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ANALYSIS OF CRESCENT CITY CONNECTION (GREATER NEW ORLEANS BRIDGE NO. 2)

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Abstract: Crescent City Connection is a crossing across the Mississippi River that consists of two bridges that were formally known as Greater New Orleans Bridges No. 1 and 2. They carry traffic for US route 90. This paper will discuss and analyse the loadings, design considerations and aesthetics of Greater New Orleans Bridge No.2

Keywords: Steel, Cantilever, Truss.

1 General

The Crescent City Connection is made up of 2 bridges that take traffic across the Mississippi river to and from. They were known as Greater New Orleans bridges 1 and 2 but after a competition to re-name the bridges Crescent City Connection (CCC) was chosen.

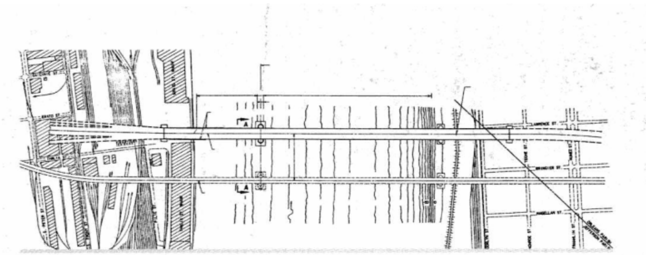
The fist bridge was opened in April 1958 and the second was opened 30 years later in November 1988. Modjeski & Masters, Inc. designed both the bridges and as a result they both look identical from an initial look. This paper will discuss the second bridge but will however obviously have some relevance to the first.

Table 1: General Information

Facts and Figures	
Total Length	920m
Longest Span	480m
Bridge Width	28m
Bridge Type	Cantilever
Bridge Material	Steel Truss with Concrete Piers

The bridges are a cantilever truss that is constructed of steel. Greater New Orleans Bridge No.2 first began construction in March 1981 and was hoped to be completed for the Louisiana World Exposition, however it was not finished in time. The bridge eventually opened to traffic in September 1988 and in 1989 both bridges were renamed.

Fig.1: Elevation of Bridge



Currently the bridges are part of US route 90 where the first bridge carries the eastbound traffic and the second bridge carries the westbound traffic. Daily traffic is about 180,000 vehicles with each vehicles having to pay a toll to cross the bridge. The bridges is currently maintained and policed by the Crescent City Connection Division (CCCD) who are part of the Louisiana Department of Transport Division (LaDOTD).

Although the bridges are very similar the main difference between is the width. The second bridge is designed to take 4 lanes of traffic as well as two high occupancy vehicle (HOV) lanes that are reversible.

The purpose of constructing the new bridge was to relieve the first bridge of congestion, increasing traffic flow over the river. Making the bridges look almost identical reflects that the use of the two bridges are identical and they in fact connected to the same road.

2 Aesthetics of the Bridge

The following is my personal view on the bridge but is based on Fritz Leonhardt's 10 areas of aesthetics. He believes these 10 areas are what makes a good bridge. The Great New Orleans Bridge No.2 was designed on the basis of the first bridge and at a glance they look almost identical. Therefore most of the following 10 areas of aesthetics also apply to the first bridge.

Fig. 2: Photo of Elevation

2.1 Fulfilment of Function

From "simplicity is beautiful" [1] it should be obvious how the bridge performs structurally, giving a sense of stability. The Greater New Orleans Bridge No. 2 does reveal its structural performance fairly clearly due the truss. The truss then gets bigger in depth over the piers, giving a sense of stability.

2.2 Proportions of the Bridge

In this area there should be a balance between the area of voids and area of mass. In my view this bridge does have reasonably good proportion but due to the large span in the middle in comparison to the depth of the truss, the depth does seem a little odd.

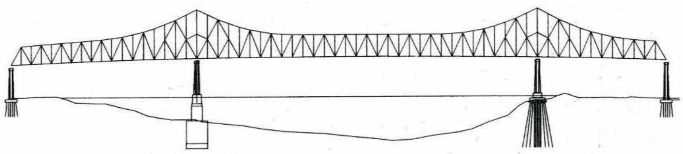
The piers however seem to be in good proportion, not being to over bulky but still making a statement.

2.3 Order within the Structure

There is good order in the bridge with a regular arrangement of truss elements, being repeated along the length. The symmetry also helps with the observer not really noticing that the lengths either side of the main span are not the same.

However, the order can be upset when not looking straight in front of the bridges. With the first bridge behind, it creates too many edges and confusion as to which edge belongs to which bridge.

Fig.3: Line Drawing of Bridge



2.4 Refinement of Design

Looking at the bridge from a severe angle the truss can look messy and slightly disorganized. However it can be imagined that when driving over the bridge and looking up the patterns of light and shade can give a sense of amazement. It is also good that the bridge is exactly parallel to the first so that it does not feel strange when driving over the bridge.

2.5 Integration into the Environment

The Mississippi river has been used for centuries to transport goods; as a result there is a need to allow ships to pass up and down it. The height of the bridge and the large central span reflects this need. The use of steel was a good choice for the urban environment and fits in well to the surroundings.

2.6 Surface Texture

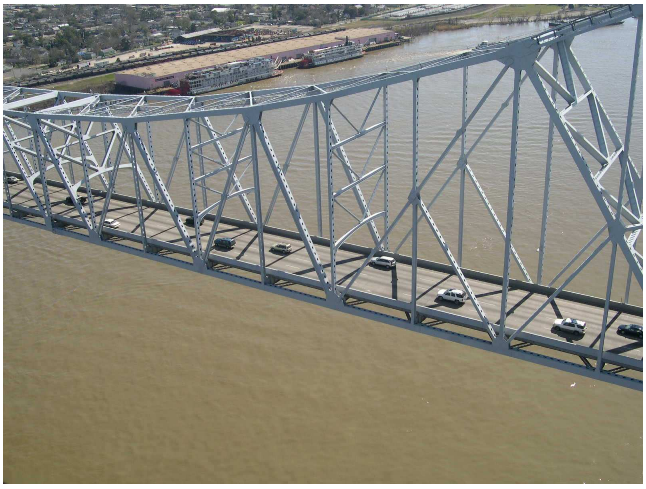
The difference in surface texture is very clear between the piers and truss. The difference in material plays the main role in this, however both the concrete and the steel did have to be painted. The concrete gives a rough feeling in comparison to the smooth steel used for the truss.

2.7 Colour of Components

The second bridge is a different colour and shade to the first, showing the bridges were built separately and at different times. The colour of the bridge gives it a sense of being light, if the bridge was painted a darker colour then combined with shadows the truss would look heavy and the bridge would become an eyesore.

Due to the difference in colour of the concrete and the steel it also clear where one ends and the other starts, so that the observer has a good idea as to what part performs which structural task.

Fig. 4: Aerial View of deck



2.8 Character

With the second bridge being built in a similar design to the first you cannot say that the second bridge has a character on its own, however, together the bridges do.

The large spans makes the public ask how the central span is being supported but still gives a sense of stability.

2.9 Complexity in Variety

The obvious steel truss does not give much complexity to the bridge. Although due to the geometry of the bridge uplift is created on the Algier side of the bridge but the thicker concrete deck is not noticeable to the observer, giving a sense of uniformity across the bridge.

2.10 Incorporation if Nature

Greater New Orleans Bridge No.2 does not have any particular form from nature and as a result I feel that some more design in the area could have produced a prettier bridge. However this was governed by the design of the previous bridge so some decisions were taken out of the designer's hands.

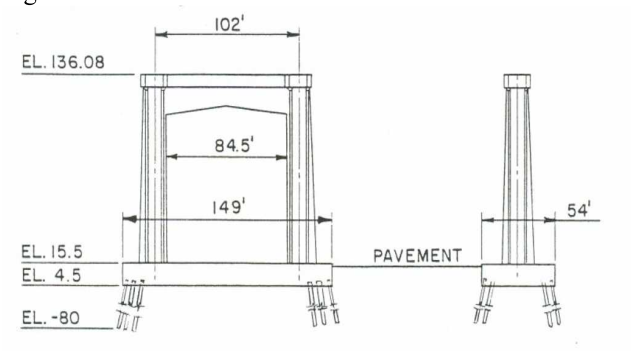
3 Bridge Design

3.1 Foundations and Piers

The bridge has 4 piers with only one being in the river bed. All the piers were identical in shape above the ground, all had the same width but the depth of the varied on the pier. Below the ground each pier had different foundations:

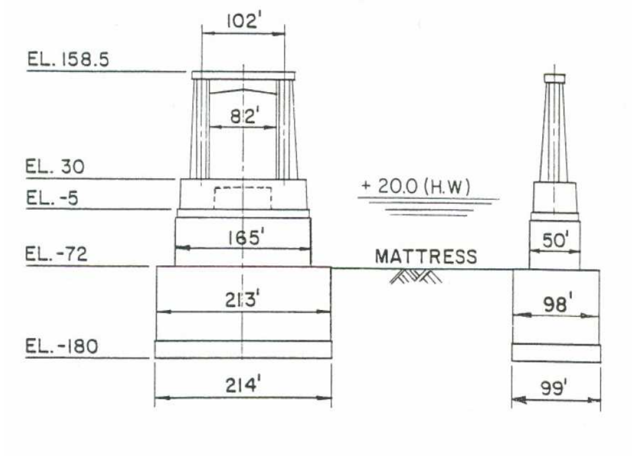
3.1.1 The first pier, the New Orleans Anchor Span pier was designed with the possibility of 2 alternatives for the foundations. Both incorporated piles in the design but using different pile diameters and driving them to different depths. Monotube piling was eventually chosen for the foundations to a depth of around 25m.

Fig. 5: Detail of Pier 1.



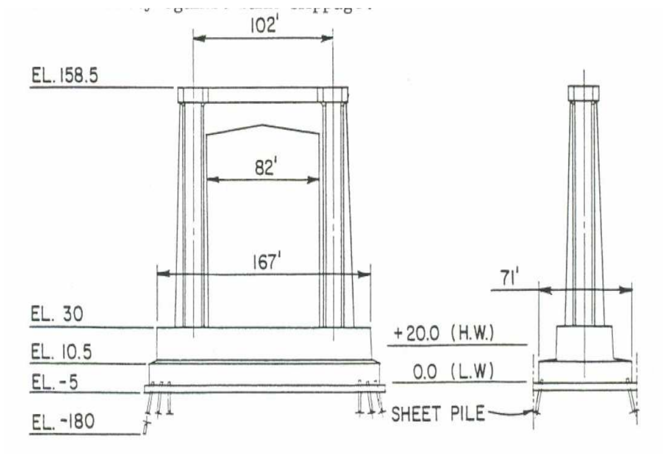
3.1.2 Pier two is the only river pier and is caisson supported. A willow mattress was designed to prevent any scouring of the river bed. The caisson was made up of two sections, the top being just over half the depth of the bottom and smaller in width. The transition between the two is roughly on the river bed where the willow mattress lies.

Fig. 6 Detail of Pier 2



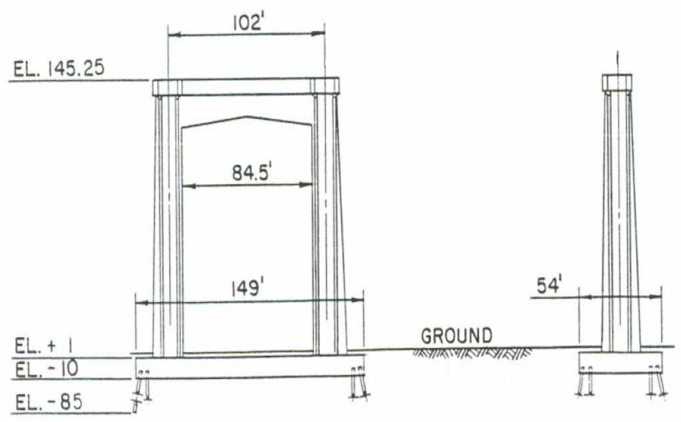
3.1.3 Pier three was designed to a pile foundation which was surrounded by a permanent sheet pile cofferdam.

Fig. 7 Detail of Pier 3



3.1.4 The Algiers Anchor Span pier, pier four was very similar to pier one however it differed in length of the Monotube piles, with these piles being slightly deeper.

Fig. 8 Detail of Pier 4



3.2 Truss

It was recognised that it would not be suitable to use the same grade of steel throughout the span of the bridge. This would lead to a waste of a valuable material and could increase costs dramatically by wasting material. As a result each member of the truss was analysed and a suitable grade of steel was chosen to reflect that particular member's properties.

Other steels which had not been used in bridge construction were considered but a lack of precedent and disapproval from the relevant bodies led to them being eventually dropped from the list.

3.3 Deck

Greater New Orleans Bridge No.1 was designed and built to take a lightweight roadway on the main span and the New Orleans anchor arm this was required due to the large central span and the need to minimise the uplift in the Algiers anchor arm. All design objectives were achieved however serviceability was not satisfactory. Heavy loads would inevitably cause some damage to the bridge as it would cross.

Therefore it was recognized that although a lightweight deck for the second bridge would dramatically reduce the dead load it was evident that from the first bridge it would be durable enough. This led to combinations of concrete filled or partially filled steel grid with varying thickness of bituminous asphalt material or a steel plate deck with a epoxy-asphalt wearing surface.

After consultation with the manufacturers and testing at Louisiana State University it was found that long-term problems would result as well as restrictions on some loads, this lead to the consideration of a normal weight concrete deck. Studies were carried out to find out whether the truss was capable of taking the extra load and if the extra cost incurred would be feasible.

The end result led to a concrete of thickness 0.18m on the main and Orleans anchor arm spans. The uplift that the extra weight on the Algiers anchor arm was researched and it was found by simply increasing the depth of the concrete to 0.254m would be enough to counter-act the extra weight.

4 Loadings when Designing the Bridge

Due to the amount of steel involved in this project and the spans involved, the designers new that it was critical that even any small percentage saving could make a big difference. This in effect led to a detailed analysis of the bridge and innovative designs to minimize the weight of the bridge. Careful considerations in factors were used in order to make efficient use of the material without compromising safety. In the final design it was estimated that by using this approach roughly $5,500,000 were saved in the final construction cost. The technique that was used to develop these factors of safety were then submitted to American Association of State Highway and Transportation Officials (AASHTO) who then adopted the new guided specification.

The design loadings were done using specifications AASHTO Interim Specifications with some added modifications. The loading considers the following:

- Dead Load
- Live Load
- Transit Live Load
- Transit Impact
- Transit Rolling Force
- Transit Longitudinal Force
- Wind
- Hurricane Wind
- Earthquake (although actually considered to be not threatening in this case)
- Thermal Forces
- River Forces
- Shrinkage forces

These were then used in the relevant factored combinations to achieve the worst possible scenario for the bridge.
There were also considerations in the substructure for a 40,000-ton vessel traveling at a speed of 3.7m/s colliding with one of the piers. To protect piers two and three from marine pier protection was provided using a combination of riprap and timber fenders.

5 Loadings

The following loading conditions are based on British Standards 5400-2: 2006.

5.1 Dead

Dead load is considered to be the self-weight of the bridge. This is calculated by working out the volume of the structure and then multiplying this by the density. This will have to be factored but is dependent on the combination of loads.

Table 2: Loading Data

General Data	
$L = 920m$	Steel unit weight = 7850kg/m^3
$\gamma_{fl} = 1.5$	Thermal Coefficient of Expansion Steel = 12x10/ºC
$\gamma_{f3} = 1.10$	

5.2 Traffic Loading

5.2.1 HA Loading is a uniformly distributed load that acts over a notional lane, this is then combined with a knife edge load which is placed at the most adverse position along the bridge's span.
For the width of my bridge, 6 notional lanes will be taken.

$$W = 36\left(\frac{1}{L}\right)^{0.1} \quad (1)$$

This means that for the Greater New Orleans Bridge No. 2 the load for each notional lane will be:

$$W = 36\left(\frac{1}{920}\right)^{0.1} = 18.19kN/m$$

This will then be multiplied by γ_{fl} and γ_{f3} to obtain the design loading. Therefore:

$$W = 18.19 \times 1.10 \times 1.50 = 30kN/m$$

As there are six notional lanes this number can then be multiplied by six to give the total design load across the width of the bridge. This is equal to 180kN/m. This HA loading is then combined with a knife edge load (KEL) of 120kN per lane.

5.2.2 HB loading takes into account the bridge being used for abnormal truck loads that maybe long, wide and be carrying exceptionally heavy objects. The length of the truck is variable and the correct length of truck must be chosen to produce the most severe effect on the bridge. The HB loading on the bridge will then be combined with HA loading and can be put together in a number of ways to create different loading combinations. When this is carried out there will always be 25m spacing infront and behind the truck and one lane will have full HA loading with the rest being factored by a third.

5.3 Wind Loads

In the British Standards any aerodynamic effect of the bridge is ignored. As Greater New Orleans Bridge No.2 is in the USA the basic wind speed for the location needs to be found. Then the maximum wind gust that could strike the bridge can be found using equation (2):

$$v_c = vK_1S_1S_2 \qquad (2)$$

Table 3: To show definition of Eq. (2)

Definitions	
v	Mean hourly wind speed
K_1	Wind coefficient
S_1	Funneling Factor
S_2	Gust Factor

So assuming the following:
v = 36m/s (likely to be higher in the USA)
K_1 = 1.21 (loaded length of 1000m and estimated height above sea level is 10m)
S_1 = 1.00 (assuming no funneling)
S_2 = 1.00
This gives a maximum wind gust of 43.56 m/s

Horizontal wind load can be calculated by using the following formula (3):

$$P_t = qA_1C_{D1} \qquad (3)$$

Table 4: To show definitions of Eq. 3

Definitions	
q	Dynamic Pressure Head
A_1	Solid Horizontal Projected Area (m^2)
C_D	Drag coefficient

C_D is calculated a function of the b/d ratio of the bridge and the British Standards do have some standard cases but generally a bridge will have to go wind tunnel testing. As the bridge is made of multiple girders with a concrete, the bridge under BS would have had to undergone testing.

The bridge itself will also be affected by wind loading. The large trussed area will undoubtedly create massive forces when hit by wind. Wind loading coming longitudinally and wind hitting traffic will also have effect on the bridge.

Wind can also cause uplift or a vertical downward force. This can be calculated using the following equation (4):

$$P_v = qA_3C_L \qquad (4)$$

Table 5: To show definitions of Eq. 4

Definitions	
q	Dynamic Pressure Head
A_3	Plan Area (m^2)
C_L	Lift coefficient

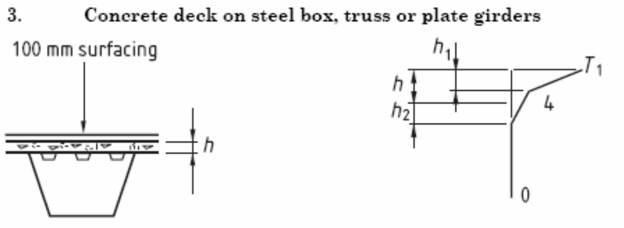
The lift coefficient is dependent on the super-elevation and if this exceed 5º then wind tunnel testing is required. This should be taken a number of combinations with the horizontal wind load.

5.4 Temperature Effects

Bridges are restrained at both ends so any temperature fluctuation is going to give rise massive strains being put on the bridge. In a normal cantilever most of these strains will absorbed by the sliding joints, however due to the innovative design of this bridge there are no sliding joints. It is therefore critical to analyse the exact strains that change in temperature is going to produce.

To look at the effect of temperature the overall temperature increases and decreases need to be known. This is known as the effective temperature. The temperature difference which is the temperature of the top and bottom surfaces also need to be known. These both vary depending on the materials used on the bridge. Greater New Orleans Bridge No.2 has a concrete deck with steel girders underneath. This will give the following temperature profile:

This diagram from the British Standards can then be



adjusted to suit particular depths of concrete

The following equation takes the temperature difference and then uses the thermal coefficient of expansion to work out the strain due tot hat temperature difference (5):

$$\varepsilon = \alpha \Delta T \quad (5)$$

The strain calculated from above can then be used in equation (6) in conjunction with the length to calculate the amount of movement.:

$$\delta = \varepsilon l \quad (6)$$

5.5 Worst Case

The previous loads are using the ultimate limit state design. Serviceability limit state design should also be checked. For both of these the safety factors will change accordingly. Both of these methods of design should be checked using the following five loading combinations:

1. All permanent loads plus primary live loads.

2. Combination 1 plus wind and any erection loads

3. Combination 1 plus temperature and any erection loads

4. All permanent loads plus secondary live loads and associated primary loads

5. All permanent loads plus loads due to friction at the support.

6 Bridge Construction

The construction of Greater New Orleans Bridge No. 2 was a very complex project and required lots of planning. The obvious problems of building the bridge is of the world's largest cantilevers over a wide, deep and fast flowing river and the close proximity to the second bridge. This led to specialist contractors being used, one was required for the foundations and four main piers, the other was contracted to fabricate, erect and complete the main bridge superstructure.

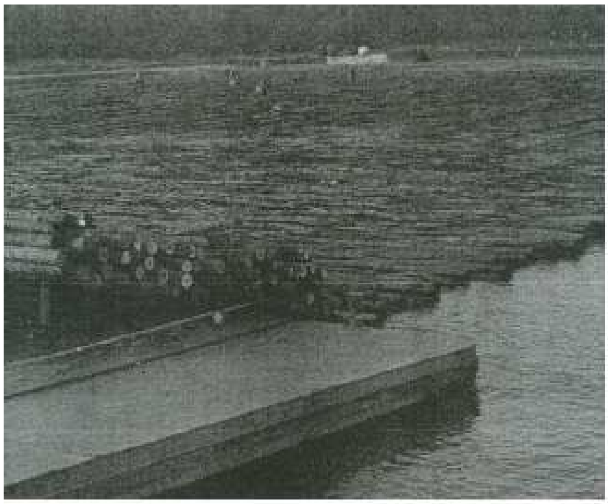
So that the bridges did not look odd the bridges had to be parallel. The centerline for the second bridge was therefore set parallel to the original bridge, with the piers being opposite each other. Survey points were set up so that location of the bridge could be monitored and to check that construction of the second bridge was not causing the first to move.

6.1 Substructure

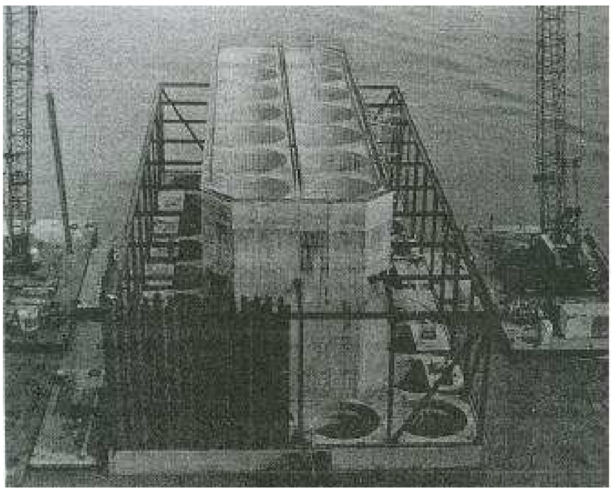
6.1.1Pier one required some demolition of the old dock before any construction could take place. Sheet piles were driven in to retain an existing roadway ramp, as the excavation got deeper and deeper. 169 piles were then driven until they reached a sand layer. As a result the depth of these piles varied as the sand layer was elevated across the site. The piles were then reinforced and concreted and the footing was cast. The construction of the shafts did not take place until the shafts from pier four were complete.

6.1.2 The second pier is the most complicated of all the piers and as a result would have been started first as it would take a long time to construct.

Before piers and foundations start to be built a willow mattress would have been placed at the bottom of the riverbed. Floating the mattress over the area that it needs to cover and adding sinking stone uniformly to the top so that the mattress slowly begins to loose its buoyancy would have done this. It would then be a case of positioning the mattress on the riverbed; barges would have been around the edge of the mattress to ensure location.



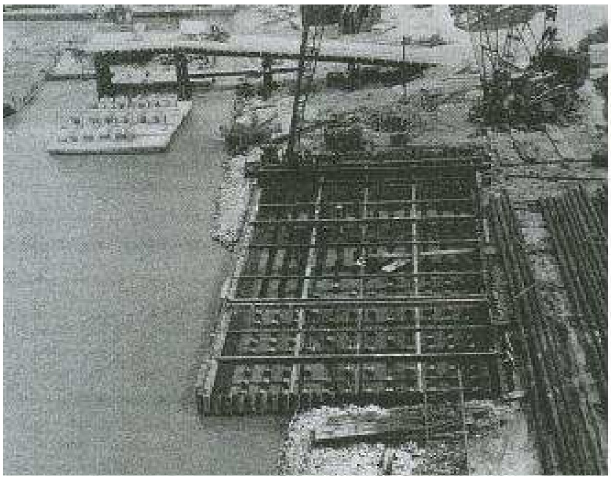
To construct the foundations to the second pier in the middle of a river a floating caisson was used. A caisson is a floating watertight structure. In this case allowing the foundations to the pier to be constructed out of concrete. This was used to reach the sea floor where the willow mattress had to be cut to allow the foundations to go through in to the soil below. The caisson at this stage can also be adjusted in location by adjusting the air pressure in it. It is then a continual process of building the concrete up on the surface and then gradual sinking of the caisson. Once the relevant depth had been reached the caisson was then leveled and construction of the upper caisson took place. Once completed to a certain height, sinking then resumed with excavated material consisting of river sand, silty sand and clay. Once the caisson reached a depth of 55m the excavation and sinking was stopped.



To protect both ships and the bridge pier a timber fender was constructed around the pier. Using pinewood coated with creosote coal-tar did this.

6.1.3Pier number three had a permanent sheet pile cofferdam and due the lower than expected river levels the cofferdam was able to be excavated in the dry. On top of the cofferdam a steel template was placed to help guide the "Ringer" crane to the correct positioning of the piles. A total of 268 piles were driven in just over a two month period. Concrete was then pumped in to create a seal so the cofferdam could be totally removed of water and allow the footing of the pier to be put in place. Then it was a case of building the subshaft and then the shafts themselves.

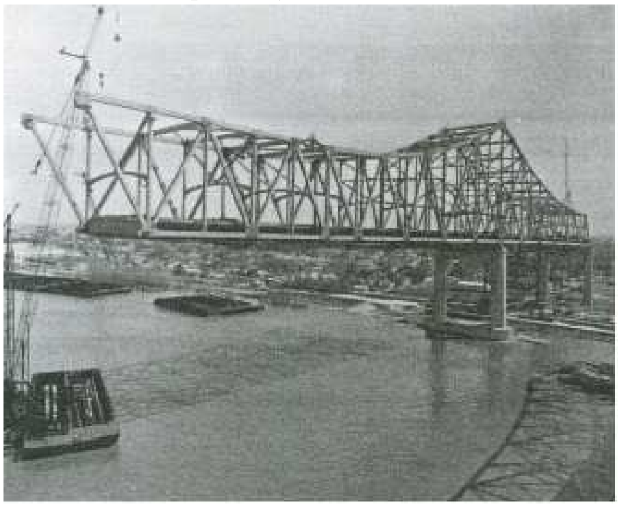
6.1.4 Pier four was the first pier to be finished, mainly due to its ease of access. For the footing a sheet pile cofferdam was installed and then 160 were driven in to the ground. Once this had been done the footing was then completed in one big pour. Then it was a simple case of building the pier shafts and the strut.



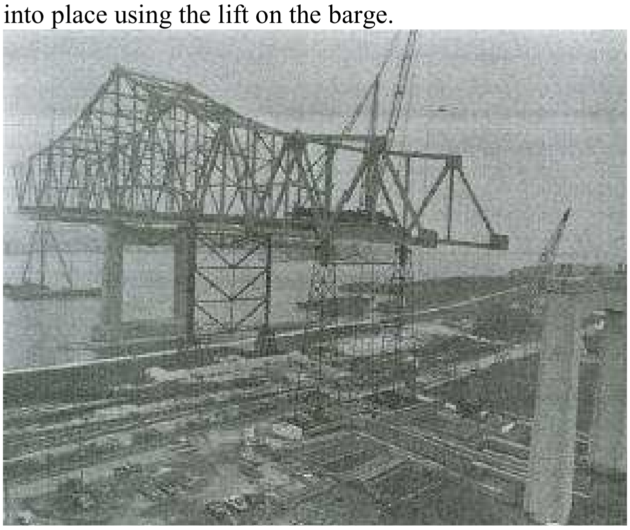
Once the piers were completed they were then painted with a coat of Thorocoat giving a uniform and aesthetically pleasing cement grey colour.

6.2 Superstructure

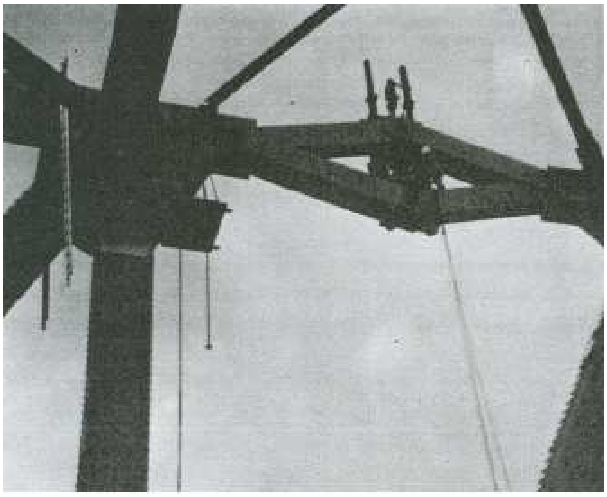
The steel for the superstructure would have been divided up and fabricated by different companies as the quantity of steel is involved is vast and would be too much for one company to be fabricating. All the domestic steel was taken to New Orleans by rail and then transferred to barge and shipped to location. Foreign steel would arrive by freighter to New Orleans then washed to remove any salt contamination and moved on to a barge to the site.
The company that were subcontracted to do the steel erection were chosen because they incorporated innovative techniques into their schedule. Site work began in November 1982. 3 lifts were used on the site each with different capabilities. One was placed on a barge, the other was placed on top of the tower which was able to reach the highest points and the third was assembled on the roadway floor system which could be transported around to reach the bits that the lift on the barge can not. The Algiers anchor span, over pier three was the first span to start the actual erection process. For temporary support a king post truss was used in the construction process. Once enough of the steel had been put in place a lift was put at the end of the steel on the roadway to lift further pieces into place. This span was the first to be completed by the contractors.



The New Orleans anchor span was next to be started, this used a balanced cantilever method. Whilst the shorter span was being constructed the longer span was also erected at the same time. After an adequate stage of construction had been reached, the contractors went back to Pier three to erect the steel towards pier two, cantilevering the span out into the river. Steels were lifted into place using the lift on the barge.

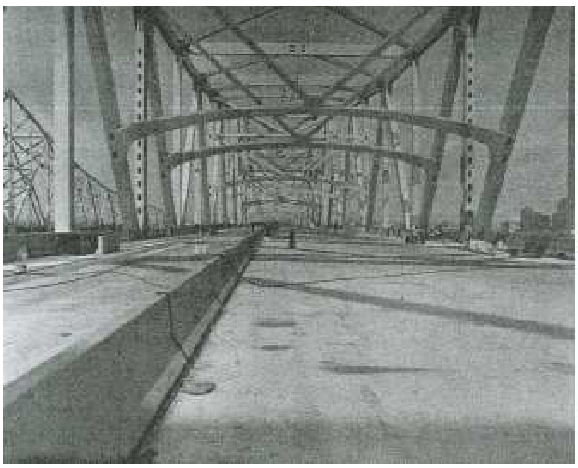


The cantilevers were then simply continued out with the help of scissor jacks. This meant that during construction the cantilevers were actually longer than when the bridge is finished. Then to close the structure a process called "swinging the span" allowed the scissor jacks to be relaxed and removed which changed the bridge from two long am cantilevers to being two shorter cantilever arms supporting a central span.



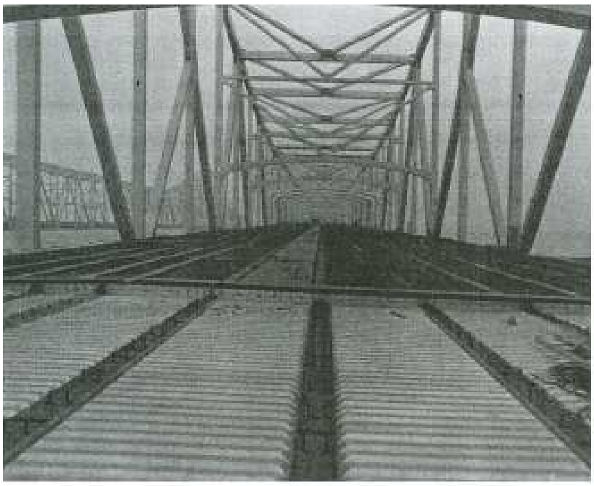
6.3 Deck Construction

The deck is made with reinforced concrete, and was started on the anchor spans whilst construction of the center span was still taking place. Reinforcing would be laid down and then concrete would be pumped up from ground level and then spread over the required area. A mechanical rolling machine helped this process. The surface texture of the road was LaDOTD standard transverse grooving was achieved using metal tining rakes.



To reduce the dead load of the bridge steel barriers were designed and erected to divide the 4 standard vehicular lanes up with the two HOV lanes. So the next process was then to erect this barrier. In the Algiers anchor span these were made of concrete in order to give the extra weight to help with the counter balancing. Lighting was then installed as well as a fog detection system at the base of pier two to notify on coming ships by a fog horn that the bridge is near.

After the fabrication of the metalwork is received two coats of zinc primer prior to arriving at the site. Once some of the pieces were being put together the connections were sandblasted and two coats of primer applied again. When these coats of paint were satisfactory a coat of vinyl wash primer was added and then followed with the final top coat of vinyl aluminum paint.



7 Conclusion

Difference to Normal Cantilevers

The cantilever bridge is designed to be rigid under the ever-increasing heavy loads. As the loads get greater and the demands on the spans get bigger the quality and consistency of the steel are crucial to the triumph of cantilever bridges. Greater New Orleans Bridge No.2 is a good example of this. Knowing that a heavier deck was originally planned had to be installed it was important efficient use of material was used. So to make the traditional cantilever more efficient the suspended span would have to be made more continuous. Using idle links initially did this and then extra links could be added which only begin to work when there are live loads. This method proved to be fractionally more efficient. This did however increase the difficulty in analyzing the bridge.

With the very nature of the middle span being supported by the two cantilever arms it allows large thermal movements to be absorbed in the sliding joints. Due to the now continuous section of the bridge there are no longer any sliding joints. This therefore means that a solution had to be found for how the extra strain is going to be taken by the bridge. It was found that the trestles could be made soft enough to allow changes in temperature as the bridges expands and contracts but stiff enough to resist wind loads.

The construction process for this bridge was a little out of the ordinary. In a normal cantilever bridge the spans are built from the piers outwards with the central span being built on the bank and then floated out and lifted into position. The continuous type design of this bridge meant that this could not be done. Instead the cantilevers kept being added to until the final piece is to join to the two cantilevers. At this stage final adjustment has to be made and if necessary jacking element to temporarily alter the length maybe required. “The force pattern in the completed structure could be adjusted to the ideal.” [3]

Acknowledgments

I would like to thank Richard Skoien, staff engineer at the Louisiana Department of Transport Division (LaDOTD), Crescent City Connection Division. I would like to express my appreciation for all his help and information he has supplied to me.

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