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Durability in the Design of American Precast Segmental Cable-Stayed Bridges

Durabilité des ponts haubanés américains construits par encorbellement

Dauerhaftigkeit bei der Segmentbauweise amerikanischer Schrägseilbrücken

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SUMMARY
As the use of cable-stayed bridges in America has continued to increase, ever greater attention has been focused on assuring the durability of these structures. This paper relates experience in the design and construction of precast segmental cable-stayed bridges in America. The summary of this experience is reflected in a design philosophy for durability. This philosophy has four parts: use high quality, long lasting material, work the materials at conservative levels of stress, provide redundant protection systems for stay cables, and develop maintainable, replaceable details.

RÉSUMÉ
L'utilisation de ponts haubanés continuant d'augmenter aux États-Unis, une attention toujours plus grande est portée à la durabilité de ces structures. L'article relate l'expérience américaine dans le dimensionnement et la construction par encorbellement d'éléments préfabriqués de ponts haubanés. Un résumé de cette expérience se retrouve dans la philosophie de durabilité, qui comporte quatre points: utiliser des matériaux de très bonnes qualité et longévité, faire travailler ces matériaux à des niveaux de contraintes modérés, fournir des systèmes de protection redondants pour les haubans, et concevoir des détails dont l'entretien et le remplacement sont aisés.

ZUSAMMENFASSUNG
Angesichts der fortschreitenden Zunahme von Schrägseilbrücken in den USA, richtete sich die Aufmerksamkeit immer schärfer auf die Dauerhaftigkeit dieser Bauwerke. Der Beitrag verbindet Erfahrungen im Entwurf und in der Bauausführung und mündet in einer Entwurfsphilosophie im Hinblick auf Dauerhaftigkeit. Diese Philosophie besteht aus vier Teilen: Verwendung hochgradiger, dauerhafter Materialien, mässige Materialbeanspruchung, redundante Schutzsysteme für die Schrägkabel und Entwicklung haltbarer, wartungsfreundlicher, austauschbarer Konstruktionsdetails.

1. INTRODUCTION

Over the last 15 years, precast segmental concrete cable-stayed construction has effectively built several of America's long span bridges. We have been fortunate to be involved in some phase of 20 of these bridges, completing 9 through final design, 4 projects of which have been constructed. The span lengths of these projects range from 300' to 1700'.

This paper presents a design philosophy, along with example projects where the philosophy has been implemented, that we believe will result in a highly durable precast segmental concrete cable-stayed bridge. The components of this philosophy are: use high quality, long lasting materials, work the materials at conservative stress levels, provide redundant protection systems for stay cables and develop maintainable, replaceable details.

2. HIGH QUALITY, LONG LASTING MATERIALS

A bridge deck constructed with precast concrete offers high quality. The precast concrete segments are produced in a near factory-like setting. This concrete mixes, with strengths between 5,500 psi and 6,500 psi, are rich in cement content and by using pozzolan admixtures, the porosity of the finished product is very low. The procedures for mixing, placing, finishing and curing the precast segments are carefully controlled, assuring high quality.

The Varina-Enon Bridge crossing the James River near Richmond, Virginia is a good example of a bridge which incorporates materials of superior quality. The bridge has a total length of 4,680'. It is constructed using twin parallel box girders of constant depth throughout the entire bridge length, including the 630' cable-stayed main span. The two box girders are connected transversely by precast delta frames, which also provide anchor locations for the central plane of supporting stay cables.

The typical concrete strength used for the segments was 5,500 psi. The strength was increased to 6,000 psi near the pylon to help resist the large compressive stresses resulting from the horizontal stay cable force components. The stay cables were made with as many as 81 - 0.6" diameter 7-wire prestressing strands, grouted inside polyethylene sheathing and wrapped with Tedlar tape.

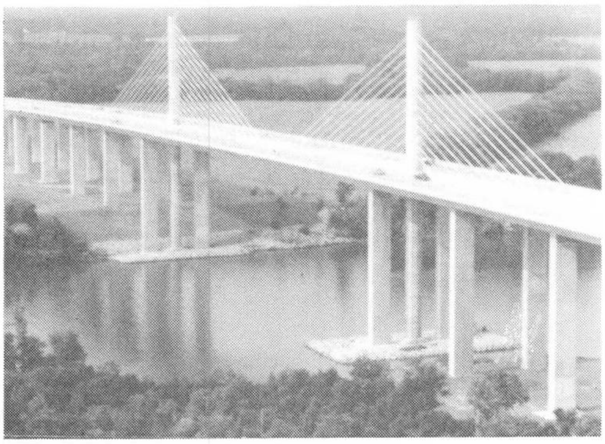


Figure 2.1 - Varina-Enon Bridge, Virginia

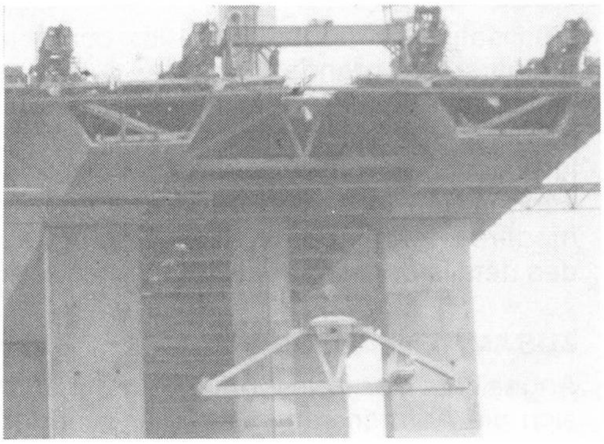


Figure 2.2 - Precast Delta Frames

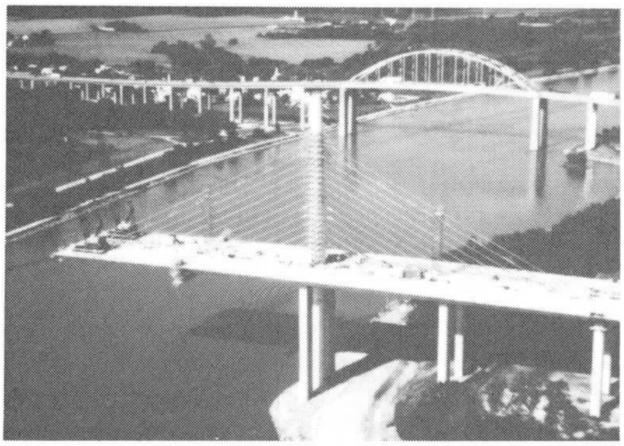
3. CONSERVATIVE STRESS LEVELS

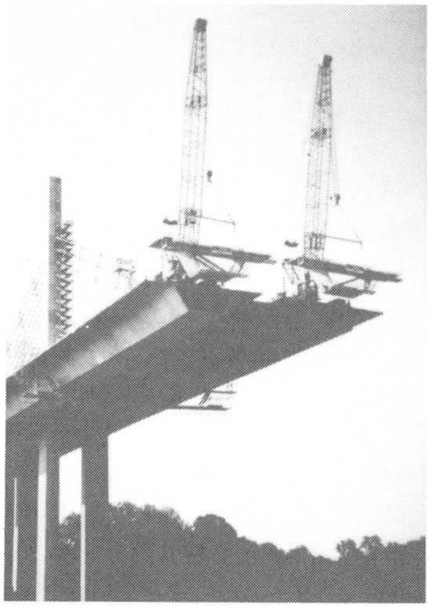
Working together with high quality materials is the fact that precast segmental concrete cable-stayed bridges operate at relatively low stresses. The precast concrete used is limited in compression to 40% its compressive strength under all combinations of loads. Longitudinally, the precast joints are prestressed to provide compression under all loads. Transversely, the top slab of these bridges are post-tensioned, producing a tension free deck design, precompressed in both directions.

The stay cables are also subject to significantly lower stresses, and stress variations, relative to design code limits than most tension elements. The maximum stress in the stay cables is limited to 45% of the guaranteed ultimate tensile strength. The weights of the precast segmental concrete superstructures, coupled with high flexural and torsional rigidities produce low stress variations in the stay cables due to traffic live loading.

The Chesapeake & Delaware (C&D) Canal Bridge is part of Delaware Route 1 crossing the Chesapeake & Delaware Canal just south of Wilmington, Delaware. This bridge, with a total length of 4,650′, was built using the same principles as the Varina-Enon Bridge. The twin box girders are joined transversely in the 750′ main span by delta-frames and transverse post-tensioning.

The bridge was designed to carry 4 lanes of HS25 loading in each direction. Extensive fatigue testing, as is typical for all cable-stayed bridges in America, was performed for full size stay cable specimen. The cables are made of up to 85 - 0.6", 7-wire prestressing strands grouted inside steel sheathing. The range of stress for the axial fatigue test is 23 ksi for 2 million cycles. The maximum stress variation in a stay cable caused by the design live load with impact is only 3 ksi. This is an extremely conservative design, even when taking into account the differences between the test amplitude and number of cycles versus the actual fatigue characteristics of the projected traffic.





Figures 3.1 and 3.2 - Chesapeake & Delaware Canal Bridge, Delaware. Progressive cantilever construction of the 750′ cable-stayed main span.

4. REDUNDANT PROTECTION SYSTEMS FOR STAY CABLES

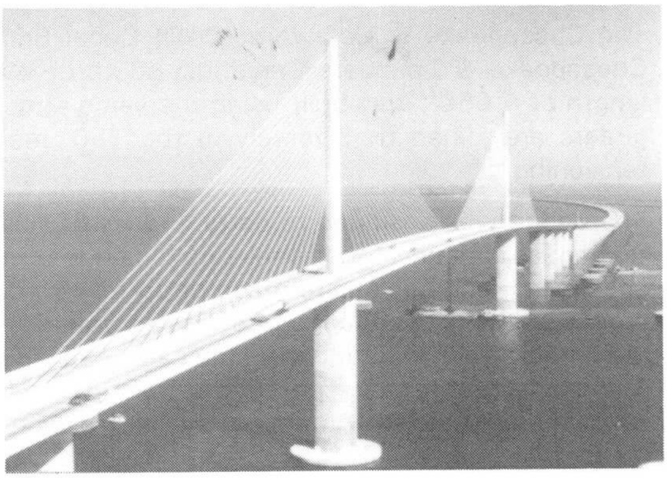
Two primary systems of corrosion protection have been employed for cable-stayed bridges in America. Both of these systems are based on using 7-wire, 270 ksi prestressing strand for the stay cable. In the first system, the multiple strand stay cable inside of steel pipes. Sections of steel pipe are welded together insitu to form the entire length of sheathing. After the stay cable is stressed, the area between the steel sheathing and stay cable is injected with a cementatious grout. After construction is compete, the stay sheathing receives a 3-part paint system. The second system uses a polyethylene sheathing instead of the steel pipe. The sheathing is grouted as before, and wrapped with a protective tape. Using either of these systems provides a protection system with three levels of redundancy; stay cable strand surrounded by grout, enclosed with sheathing that is protected with an externally applied continuous coating. An additional level of protection is sometimes used to isolate the strands from the surrounding grout. The strands are either epoxy coated or placed in individual plastic sheaths.

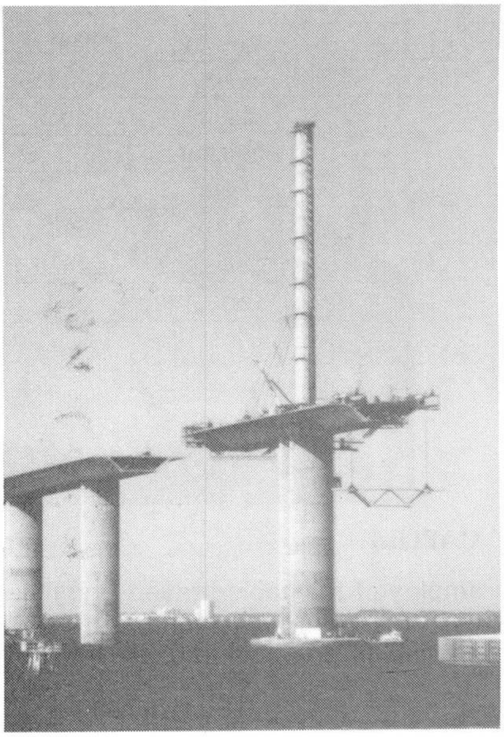
The Sunshine Skyway Bridge crosses Tampa Bay, Florida, and connects St. Petersburg with the Sarasota/Bradenton area. The total project length is 21,878′. The main span unit is continuous over its 4,000′ length. The main span length is 1,200′. Construction of the 4,000′ main unit uses 95′-3" wide precast segments erected using the balanced cantilever method. The stay cables for this project are protected by grout, continuous steel sheathing, and a 3-part paint system. The stay cables are continuous through the pylon and are anchored at either end in the bridge deck.

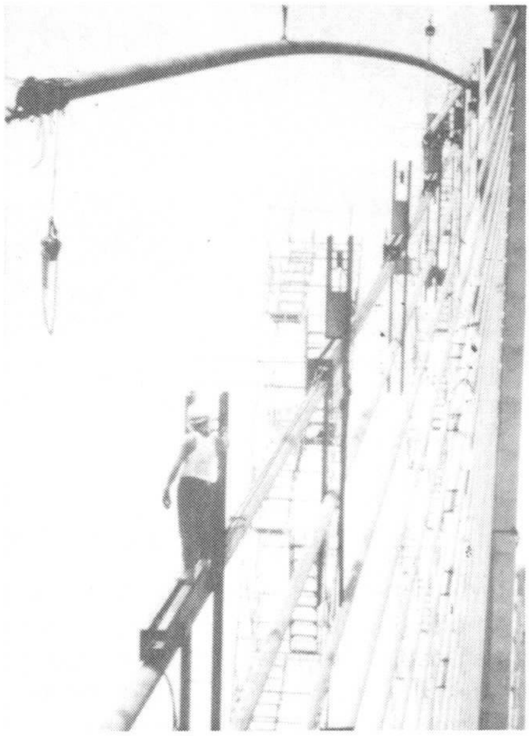
Figure 4.1 - (Right) Sunshine Skyway Bridge, Tampa, Florida.

Figure 4.2 - (Below) Balanced cantilever construction of the 1,200′ cable-stayed main span.

Figure 4.3 - (Below Right) Installation of the steel pipe sheathing for the stay cables.







5. MAINTAINABLE, REPLACEABLE DETAILS

Not withstanding high quality materials, low stress levels, and redundant stay cable protection, maintenance will be required to ensure the ability of these bridges to stand up to the wear and tear of everyday operation. The designs of these bridges must therefore accommodate this anticipated maintenance by developing details that facilitate maintenance and, where necessary, replacement of key components.

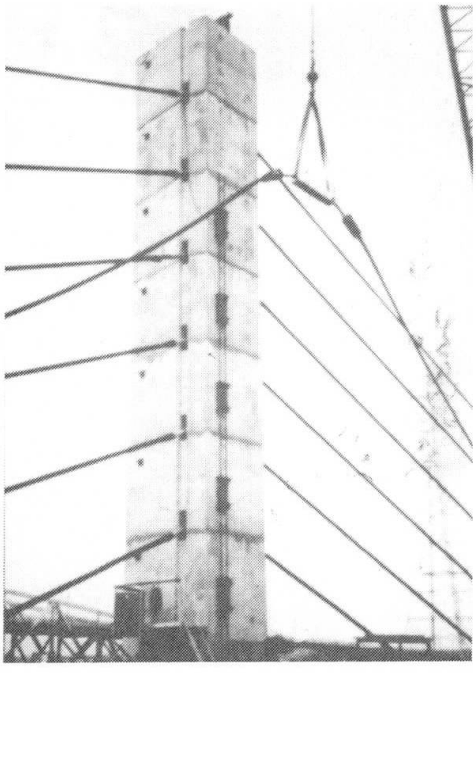
The most critical elements that need to be detailed for maintenance and possible replacement are the stay cables. The design criteria for the removal of stay cables for each of the bridges presented in this paper is that any one cable may be replaced under full live loading. To accomplish this, the concrete details should be selected for easy access to the ends of the stays for slackening. The stay cable anchor details should allow for removal of the stay cables through larger diameter guide pipes with relative ease.

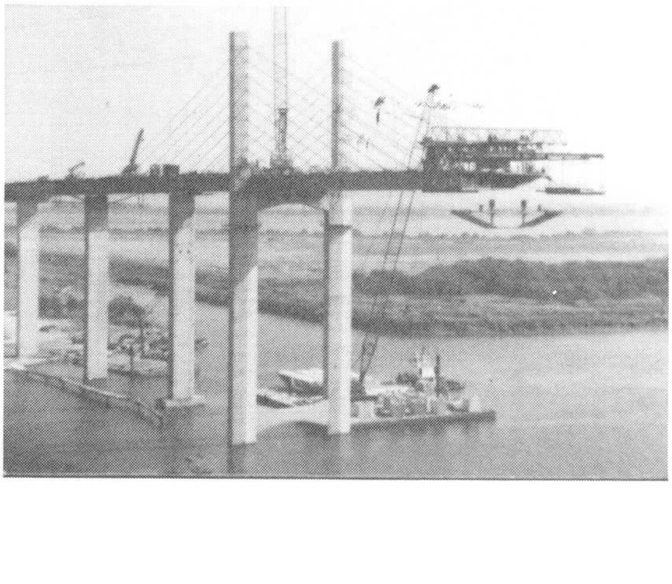
The Neches River Bridge in Port Arthur, Texas is a good example of the implementation of these principles. The bridge made of a single trapezoidal box girder with a width of approximately 61 feet. In addition to having a precast segmental superstructure, the pylons and side piers were also built using precast segments. As the bridge is cantilevered in one direction from the pylons, the pylon itself is built vertically in segments. One precast pylon segment is added for each two segments added to the bridge deck. The stay cables were prefabricated to their full length on the completed portion of deck. The stay strands are enclosed in polyethylene sheathing and passes through a prefabricated steel saddle at its midpoint. When needed, the stay is lifted and the steel saddle is placed on bearing seats at the top of the pylon. In addition to simplifying the construction process, the steel saddles are easily accessible and removable.

Figure 5.1 - (Right) Neches River Bridge, Port Arthur, Texas.

Figure 5.2 - (Below Right) Progressive cantilever construction of the 640' cable-stayed main span.

Figure 5.3 - (Below) One of the stay cable assemblies being lifted in place. The stay cables are continuous through the pre-fabricated pylon saddles.





In addition to developing details that facilitate the maintenance of cable-stayed bridges, the designer, with his intimate knowledge of the behavior of the bridge, should develop procedures to assist the owner in his maintenance efforts. This information is often developed in the form of a maintenance manual. These manuals provide the following types of information:

- a brief description of the behavior of the bridge
- definitions of the key elements for maintenance
- recommendations for the frequency and method of inspections
- limiting criteria which would indicate remedial action is required
- descriptions of the approach to remedial actions

6. CONCLUSION

There are few objective guidelines for developing durable bridge designs. In addition, there is only a limited amount of performance history of cable-stayed bridges in America. However, by applying the design philosophy presented above, verified by complete construction and service experiences, durable precast segmental concrete cable-stayed bridges can be obtained.