HEAVY MOVABLE STRUCTURES, INC.

NINTH BIENNIAL SYMPOSIUM
"Preserving Traditional Values with New Technologies"

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A STUDY OF GREMLINS

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MACHINERY/MECHANISMS

Introduction

The idea for this presentation first came to us after reading To Engineer is Human by Mr. Henry Petroski. In this book Mr. Petroski describes the great strides in engineering design made possible through the knowledge gained from catastrophic failures. In fact the main point of the book is to illustrate that we can learn much more from our mistakes than our successes. We believed this to be true, and further more, that it could be applied to the world that we work in. This is the world of less than catastrophic results and less than earth shaking advancements but where the reduction of mistakes (hereinafter referred to as containment of gremlins) is none the less very important, especially to the taxpayers of Louisiana; for each gremlin released to cause his bit of mischief converts directly into additional cost to the contract; money that should not have had to be spent -- wasted money.

There are a few things to keep in mind if the maximum benefit is to be derived from an evaluation of gremlin mischief (and here as throughout the report we will be addressing the subject from the design engineer's point of view.)

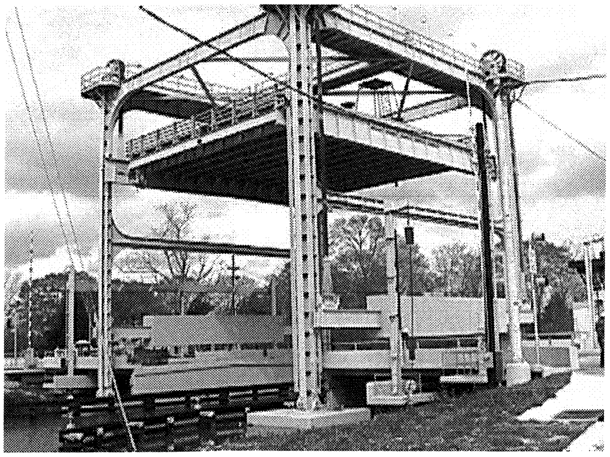
1.) For the evaluation to be helpful, it must be honest. It is of no value to conduct an evaluation of gremlin activity without enquiring what the action was that let them out. If the evidence points to us, then good, it will be the easiest gremlin to cage up next time because it is under our direct control. To be good evaluators our egos must be checked at the door.

2.) If the evidence points to someone else we still can't relax. Although we might think the contractor or fabricator was the culprit the chances are no one else will. In the vast majority of cases the taxpayers will pay. And we must remember that saving money on the next project is the primary object of the entire exercise. In this case we not only have to check our egos at the door we have to bury them under the porch. We must look for ways to amend *our work* to lesson the likelihood of the culprit letting out the same gremlin on the next project.

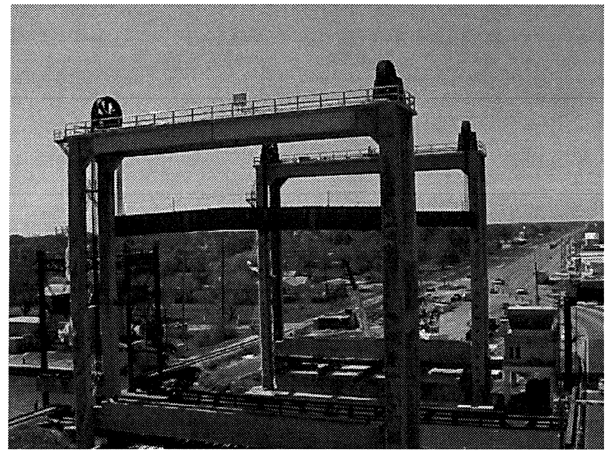
3.) Gremlin activities sometimes lead to litigation. All litigation must be ignored. The evaluation must be conducted in the rarified atmosphere of a lawyer less world. Nothing will so quickly distort our perception of the truth than having to defend the corporative position.

We were exceptionally blessed this year with a project that had a plethora of gremlin activity for us to evaluate. Since it was our first vertical lift bridge with concrete towers and machinery decks it is perhaps not too surprising that this was the case.

We will examine these activities on a case by case basis with an eye toward discovering the contributing factors that led to the gremlin activity and then those measures that can be taken to lesson the chance of this particular gremlin becoming active on future projects.

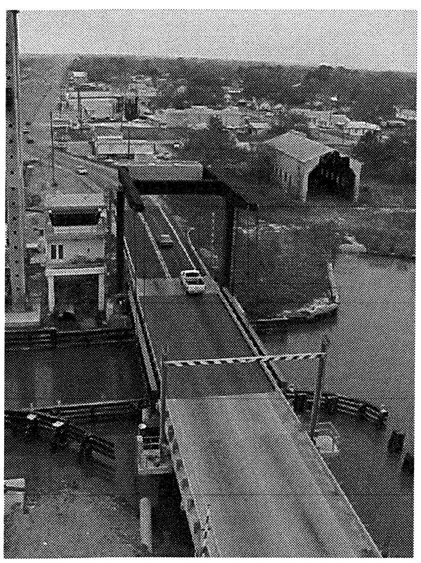


CAPTION: Typical steel tower V-lift bridge



CAPTION: New concrete tower V-lift bridge

Before beginning, we will quickly describe the project in question so that certain discussions that follow will be better understood. We are concerned with a vertical lift bridge, five lanes in width, and approximately 100 feet in length with a lift of 75 feet. It was constructed (that is the lift span, the machinery decks, and the towers) of reinforced concrete. The first such we have ever tried. The reasons for using concrete were partially for aesthetics but mainly for maintenance. We feel that the concrete towers are more elegant and pleasing to the eye compared to our typical steel towers, and we also hope to save on maintenance by not having to routinely paint it. It did turn out to be a very attractive structure.



CAPTION: Temporary bypass bridge. Bascule span with overhead counterweight

The bridge was constructed on the same alignment as the existing bridge and therefore required a detour bridge to be constructed before the existing bridge could be demolished. The detour bridge was a bascule span with overhead counterweights. It was constructed with the intention of being relocated to a permanent location after its duties were no longer needed at this site. The bridges were located in such proximity as to allow the operator's house intended for the permanent structure to be used for both; that is, used to operate the detour bridge and then operate the permanent bridge when it was completed. This of course meant that the permanent operator's house had to be constructed before the permanent bridge… which leads us to case I.

CASE I: The Gremlin Who Could Not Stand Still

It was decided early in the design phase of this project that we would use the permanent operator's house to operate the temporary bypass bridge. Therefore, we located the permanent operator's house between the alignments of the two bridges. The permanent operator's house would be constructed at the same time as the temporary bridge, then the temporary bridge's control desk and switchboard would be placed so that the permanent bridge's control desk and switchboard could be added later. This was important because both bridges would have to be operated from the operator's house during the testing phase of the permanent bridge. We would not be able to install the generator for the permanent bridge until the switchboard for the temporary bridge was removed.

CAPTION: Proximity of operator's house between spans

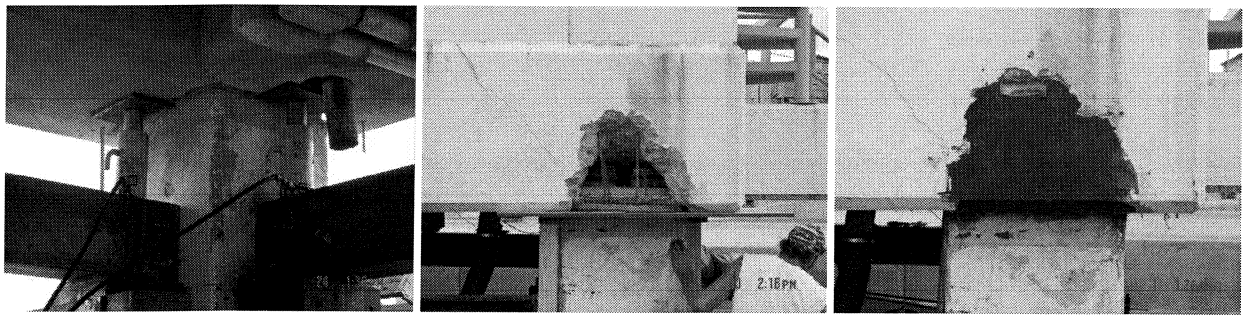
The initial construction phase went fine. The temporary bypass bridge was completed and vehicular traffic was diverted on to it. This is not to say there were no problems during the construction of the bypass bridge, just nothing out of the ordinary.

The existing bridge was demolished, and construction began on the permanent bridge. After the contractor drove the piles for the main pier nearest to the operator's house, it was discovered that the gremlin who could not stand still had been at work. The new piles had pushed on and lifted the two nearside piles of the operator's house about 4 inches. This had caused the deck of the operator's house to break away from the farside piles, which resulted in the house leaning away from the permanent bridge.

CAPTION: Farside pile on operator's house

As repair solutions for the operator's house were being discussed, the gremlin who could not stand still went back to work. The contractor finished constructing both main piers including pouring the caps. He then began driving piles for the approach spans. During this phase, it was discovered that the approach span piles were pushing the already completed main piers closer together. The decision was made to finish driving all piles, then reassess the situation. In the end, it was determined that the main piers had moved three inches closer together.

All this pile driving moved the temporary bypass bridge also, but since it was temporary, less permanent solutions such as chipping away at the approach span whenever interference occurred were used to keep it operational.



CAPTION: Repairs to the operator's house.

To repair the operator's house, the contractor chipped away part of the cap by each pile, then jacked up the cap until it was level. He then inserted shims on top of the piles to hold the cap level. Forms were then placed around the exposed portion of the cap and a non-shrink epoxy grout was injected into the cavity.

To account for the movement of the main piers, we had to either shorten one approach by three inches, or shorten the span by three inches. It has been a standard detail on our vertical lift bridges to have the concrete wall that supports the end of the approach span on the main pier flush with the end of the approach span girders. If we shortened the approach span, we would also have to move the support wall. Because of this, we felt it was less trouble to shorten the movable span steel three inches. The steel for the span had already been fabricated, but it was still at the fabrication shop.

Evaluation of Case I

Movement of the Operator's House: At first, the movement of the operator's house appears obvious. The operator's house was too close to the main pier of the permanent bridge. But operator's houses are often close to the bridge they service. The problem was that the operator's house was built **first** so it could service the temporary bridge. Often, the piles for the house and the bridge are driven at the same time. Later, any movement of the piles can be fixed when the caps are poured. Another factor was the sequence in which the piles were driven. The contractor drove the interior piles of the main pier first and then moved outward. Had the contractor driven the exterior piles first, the movement of the operator's house would have been reduced.

What could we have done differently to prevent this problem? It was not feasible to locate the operator's house far enough away from the permanent span to prevent movement when the main pier piles were driven. If we had thought of it, we might have been able to drive the main pier piles that were closest to the operator's house at the same time the operator's house piles were driven, but this may have caused problems with the existing span. Better sequencing when driving the main pier piles would have minimized the movement, but it probably would not have prevented it. For this project, the only sure solution would have been to operate the temporary bridge with a temporary house, and to build the permanent house at the same time as the permanent bridge.

Movement of the Main Piers: This occurred because the contractor poured the pier caps before he finished driving the piles for the approach spans. He wanted to do this because he felt that the towers were a critical path item. He needed the main piers completed so he could start work on the towers. The approaches, he reasoned, could be completed at any time.

What could we have done differently to prevent this problem? Had the contractor waited at least until the approach piles nearest to the main piers had been driven, he could have adjusted for the pile movements when he poured the main pier caps. But who is responsible for construction sequences. It has always been our policy to put a minimum amount of construction instructions on our contract plans. We don't want to "tie the hands" of the contractor who may know a better, faster, or simpler method of construction. Before the contract, most of the contractors agree with this method. However, it has been our experience that once a construction error has been made, the contractor usually complains that there should have been more guidance in the plans. We usually agree and at least partially pay for the repair. Since we can't rely on the contractors for movable bridge projects to have the experience to build an error free bridge, we believe that more construction information should be given on the contract plans.

Also, if the approach span end support walls on top of the main piers had been set back from the end of the approach span, the contractor could have simply shortened the approach spans when they were poured.

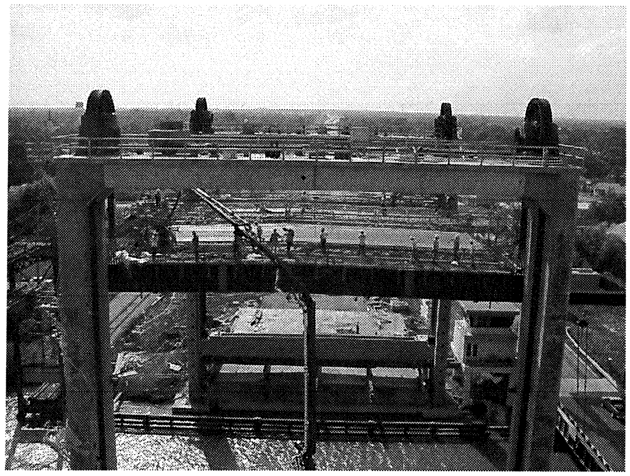
Actions as a Result of the Case I Evaluation

1.) In the future, we will not plan for structures requiring driven piles that are in close proximity to each other to be constructed at different times.

2.) We will state critical construction sequences on the plans.

3.) We will change our standard detail for our approach spans to make our approach spans more easily shortened. This will provide for larger adjustments than the normal span end plates can provide.

Case II: The Gremlin Who Put On Weight



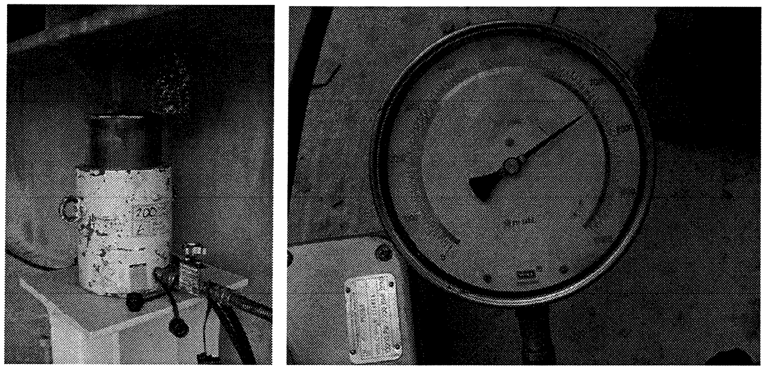
CAPTION: Pouring the span deck

Overweight gremlins may not be a problem in general, but this one chose to reside on the movable span and therefore had to be taken seriously. His presence was first suspected when it was noticed that the total amount of concrete probably poured on the span exceeded the design amount by 22%. This figure was based on the total amount of concrete delivered to the site minus the concrete needed to prime the pump trucks, the concrete left in the trucks, and spillage. The contractor was then asked to take cores samples from the span to estimate the span thickness. This also indicated that the span was overweight, but not by as much as the first method. It was then put to the structural and mechanical design units to determine what was the maximum acceptable weight of the span.

This is always an interesting question to put to a designer: does it mean what room did we have in the design over the prescribed AASHTO Standard Design, or did it mean the maximum weight considering some reduction in the prescribed safety factor or with no safety factor at all. We took it to mean the first and in doing the computations came upon an interesting problem. (The structural folks on the other hand had found no real structural problem.)

Our job in mechanical was in effect to determine the part that was designed closest to its allowable and this turned out to be the trunnion. When you design a trunnion according to the AASHTO specifications, AASHTO assumes that you will have no stress raiser on the trunnion greater than 1.4. This allows for keyways, shoulders, dowels, and any other normal design element of the trunnion as long as the designer is careful to minimize the stress raising capabilities of these elements. For this particular bridge, the AASHTO required trunnion bearing had a bore size similar to the required trunnion diameter. Therefore, we basically designed a straight shaft from the bearings through the sheave hub with no shoulder at the face of the sheave hub. This interface between the trunnion and the sheave hub creates a stress raiser that we assumed would be below 1.4 since we had taken steps to minimize it.

During this time when we had been asked by the construction section to determine the maximum span weight our machinery could allow, we noticed in a consultant's calculations submitted for another project that the stress raiser created by a trunnion press fit in a hub could be as high as 4. After more research into the subject, we learned that apparently very little analysis of this type of stress raiser has been performed because it is expected that a shoulder will be placed at the interface between the trunnion and the hub. Stress raisers due to a shoulder have been thoroughly analyzed and can be determined to a high degree of accuracy. *Mechanical Engineering Design*, fifth edition, by Joseph Edward Shigley and Charles R. Mischke, page 63, states that the stress raiser due to a shaft press fit in a hub is seldom greater than 2. However, we were concerned that this was referring to small shafts. *Peterson's Stress Concentration Factors*, second edition, by Walter D. Pilkey, page 387 states that a press fitted ring on a shaft produces stress concentration factors between 2 and 4. Peterson was the guy we were worried about.



CAPTION: Weighing the span using 200 ton hydraulic jacks

We wanted a more accurate span weight, so we made the contractor jack up the counterweights and weigh the span using hydraulic jacks. The design weight of the span was 1,150,000 lbs. or 287,000 lbs per corner. One corner of the span weighted in at 314,000 lbs. Add 3% error in the pressure gauges and the corner potentially weighed 323,000 lbs or 12-13% overweight. After more careful analysis, we determined that if the stress raiser at the sheave hub interface was less than 2, we were O.K. But Pilkey said it was between 2 and 4.

We referred our problem to the Chairman of the Mechanical Engineering Department at LSU who recommended a value of 2 or less based upon the following reasons :

- The sheave has a single spoke support allowing some flexibility at the hub ends.
- The trunnion has a hole drilled through the middle allowing some flexibility in the trunnion.
- The inside of each end of the sheave hub has a ¼" radius.

All this taken into account plus some additional supporting information gleaned from here and there and we had our justification for assuming a value of 2 or lower. This was enough to approve the trunnion design for the additional weight.

The professor in reporting his conclusions brought up an interesting point in regards to the sheave hub/trunnion connection. He pointed out, and rightfully so, that the effect of the stress concentration factor could be reduced by half simply by lowering the interference fit from an FN3 to an FN1. Since the hub trunnion connection carries no torque, he did not see why this could not be done.

Evaluation of Case II:

The Overweight Span: The gremlins were let loose on the span through a combination of ignorance and poor prioritizing. This contractor was unaware, as any contractor who deals for the most part in fixed structures might be, of the need for a greater accuracy in erecting structures for movable operations. He did not make the connection between the design of the mechanical system and the span weight.

On the other hand it seems the contractor paid very close attention to matching the existing contours of the approaches with the span pour thus adding concrete with no thought to the weight until he was happy with the configuration.

From our point of view, the overweight span Gremlin awoke in our own structural designers an understanding of the importance of erecting the span to the specified design weight.

The Unknown Stress Raiser: The lack of a thorough knowledge of an important design factor almost got us into deep trouble. Again the "Hider of Important Knowledge" Gremlin raised his ugly head.

The Press Fit: Questions as to the appropriateness of the AASHTO prescribed press fit and the advantages that can be gained by reducing it warrant analysis. Although the professor was correct in that there is no torque at the connection still the press fit is considered to be necessary to counter the effect of warping the hub under the span load during operation thus creating a clearance between the sheave hub and the trunnion at the point opposite the point of application of the load. However it was found that in "walking over" the old AASHTO specs to the new the effective fit for larger diameters was increased and in some cases created an over stressed condition in the hub.

Actions as a Result of the Case II Evaluation:

1.) It will be clearly stated on the plans that the span overage will be held to a strict 10% of the design weight. The span will be weighed to verify. The mechanical design will be done assuming the weight of the span is the design weight plus 10%. The highest allowable density for the concrete will be used for the calculations.

2.) The contractor will be encouraged to pour the lift span before pouring the approaches. We hesitate to make this a requirement because to so restrict the contractor may end up costing use more money than if he had over poured the span. In this case the contractor wanted to use the approaches to pour the counterweights. In some instances the contractor wants to use the approaches as lifting platforms (although this is rarely allowed) or storage areas. In any case, if he chooses to pour the approaches first, it will be clearly stated that the span will be poured to the correct weight and any adjustments to grade must be made on the approaches.

[An interesting Gremlin also appeared in connection with this question. As stated above the contractor wanted to use the approaches to pour the counterweights. However, since the designers expected the approaches to be built last, the counterweights were designed to be poured in the air hanging by two points from the towers. The counterweight beam was designed with a camber appropriate to that expectation. With the counterweight supported by the approach slab the camber did not come out fully leaving the beam curved and the attached counterweight guides skewed.

As far as evaluation of this gremlin, it only served to reinforce our opinion that it is bad policy to do design during construction and the instances of this should be kept to a minimum. There is a certain amount of information that is carried from one step of a design to the next, such that, when a part of the design is singled out for change in midstream so to speak, that information is lost to consideration. (This by the way was the main contributing cause to the Hyatt disaster according to Mr. Petroski.)

We will in the future require the contractor to erect the counterweight in accordance with the design assumptions and these assumptions will be stated on the plans.]

3.) The stress raiser at the sheave hub and trunnion interface will be avoided by having a shoulder on the trunnion at the interface.

This event also served notice to us that not all information necessary to design a bridge is contained within the AASHTO Specifications and surely not within our own knowledge. Continued reference to sources outside the AASHTO Specifications is always appropriate.

4.) We will further investigate the relationship between trunnion/sheave hub fits and the developed internal stresses with the ultimate object of justifying the use of lesser interference fits than those found in the current AASHTO specifications. In the interim we will limit our fits to a class FN3 as per the old specs.

Case III: The Gremlin Who Could Not Stand Straight

CAPTION: Honeycombing that required this tower to be torn down and rebuilt

It is assumed in working with steel bridges that they will be erected very close to square and that the locations of the sheave/trunnion assemblies can be defined on the plans in relation to the structure. Not so when a gremlin takes on the erection of a concrete tower. The towers proved to be a problem from the beginning. First, in the pour itself, where honeycombing existed to such an extent that one tower had to be completely redone, and then, in the final erection, where the results were large deviations in every direction from the theoretical square and plum positions. Adding to this condition was the movement of the piers as described in CASE I The result of these combined gremlins was that a portion of the span had to be cut-off in order to fit between the piers, and the locations of the sheave assemblies, the span guide assemblies on the span and counterweights, and the span guides on the towers had to be relocated and/or modified from the theoretical design locations and/or details.

CAPTION: Guide rail before shimming - shows how tower bends in at the top

The towers were surveyed and a new layout developed to effectively create a square and plum operation superimposed upon an asymmetrical foundation. The longitudinal centerline of the span had to be maintained and the sheave assemblies aligned square to each other and consistent with the span attachments while providing proper clearances for the span operation and avoiding imposing an intolerable eccentric load upon the towers. The tower span guides had to be located under the new positions of the sheave assemblies and shimmed to be vertically plum. Since the span was no longer a set length the tower guide arrangement could be fixed as required and then the span cut to the required length to properly fit the newly created spacing between guides. The only victim to these measures was one counterweight guide roller assembly that ended up too close to its guide and had to be "field engineered" to eliminate the interference.

Evaluation of Case III:

The towers were erected with significant deviations from the design alignment due primarily to ignorance of the need for accurate construction when dealing with movable bridges.

Actions as a Result of the Case III Evaluation:

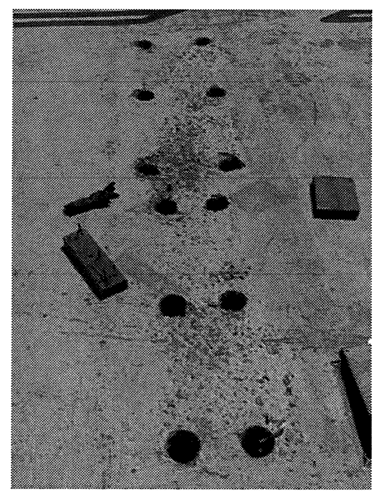
The erection of the towers has an effect on many machinery parts' installations. Another contractor may have the skill and determination to erect the towers to the accuracy required, but the ramifications if he cannot are so wide spread that we believe the safest course is to assume that it cannot be done. To prepare for this we must make the alignment of the machinery independent of the accuracy of the tower erection. In fact this would result in an installation procedure very much like the one done on this project out of necessity. The primary change will be that the machinery locations will no longer be dimensioned from the structure but relative to each other and certain absolute geographic points such as elevation above sea level and centerline of roadway. Acceptable alignment tolerances will be included to provide assistance to the field engineers and erectors.

Case IV: The Gremlin Who Returned and Brought an Uncertain Friend

It will be recalled that the a Gremlin had skewed the towers causing them to lean away from vertical, more directly to the situation now being addressed; it also caused a discrepancy in heights between the towers and thus the sheave pedestals.

We had designed the layout for the machinery on the machinery deck just as if it were to be put down on steel with the exception that instead of high strength bolts we had substituted cast-in-place anchor bolts. The sheave pedestals had been designed to lie flat against the concrete deck separated from it by a lead shim. To adjust the pedestals to equal elevations it would be necessary to add shims and plates to make up the discrepancies. There were other gremlins however that made this approach unattractive.

The contractor did not think he could provide the surface under the pedestals required for a proper foundation; that is, a surface consistently level over the entire area of pedestal installation. The contractor did not think he could maintain an accurate cast-in-place anchor bolt relationship either to the local arrangement or to the overall bridge arrangement while making the pour for the deck (bear in mind that the pour would be made almost 100 feet above the ground.) The structural design called for a camber in the machinery deck that carried through the pedestal locations so that even if the deck could have been poured perfectly to the design, the pedestals would have been installed on a slope and the shimming made very tricky. (Later we will show how this camber also caused problems with the layout of the span drive machinery.)



CAPTION: Blockouts for sheave pedestals

To address the last mentioned problem first, we approached the structural folks with a request to change the design to terminate the camber before it got into the pedestal mounting area. This they readily did. The other two problems were in many ways tied together in that the problem of obtaining a consistent and level surface was compounded by having to work around the cast-in-place bolts. We were eventually and reluctantly convinced that the dependability of cast-in-place bolt connections had to give way to a more feasible installation.

The pedestals were placed on risers of non-shrink epoxy grout. The heights of the risers were determined by setting a minimum height for the pedestals located on the highest tower (around three inches) and adjusting the pedestals on the other towers to equal that elevation. The maximum required came to be about five inches. Grout was selected as it would take out the irregularities in the concrete surface and give a level foundation for the pedestals. The pedestals' elevations were set and the bases leveled using stacked washers. The grout was poured under the pedestals and around the washers. The washers stayed in place. The anchor bolts were located using cast in place sleeves of 4" diameter and set with an epoxy grout system from our qualified products list.

Evaluation of Case IV:

Leveling the pedestals: The mischief brought on by the gremlin that laid out the towers has already been addressed. It is plain however that even if the towers had been erected perfectly our plans would still have been of little use in installing the pedestals. We failed to appreciate or understand the uncertainties involved in concrete construction. On the other hand, in carrying the camber through the pedestal mounting area the structural folks showed a lack of understating of the mechanical requirements. Clearly this case indicates a need for better communications between our structural and mechanical units if nothing else.

It is not yet possible to evaluate the effectiveness of the leveling method adopted for this bridge. Very much depends on the performance of the grout under load, the ability to obtain full or nearly complete bearing of the pedestal bases on the grout pad and of course both of these characteristics depend in turn on the skill and care taken in the application of the epoxy material. As far as we could ascertain there is only one epoxy grout that is guaranteed non-shrink and that is the one applied here. If that claim turns out to be untrue or the application was faulty then our sheave pedestals will be supported by piles of washers.

Anchoring the sheave pedestals: The reliance on cast-in-place anchoring was misplaced and its incorporation into the plans was again a gremlin let loose due to a lack of understanding of the construction difficulties involved. We were in fact convinced that not only this contractor but any average contractor would be able to guarantee acceptable results using cast-in-place anchors under these conditions.

The alternate anchoring solution provided the contractor with the confidence necessary to perform the work. However a final evaluation cannot be reached without the passage of time. As in the case of the risers the concrete grouted system can be said to depend mostly on the skill of the applicators and the ability of the product to hold up under repeated loadings.

Actions Taken as a Result of the Case IV Evaluation:

1.) There will be a formal pre-design meeting between the mechanical and structural units on each movable bridge project so that each will come to an understanding of the requirements, capabilities and limitations of the other.

2.) The pedestals will be designed with an epoxy grout riser of the thickness required to bring the trunnion centerlines to a specified elevation. This elevation will take into account the minimum thickness recommended by the grout manufacturer. A method of leveling the pedestal bases will be developed using leveling nuts that can be backed off after the grout pour to insure full bearing.

3.) The anchor bolt system agreed to here on the fly will be adopted into the design plans. The pedestal anchors will be blocked out using four-inch pipe sleeves and set using a Class A concrete grout system from the qualified products list (QPL).

Case V: The Gremlin Who Was Raring to Go

There is a final alignment opportunity when the trunnion bearings are placed upon the bearing supports. At this time misalignment that has occurred during the pedestal mounting may be rectified in the bearing mounting. In our case however the gremlin went to work before the final survey could be conducted and one bearing was installed assuming the pedestal was true. Of course it was not.

Using the installed bearing as the fixed point the other bearings of the machinery layout had to be aligned to it as best we could within the deflections allowed by the bearing manufacturer. We were aided in this by a change in the reducer installation from cast-in-place anchors to drilled-in-place. The positions of the reducers were therefore yet to be set and we were thus allowed to locate them in the most advantageous positions for a square or nearly square alignment. In fact without this lucky decision we would not have able to obtain an alignment within the allowable tolerances.

Evaluation of Case V:

In this case, the gremlin was released because of a lack of understanding on the part of the contractor that each of the sheave assemblies must be aligned to each other and the theoretical position of the span without regard to the bearing pedestal position such that they create one integrated lifting system.

Actions as a Result of the Case V Evaluation:

It is hard in this case to determine if this gremlin would have been turned loose under most instances or whether he is most unlikely to be let out again on another project. To be on the safe side our plans will include a requirement to survey the bearing bases relative to the total layout before the installation of the bearings is begun.

Case VI: The Gremlin Who Straightened Out

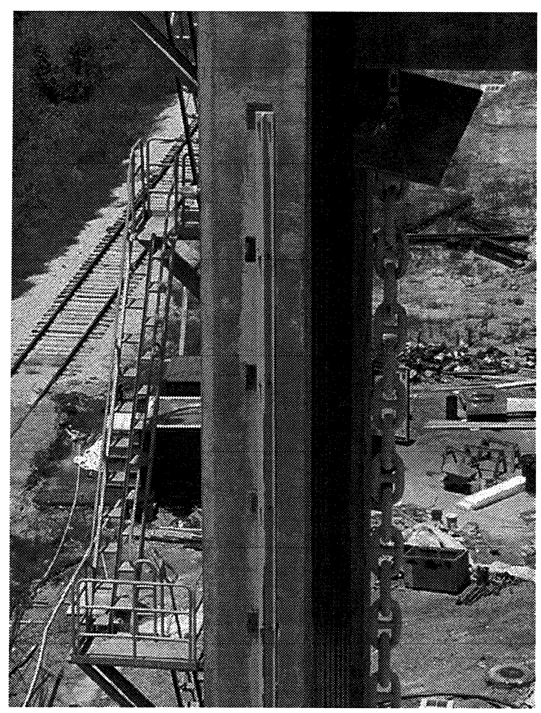
The plan for the drive machinery layout called for the main drive shaft centerline to be installed at a certain distance above and parallel to the deck. The supports for the intermediate bearings, the reducer mounting and the sheave drive pinion mount were designed to maintain the centerlines of the equipment mounted on them at the designated height.

Three factors were involved in making our layout details of little use, two of which have already been discussed. The pedestals mountings, on which were located the sheave drive pinion mountings, were raised due to the insertion of the risers. Thus all the machinery had to be raised to meet the new drive pinion height predicated by the pedestal risers. The premature installation of one trunnion bearing required the realignment of the reducers. The third factor was the gremlin who was bound to relax. The camber the structural folks put (snuck) into the machinery deck.

The theoretical camber amounted to about two inches difference between the center of the machinery deck and the top of the towers and was intended to relax over time to the horizontal position. The machinery was therefore mounted so that the shafting ran parallel to the theoretical camber slope so that the alignment would improve with time. The allowable angular displacement of the couplings limits the degree of slope to which the transmission shafting can be installed. In our case following the slope of the theoretical camber did not exceed this allowable angle.

[This allowable angle also had to be satisfied when positioning the reducer. The actual total misalignment in the couplings was a combination of the vertical displacement due to the camber and the horizontal displacement due to the location of the reducer.]

Cast-in-place anchors were designed for the drive machinery installation, but, just as for the pedestals, they were discarded in favor of a less restrictive method. And as pointed out in Case IV, this decision turned out to be very lucky because it allowed us enough freedom to place the reducers. The method employed here was to use a drilled-in-place epoxy system from the QPL. Since this method was bound to result in some of the steel reinforcement being cut, the contractor was required to place additional reinforcing steel in those areas where anchor bolts would be installed.



CAPTION: Span guide rail that missed embedded plates

The height of the machinery was established using the method adopted for the pedestals. The intermediate bearings, the reducer, motors breaks, limit switch, and clutch operator were all shimmed to the required height and the grout poured around the washer shims which stayed in place.

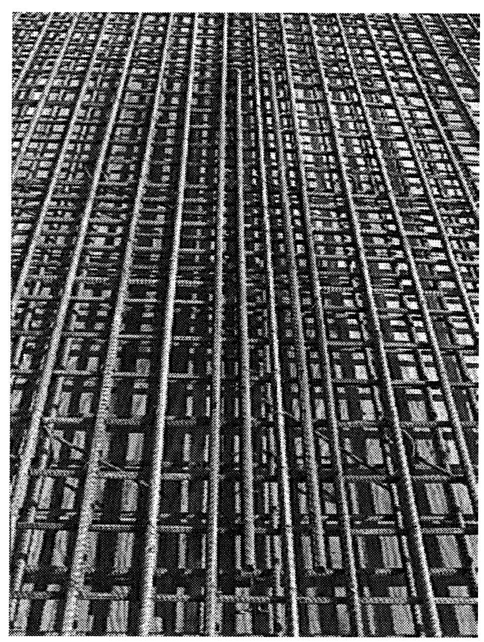
The tower guides were also designed to be installed with cast-in-place anchors. The contractor however had the foresight to change this method before he made the tower pours. He instead opted to embed steel plates at regular intervals on which he welded studs using the rails as templates. The stud lengths were adjusted as required for the amount of shimming. This method proved successful except for one guide where the embedded plates were not wide enough to compensate for the lean of the tower and errors in the placement of the plates. For these attachments, the concrete next to the plate was chipped away and another plate was butt-welded to the existing plate. Then the weld was ground smooth.

Evaluation of Case VI:

Machinery Deck Camber: If there had been no other Gremlins, and the machinery decks had been poured accurately to the design camber, then this Gremlin alone would not have caused any serious conflicts between the actual installation and the layout as represented on the plans; that is, installing the transmission shafting parallel to the machinery deck, would have resulted in a workable alignment. But this gremlin does not exist apart from his buddies, the machinery deck was not poured accurately to the camber or even accurately to the horizontal and there is no guarantee that in the future the theoretical camber slope will fall within the allowable deviation of the couplings.

The use of grout pads for installing the machinery provided both the correct elevation and a smooth, level surface. Even if the machinery deck were poured accurately to the required camber, there could be the need, because the camber slope exceeded the allowable coupling deviation, to align the transmission shafting on a slope neither parallel to horizontal nor to the camber slope. In that case the use of grout pads would be essential. According to our experience on this project, however, it seems unlikely that we can get an accurately poured machinery deck. By using grouted risers we are given the flexibility to allow the height and levelness of the supports to be established in the field independent of the results obtained during the tower and machinery deck erections.

Drilled-in-Place Anchors: As stated above, the use of drilled-in-place anchors for the machinery deck installation saved us from being forced into an undesirable alignment. There is, however, no getting around the fact that reinforcing steel will be cut during this process. The solution employed here was to install extra "sacrificial steel". However, our structural unit did not allow this method on a subsequent bridge.



CAPTION: Extra steel in machinery deck

There is no clear-cut answer to the question of what type of anchoring system to use. Cast-in-place systems require a higher degree of accuracy than this contractor could confidently provide. Will this be the attitude taken by subsequent contractors, and is it a legitimate one? On the only other bridge of this type with which we have experience, the answer was yes. The contractor used block outs for all the anchor bolts on the machinery deck. Curiously, he had the confidence to cast-in-place the guide rail anchor bolts. (But it was misplaced, as he missed on one tower.)

A blocked out system requires less accuracy in the erection of the structure. On this bridge however the additional latitude would not have been enough to compensate for all the gremlins encountered. Given that a blocked out system may yield the degree of flexibility required for an erection of average accuracy, non-the-less it still has a drawback. To understand the problem one must grasp the vision of the quantity of reinforcing steel required for this type of construction. When one sees it, it gives the impression that we are not building a concrete bridge but a steel bridge with a concrete veneer. Wherever the sleeves will be located the reinforcing pattern will be disrupted and the contractor is furnished no guide as to how to compensate for it.

The drilled-in-place method has the distinct advantage (to the structural erector) that it postpones all alignment concerns to later in the project and shifts the responsibility from the structural erector to the machinery installer. It also puts the disruption of the reinforcing system out-of-site (and maybe out-of-mind). It nonetheless occurs and at a time when it is much more difficult to compensate correctly.

Cast-in-Place Plates: The other option is demonstrated by the installation of the span guides on the towers. This was the only instance where we retained the confidence of a steel connection although I don't think we obtained a very good weld on the studs. The connection could be improved by utilizing tapped holes and cap screws. The idea of installing plates on which to field install the machinery of course could be extended to some of the smaller equipment of the machinery deck. I do not think it would work well for the reducer or the sheave pedestals. Nor would it be consistent with our concept of having the motor, break, clutch actuator, and limit switch be shop installed on bases. The bases would still have to be accurately located on the concrete deck. However, it could be useful on the intermediate bearings to have the bases installed using a cast-in-place system and provide an attachment area to the base large enough for a proper drilled-in-place-bolted connection.

All of these alternate systems of attachment depend upon methods on which we have very little long time data and whose performance depends a great deal on the skill and care of the installer. Although they may serve to get us through design and construction (and I really don't know if we have any other choice) time will only tell whether they are capable of maintaining alignment throughout the life of the bridge.

We have come to realize that the confidence obtained in anchoring to steel plate is one of the things that will be sacrificed by the nature of installing on a concrete structure.

Actions Taken as a Result of the Case VI Evaluation:

1.) The transmission shafting will be installed on a slope to compensate for the expected creep of the camber over time. The slope will be checked against the allowable displacement of the couplings.

2.) The anchoring of the machinery will be by the most appropriate system described above for the part in question. Whatever system is selected it will be in full cooperation with the structural unit who will provide supporting details as required to fully define the proper erection procedures.

3.) The guide rails will be installed using embedded plates and a taped-in-place /cap screw connection using the rails as templates.

Case VII: The Gremlin Who Wouldn't Back Up

The LADOTD has an in-house design for the traffic barriers that consist of a counterweighted beam operated vertically between two columns. The beam goes across all lanes of traffic. The prime mover is a gearmotor controlled (turned off) by a limit switch. The object of this study is a five lane bridge requiring an 80 ft. long, 10,000 lb. movable barrier, by far the longest and heaviest barrier we have had to design to date. The beam is designed to follow the roadway contour that has, because of the odd number of lanes, an offset crown.

After being put into service but during the testing phase of construction, the gearmotors failed, and they failed by breaking the worm gear. Our first reaction was to assume a construction error of some kind because "the design was the same as the dozen previous and we had never had any problems with it". When the gearmotors were replaced in kind and failed again we finally woke up to the possibility that it may be a design problem. When finally moved to analyze the problem we quickly determined that the gearbox was being overstressed due to a back drive being imparted when the barrier operation was stopped. The momentum of the barrier was continuing to carry it forward thus overdriving the gearbox and breaking the worm gear.

To correct the situation the obvious solution would be to replace the gearbox with one sturdy enough to withstand the torque generated in the overdrive condition. But this gremlin did not appear until late in the project. The time required to deliver the new gearmotor, and the time to modify the existing configuration to accept the new gearmotor, was too great for a public anxious to get the bridge into operation in time for the sugar cane harvest.

So for the interim a frequency speed controller was put on the motors set so as to bring the motors to zero speed and to shut them down at the fully seated position. The rate of deceleration was set so that no back drive was imparted to the gearmotor. This turned out to be a successful interim measure, so good in fact that our field personnel questioned the need to ever change to a larger gearmotor.

Evaluation of Case VII:

The perpetuation of a design or detail from project to project without it ever being re-evaluated is a more common gremlin than we would like to acknowledge, and the confidence placed in existing designs because of their past histories is in many cases misplaced. A design that is acceptable under one set of circumstances can easily become a bad design under some other. This gearmotor design had never been a good one. In fact while investigating these failures we found instances of others that had never been brought to our attention, or had been so understated as to cause no doubts to arise in the soundness of the design.

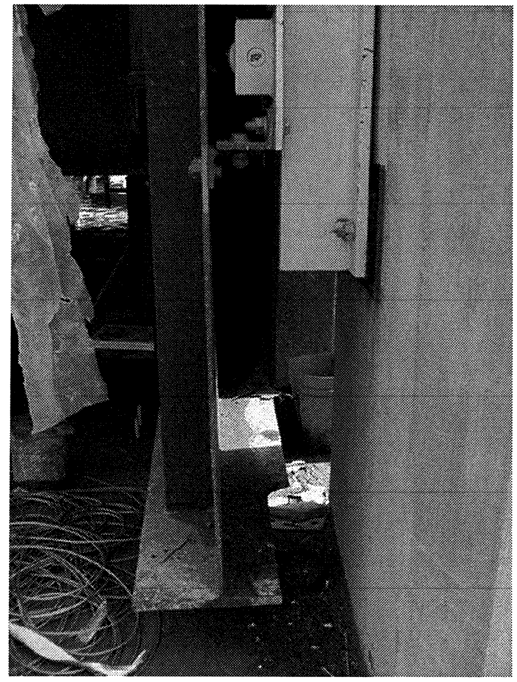
Action as a Result of the Case VII Evaluation:

We will initiate a policy meeting with the bridge maintenance engineers in each district with the intent of establishing a vehicle whereby we can obtain feedback on machinery failures.

Although the field engineers are very pleased with our temporary solution; and it is in a way elegant, in that we get by with a lesser and less expensive gearmotor and with a relatively easy and inexpensive field repair, it is still very uncomfortable knowing that the barrier gearmotor will break if anything goes wrong with the frequency drive. If this does occur then time lost and cost for repairs will be substantial. We therefore made arrangements for a future bridge closure at which time we will, with some modifications, install a sturdier gearmotor. These modifications include a double reduction worm for easier back drive, a time delay on the brake to allow the barrier to come to a full stop before the brake is applied, and a relocation of the limit switch somewhere above fully seated to allow the barrier to back drive the gear motor to a smooth stop. These are in addition to the substantial changes in the gear train layout required to accommodate the new unit.

Case VIII: The Gremlin Who Leaned

The lifting girders on this bridge are at either end of the lift span perpendicular to the centerline of roadway. They were designed to be attached tangent to the camber of the span girders. The intent was that as the concrete deck was poured, the camber of the span girders would be taken out and the end lift girders would rotate vertical. The steel fabricator, however, attached them to the span girders vertically such that when the concrete deck was poured, the end lift girders rotated out of vertical. The result was that the bottom flanges were deflected outwards toward the main piers for a distance of about 2 inches effectively reducing by more than half the clearance between the girder and the pier. This action had two practical considerations that would determine if the span could remain as deformed; that is after extensive evaluation to determine if there was any real structural problem. Eventually it was determined that the span was still structurally sound, but the lean of the end lift beams had reduced the gap between the lift girder and the approach span to near zero.



CAPTION: Span lift girder with bottom flange kicked out toward approach span

Since the span guide rollers were attached to the lifting girder, their clearances were also affected. One guide roller could not be adjusted far enough away to avoid pressing against its guide rail. In this instance they were in effect holding the bridge another ½ inch or so farther away from the pier than would be the case if the roller could be made to come into its proper relationship to the guide rail (and it would eventually have to or it would be worn out).

The span, already so close as to cause some cutting away of the flanges to facilitate its movement, the fear existed of some future movement of the piers inward toward the channel (they had already indicted a propensity for such a movement).

It was decided something had to be done because of the clearances (or lack of the same). Instead of moving the span away from the approaches by rotating the end girders (which is what we had wanted them to do), it was decided to bring the mountain away from Mohammed; i.e., move the approach support wall away from the span. Of course that didn't help our roller situation much but they promised they would. Jacking the approach slab and removing and reconstructing the end wall on the rest pier will accomplish the structural modifications.

The span locks attach to the bridge on the channel side of the lifting girder and were required to be moved closer to the girder in order to make good connections with their pins. The buffers are also attached to the sloping girder and had to be adjusted with shims to come to a vertical alignment.

Evaluation of Case VIII:

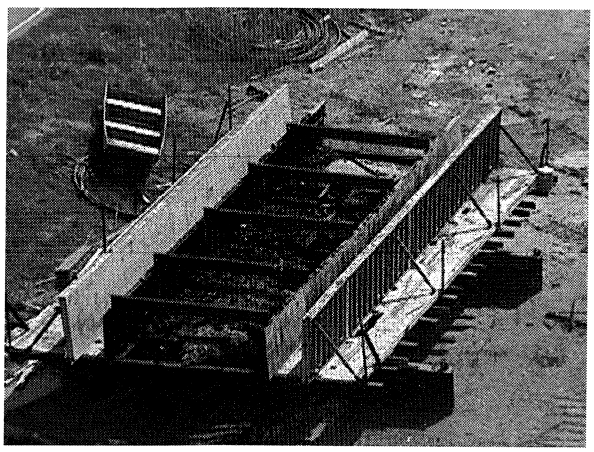
The fabricator interpreted the contract plans in a way that led to him to develop shop drawings showing the lift girders attached vertically to the span girders. Our checker approved them. Both the erector and our field personnel failed to catch the error.

Actions Taken as a Result of the Case VIII Evaluation:

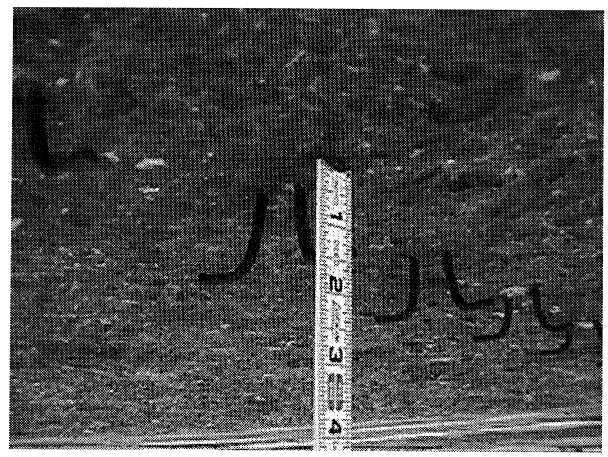
There is really very little to learn from this gremlin. It is a matter of how much skill and knowledge the contractor should bring to the job. The court gremlins will most likely decide.

Case IX: The Gremlin Who Lit a Fire Under Us

The machinery deck forms were fabricated using a combination of wood and steel. To expedite the removal of the forms, a cutting torch was being used to cut the steel members. The workers broke for lunch. They returned to find the forms on fire. The fire was not bad and they quickly had it extinguished. Quitting time came and the workers left for the day. Sometime in the middle of the night, the contractor was notified by the fire department that the bridge was on fire. The forms had re-ignited and this time the fire was more intense. The local fire department did not have a ladder truck that could reach the height of the machinery deck so the contractor raised two firemen with a hose in the man basket attached to their construction crane. These two firemen just about had the fire out when the fire chief arrived and ordered them down from the man basket sighting safety concerns. The contractor had to watch the bridge burn for two more hours while they waited for a hook and ladder truck from a neighboring community to arrive that was tall enough to reach the machinery deck.



CAPTION: Section of the burned forms



CAPTION: Steel exposed when the concrete spalled off from heat of fire

In the morning, it was discovered that 2 - 3 inches of the concrete on the underside of the machinery deck had spalled off from the heat. The contractor brought in an expert on fire damage to concrete structures. We brought in an expert on fire damage to concrete structures. After much investigative work it was determined that there was "no real structural problem". The spalling was patched and we continued the march.

Evaluation of Case IX:

Haste makes waste.

Actions Taken as a Result of Case IX Evaluation:

We added a note to the plans to the effect that burning was no longer an acceptable method of form removal. Just kidding.

Summary and Conclusions

For those of you who have spent some time in the services you will recognize the procedure just described as similar to what was called an after action report. For those of you who have not served this is the time in the movies where the captain says to the tired and frazzled lieutenant just off a hazardous mission, "go get some sleep, I'll get your report in the morning". Well this is his after action report and in the morning he will be debriefed and then critiqued on his efforts with the goal that the next mission he goes on will be better performed than the last.

In our situation the report is not delayed just until the morning but of necessity it is delayed for months in some cases even years. In the meantime we have gone on many other missions and have fought many other gremlins. It therefore takes an effort of will to follow up on our designs to see their particular effects. This means visiting the work site and talking with our field personnel and those responsible for the erection; making periodic phone calls that keep us in touch the project's progress; and performing an after acceptance "debriefing session" with our field people to pull together all things learned on the project that can be helpful on those designs to come. The resulting report should be formalized and placed in the project folder so that the knowledge gained does not just fritter away.

The things learned on this project can be divided into those specific to a concrete vertical lift bridge and those of value to any project.

The following things we have learned about concrete vertical lifts:

1.) That the mechanical design allows little leeway in the weight of the span and that the tendencies to have this gremlin let loose in the field, such as matching the approach grades and contours, and the lack of information regarding the tolerances allowable for the span construction, should be addressed on the contract drawings.

2.) That the structure cannot be relied upon to be erected to the accuracies required to base the machinery layout. The method of layout and attachment should therefore be selected so that it is not dependant on structural accuracy. Use of grouted risers, embedded plates, and blocked out or drilled in place bolts were adopted here. The importance is not so much the method but that the method chosen removes from play the squareness and levelness of the structure.

3.) That the methods selected should be thoroughly supported by structural details and to this end a commitment to cooperation should be established at the earliest possible time between the mechanical and structural designers.

4.) That the machinery deck will be designed structurally with a camber that must be considered when designing the machinery layout.

The following we have learned as regards to technical issues:

1.) That there exist a stress raiser at the interface between the trunnion and sheave hub and because of this knowledge the designs of existing bridges where this stress raiser comes into play will be evaluated as to their status as regards possible fatigue failures. And that in the future the detail that causes this stress raiser to come into play will be avoided if at all possible.

2.) That the specified press fit between the trunnion and the sheave hub can cause over stressing of the hub, and if not that, certainly exacerbates any stress raisers that may be around. That a mechanical engineering professor did not see the need for it and that there may be justification for substituting a lesser requirement under some circumstances.

3.) That we have under- designed the barrier gearmotors. Wherever this design was incorporated in projects under construction or about to be, a plan change was developed to redesign the installation.

4.) That there are serious repercussions to haphazardly driving piles in poor soil conditions. That because, in our state such conditions cannot be avoided, we must learn to anticipate them.

The following we have learned as regards to in-house procedural matters:

1.) That early on cooperation between the design units especially in projects where there are new concepts being tried is essential and should be formalized.

2.) That there exist a large gap between the design section's reluctance to define erection methods or tolerances and the construction sections reluctance to direct such without support from the plans.

To summarize we think a list like this one can and should be constructed for every project we design, and that these lists will prove very valuable in improving our future designs and therefore providing better bridges for the people of Louisiana.