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Design and Construction: Recent North American Experience

Projet et construction: expériences récentes en Amérique du Nord

Entwurf und Erstellung: neuere nordamerikanische Erfahrungen

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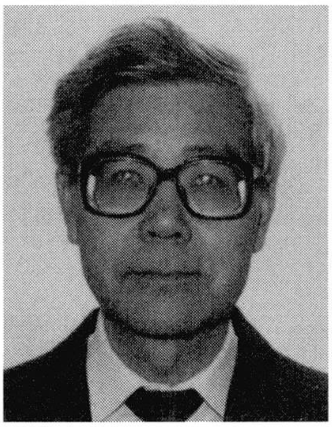

Man-Chung Tang received his Dr.-Ing. degree from TH Darmstadt, Germany. He has designed many bridges especially segmental bridges and cable-stayed bridges, including several world records and other structures. He has presented over fifty technical papers on bridges, stability theory, long span roofs and other topics.

SUMMARY

By absorbing ideas from abroad and by developing new techniques of their own, engineers on the North American Continent have constructed many beautiful bridges successfully in the last two decades. Some of them were built under severely restricted conditions. This significant evolution will be described by using several special projects as examples.

RESUME

Grâce à certaines idées provenant de l'étranger et au propre développement de nouvelles technologies, les ingénieurs d'Amérique du Nord ont réussi à construire de nombreux ponts admirables au cours des deux dernières décennies. Certains ponts furent d'ailleurs érigés dans des conditions extrêmement sévères. Le présent article expose cette évolution significative en s'appuyant sur la description de divers projets spéciaux.

ZUSAMMENFASSUNG

Die Ingenieure in Nordamerika haben durch Aufnahme von ausländischen Ideen und durch Eigenentwicklungen neuer Technologien in den letzten zwei Jahrzehnten erfolgreich viele schöne Brücken gebaut. Einige dieser Brücken sind unter extrem einschränkenden Bedingungen gebaut worden. Diese bemerkenswerte Evolution wird anhand einiger spezieller Projekte beschrieben.

INTRODUCTION

The bridge industry in North America went through a significant evolution during the last two decades. Not a single suspension bridge was built in this period of time. The last one was the Newport Bridge in Rhode Island which was completed in the late 1960's. Cable-stayed bridges became popular. Their span limits have been increased to a great extent to encompass very wide crossings. Prestressed concrete gained significant inroad into the area of long span bridges. The versatility of segmental bridges both in form and type gave many bridge structures in North America a pleasant new look.

In the area of short span viaducts, engineers are experimenting with optimization as an alternative to the AASHTO precast girders.

Steel construction is now slightly less competitive. However, the load and resistance factor design (LRFD) method now introduced to the steel bridge design should achieve better economy.

Several bridges were successfully built in extremely environmentally sensitive areas - representing the innovative answer of the engineers to meet the challenges.

Generally speaking, the new generation of bridges are more economical to build, their structural behaviour more predictable and are aesthetically more pleasing.

The following are brief descriptions of some significant developments.

PRECAST I-GIRDERS:

Although the AASHTO Type Girders are still being used very extensively for short span viaducts, many States have developed more optimum cross-sections. The most popular tendency is to stretch the height of the AASHTO girder to get them to bridge a longer span. The bulb tee section is the latest development in this direction. These precast girders are comparatively light and have been used for spans up to 50 meters. Very often post-tensioning tendons were used to make the originally simply supported beams into continuous girders.

The design method of these types of structures has also been more refined by using grid analysis or finite element method to calculate the stresses and load distributions of the structure.

Precast girders are more adaptable to areas like Florida and Texas, where access to the construction site is easy. In the Northeastern areas such as New York City and Boston, it is very difficult to deliver them to the site. Therefore, their use are less common.

PRECAST SEGMENTAL BRIDGES

A large number of precast segmental bridges have been completed in North America in the last two decades. Considering that this type of construction actually started only in the early 1970's with the Bear River Bridge in Nova Scotia and the JFK Memorial Bridge in Texas, the speed of its development and application is very significant.

Several relatively small segmental bridges were built in Indiana and Colorado after the above two introductory projects. They were all erected by balanced cantilever method.

The first overhead erection gantry was used in the Kishwaukee River Bridge in Illinois, Fig. 1. This twin five span (51.8 + 3 @ 76.2 + 51.8 meters) structure used Dywidag bar tendons for the longitudinal prestressing. The erection was extremely swift. The speed of seven segments a day was restricted by the ability to supply the segments from the yard to the site and the design of the single shear key before the filler epoxy had hardened. The overhead gantry was used to build one superstructure first and then rotated at the abutment to build the second superstructure.

Overhead gantry was also used in the Islington Avenue Bridge and, subsequently, in the Twelve Mile Creek Bridge, both near Toronto, Canada.

Then Zilwaukee Bridge, one of the largest precast segmental constructions in North America, was built in Michigan. But construction was delayed for a long time.

Confidence in this type of structure expedited its wide acceptance in the last decade. Starting with the successful completion of the Florida Key Bridges: Long Keys, Channel V and Seven Mile Bridges, precast segmental bridges have gained high visibility and popularity in the North American continent.

The development and application of external tendons in conjunction with span by span construction offered a good solution for both economy and aesthetics.

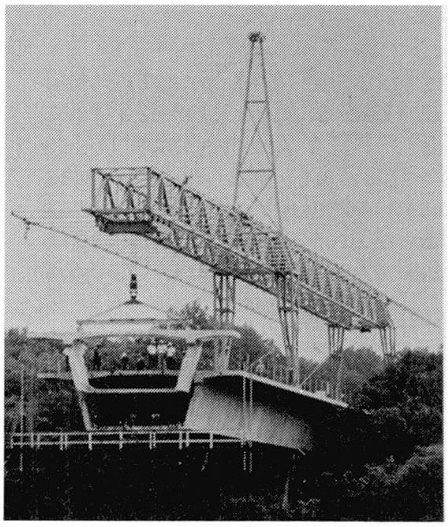

Fig. 1
Kishwaukee River Bridge

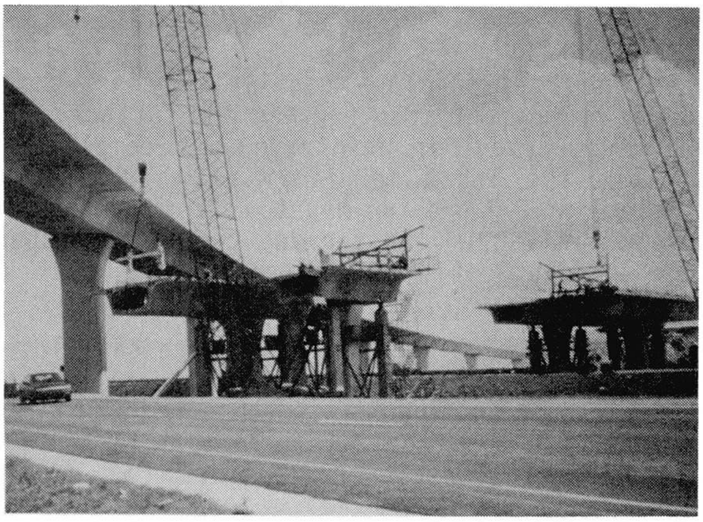

Fig. 2
I-75/I-595 Interchange, Fort Lauderdale

Florida now has the most precast segmental bridges. The recently completed I-75/I-595 Interchange in Fort Lauderdale, Fig. 2, is another story of success. With detailed planning and good knowledge of precast construction, the contractor was able to reduce 300 days from a 1050-day construction schedule.

Many other States, such as Texas, Colorado, California, etc., are building major precast segmental bridges. It is a good alternative to the precast I-Girder construction.

CAST-IN-PLACE CANTILEVER CONSTRUCTION

The first free cantilever bridge in North America was the Knight Street Bridge in Vancouver, Canada. It has a main span of 110 meters and was built by the end of the 1960's.

The Pine Valley Creek Bridge, Fig. 3, with a span of 137 meters in Southern California was the first one built in the United States. This bridge was built in an environmentally sensitive area. The access to the 120-meter deep valley is limited. To reduce the possible disturbances to the valley, to save travel time and to make material transport easier, a steel truss alongside the superstructure was used to carry personnel and material from pier to pier.

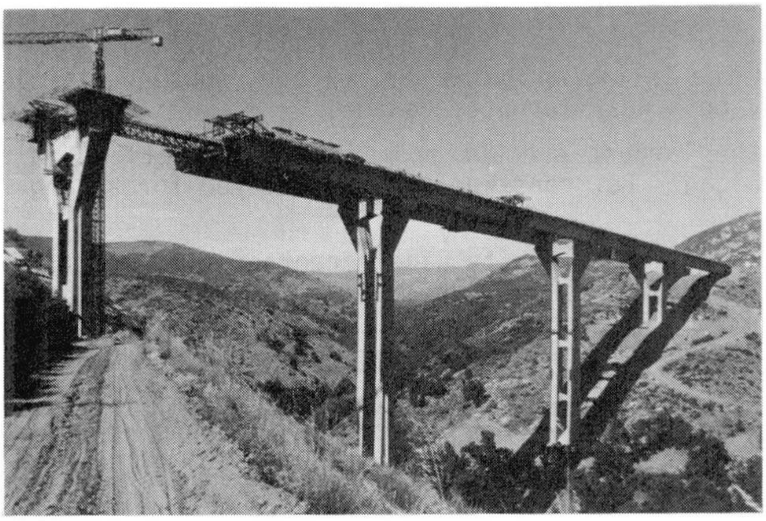

Fig. 3
Pine Valley Creek Bridge
California

Since then cast-in-place cantilever construction has pushed the prestressed concrete box girder span further and further. In the United States the 620 feet Snake River Bridge in Washington was completed in 1982. The Koror-Babelthuap Bridge in the Trust Territory with a world record span of 241 meters was completed in 1977 and the Houston Ship Channel with a main span of 229 meters was completed in 1982. In Canada, the longest span is the 213-meter Shubenacadie Bridge in Nova Scotia, completed in 1978 which surpassed the Grand Mere Bridges (181-meter span) in Quebec.

The basic concept of the cast-in-place cantilever construction in North America is the same as that in other countries. It was originally developed in Germany. A difference in the industry is that in North America, contractors usually do not have their own formtravelers. In most instances, they rent their formtravelers from prestressing material suppliers.

Concrete strength used for most cast-in-place cantilever bridges is 5000 psi (34 mpa cylinder strength). The early bridges all used Dywidag bar tendons. Later bridges, however, have practically all changed to seven wire strands for economic reasons. Transverse tendons are mostly three or four 0.6" dia. seven wire strands. Dywidag bars are still most common for vertical tendons in the webs. To avoid corrosion, PE ducts were introduced to replace the spiral metal ducts.

Due to the further development of cable-stayed bridges, prestressed concrete box girders for spans over 180 meters became less competitive in recent years. However, under various conditions prestressed concrete box girders are still being built for this range of spans. A good example is the Acosta Bridge over the St. John's River in Florida, Fig. 4. Although a cable-stayed alternate was studied in the preliminary stage, it was felt that a girder bridge will be more appropriate at this inner City site. The bridge has an unsymmetrical span of 192 meters. The unsymmetrical shape was derived so as to accommodate the restriction of the existing navigation channel. It limits the construction depth of one end span to approximately 2.9 meters. This limits the length of this end span to about 83 meters. Consequently, the main span of a symmetrical configuration would only be able to reach approximately 170 meters economically.

To bridge over the 192-meter main span, an unsymmetrical configuration with an 83-meter end span at one side and a 110-meter end span at the other side to balance the larger mid span results in a structurally satisfactory solution. This bridge is under construction at this moment using classical cantilever method.

Another noteworthy structure is the West Seattle Swing Bridge over the Duwamish River in Seattle, Fig. 5. The 152-meter span, double swing bridge is being built by means of cast-in-place cantilever method alongside the river bank. Upon completion this will be the longest concrete swing span. As most movable bridges are steel bridges, this concrete alternate was quite a surprise because of its competitiveness against all other steel proposals.

To avoid possible uneven deformation due to creep, the design provided slightly more prestressing forces in the deck to reduce the bending moment to a minimum.

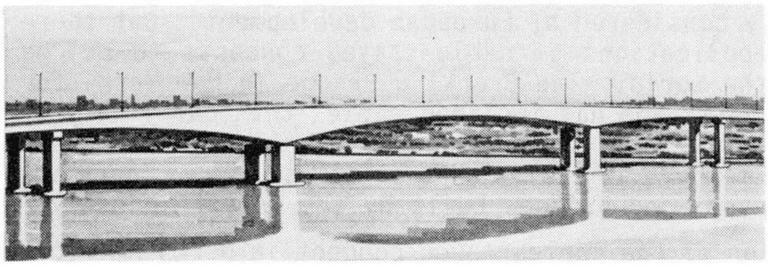

Fig. 4
Acosta Bridge, Florida

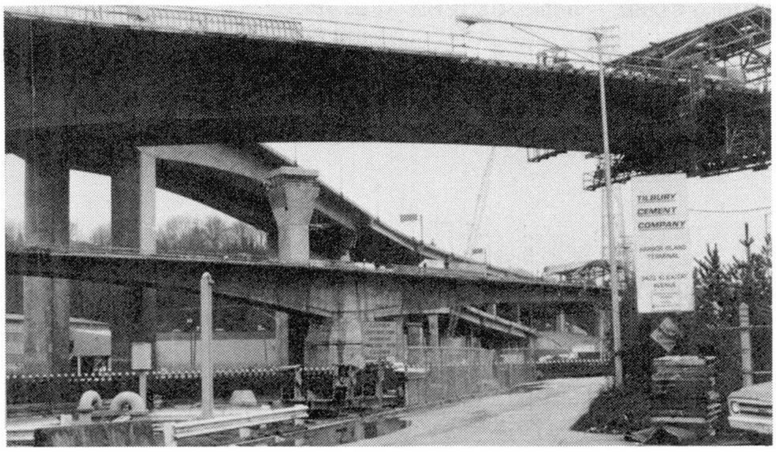

Fig. 5
West Seattle Swing Bridge, Washington

ARCHES

There are many beautiful old arch bridges in the United States. The Bayonne Bridge in New York City is one of the most well-known arches in the world; the New River Gorge Arch in West Virginia is a steel truss arch built in the 70's; the Freemont Bridge in Portland, Oregon is a cantilever tie arch completed in 1978.

Because failure in the tie member may cause collapse of the whole bridge system, they have become less popular in the United States. This is mainly because tie arches do not possess the redundancy most engineers now prefer. However, the proposed use of multiple ties with higher safety factors, although reducing the competitiveness of this type structure slightly, may provide the expected redundancy to render the arches as a more acceptable bridge form for the engineers.

The new steel arch over the Roosevelt Lake Dam is a very nice looking structure. This steel arch is erected on a concrete base which is sometimes submerged in the water.

STEEL TRUSSES

Steel trusses are quite popular for long span bridges. But due to the difficulty in painting and maintainance they are often not the preferred bridge type of many engineers. The very variable steel prices also made them less competitive against other forms of long span bridges.

The philosophy of design and construction of steel truss bridges has not changed much. Box type members have been used to offer better maintenance and aesthetics.

CABLE-STAYED BRIDGES

Cable stayed bridges are usually considered of European development. But there had been various examples of applications of cable-stayed concepts to bridge construction in many parts of the world. The Brooklyn Bridge in New York, for instance, built over a hundred years ago has inclined cables that carry part of the load of the suspended bridge girder. The Bentone City bridge in the State of Washington with rolled steel members as cables, was built in 1957. There are also many examples of cable-stayed wood bridges built by the forest industry.

The more systematical application of the cable-stayed concept in North American construction started in the late 1960's with the construction of the Sitka Harbour Bridge in Alaska, and the Papineau Bridge in Quebec. Since then many cable-stayed bridges have been completed. Some others are under construction or in the design stage.

Categorizing them by type of construction material, they can be separated into four basic groups: 1. Steel; 2. Composite - steel frame with concrete deck; 3. Cast-in-Place Concrete, and 4. Precast concrete.

STEEL CABLE-STAYED BRIDGES

In North America, steel orthotropic deck had not been competitive due to the high cost of labor. There is only one major steel cable-stayed bridge in North America built in the last two decades - the Luling Bridge.

This is a high level bridge over the Mississippi River with a vertical clearance of 41 meters. The bridge girder is composed of two single-celled boxes; the deck is an orthotropic plate with trapezoidal ribs. An inclined steel flairing plate is attached to the outside of the box girder along the main span to achieve better aerodynamic stability. Cables consist of parallel wires with Hi-Am anchorages. They were encased in polyethylene tubings and were grouted with cement after the bridge was completed. The erection was done by cantilever method utilizing a custom made barge mounted derrick crane which was capable of erecting a total steel segment at a time.

Certain problems developed in the PE pipe during grouting. Cracks appeared. To avoid possible corrosion of the cable tendons, two layers of PVF tapes were applied afterwards.

After the completion of the Luling Bridge, no other steel cable-stayed bridge was built in North America. It will probably take some time until significant improvements in welding techniques are made before steel cable-stayed bridges can be competitive once more against composite or concrete structures.

COMPOSITE CABLE-STAYED BRIDGES

The first composite cable-stayed bridge built in North America was the Sitka Harbour Bridge in Alaska. It has a main span of 137 meters and side spans of

45.7 meters.

The Annacis Island Bridge, Fig. 6, was completed in 1986. This world record span has a main span of 465 meters. The side spans are 182.75 meters long. It has a vertical clearance of 56.4 meters at the main span. The towers are concrete box sections constructed in vertical lifts by jump forms. The girder consists of two steel edge girders with steel floor beams spaced at 4.5 meters on center. The 215 mm deck slab is precast concrete supported by the floor beams, the edge girders and a longitudinal stringer at centerline of the bridge deck.

This cable-stayed bridge is a very flexible structure. It is important to use the lightest equipment possible for construction. Otherwise, additional weight may require additional maneuvering during construction such as cable adjustments, restricted working cycles, etc. This is because both the girder and the cables may experience higher stresses during construction than in the final stage under service loading.

Comparison of the various lifting equipment resulted in the selection of the American derricks. To facilitate movement from segment to segment, each derrick was seated on a steel frame anchored to the bridge by tie downs.

One derrick crane was placed at the tip of each cantilever to erect all the steel elements piece by piece. It was also used to pick up the precast panels and placed them on the steel frame. A segment is approximately 18 meters long. Cables were delivered to the site in reels, and placed on the deck at the cantilever end. They were then pulled up to the tower by an electric winch. Stressing was done at the tower end after the precast deck panels were erected. The joints were filled with a non-shrinking concrete. The derrick was moved ahead to the next segment after the filler concrete had gained sufficient strength.

Fig. 6
Annacis Island Bridge
Vancouver, B.C.

A full model wind tunnel test was carried out for the construction stages to study the buffeting effect. The test found that the bridge would respond violently during construction if it was built as simple cantilevers. Therefore, diagonal and vertical cables were used to tie down the bridge girder in order to increase its stiffness, thus reducing the buffeting effect.

The Quincy Bridge, Fig. 7, over the Mississippi River in Illinois has a main span of 274.4 meters and side spans of 134 meters. It has concrete towers of box-type sections. The bridge girder consists of two steel edge girders connected by 915mm deep floor beams at 3.81-meter spacings. Five 457mm deep stringers run on top of the floor beams supporting a 25.4mm thick precast concrete slab. The slab panels were precast six months ahead of erection. They run full width across the bridge deck with pockets blocked out at locations of the stringers and the edge girders to allow welding of the shear studs. These pockets were grouted after completion of the deck section to achieve composite action between the deck slab and the stringers as well as the edge girders. In addition, a grout layer was provided between the deck slab and the top of the stringers and the edge girders to assure full support. The cables are 0.6" dia. seven wire strands grouted in a polyethylene pipe. The pipe was welded into the required length at the site from 12-meter sections. The cables were grouted after all permanent loadings were in place.

Again, erection of the girder was by means of derricks placed at the tip of the cantilevers. In addition, a barge mounted crane was used to erect part of the steel sections to expedite the operation. Since the towers were not designed to support the unbalanced loading during construction it required back and forestay guide cables for stability.

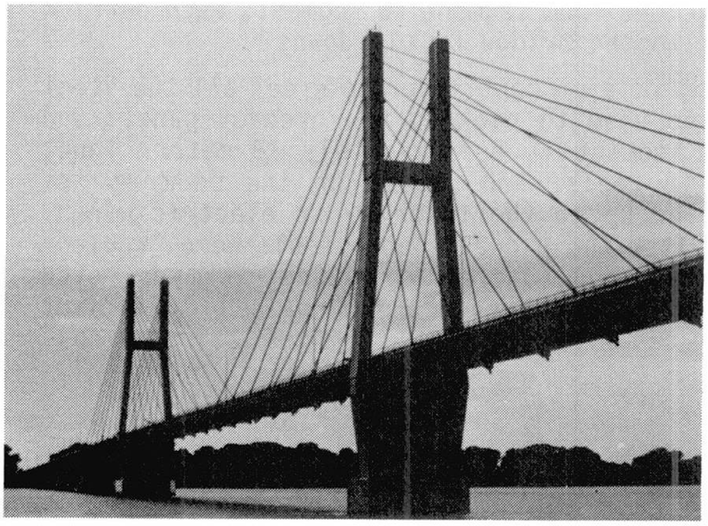

Fig. 7
Quincy Bridge over the Mississippi River
Illinois

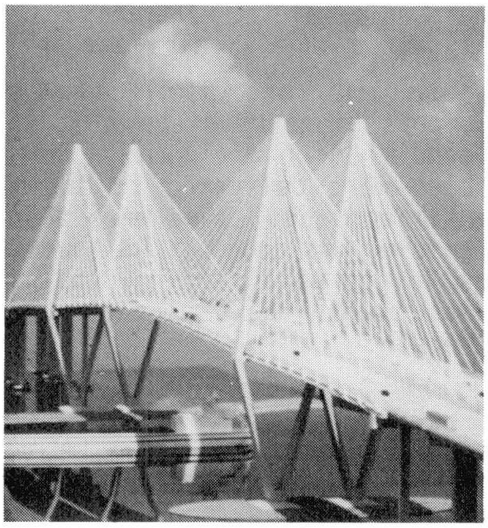

Fig. 8
Baytown Bridge
Texas

The Baytown Bridge, Fig. 8, across the Houston Ship Channel in Texas has a main span of 381 meters. Each of the twin decks is 24.1 meters wide. This bridge will be the largest cable-stayed bridge in the world after its completion with respect to deck area. The twin pylons are diamond shaped. They are connected to each other at the deck level. The tower legs have concrete box sections. The deck consists of two main girders connected by floor beams spaced at 5.34 meters on center.

The original design called for fabricating a complete section of the deck, approximately 15 meters long and 24 meters wide with a cast-in-place deck slab completed before transporting to the site for erection. The floor beams were not designed to support the dead weight of the concrete. They were to be supported during the casting of the concrete. This reduced the steel quantity of the floor beams to a minimum.

To simplify construction, the contractor modified the construction method by erecting the steel frames alone. The concrete deck now consists of precast panels. They are to be erected by means of a derrick crane mounted at the end of the cantilevers. The steel floor beams are strengthened to carry the weight of the concrete top slab before they become composite.

Due to the special configuration and flexibility of the towers and the twin deck sections, extensive aerodynamic testing was carried out to assure the stability of the structure under hurricane. Section model testings and full model testings were carried out for both the completed and the partially completed structure during construction stages. Diagonal and vertical tie downs will be used to stabilize the bridge against buffeting during construction. It is worth mentioning that full model wind tunnel tests confirm the theoretical analysis using data collected from the sectional model wind tunnel tests.

CAST-IN-PLACE CONCRETE CABLE-STAYED BRIDGES

There are three cast-in-place concrete cable-stayed bridges in North America : The Dame Point Bridge in Florida, the Talmadge Memorial Bridge in Georgia and the Cochrane Bridge in Alabama.

The Dame Point Bridge, Fig. 9, has a main span of 396.34 meters with side spans of 198.17 meters. Although the original design called for precast concrete floor beams the actual construction has the full concrete deck cast-in-place using a specially designed formtraveler. The towers consist of vertical columns of solid sections. The cables are 32 mm diameter Dywidag Threadbar tendons encased in steel pipes. The pipes were grouted after all permanent loads were in place. The concrete deck is 30.5 meters wide. The cables are spaced at 5.33 meters on center. The 115-ton formtravelers were designed to allow casting of the complete segment of 30.5 meters by 5.33 meters. To reduce the bending moment due to the weight of the concrete and the equipment, the formtraveler was supported by the permanent cable during the concrete casting operation. This enabled the formtraveler to de designed much lighter and, consequently, very easy to maneuver.

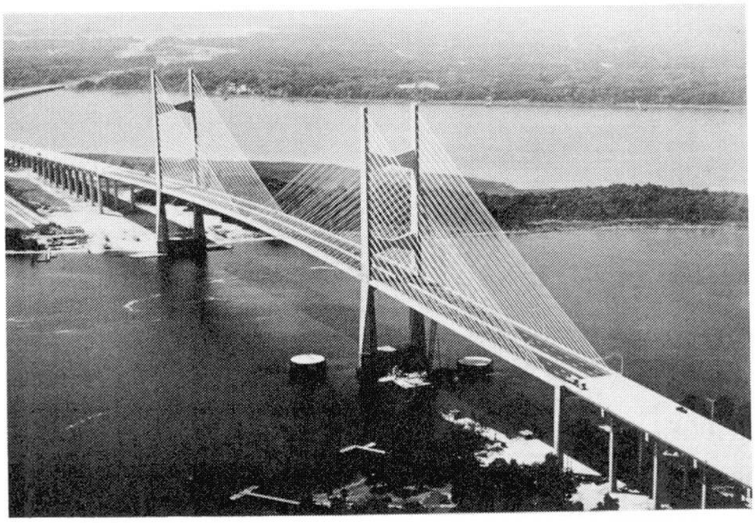

Fig. 9
Dame Point Bridge
Florida

The steel cable pipes were welded on the deck to their final lengths. All welds were tested to assure their quality The bar tendons were then pulled into the pipe as they were coupled in 18-meter lengths by couplers to their required lengths. Cables were erected by cranes on the deck. Erection of the cables had been very swift. Stressing of the cable was done by stressing individual bars. To assure that the bar tendons were stressed to the right force, each bar was verified by a lift-off test after the stressing operations were completed.

The Talmadge Memorial Bridge in Savannah, Georgia, Fig. 10, has a deck configuration similar to the Dame Point Bridge. It consists of two uniform 1.37 meters deep and 1.37 meters wide solid edge girders. The 280mm thick top slab is supported by transverse floor beams spaced at 8.92 meters in the main span and 8.61 meters in the side spans.

The center span is 335.37 meters flanked by two side spans of 143.19 meters each. It is a high level crossing with a vertical clearance of 56.4 meters.

0.6" dia. seven wire strands were used for the cables. They were encased in a PE pipe which was grouted after all permanent loads were in place. The cables were stressed at the tower end anchorages. The anchorages were designed such that adjustments are possible at a later date. White PVF tape is used to wrap the cables after the grouting operation.

The bridge was built in cantilever method using formtravelers which allowed casting of a complete segment in one operation. The formtravelers were basically the same as those used in the Dame Point Bridge. But water ballast was used to reduce the requirement of some cable adjustments so that the cables could be stressed close to their final forces before the segment was poured. Water ballast tanks were placed in the formtraveler. The weight of the water was approximately 70% of the weight of the concrete. The water was released as the casting of the segment progressed.

Vertical and diagonal tiedowns were used for stabilization of the bridge against dynamic wind vibrations during construction.

The Cochrane Bridge has a 238-meter main span. It has a double box cross-section with transverse diaphragms. Due to the stiffness of the boxes, construction was done by using two formtravelers similar to those used on box girders.

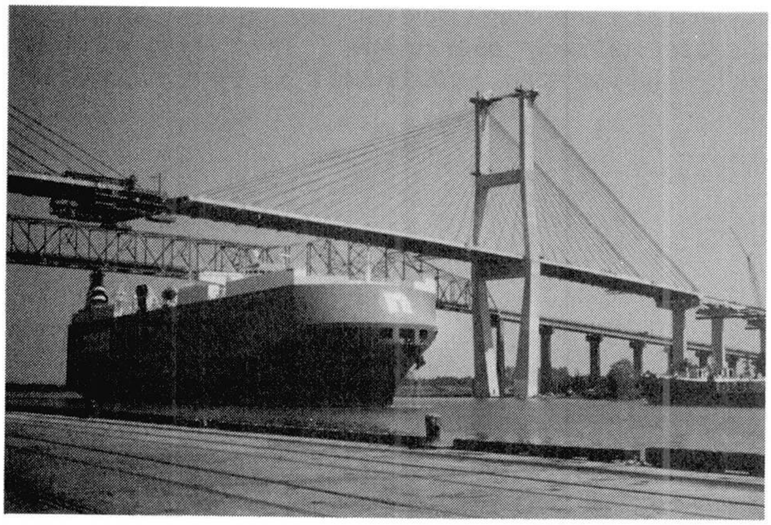

Fig. 10
Talmadge Memorial Bridge
Georgia

PRECAST CONCRETE CABLE-STAYED BRIDGES

The Pasco-Kennewick Bridge in the State of Washington was completed in 1978. The bridge has a main span of 299 meters and side spans of 123.9 meters. The bridge girder is 24.4 meters wide and 2.13 meters deep. It is 17 meters above the water level.

The cables consist of 6mm parallel wires with Hi-Am anchorages. The wires are encased in polyethylene pipes. They were preassembled in the factory and delivered to the site on reels. The cables were grouted with a cement grout after all permanent loads were in place. PVC tape was used originally to wrap the PE pipes. It deteriorated under the weather and, new PVF tapes were used to retape the cables.

The girder consists of a 200mm thick slab supported by floor beams spaced at 2.74 meters on center. The edge girders are triangular box sections which give it excellent aerodynamic stability. The girder is composed of match-cast segments. Each segment is 8.23 meters long and weighs about 3 tons. The towers are simple portal frames. The pier table, that is, the first segment on top of the pier, was cast-in-place on local falsework supported by knee bracings. A starter precast segment was placed at each end as bulkhead forms of the cast-in-place pier table. Other segments were delivered and lifted from a barge underneath by lifting jacks attached to an erection traveler at the end of each cantilever. The erection traveler was supported by an erection cable suspended from the top of the tower. Due to the limited flexural capacity of the bridge girder, several cable adjustments were required in each operation to control the bending moment due to the load of the newly added segment.

The pylons were stabilized by temporary back and forestay cables to reduce the unbalanced bending moment during construction.

The East Huntington Bridge has a main span of 274.4 meters and an end span of 185.4 meters. It has only one tower which is 88.4 meters high. A variable depth girder of 91.4-meter span is located at the other end of the main span. The 12.2 meters wide bridge deck is very narrow for such a long span and, therefore, an A-frame tower is used to provide the required lateral and torsional rigidity. Cables are parallel wires with Hi-Am anchorages grouted inside a PE pipe. The PE pipes are further protected by wrapping with tedlar tape. The white color of the tape also offers good aesthetic appearance.

The bridge deck consists of 20mm thick slab supported by steel floor beams spaced at 27.4 meters on center. The edge girders are 1.52 meters deep and 1.22 meters wide constant through the total stayed portion of the bridge. The girder is made up of 13.7 meters long precast segments weighing approximately 250 tons.

Original plans recommended to build the bridge in the same manner as the Pasco-Kennewick bridge. Although the weight of the segment is similar, the length of the segment (45 feet vs. 27 feet) increases the local bending moment during construction significantly. The contractor decided to erect the segment by a barge mounted crane. The segments were match-cast in a long line and brought to the site by barges. The crane picked up the segment and attached it to the previously erected cantilever by means of a hinge mechanism. The segment was suspended by the crane until the permanent cables were installed and stressed.

The East Huntington Bridge was completed in 1985.

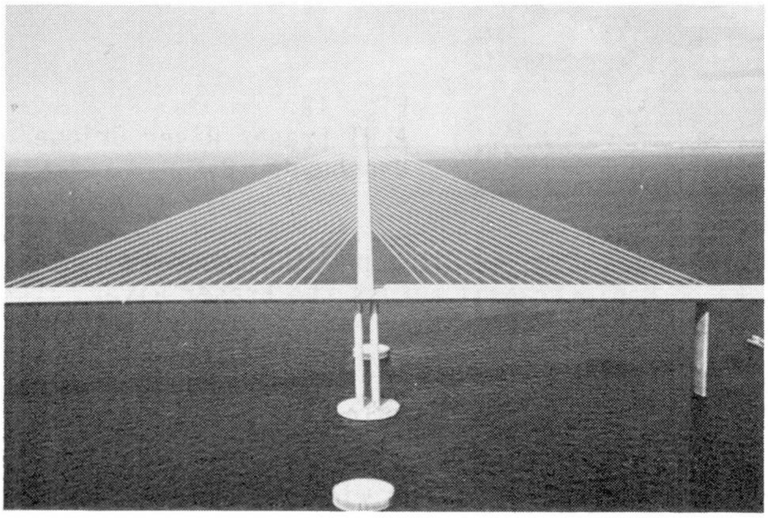

Fig. 11
Sunshine Skyway Bridge
Florida

The Sunshine Skyway Bridge, Fig. 11, is kilometers long across the Tampa Bay in St. Petersburg, Florida. The cable-stayed precast concrete structure has a main span of 365.85 meters flanked by two side spans of 164.43 meters each. It is a high level bridge with a vertical clearance of 53.35 meters. The bridge is very similar to the Brotone Bridge in France except that the segments in the Sunshine

Skyway were fully precast in one piece. These precast segments are 28.96 meters wide and 3.66 meters long. It is a single-cell box with struts to transfer the cable forces from the anchorage point at the top slab to the bottom of the girder. The segments weigh approximately 175 tons each. They were lifted to position from barges by a pair of winches attached to the end of the cantilevers. A 300mm wide gap was provided at each segment joint to avoid possible deviations. This gap was filled after the segments were erected. Cable spacings are 7.32 meters on center. Therefore, cables are anchored at every second segment of the deck. The cables consist of 0.6", seven wire strand tendons encased in steel pipes for corrosion protection. The cables were grouted with cement grout after all permanent loads are in place. In order to introduce a compressive stress in the grout, the cables were overstressed before grouting and then released after the grout had set.

The steel pipes for the cables were welded together on bicycle supports. They were then connected to saddle pipe which run through the tower. The strand tendons were pulled from one end of the anchorage up the saddle to the other end anchorage by means of a Lucker cable puller. To facilitate this erection scheme the strand tendons were preassembled in the yard to full bundles and the ends were welded together and attached to a pulling device. These tendons were pulled directly from the barge at the beginning but were later on pulled from reels placed on top of the deck instead.

The Sunshine Skyway was completed in 1987.

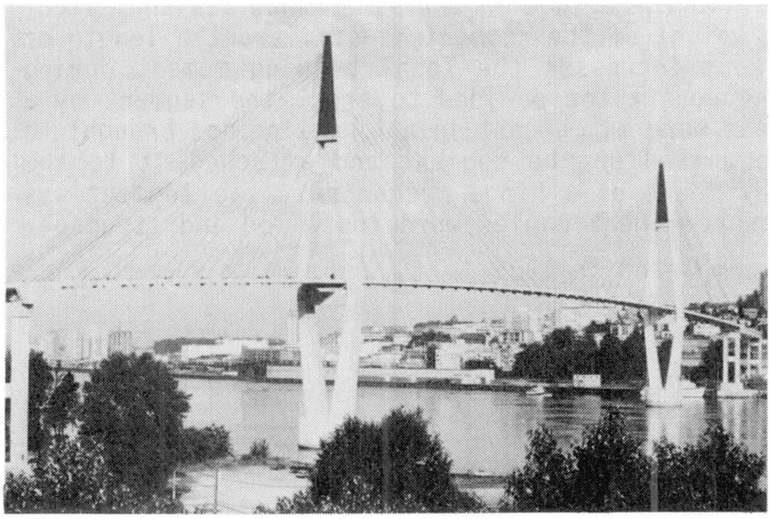

Fig. 12
ALRT Fraser River Bridge
Vancouver, B.C.

The ALRT Fraser River Bridge in Vancouver, Fig. 12, is a precast concrete cable-stayed bridge providing two tracks of rapid transit across the Fraser River. It has a main span of 340 meters with side spans of 180 meters. It's vertical clearance is 45 meters above the high water level. The piers are diamond shaped to provide lateral and torsional rigidity for the very flexible girder. Cables consist of preassembled long-lay wire strands in a PE pipe. The cable spacing at the deck level is 11 meters.

The bridge deck is a solid slab section with 1.4 meters wide by 1.1 meters deep edge girders above the deck forming a widened U section. The total width of the bridge girder is 12.4 meters. The segments are 5.5 meters long. Cables are, therefore, anchored at every second segment of the deck. The match-cast precast deck segments were delivered to the site on barges. They were lifted into position by winches attached to an erection traveler. The traveler was supported on the deck and by an erection cable suspended from the top of the tower. The division of the segment into 5.5 meters instead of 11 meters long resulted in the equipment being much lighter and easy to maneuver.

Cables were erected by pulling directly from reels delivered by barges to the site. To prevent the cables from rubbing against the deck, a minimum cable force was maintained during the whole operation of erection.

BRIDGES IN ENVIRONMENTALLY SENSITIVE AREAS

Protection of the environment against the disruption of construction has been figured prominently in various projects in North America. Discovery of archeological artifacts have forced many bridges to change alignments. Protection of local vegetation has required some bridges to be built without any disruption of the site. The bridge engineer, however, has met all these challenges successfully every time and have provided the public with the bridge structures they need. Some examples:

The Denny Creek Bridge, Fig. 13, is in a scenic region where the rock formation is very unstable so that the footings must be excavated manually and no falsework support was allowed for this 51.3 meter-span, 1100 meters long, multi-span bridge. To accommodate these restrictions, a special staged construction was developed.

Fig. 13 Denny Creek Bridge
Washington

The superstructure was designed in such a way that the bottom slab and the webs, forming a U-shaped section was made stable by itself after post-tensioning and was capable of supporting the inside of the foundation from the middle part of the top slab. The box girder thus created supported an after runner to cast the overhang slabs. The first-stage construction of the U-section was done by an overhead truss. The basic idea of this construction was to allow the use of a relatively light truss for the construction of the U-section which weighs only approximately 30% of the total cross-section. The division of the work into three separate locations, namely : the U, the middle part of the top slab and the wing slabs, made the utilization of labor crew much more efficient.

The Linn Cove Viaduct, Fig. 14, poses even more restrictions to construction by not even allowing access for the construction of the piers and foundations. The bridge, therefore, had to be constructed from one abutment to the other successively from overhead. The original design called for a special custom-made segment erector for the construction of the superstructure. This equipment, however, would not have provided the capacity for the construction of the foundations. The contractor, in close cooperation with the construction engineer, selected an American derrick S20 with an additional boom. This derrick not only was capable of erecting the segments successively, but also had sufficient boom to reach to the next pier for the construction of the next substructure.

Due to the severe superelevation of the superstructure, the derrick was supported by a steel frame. The steel frame could be adjusted to provide a horizontal base for the derrick. Although the requirements of the geometry control were very severe due to the sharp curvature of the superstructure construction was very successful.

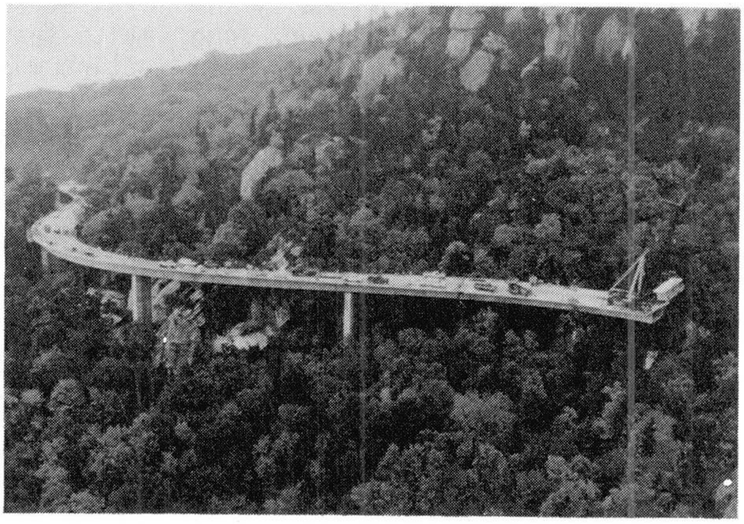

Fig. 14
Linn Cove Viaduct
North Carolina

CONCLUSION

Due to the separation of engineering and construction firms in the North American construction practice, contractors were quite reluctant to take on a complicated construction task such as cable-stayed bridges at the beginning because these projects require a significant amount of construction engineering. Actual problems encountered in some early projects. To help them build the more complicated structures, the contractor usually engages the services of a consulting engineer to provide them with the required construction engineering. This generally includes the construction stage structural analysis, camber calculation and equipment design or selection. Close cooperation between the parties and thorough planning is the key to the success of construction projects.

With more of this type construction being successfully executed, many contractors now have gained confidence. They are more familiar with these types of structures so that the competition has increased significantly. The contractors and engineers also become more innovative in their construction planning and execution, thus, contributing to the progress of the Construction Industry.