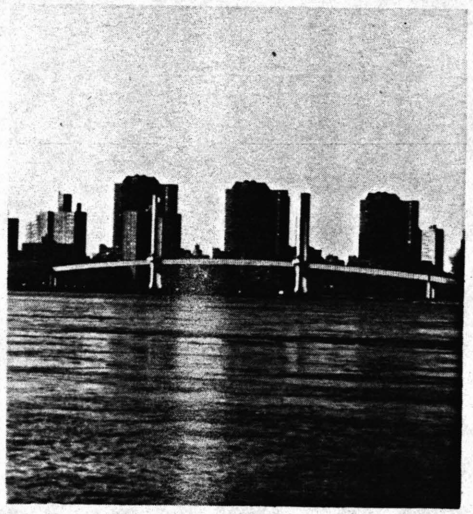


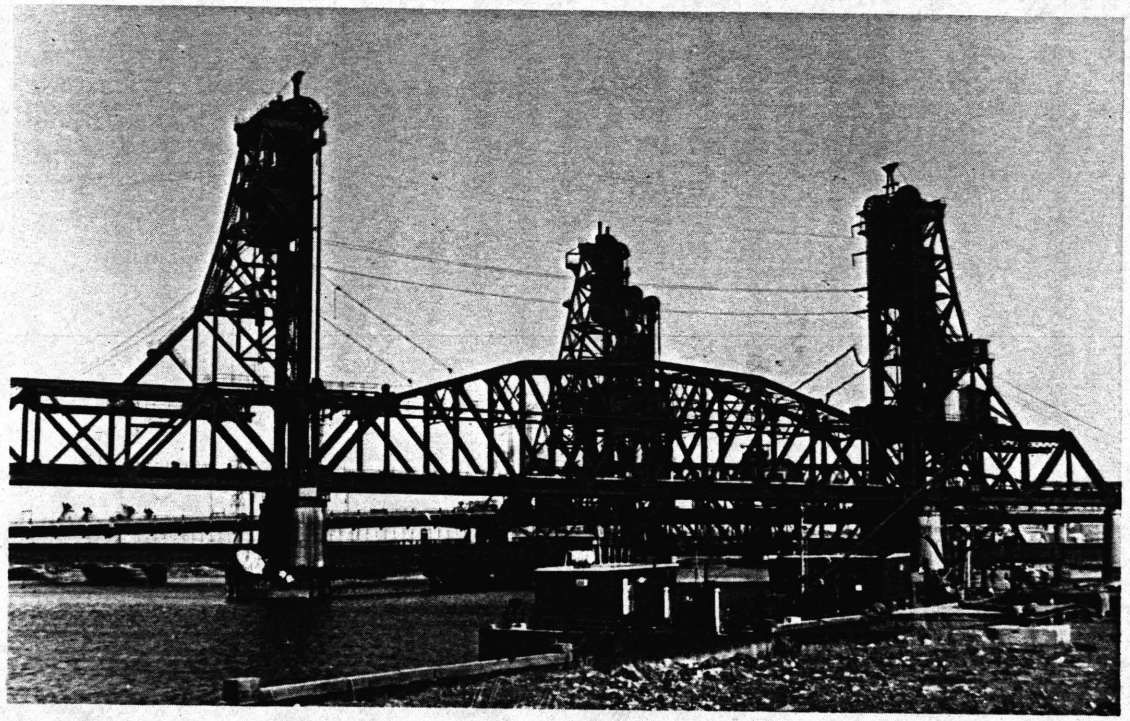
Elevated

The most modern of movable bridges are vertical lift bridges. Two towers on either end lift the superstructure and elevate it in the air. It is the bridge makers' answer to the elevator.



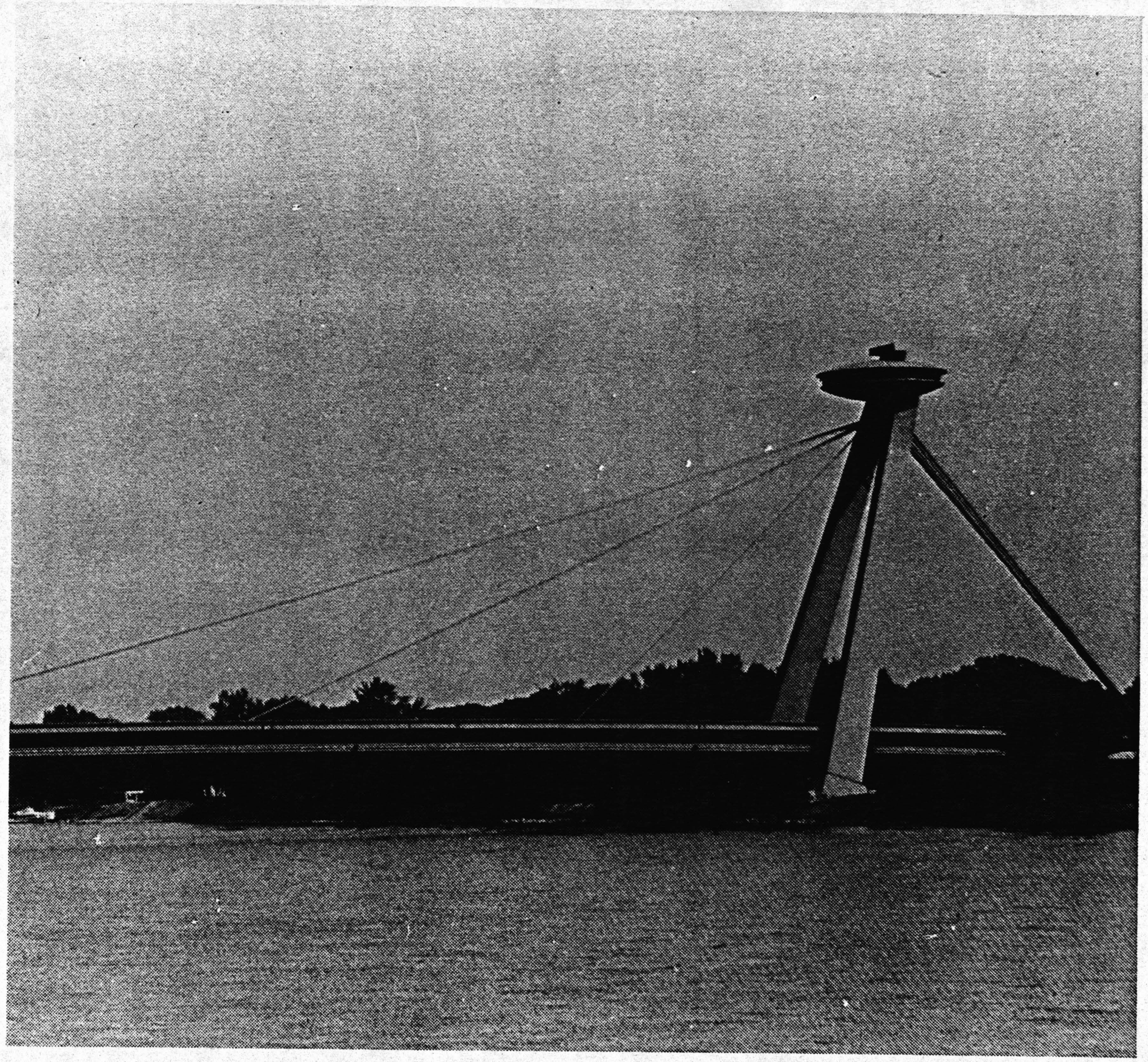






CABLE STAYED BRIDGES

Cable stayed bridges are the offspring of the suspension bridge. Stays were used as far back as the Egyptians for masts of ships. John Roebling used inclined stays on his suspension bridges to stiffen the deck. Since the 1950's cable stayed bridges have overtaken the suspension bridge's domain. Shooting rays of cables from its towers, it streamlines the forces of the suspension bridge. Reducing the number of cables needed to suspend the roadway, and with a new deck system lightens and strengthens the bridge. Breaking the tradition of arched towers of a suspension bridge, the cable stayed bridge uses anything from A shaped to straight column towers. Combining box beam and deck into one, the road surface is greatly stiffened and resists wind loads as well or better than trussed decks. The combination is known as an orthotropic deck. A special asphalt that adheres to metal is then placed directly on top of the steel decking. Cable stayed bridges have a unique character all their own. They are the new dare and challenge of bridge building.



CONCLUSION

Each civilization has contributed to bridge building. The Roman contributions were: the development of the arch, the selection of materials, falsework, cofferdams, the pile driving machines and the invention of concrete.

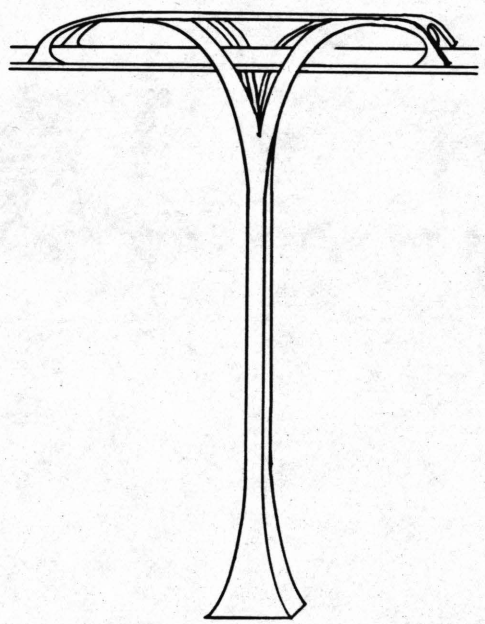
During the Dark Ages new forms of arches appeared and cutwaters were placed on both sides of the piers.

From the Renaissance emerged the trussed bridge and the diving bell caissons.

In the 18th century man-made materials caused natural materials to become obsolete. Iron was the dominant material used in the construction of bridges in the latter half of the century. In the beginning the modern suspension bridges were built of iron.

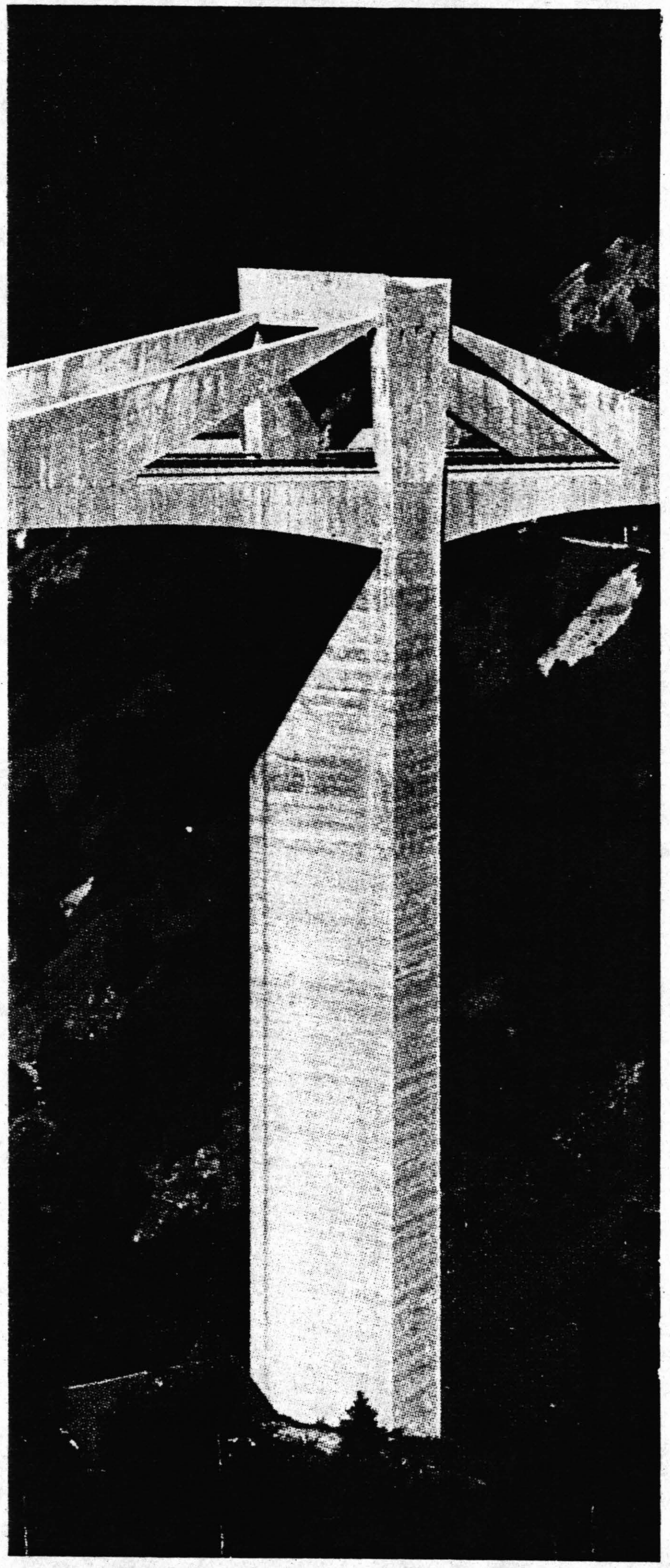
The Modern period introduced steel as a new material. When used by itself it could be formed into wire to suspend bridges, it could form beams and truss members. When combined with concrete it gave the extra tensile strength neeeded for a larger span bridge. The most important invention in the construction of underwater foundation was the pneumatic caisson. The final contribution is the cable stayed bridge.

The evolution of bridge construction makes us wonder what new material and consequent forms will appear. Who will meet the dare and what philosophy will guide them?



As the bridge pierces through space it complements the horizon. Cross the bridge we are like Heidegger's stream held up to the sky, passing through it for a moment under its valuted gateway and then set free once more. A bridge is like encountering a stranger. The person's face reveals his origin, his wrinkles a mysterious story. The cracks, curves and form of the bridge are statements of a time, a place, a feeling.

The bridge is a metaphor of iife. The passage across a bridge has a beginning and an ending. Crossing reminds us of our ephemeral stay, the width of the road, the limitations of travel and the vanishing perspective, which gives direction and focus. Humbly we cross this support system of society. The bridge is a symbol of life, a celebration of passage.



FOOTNOTES

[1]Martin Heidegger, Poetry in Language and Thought, Harper & Row, New York, 1971, p. 154.

[2]Paul Friedman, "The Bridge: A Study in Symbolism" The Yearbook in Psychoanalysis, Vol. IX, International University Press, Inc., New York, 1953, p. 271.

[3]Shirley Smith, The World's Great Bridges, Harper & Row, New York, 1953, p. 19.

[4]Majorie Boyer, Medieval French Bridges, The Medieval Academy of America, Cambridge, Mass., 1976, p. 35.

[5]Ibid., same as footnote 4, p. 33.

[6]David Billington, The Tower and the Bridge, Basic Books, Inc., N.Y., 1983, p. 113.

[7]Alan Trachtenberg, Brooklyn Bridge Fact & Symbol, The University of Chicago, Chicago Press, Chicago, 1965, p. 136.

[8]Ibid., same as footnote 7, p. 146-147.

[9]Ibid., same as footnote7, p. 277.

[10]Andrea Palladio, The Four Books of Architecture (1520), 1965, Dover Publications, Third Book Chapter IV, p. 62.

[11]Marcus Vitruvius Pollio, The Ten Books of Architecture, Dover Publications, New York, 1960, p. 162-164.

[12]Charles Whitney, Bridges, Their Art Science & Evolution, W. E. Rudge, New York, 1929, p. 53.

[13]Ibid., same as footnote 4, p. 78.

[14]Ibid., same as footnote 10, p. 62 & 68.

[15]Op. Cit., same as footnote 10, p. 65.

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