**Zeitschrift:** IABSE reports = Rapports AIPC = IVBH Berichte
**Band:** 73/1/73/2 (1995)

**Artikel:** Investigation of corrosion protection systems for bridge stay cables
**Autor:** Hamilton, H.R. III / Breen, J.E. / Frank, K.H.
**DOI:** https://doi.org/10.5169/seals-55283

# Investigation of Corrosion Protection Systems for Bridge Stay Cables

## Systèmes de protection contre la corrosion pour les câbles de ponts à haubans

## Untersuchung von Korrosionsschutzsystemen für Brückenschrägkabel

**H. R. HAMILTON III**
Assist. Res. Engineer
Univ. of Texas at Austin
Austin, TX, USA

**J. E. BREEN**
Professor
Univ. of Texas at Austin
Austin, TX, USA

**K.H. FRANK**
Professor
Univ. of Texas at Austin
Austin, TX, USA

**SUMMARY**

Of paramount importance for bridge stay cables is a dependable corrosion protection system. A recent survey indicated a general concern over the ability of the traditional cement grout system to provide dependable corrosion protection. The initial phases of a current experimental program investigated the effectiveness of the cement grout corrosion protection system with and without temporary corrosion protection on the strands. The baseline specimen used bare strand in Portland cement grout with no temporary corrosion protection added. Variables included use of temporary corrosion protection and different axial and transverse loading configurations.

**RÉSUMÉ**

Des systèmes fiables de protection contre la corrosion pour les câbles de ponts à haubans sont d'une importance extrême. Une étude récente a indiqué que les coulis de ciment traditionnels ne sont pas très fiables dans la protection contre la corrosion. Les phases initiales d'une recherche expérimentale en cours se sont axées sur l'efficacité des coulis d'injection comme système de protection contre la corrosion, avec ou sans protection des torons contre la corrosion. Le spécimen de comparaison comporte un toron dans du ciment portland sans addition de protection temporaire contre la corrosion. Parmi les variables d'études figurent la protection temporaire contre la corrosion et des procédures différentes de chargements transversaux et longitudinaux.

**ZUSAMMENFASSUNG**

Ein zuverlässiges Korrosionsschutzsystem ist von höchster Bedeutung für Schrägkabel in Brücken. Eine vor Kurzem durchgeführte Umfrage wies darauf hin, dass Bedenken hinsichtlich der Zuverlässigkeit traditioneller Zementmörtel Korrosionsschutzsysteme bestehen. Dieser Aufsatz berichtet von der ersten Phase eines Forschungsprojektes in dem die Wirksamkeit von Zementmörtel Korrosionsschutzsystemen mit und ohne provisorischem Korrosionsschutz für die Litzen untersucht wurde. Im Grundversuch wurden nackte Litzen mit Portland Zementmörtel ohne temporärem Litzen-Korrosionsschutz geprüft. In weiteren Versuchen wurde die Benutzung von temporärem Litzen-Korrosionsschutz und verschiedene axiale und transversale Belastungskombinationen als Variable eingeführt.

## 1. Introduction

An experimental program is currently underway at the University of Texas at Austin to investigate the effectiveness of corrosion protection systems of several currently used stay cable systems. The major component of the experimental program involves durability testing of eight large-scale stay cable specimens. The results from the tests on the first four specimens, which have been completed, are presented in this paper. The second set of tests, which are currently underway, focus on improved systems of corrosion protection for the individual strand including galvanizing, epoxy coating, and greasing and sheathing. In addition, an improved grout over bare strand will be tested. The specimens are subjected to an artificially severe exposure which is not intended to represent a specific exposure condition but rather a loss of sheathing and exposure to an aqueous salt solution to illustrate the relative effectiveness of the different protective systems.

## 2. Specimen Design and Construction

### 2.1 Materials and Configuration

Each specimen was constructed with twelve 12.7 mm dia. seven wire strands (Figure 2.1) with a guaranteed ultimate tensile strength (GUTS) of 1860 MPa. The sheathing along the free length of the specimen was transparent PVC pipe while the transition sheathing was transparent acrylic pipe. This allowed visual observation of the internal stay during tensioning, grouting, loading, and accelerated corrosion tests. The "live end" anchorage was a 254 mm dia. threaded anchorhead with a ring nut to allow adjustment in the tension of the stay. The opposite "dead end" anchorage utilized a 152 mm dia. anchorhead.

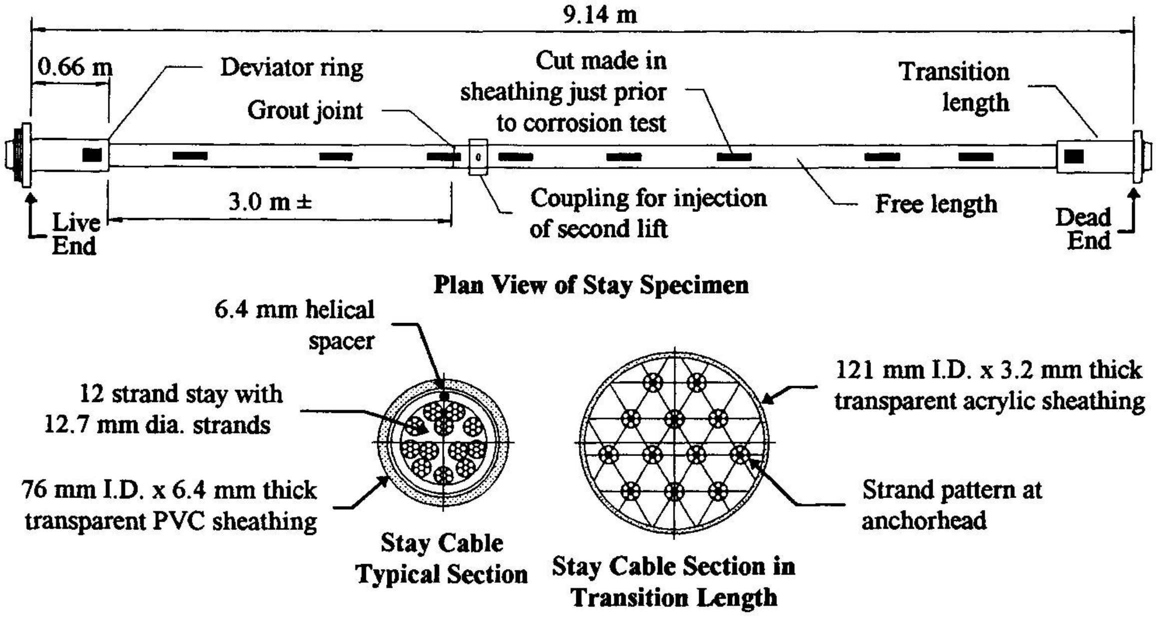


*Figure 2.1 - Details of Large Scale Stay Cable Specimens.*

The stay specimens in this initial series were:

- **LS1**: Bare strand stressed to axial dead load levels but with no additional axial or transverse load prior to and during corrosion test.
- **LS2**: Bare strand stressed to axial dead load levels and then loaded with additional axial or transverse load prior to and during corrosion test.
- **LS3**: Strand with temporary corrosion protection (TCP) and stressed to axial dead load levels but with no additional axial or transverse load prior to and during corrosion test.
- **LS4**: Strand with TCP and stressed to axial dead load levels and then loaded with additional axial or transverse load prior to and during corrosion test.

PTI *Recommendations for Stay Cable Design, Testing and Installation* (PTI Recommendations) requires the use of temporary corrosion protection on bare tension elements for corrosion protection in the time between erection and injection with grout.[2] An emulsifiable oil (Dromus B manufactured by Shell Oil) was used for the temporary corrosion protection in these tests. The stay was not flushed prior to grouting.

## 2.2 Assembly

Each stay was assembled, stressed, grouted, and tested in a structural steel reaction frame. The frame reacted the specimen force which allowed the specimens to be moved to different areas in the laboratory for each phase of testing.

Following assembly of the stay each strand was stressed individually from the dead end with a monostrand jack. The strands were retensioned once to reduce the difference in stress between each strand due to elastic shortening of the frame. The basic tension level was 30% GUTS which simulated a typical bridge dead load level. The final adjustment to the tension prior to grouting was made from the live end by adjusting the ring nut.

After stressing, the frame was placed in the grouting position at a 35 deg. angle with the live end at the bottom. This was to simulate a typical stay grouting orientation in the field. The grouting was completed in two lifts. The first lift was injected into the live end grout cap, through the anchorhead, and up the stay approximately half the free length. After the grout had cured for 24 hours the second lift was injected into the stay just above where the first lift ended, was pushed through the remainder of the stay, the dead end anchorhead, and discharged from the dead end grout cap. The grout mix used a 0.4 water/cement ratio (by weight) with the addition of an anti-bleed admixture Sikament 300 SC (as manufactured by Sika Corporation) at the rate of 2.2% cement weight.

## 2.3 Loading Prior to Corrosion Test

Following the 28-day curing period for the grout, the corrosion tests were started immediately on LS1 and LS3 with the stay stress levels at the dead load level. However, LS2 and LS4 were given temporary additional loads prior to starting the corrosion tests to simulate loading conditions which a stay might experience following grouting. Two temporary additional load configurations were imposed on the specimens.

The first additional load configuration was a single point load perpendicular to the stay axis applied at midspan (Figure 2.2). During the application of this load, supports were installed at the interface between the transition length and the free length. These supports simulated dampers which are typically installed on stays to reduce vibrations. They also alter the pattern of bending stresses in the stay when it is subjected to lateral loads. The intent of applying this lateral load was to simulate the stresses which may occur near the anchorage region caused by wind or light earthquake loads and to determine their effect on the corrosion protection provided by the grout.

The second additional load configuration was the application of additional axial load through the live end anchorage to simulate live loads. The stay axial load was increased from 30% GUTS to 45% GUTS, which is the prescribed dead plus live load allowable stress in PTI Recommendations.

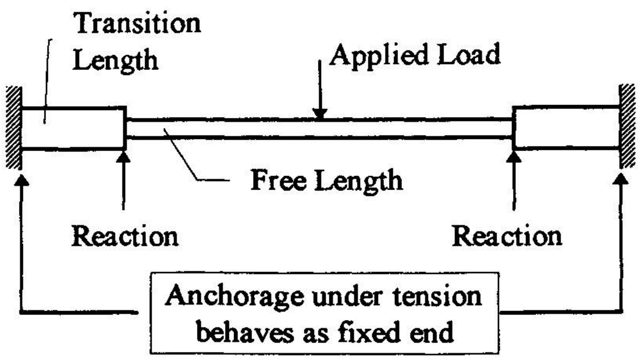


*Figure 2.2 - Lateral Loading Conditions for Large Scale Specimens*

The transparent sheathing allowed the specimen to be monitored visually for cracking in the grout during loading. Crack locations were marked on the sheathing for reference during the accelerated corrosion tests. Crack widths were also measured using a portable microscope at regular intervals throughout the loading cycle. Some portions of the specimen such as the anchorage region and load points were hidden from view by the frame or loading devices. This prevented the search for cracks in these areas during the application of additional load. Upon completion of the loading the specimens were subjected to the accelerated corrosion test.

### 3. Accelerated Corrosion Tests

In a comprehensive international survey, it was found that the average life which the bridge owners surveyed expected from the stay cables on their bridges was in the range of 75 years.[3] This presents a dilemma when designing an experimental program which is intended to test the durability of a bridge stay cable. Static and fatigue loading can be simulated in the laboratory in such a way as to mimic, reasonably well, the critical load effects which the structure might experience in its lifetime. However, durability is very much a time related and site specific characteristic. Ambient temperature, thermal heating, precipitation, humidity and pollutants all combine to "load" the structure in a very complex and little understood manner. To develop a test which directly addresses all of these areas is not economically feasible or considering the extremely long time duration not even technologically desirable.

Accelerated corrosion tests have been developed which can provide a basis with which to select corrosion resistant materials for long term use without having tested them for the expected life of the structure. One example of this is the macrocell test which is designed to represent corrosion of reinforcement in a concrete bridge deck.[4] The macrocell specimen is constructed to represent a small section of bridge deck and is then ponded with salt water in wet/dry cycles to represent the application of deicing salts, but in a much accelerated manner.

The goal in designing the accelerated corrosion test was to identify a realistic but severe corrosion mechanism, somewhat similar to the macrocell test, by which the cable could be tested in a reasonable amount of time. The stay configuration which was tested in this first series has essentially two layers of protection: the PE sheathing and the portland cement grout. PE pipe, when intact, provides an excellent barrier to moisture. However, it has been documented that some bridges in service have developed cracks or breaks in the PE sheathing.[5] Consequently, it was decided that the protection provided by the portland cement grout after a local break in the PE sheath would be the focus of the accelerated corrosion tests. Small local openings were made in the sheathing (to simulate accidental breaks) of each specimen and salt solution was ponded on the exposed grout surface in wet/dry cycles. Application of the salt solution represents an accelerated version of the intrusion of airborne chlorides which would occur on a bridge near the seacoast or in a region where heavy applications of deicing salts are used.

There were 8 locations along the free length of the specimens where a 25 mm by 280 mm section of the sheathing was removed (Figure 2.1). There was also one location on each transition length where a 50 mm by 150 mm section of sheathing was removed. An acrylic dam was attached to each of the openings to allow ponding of a 5% (by weight) salt water solution. Once the sheathing had been removed and the dams were in place the salt water was applied in cycles of two weeks wet and two weeks dry. The accelerated corrosion test lasted for a total of three months which permitted three wet and three dry cycles. Half-cell potentials were taken on the surface of the grout in each of the openings prior to initiating the accelerated corrosion test and at every interval between cycles.

All specimens were at a minimum axial stress level of 30% GUTS during the corrosion tests. In addition, specimens LS2 and LS4 were given additional axial loading during the accelerated corrosion tests. One week into each wet cycle, increased axial load was applied to specimens LS2 and LS4. Each was loaded from 30% to 45% GUTS for ten cycles. The load was held at 30% and 45% GUTS for one minute during each cycle. Following ten load cycles the stress was reduce to 30% GUTS.

After completion of the accelerated corrosion tests, the specimens were detensioned and completely disassembled. Each part of the stay was inspected for corrosion including the strands deviator ring, wedges, anchorage, and end cap.

### 4. Results and Discussion

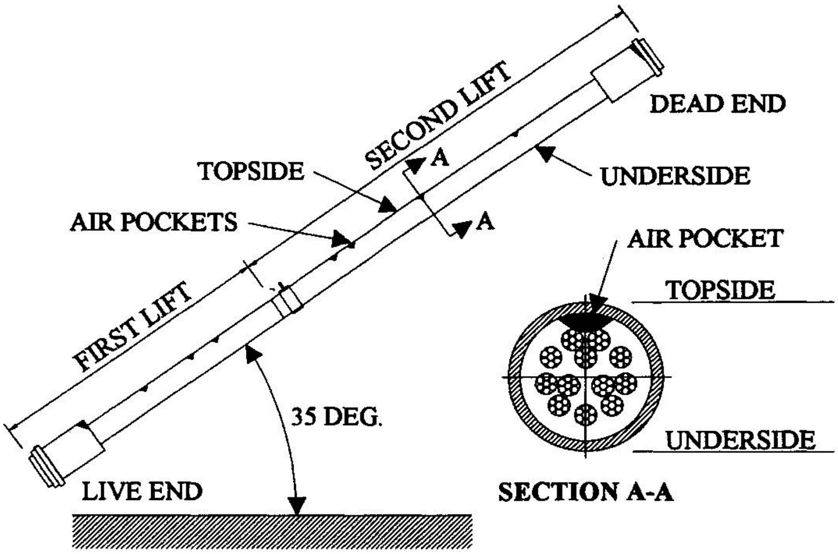


*Figure 4.1 - Schematic Elevation of Specimen in Grouting Position*

*Air Pockets in Grout* - Figure 4.1 shows the orientation of the specimens when the grout was injected. Although the stays were grouted under ideal laboratory conditions, air pockets formed in the grout in all of the specimens. As Figure 4.1 indicates, some formations were more severe than others with all of the air pockets forming in the top side of the stay. In addition, air pockets formed in the unvented corners of the specimen such as at the top end of the live end transition length and the underside of the dead end anchorhead. Generally, the shape of the air pockets along the free length of the stay could be described as very wide cracks in the grout. They were not actual grout cracks because they formed prior to the grout setting. The anti-bleed admixture thickens the grout as well as retarding the initial set. It is hypothesized that, because of the high viscosity of the grout, air was trapped between the strands during injection. After injection, while the grout was still fresh, the air pockets slowly migrated to the top side of the stay, leaving the strand unprotected in that area. This is consistent with observations made after the grouting. After completion of the grouting, the air pockets would initially appear at the top side of the stay and migrate slowly towards the top of the grout lift. The air pocket would then stop moving when the grout reached initial set. Injection of the stay at an angle to simulate field conditions rather than vertical, as is generally done in stay acceptance tests, was an important aspect of the stay testing. If the stay specimens had been injected in the prone or vertical position the air pockets may not have formed.

*Shrinkage Cracking of Grout* - Prior to the application of additional axial load on specimens LS2 and LS4 and prior to cutting openings in the sheathing on all specimens, the grout remained uncracked, as determined by visual observations. Once the sheathing had been opened locally, the exposed area of grout dried and localized shrinkage cracking occurred. The cracks were oriented both perpendicular and parallel to the axis of the stay. Depending on the ambient humidity, the cracking usually occurred within 2 to 3 days after the sheathing had been opened locally and only occurred in and around the opening in the sheathing.

*Cracking of the Grout under Load* - Specimens LS2 and LS 4 were given additional loads axially and laterally after grouting but prior to initiating the accelerated corrosion tests. During lateral loading a small amount of cracking was audible through the complete loading cycle. However, cracks were not visible at any of the visually accessible locations along the length of the stay. During additional axial loading, cracks were also audible but a much larger number of cracks were heard than in lateral loading. Cracking was heard immediately upon initiation of the increased axial loading at slightly above 30% GUTS and was audible through 34% GUTS. Above 34% there was no audible cracking detected. Cracks were noted at 33% GUTS on LS2 and at 36% GUTS on LS4. However, it is suspected that the cracks on LS4 may have been visible at a lower stress level because, on that specimen, crack inspection did not begin until the load was at 36% GUTS. In summary, the cracking occurred at very low increased stress in the stay relative to the allowable stress range. This indicates that a stay does not have to be heavily loaded in order to cause grout cracking.

*Corrosion Occurred Rapidly* - Corrosion product had appeared on the surface of the grout in at least one opening in all the specimens by the end of the second wet cycle. Typically, this corrosion was occurring at the intersection between the strands and the grout cracks. This location was determined during demolition of the specimens following completion of the corrosion tests. This behavior indicates that the permeability of the grout is of little significance when the sheathing is broken and the grout cracks.

*Location of Corrosion* - Although the majority of the corrosion found during the demolition of the specimens was on the strands under openings cut in the sheathing, corrosion was also found in locations away from the openings especially under air pockets in the grout. Corrosion was found in the anchorage region including especially the interface between the wedges and strand. Very heavy damage was found between the inner and outer wires of the top strand in specimen LS2, while there was no damage found on the exterior wires. This indicates wide ranging transport or migration of the salt water along the stay.

*No Additional Protection Provided by TCP* - There was no discernible improvement in the performance after grouting of the specimens which were coated with TCP during assembly.

## 5. Conclusions

Four large scale stay cable specimens have been subjected to an artificially severe environment with the purpose of providing a comparison of the relative effectiveness of the currently used corrosion protection systems. Openings were made in the sheathing which represented accidental breaks in an actual stay. The exposed surface of the grout was then ponded with salt water. In addition to providing a basis with which to compare the improved systems, the testing uncovered many interesting behavioral tendencies. The most important of these is that within two to three days of cutting an opening in the sheath the grout in the immediate vicinity of the opening will shrink and crack. This finding essentially voids the concept that a stay system which has bare strand with or without TCP in a PE sheath and is injected with portland cement grout is a "two barrier system." At any location where a break in the sheathing occurs the grout will probably crack, allowing immediate access of air and moisture and also chlorides or pollutants, if present. Effectively, the corrosion protection system of the stay cable is reduced to the PE sheathing. Based on these findings, it is recommended that this method of providing corrosion protection be improved. Additional layers of protection should be used to provide more redundancy in the current corrosion protection systems. Examples of some improvements are epoxy-coating, galvanizing, or greasing and sheathing. It would appear that improvements in the grout which can inhibit or prevent corrosion of the strand might also be compromised by the cracking. The second series of stay specimens in this study will investigate some of these possible improvements.

## 6. Acknowledgements

This research was sponsored by the Texas Department of Transportation and the Federal Highway Administration under an agreement between the University of Texas at Austin and Texas Department of Transportation. Conclusions are those of the authors and not necessarily those of the sponsors.

## 7. References

1. HAMILTON III, H. R. and BREEN, J. E., International Survey of Current Operation on Bridge Stay Cable Systems, IABSE Symposium, San Francisco, August 23-25, 1995.
2. Post-Tensioning Institute Committee for Cable-Stayed Bridges, Recommendations for Stay Cable Design, Testing and Installation, August, 1993.
3. HAMILTON III, H. R. and BREEN, J. E., Stay Cable Survey, Phil M. Ferguson Structural Engineering Laboratory, The University of Texas at Austin, February, 1995.
4. ASTM G109-92, Standard Test Method for Determining the Effects of Chemical Admixtures on the Corrosion of Embedded Steel Reinforcement in Concrete Exposed to Chloride Environments.
5. WATSON, S. C. and STAFFORD, D., Cables in Trouble, ASCE Civil Engineering, April, 1988.