Repair of Duck Creek Culvert

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The October 2006 edition of STRUCTURE® magazine presented an article on the assessment of damage to a section of reinforced concrete arch culvert at the Duck Creek flood protection culvert, located near Cincinnati, Ohio. (*See article online at* **www.STRUCTUREmag.org**, *Archives*) The Duck Creek Flood Protection project was designed by the U.S. Army Corps of Engineers, Louisville District. The culvert that was damaged by an accidental overload was designed by CON/SPAN® Bridge Systems for the general contractor, Ahern & Associates.

The previous article described how the damage occurred; summarized the initial visual inspections of the damage; described the non-destructive testing program developed by and performed by CTLGroup, and summarized the condition assessment of the structural damage. This article will describe 1) the two-phased repair program; 2) the many logistical challenges faced by Ahern in order to complete the repairs; and, 3) the types and locations of the repairs.

Repair Plan

Once the results of the Field Investigations were summarized, a meeting was held between the structural engineers from the Army Corps of Engineers, CTLGroup and CON/SPAN®, and the engineering staff from Ahern and Associates. Additionally, members of the Corps' Construction Division Quality Assurance staff were present. At this meeting, an overall repair plan was formulated jointly by all parties. It was recognized that the repairs would have to be made in two major phases. A significant portion of the damaged culvert was below a newly completed temporary road that Ahern had constructed in order to divert traffic from where they were constructing a new four lane roadway. It was decided that approximately 105 linear feet of the culvert, comprising 15 CON/SPAN® precast arch units, could be repaired in the first phase (*Figure 1*), since none of these segments were located below the temporary roadway. The remaining 10 segments, located below the temporary roadway, would be repaired in Phase 2 (*Figure 2*). These repairs and improvements addressed the following:

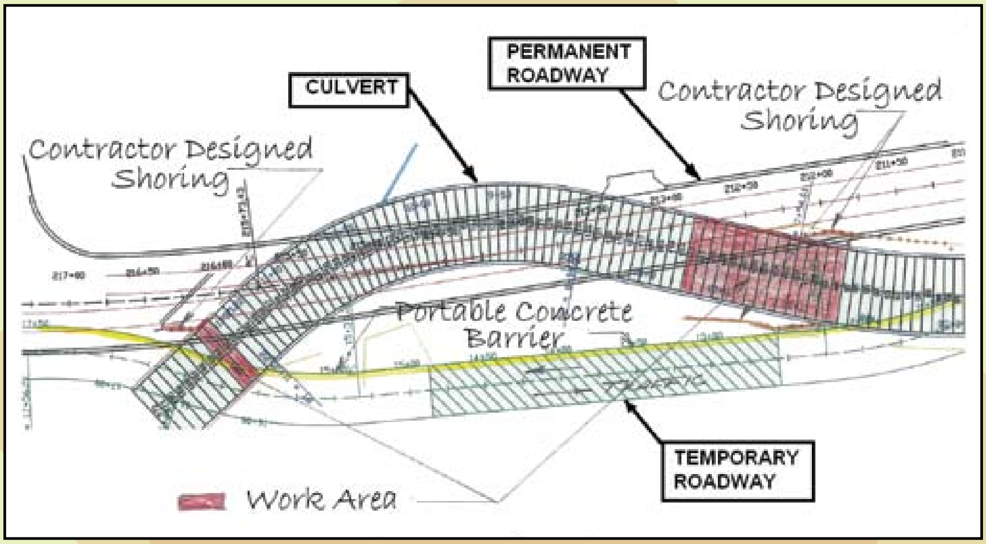


Figure 1: Phase I repair sequencing.

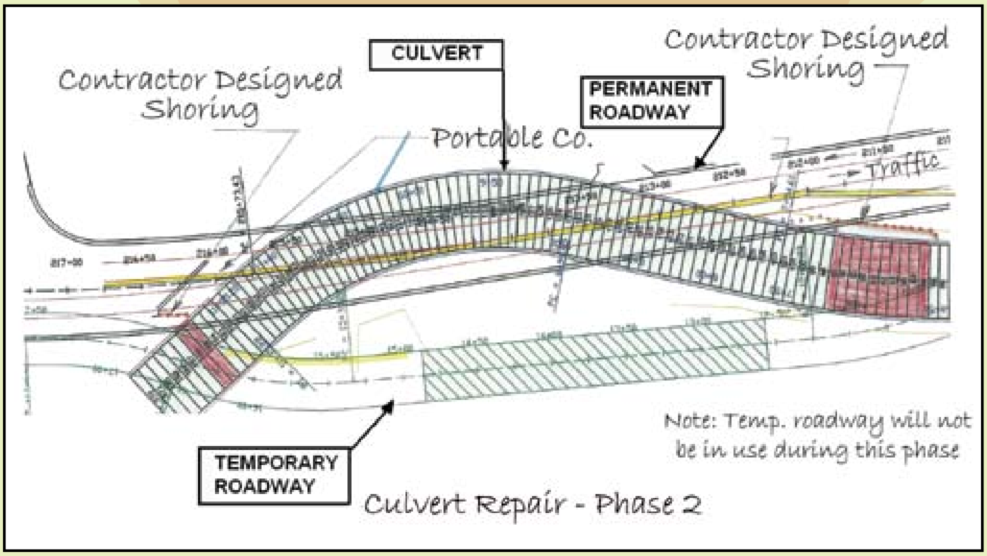


Figure 2: Phase II repair sequencing.

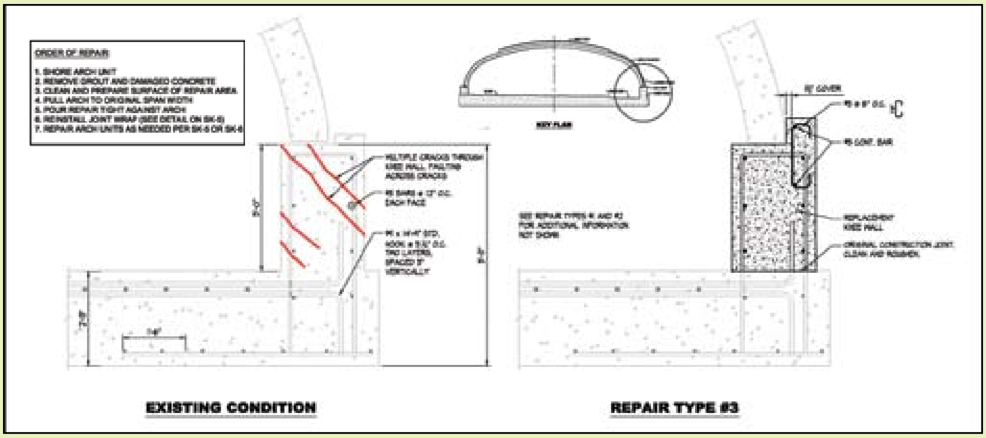


Figure 3: Full section knee wall repair, with reinforced keyway

1. Repair of shear failure in the knee wall: some knee walls were distressed as a result of excessive spreading forces generated within arch segments due to the overload (drawings for each type of repair are included in the on-line edition of this paper):
   a. Simple shear failure of the key way (*Figure a*)
   b. Key way failure with partial knee wall spall(*Figure b*)
   c. Key way failure with extended knee wall spall(*Figure c*)
   d. Partial knee wall shear failure (*Figure d, see page 32*)
   e. Complete knee wall shear failure (*Figure e, see page 32*)
2. Repair of arch unit damage: base of some arch units were distressed as a result of excessive shears and/or sliding forces generated due to overload (*drawings for the partial and full section repairs, are included in the on-line version of this article*):
   a. Partial section
   b. Full section
   c. Jacking of the arch units to restore original geometry
3. Crack injection on the interior knee wall:
   Knee walls exhibited fine-width cracking at interior surfaces in some locations, likely as a result of excessive flexure generated by spreading forces in arches. Identified cracks were injected with epoxy resin. Typical cracks requiring injection were approximately 0.01 inch or wider over a length of at least 1 foot.
4. Waterproofing of the exterior of the arch:
   Exterior surfaces in "haunch" regions of some arches exhibited hairline cracking (less than 0.01 inch wide) likely as a result of excessive flexure generated by the overload. The exterior of the arch is exposed to aggressive environmental factors including road salts. Regions exhibiting tension cracks were waterproofed using a high-build cold-applied waterproofing compound. Repair of individual cracks prior to waterproofing application was considered unnecessary because the fine width of the cracks indicated that they would not substantially increase the transport of corrosives to the reinforcing steel.

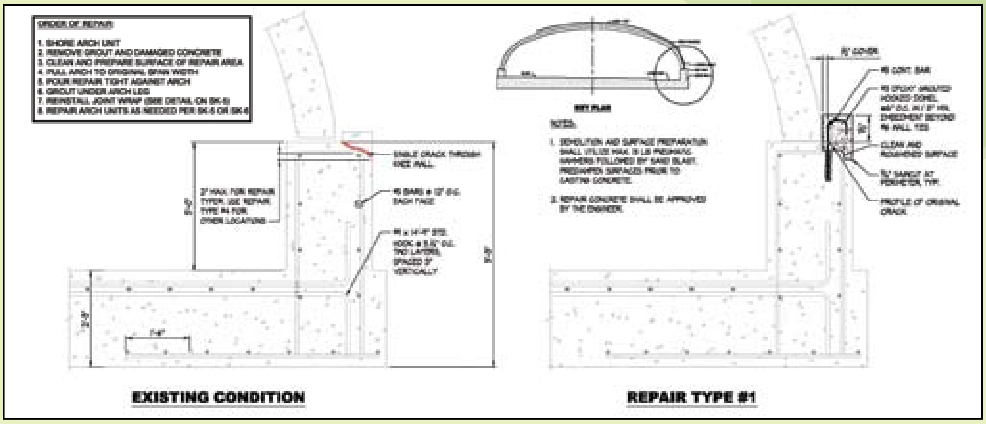


Figure a: Shear failure of the key way

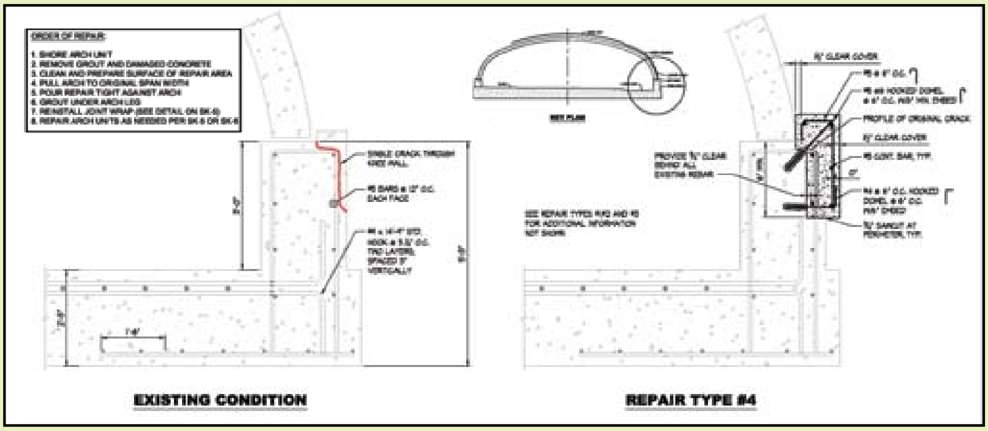


Figure b: Key way failure with partial knee wall spall

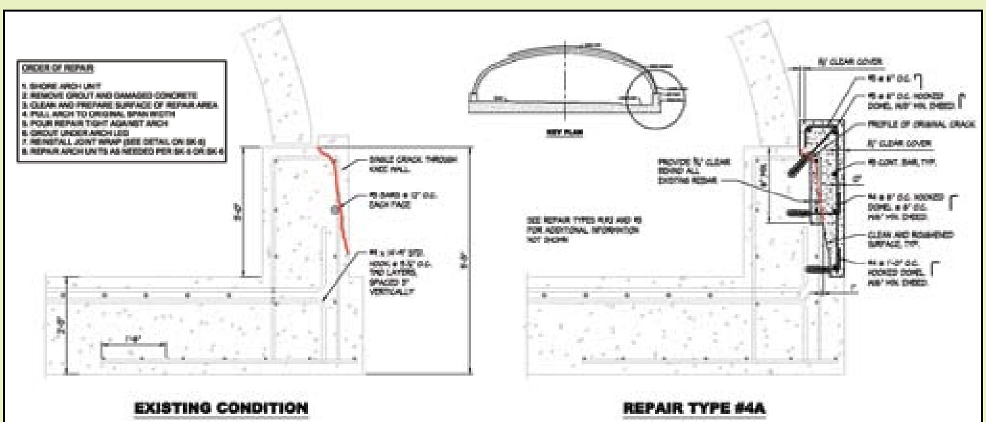


Figure c: Key way failure with extended knee wall spall

5. Sealing of the culvert base slab: Some regions of the slab within ten feet of the knee wall exhibited fine-width flexural cracking parallel to knee walls, less than approximately 0.015 inch wide, likely as a result of excessive flexure transferred by knee walls during the overload. Cracks were sealed using a low viscosity penetrating epoxy sealer.

Structural continuity was developed between the original structure and the repair region. This was accomplished by full encapsulation of the original reinforcing within these repair sections, in conjunction with the addition of new reinforcing steel. The new reinforcing steel was set in epoxy-grouted holes drilled into the non-damaged adjacent base slab and kneewall sections. Repairs to knee walls generally provided an opportunity to construct a more substantial keyway than was provided in the original design. Specifications were developed including repair construction sequencing, demolition notes, repair materials, and repair procedures.

The first step at each location was to provide temporary shoring (sheeting) required to maintain traffic on the temporary road.

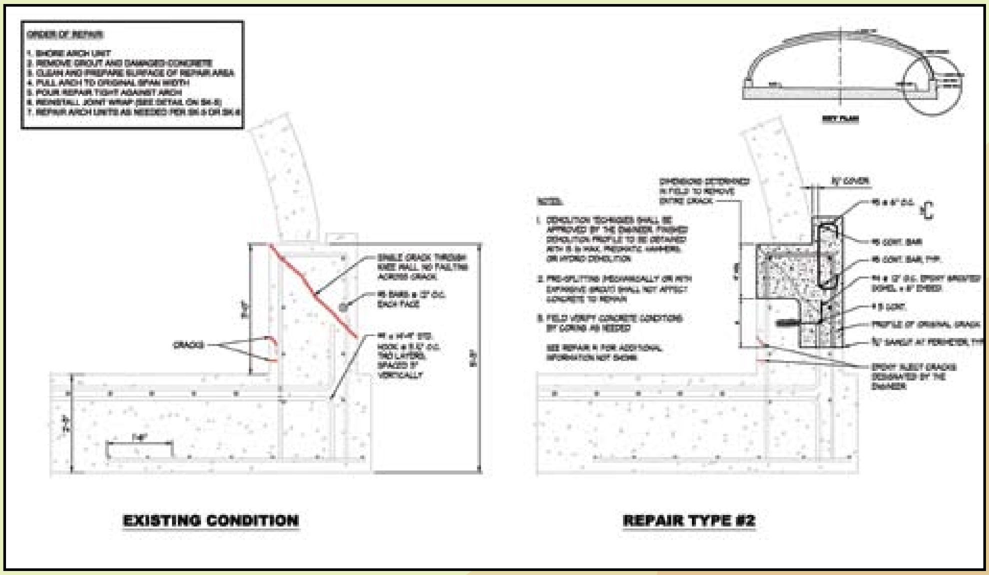


Figure d: Partial knee wall shear failure

The arch units were then shored up vertically and cable ties were installed to keep the legs from spreading when the removal of the side fill would no longer provide lateral support. Earth fill was then removed evenly on each side of the precast arch units to minimize any unbalanced loading. Concrete demolition proceeded based on the extent of damage and the required repair. Knee wall sections requiring substantial demolition necessitated the contractor to drill holes and to use hydraulic splitters to break up the damaged concrete (*Figure 4,*). Care was exercised during demolition to avoid damage to existing reinforcing. The arch unit span was then adjusted by a combination of jacking up the arch units to bring the legs in and by tensioning the cable ties to bring the arch back as close to the original span, 48 feet-10 inches, as possible. The knee wall repairs were then completed with the arch segments in place (*Figure 5, see page 33*).

Once the knee wall repairs had cured, spall repairs for the arch unit legs were made by applying shotcrete to the prepared surfaces. A close watch of the weather forecast was kept during the repairs, because any heavy rain event brought the possibility of heavy flows and large debris through the culvert. The vertical shoring elements that were in place for the arch units would be particularly vulnerable to damage from the types of debris (large trees, concrete chunks, discarded appliances etc.) previously witnessed to be transported by Duck Creek during flood events. In the event of these heavy rains, secondary shoring was planned as a fallback, though this was never actually required as Mother Nature cooperated.

The complete knee wall repair, consisting of concrete removal, reinforcing placement, formwork, and concrete placement and curing, was completed in a two to three day window depending on the number of arch unit sections repaired at one time. Sealing of cracks on the exterior of the arch surface was also performed during this phase for units 100 through 105.

Conclusions

The local sponsors, the Corps of Engineers, the general contractor (Ahern & Associates), the culvert designer (CON/SPAN®) and the forensic consultant (CTLGroup) all had a strong interest in understanding this overloading event, the damage investigation and the repair operations. More importantly, all of these parties hope that dissemination of information related to work at Duck Creek can prevent similar overloading events from occurring on other projects in the future.

There were a variety of contributing factors that led to the overloading. The congested nature of the jobsite, with temporary routings of heavy urban traffic on one side and an active freight railroad on the other, combined with the curving alignment of the large culvert, probably contributed to both the contractor's and the government inspectors' lack of attention to loading issues. The project site was also relatively tight and provided little space for temporary stockpiling of overburden. The fact that several overloading events occurred over a period of months in numerous different locations might lead one to conclude that the project's designers, contractors and inspectors likely had never considered the potential of overloading from fill stockpiles.

The specification stated "The load case reviewed for this design is HS20-44 loading with 2 feet-0 inches to 4 feet-0 inches of fill." Despite this specification statement, it is likely the people in the field for both the contractor and the Corps of Engineers did not have such design issues foremost in their minds in their dedication to complete this very complex and challenging construc-

Figure 4: Demolition of damaged knee wall

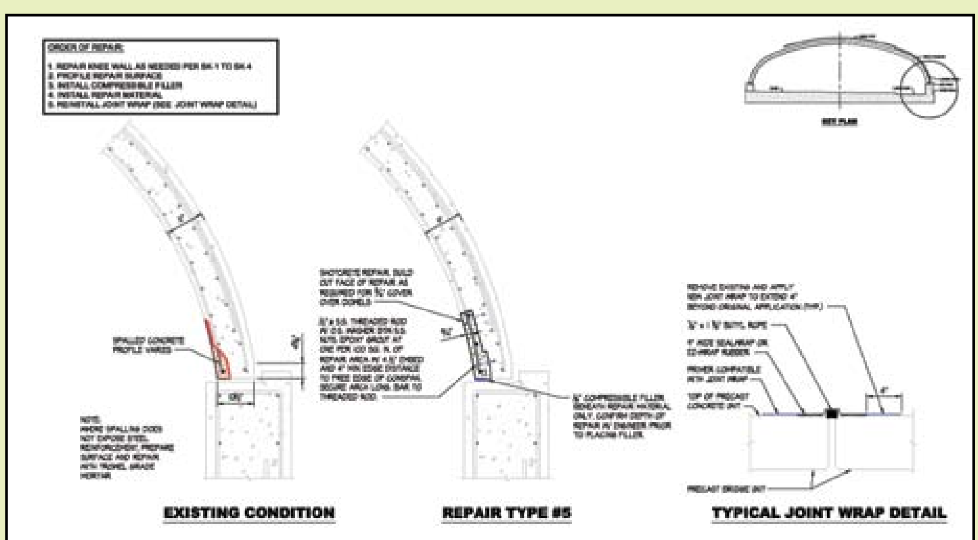
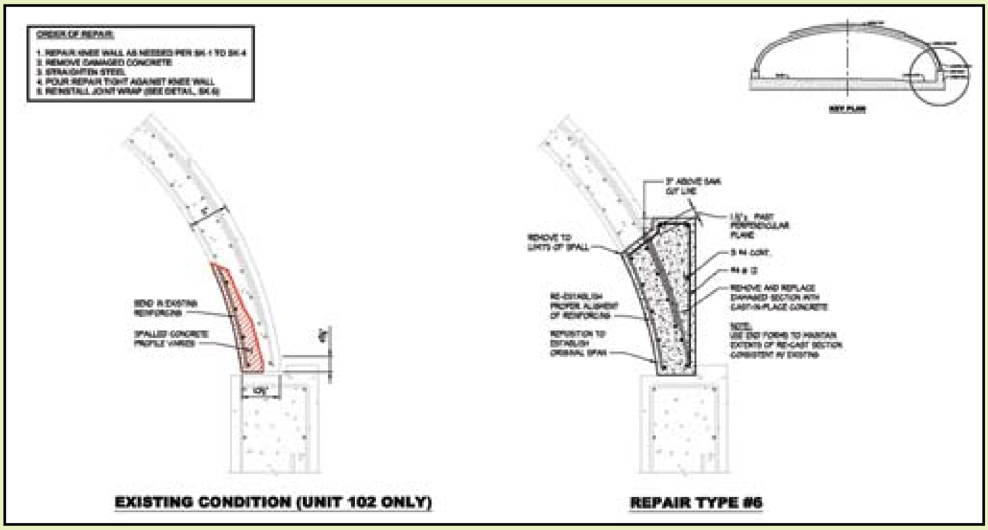


Figure e: Complete knee wall shear failure



Full arch section repair

The repairs to the culvert were completed successfully in 2005 and the entire project, including the culvert, adjacent flood walls and the roadway relocation, has now been completed. The repairs are expected to restore long-term durability and serviceability. The completed project is a tribute to the vision and hard work of the designers, consultants and constructors and a testament to the effectiveness of resolving problems in a spirit of mutual cooperation. The culvert will reduce flooding as a benefit to the Village of Fairfax and the City of Cincinnati, Ohio for many years to come.▪

tion project. Because of the repetitive nature of the construction of this long culvert, both the Corps' designers and the culvert's designers were not frequent visitors to the project site after initial construction issues were resolved. The overloads occurred long after the construction activities related to the culvert had become "routine."

In the future, discussion about potential construction overloading issues should be better highlighted on the plans and in the specifications, and should be discussed more clearly and boldly in instructions to field personnel. Designers of Record should visit the project site on a more frequent basis, even if constructability issues are not arising. For the culvert designers, the lessons are more complex. In retrospect, the Corps-designed knee walls could have been designed with more shear reinforcement to guard against a greater potential variation in loads. The keyway shown on the Corps contract documents was a detail recommended by CON/SPAN® based on many prior arch culvert installations; it too could have been designed as a more robust structural keyway with more capacity, as this culvert section was a shallow arch and the thrust loads were somewhat higher than those generated by a conventional CON/SPAN® arch installation. The precast CON/SPAN® elements survived largely intact, demonstrating the great structural load-carrying capability of a true arch. The culvert designers will in the future provide more clarity on their shop drawings regarding what constitutes an allowable construction load.

The initial field damage assessment conducted by CON/SPAN® provided a detailed overview of the types and extents of damage. This assessment serves as a reminder that a significant amount of structural information can be gleaned from conventional methods when applied carefully and thoughtfully. The concealed damage required more intensive inspection methods. The use of advanced non-destructive test methods, calibrated with coring, provided an efficient method for determining accurate identification of damage types and locations that allowed the design of tailored repairs and development of efficient repair construction staging.

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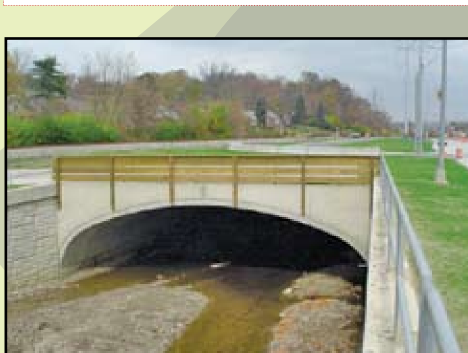
Figure 5: New knee wall reinforcing steel



The Completed culvert