Bridge Factors Factual Report Attachment 74 – FHWA Turner-Fairbank Highway Research Center Factual Report for Concrete Interface Under Members 11 and 12

Miami, FL

HWY18MH009

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TURNER-FAIRBANK HIGHWAY RESEARCH CENTER

FACTUAL REPORT

Concrete Interface Under Members 11 and 12

Prepared For:

National Transportation Safety Board

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SCOPE

This report provides a compilation of facts related to a horizontal concrete surface between the deck and Members 11 and 12 at the north end of the bridge. This surface was an interface on which a large shear demand was placed at various times in the life of the structure. A portion of this surface under Member 11 became debonded prior to the structural failure, resulting in a pair of horizontal surfaces on which relative horizontal sliding was possible. Investigation of the competence and geometry of the concrete at this location was necessary as part of an overall performance assessment of the structure.

CONCRETING FUNDAMENTALS

Concrete is mixed and placed in a semi-liquid state, later developing mechanical properties through a series of chemical reactions that transform the semi-liquid material into a solid. Concrete is commonly placed into preconstructed formwork that is designed to hold the semi-liquid concrete in a desired shape while supporting the material's self-weight. This formwork is commonly removed after the placed and hardened concrete is capable of carrying the necessary loads. The placement of concrete progresses as multiple discrete batches of material are deposited into the formwork. These discrete batches of concrete are commonly vibrated (i.e., agitated) in order to consolidate the concrete and merge concretes from successive semi-liquid batches along locations where successive batches meet.

It is often the case that a particular portion of formwork will need to be filled to the top with concrete and that this concrete will need to harden prior to the installation of subsequent formwork and the placement of subsequent concrete batches. In these cases the subsequent castings of concrete will often rest upon the earlier, hardened casting of concrete. The plane between the earlier and later concrete castings is commonly referred to as a cold joint. The American Concrete Institute defines a cold joint as "a joint or discontinuity resulting from a delay in placement of sufficient duration to preclude intermingling and bonding of the material" and defines a cold joint line as "indicating the presence of discontinuities where one layer of concrete had reached final set before subsequent concrete was placed".[a]

The mechanical properties of a structural concrete element differ locally in a cold joint region as compared to properties in nearby monolithic concrete. As previously noted, concrete from the initial placement will have hardened prior to the placement of the secondary concrete casting. As the second casting hardens, chemical and mechanical bonds will form at the interface between the two castings; this interface constitutes the cold joint. The strength of these bonds is dependent on numerous factors. Yet, even in ideal conditions, the cold joint region will have different mechanical properties than those that occur within a monolithic pour of concrete. Thus, cold joints must be recognized within the context of the demands placed on the structural concrete and detailed to ensure appropriate overall performance.

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[a] ACI CT-18. (2018). "*ACI Concrete Terminology*." American Concrete Institute. Farmington Hills, Michigan.

COLD JOINT SURFACE PREPARATION

The plane of a concrete cold joint may perform differently than an arbitrary plane of monolithic concrete within the same structural element. Thus, concrete construction commonly requires that cold joint regions receive special design considerations and receive special concrete placement techniques to enhance their performance. Of note, the Florida Department of Transportation's *Standard Specifications for Road and Bridge Construction, Division II – Construction Details* pertains to the bridge under discussion in this report and includes the following:[b]

> ***400-9 Construction Joints***
>
> ***400-9.3 Preparations of Surfaces:*** *Before depositing new concrete on or against concrete which has hardened, re-tighten the forms. Roughen the surface of the hardened concrete in a manner that will not leave loosened particles, aggregate, or damaged concrete at the surface. Thoroughly clean the surface of foreign matter and laitance, and saturate it with water.*

Additionally, the AASHTO LRFD Bridge Design Specification[c] prescribes that certain structural resistance levels will be provided by cold joints that are prepared in certain ways. This design specification also requires that a minimum amount of discrete reinforcement cross a cold joint subjected to certain types of loads. Section 5.8.4 of the specification is titled "Interface Shear Transfer—Shear Friction" and discusses the resistance provided along a concrete interface depending on the characteristics of said interface. The interfaces discussed include:

- interfaces composed of monolithic concrete,
- interfaces composed of cold joints whose substrate concrete was intentionally roughened, and
- interfaces composed of cold joints whose substrate concrete was not intentionally roughened.

Section 5.8.4 of the AASHTO LRFD Bridge Design Specification[d] describes intentionally roughened concrete as a "clean concrete surface, free of laitance, with surface intentionally roughened to an amplitude of 0.25 in." This same section states that surfaces that are not intentionally roughened are required to be clean and free of laitance.

Bridge elements containing cold joints that will be subjected to interface shear commonly have construction requirements that call for the roughening of the substrate concrete on the cold joint. This roughening is commonly completed after the concrete has been placed in the formwork and consolidated, but while it is still in a semi-liquid-like state. In order to complete the actions of

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[b] Florida Department of Transportation. (July 2015). *Standard Specifications for Road and Bridge Construction, Division II – Construction Details.* page 384.
[c] AASHTO. (2014). "*AASHTO LRFD Bridge Design Specification, 7th Ed.*" American Association of State Highway and Transportation Officials. Washington, D.C.
[d] AASHTO. (2014). "*AASHTO LRFD Bridge Design Specification, 7th Ed.*" American Association of State Highway and Transportation Officials. Washington, D.C.

finishing and roughening of the concrete, construction personnel must be able to access the relevant concrete surface and to impart the needed mechanical actions on the surface.

INTERFACE BETWEEN MEMBERS 11 AND 12 AND THE DECK OF THE BRIDGE

The construction process for the superstructure of bridge included three distinct concrete pours. The first was for the deck of the bridge, the second was for the truss diagonal and vertical members, and the third was for the canopy of the structure. These pours were completed sequentially with significant time allotted between pours to allow for development of the mechanical properties of concrete from earlier pours. The design plans for the bridge indicated that the cold joints between pours would be at the following locations:

- between the bridge deck and the bottoms of the diagonal/vertical members, and
- between the tops of the diagonal/vertical members and the bridge canopy.

An image of the bridge superstructure captured just prior to the placement of the bridge on the piers is provided in Figure 1. This figure includes an annotation highlighting the region of interest on the north end of the bridge at the location where Members 11 and 12 framed into the deck. An elevation view of the north end of the superstructure is provided in Figure 2, again with annotations to indicate the region of interest.

Figure 1. Main span of the bridge highlighting the portion of the bridge this is of interest to this factual report.

Finally, Figure 3 provides a local view of the location where Members 11 and 12 meet the bridge deck. The provided photograph shows the east face of diagonal Member 11 and the south and east faces of vertical Member 12. The deck surface can be seen around the base of where the two members frame into the deck. The interface under discussion is annotated in this figure.

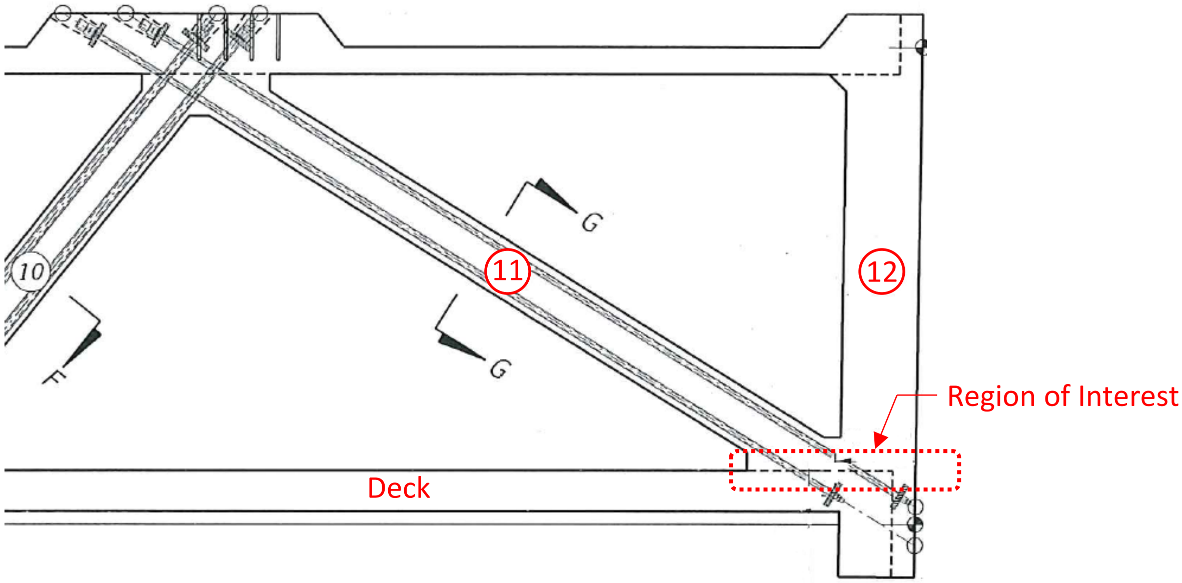

Figure 2. Elevation view of region of interest at the intersection of members 11 and 12 and the deck.

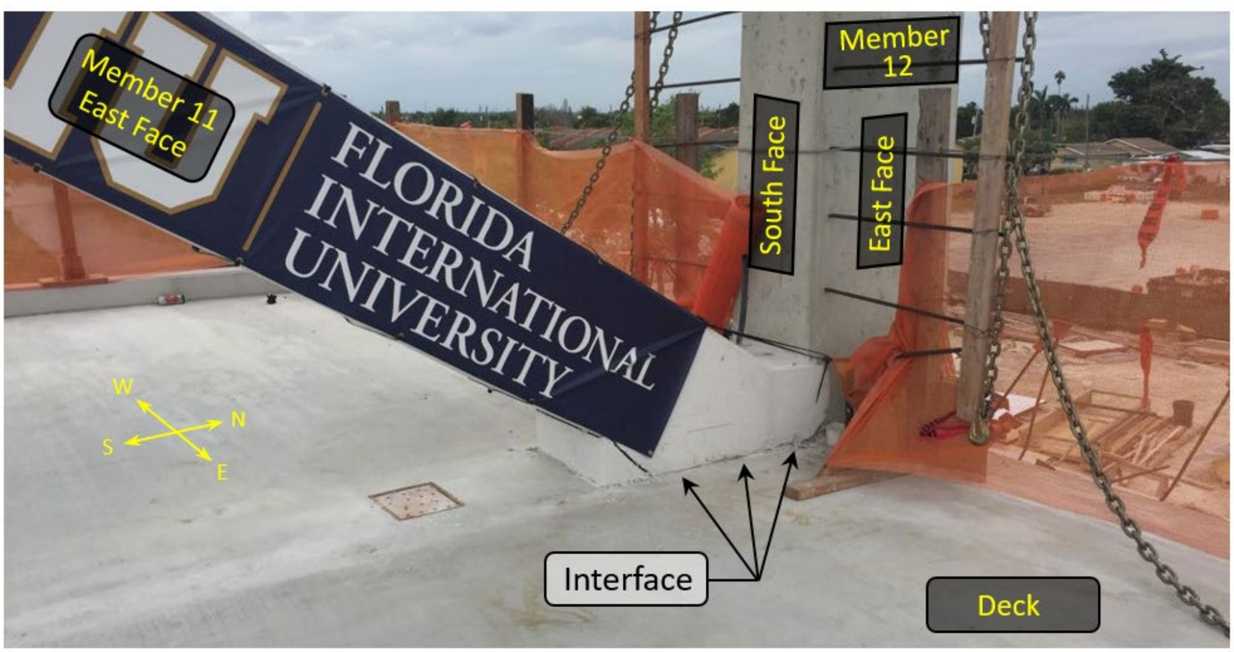

Figure 3. Annotated image showing elevation view of region of interest at the intersection of members 11 and 12 and the deck.

INTERFACE BEFORE COLLAPSE

Numerous photographs of the interface under discussion were captured prior to the collapse of the bridge. These photographs were captured in relation to the cracking and apparent relative horizontal translation of the elements immediately above and below this interface in the weeks leading up to the collapse.

Figure 4 provides a set of photographs that document a portion of the east face of the interface in the days immediately before the collapse. The compound figure shows the overall location in the structure (Part A), followed by a local image of the structure (Part B), followed by three close-up photos of the interface between the bridge deck and the bottom of Member 11 (Parts C through E). The specific location shown in the three close-up photos is within the line of action of Member 11 near the intersection with Member 12. The three close-up images appear to show that the secondary pour sits slightly above the surface of the deck. It is also apparent that the secondary pour was not completely consolidated, with a small amount of less consolidated concrete visible on a portion of the bottom edge of the casting (annotated in Parts D and E). The indication of this less consolidated concrete is the observation of apparent paste-covered aggregates that reside in a void that is recessed from the vertical finished surface of the member. A small void of this type could occur at the bottom corner of a concrete casting, such as on a vertical surface adjacent to a horizontal cold joint.

Figure 5 provides a set of photographs that also document a portion of the east face of the interface in the days immediately before the collapse. This compound figure shows the overall location in the structure (Part A), followed by a zoomed location in the structure (Part B), followed by three close-up photos of the interface (Parts C through E). The specific location shown in the three close-up photos is near the southern end of the east face of where Member 11 meets the deck.

These close-up images show that the interface, labeled as “Apparent cold joint” in Parts C through E, does not appear to be roughened. Additionally, the chamfer at the southern end of the interface between Member 11 and the deck appears to have remained connected to the deck, while the crack that runs along the northern portion of the interface departed from the interface and began following the extension of the southern face of Member 11. Thus, the cold joint at the southern end of the interface being investigated may have remained intact until the collapse began.

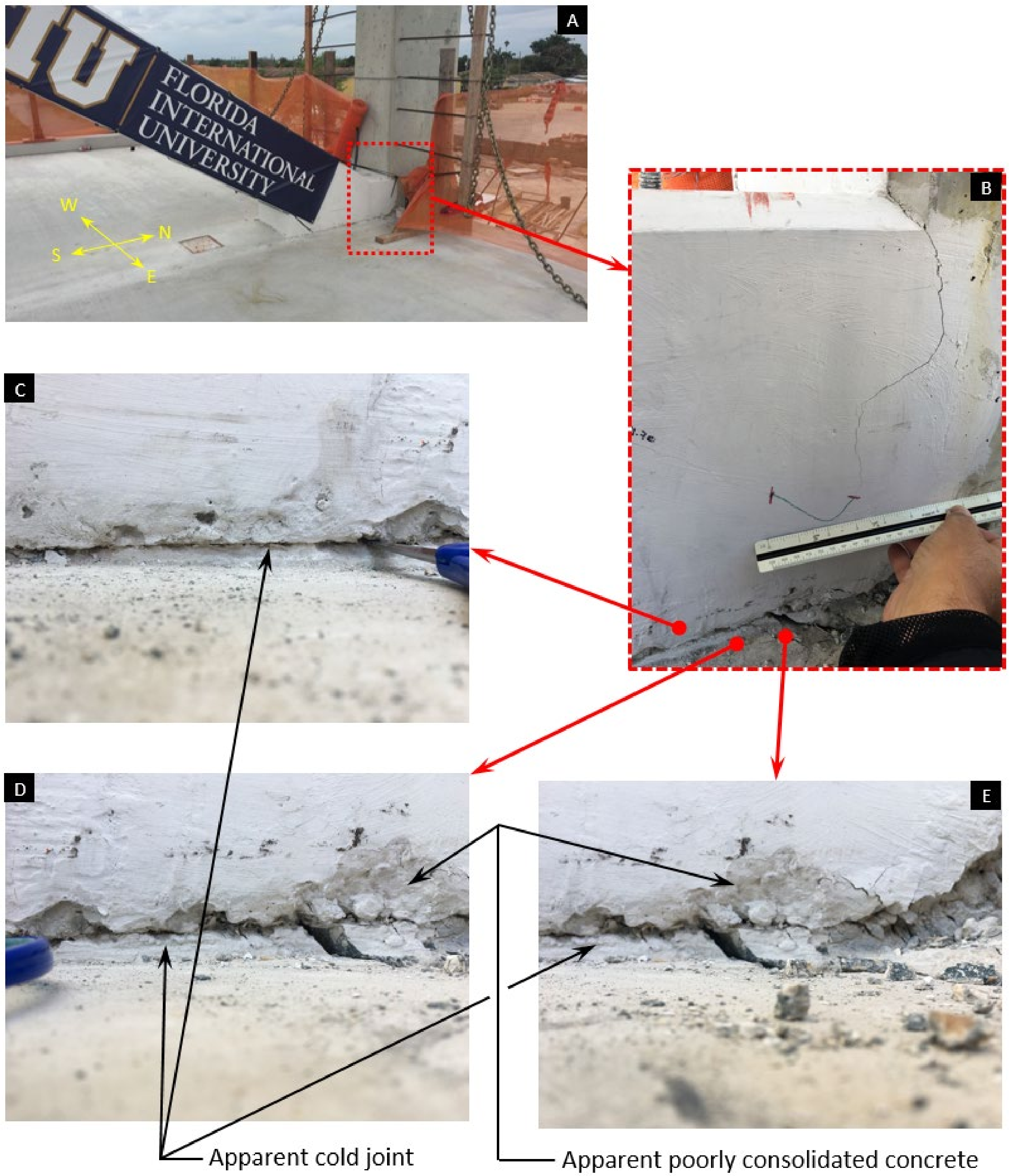

Figure 4. Annotated images demonstrating interface condition on east face of member 11 near member 12.

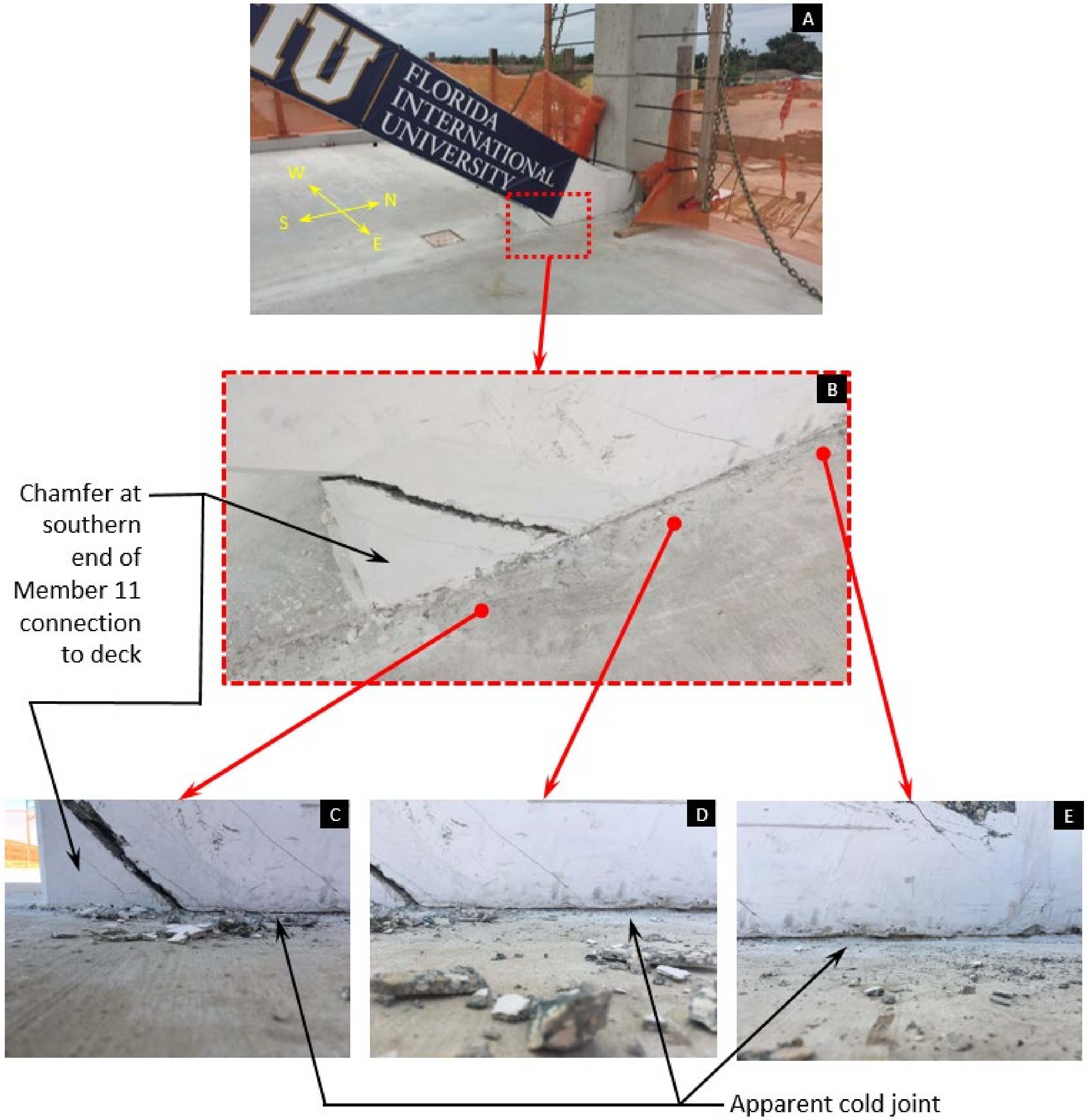

Figure 5. Annotated images demonstrating interface condition near the south end of the east face of Member 11 with the deck.

INTERFACE AFTER COLLAPSE

The collapse of the bridge superstructure caused significant damage to many parts of the structure, including portions of the structure near the region of interest; the location where Members 11 and 12 intersected with the deck. In particular, the concrete in the lower portions of Members 11 and 12 was pulverized into rubble, as was the concrete in the deck immediately under Member 12. Post-collapse assessment of the cold joint was completed using remaining intact pieces of concrete from the region of interest in the structure.

Figure 6 and Figure 7 provide a set of photographs showing the bottom end of Member 12. Figure 6 focuses on the north face of the member, with the left side of the photo in Part A showing the location where the member intersected with the bridge deck. Part B and the annotation call attention to the location of a cold joint interface between concrete pours. From a construction process standpoint, this surface feature indicates a location where vertical formwork for a secondary pour of concrete was nearly pressed against the existing hardened concrete of the first pour. The small gap between the formwork and the first pour allowed a small amount of concrete paste to flow slightly past the leading edge of the hardened concrete on the north face of the member, thus creating the ragged horizontal paste line at the cold joint location.

Figure 7 focuses on the same portion of Member 12 except viewed from the south and below. The boxed area in Part A draws attention to bottom end of Member 12 where it met the bridge deck. The key feature in this image is shown in Parts B through E. A flat, nearly smooth plane of concrete paste that aligns with the cold joint shown in Figure 6 is visible. As the viewpoint is rotated from below toward the south in Parts B through E, the scale shows that there is minimal roughness on the plane. This plane is part of the secondary casting of concrete that was placed and hardened against the first casting of concrete. The concrete in this plane and nearby appears well consolidated, indicating that this concrete replicated the surface geometry of the surface on which it was cast. Prior to or during the collapse, the concrete from the secondary casting debonded from the concrete from the original casting, leaving behind this preserved portion of the cold joint. This flat, nearly smooth plane does not show indications of abrasion or other mechanical actions that could have left a smoother surface than was originally present after the secondary pour of concrete was completed.

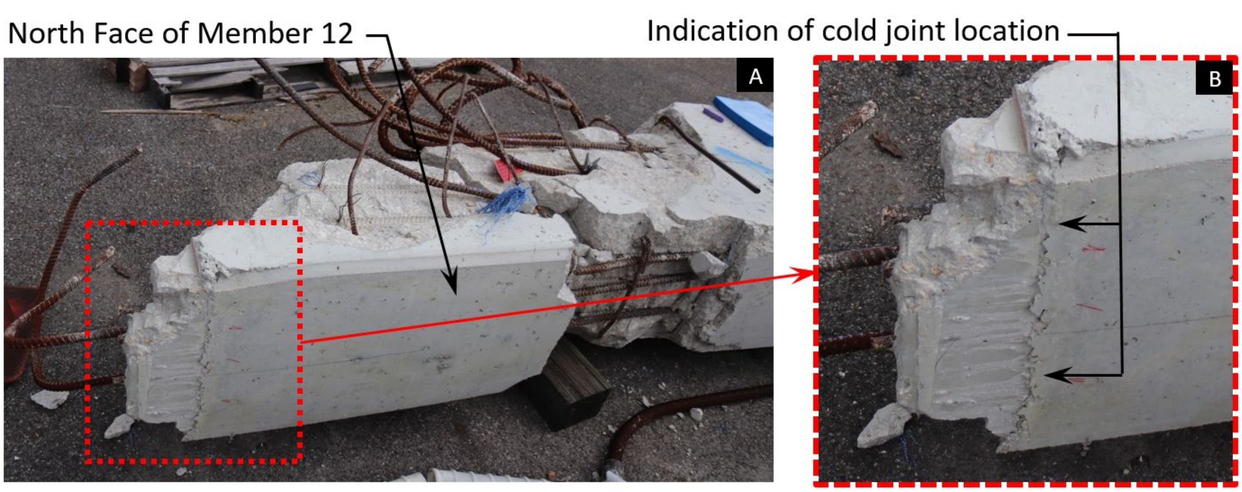

Figure 6. Indication of cold joint on north face of Member 12.

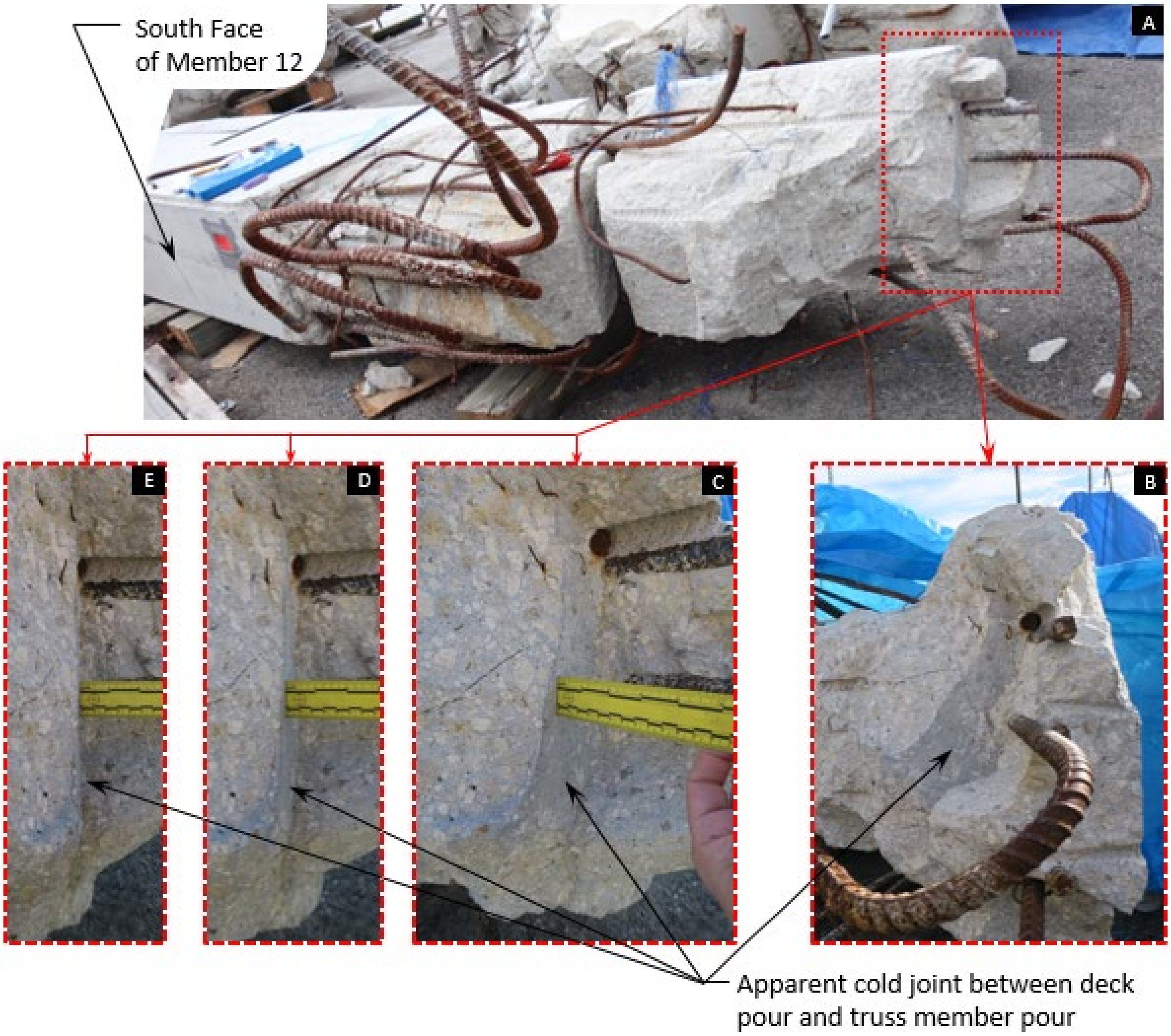

Figure 7. Indication of cold joint near the bottom end of Member 12.

After the collapse, the deck under Member 11 was partially intact; this shown in Figure 8. This photo was captured in the days after the collapse once pulverized concrete and other debris created by the collapse had been carefully removed from the surface. This northward looking photo is taken from the vantage point of where Member 11 was heading diagonally toward the deck. The hole in the north end of the deck is the location where Member 12 met the deck. The visible post-tensioning rod was the lower rod within Member 11.

The portion of the deck under the southern end of Member 11 is largely intact from the post-tensioning rod to the southern end of the interface. This surface appears relatively smooth. The isolated depressions on the concrete surface, identified in Figure 8, are locations were reinforcing bars previously passed upward through the interface between the base of Member 11 and the deck.

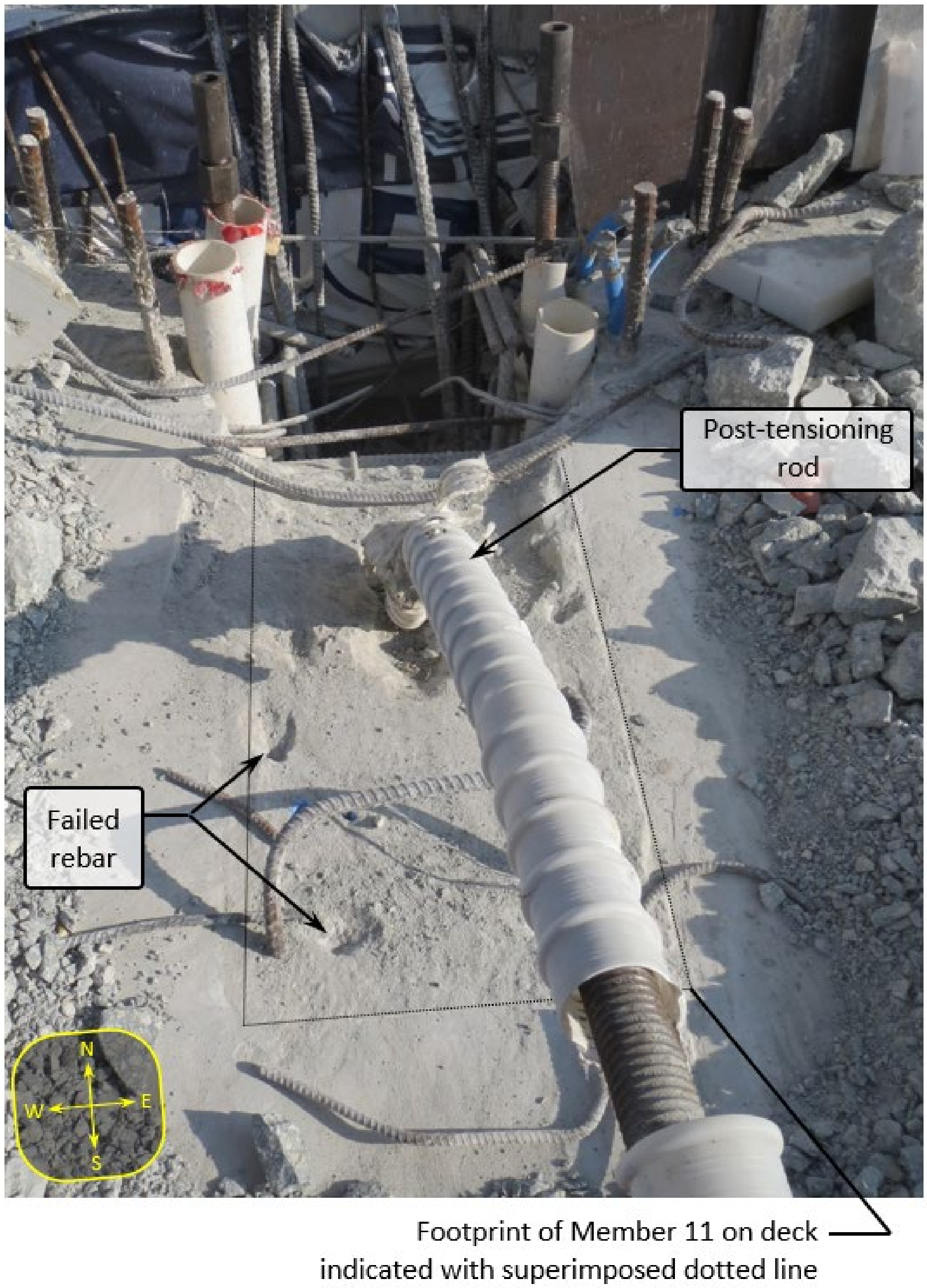

Figure 8. Interface under Member 11 after loose debris removal.

Further photographic evidence of this surface is provided in Figure 9 which shows the southeast corner of the interface after the surface had been washed with water. The foreground includes the southern end of the interface near the interface shear rebar that remained intact through the collapse. The upper portion of the photo includes the portion of the interface near the lower post-tensioning rod from Member 11. A concrete fracture surface within a cone of failed concrete near a fractured rebar is labeled. The apparent cold joint surface between Member 11 and the deck is also labeled. The visual difference between the fractured concrete surface near the fractured rebar and the apparent cold joint surface is notable. The fractured surface shows fractured aggregates as well as fractured paste, whereas the apparent cold joint surface is largely covered in relatively smooth concrete paste. It is also important to note that the apparent cold joint surface does not show scratches or gouges near the southern end of the interface; scratches and gouges begin to appear as one traverses northward toward the lower post-tensioning rod. These scratches and gouges have a north-south orientation and appear likely to have occurred during the collapse as the concrete in the bottom end of Member 11 slid northward across the deck surface.

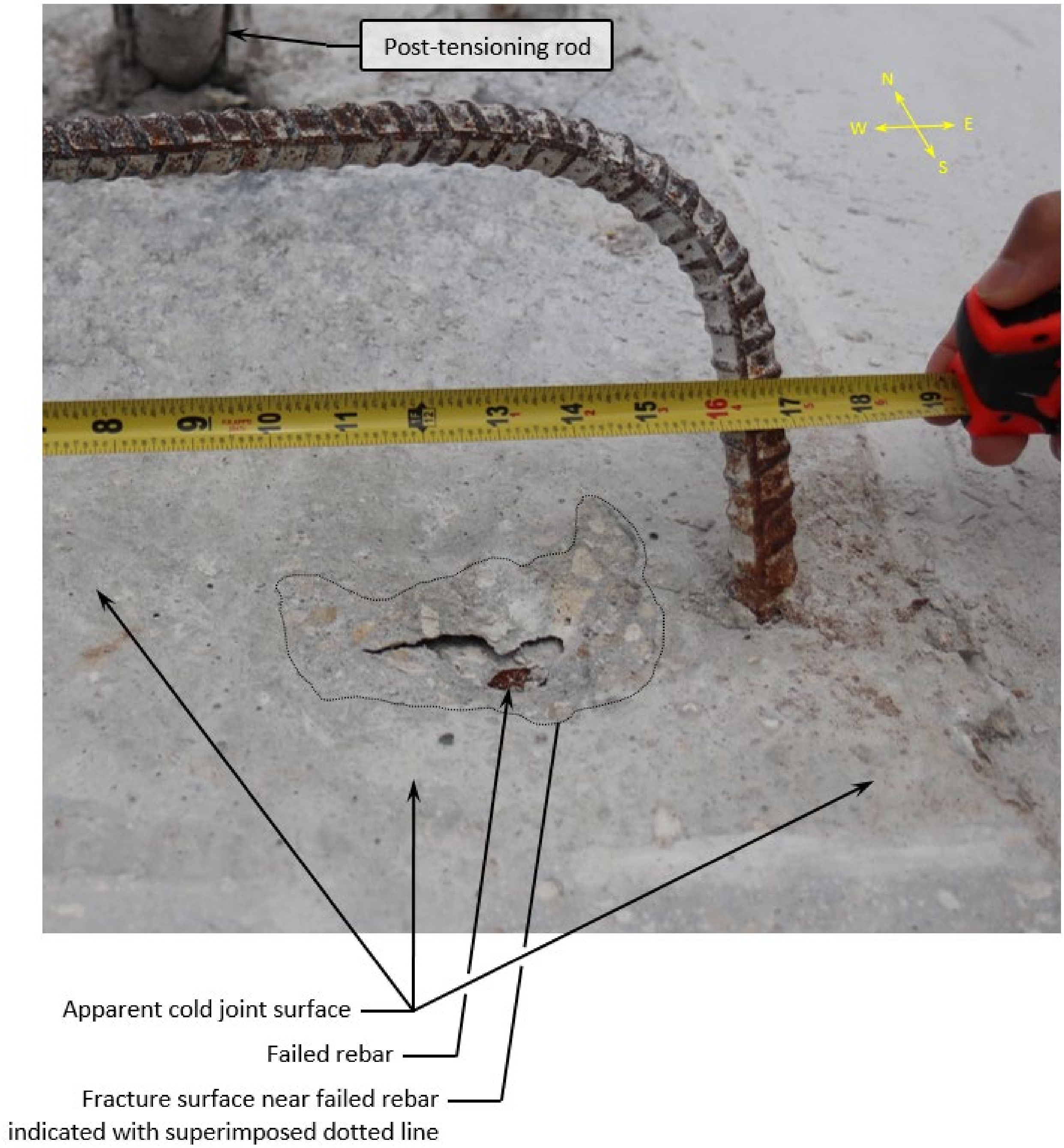

Figure 9. Interface under southeast corner of Member 11 after cleaning.

Further investigation was completed on the portion of the interface on the southern end of the connection between Member 11 and the deck. Figure 10 provides a series of photos related to the interface after it had been removed from the collapse site. The photo in Part A shows the interface, this time after the free length of the post-tensioning rod had been removed and a core hole had been cut into the south end of the interface. The concrete under the southern portion of the interface had become delaminated on a horizontal plane at a depth approximately 1 inch below the visible surface. A portion of that delaminated concrete was collected as evidence and is shown in the photo in Part B. Note that the delamination extended beyond the area under Member 11 into the area under the finished concrete surface of the deck. It is likely that this delamination occurred after the collapse initiated, quite likely in relation to the deck impacting the ground after falling off the pier.

The image in Part C shows a view along the deck looking south to north along the east edge of where Member 11 met the deck. An elevation increase from right to left is visible in the center of the photo; this location coincided with the eastern edge of Member 11. The relative smoothness of the surface of both the finished deck and the interface under Member 11 is evident.

The photo in Part D shows an east-west vertical slice of concrete that was cut from the delaminated concrete along the line identified in Part C. Note that the right side of the image shows concrete that was from the deck east of the member and the elevation change in the horizontal concrete surface indicates the eastern extent of where Member 11 met the deck. By looking at the combination of the paste and aggregates in this concrete slice, it is apparent that there is no other cold joint throughout this depth of concrete. The smoothness of the top surface of the interface is also apparent.

Part E shows a close-up isometric view of the concrete along a small portion of the interface. The vertical slice shows concrete paste and fine aggregates. The top of the image shows the interface surface. This surface is largely composed of cementitious paste, which in some locations appears to cover slightly protruding larger aggregates. Throughout the southern half of the interface between Member 11 and the deck there are relatively few locations where an aggregate piece in the concrete appears to have protruded through the interface and been sheared off prior to or during the collapse.

Further evidence related to the interface is provided by a core that was taken vertically down through the interface near the southern end of where Member 11 met the deck. This core is shown in Figure 11. As was discussed previously, there was a delamination layer under the interface surface. The photo in the figure is annotated to identify key features. The top of the core shows the apparent cold joint surface at the interface. This surface is largely concrete paste with a small number of fractured aggregates. The vertical fractured surface in the delaminated piece shows small aggregates immediately under the top surface. On this surface there are also a few larger aggregates, one of which is identified as being fractured where it crosses the delamination plane. This is indicative of the delamination plane having been caused by mechanical stressors and not by its having originally been a cold joint. Further examination through the depth of the core make apparent that 1) the concrete under Member 11 was well consolidated, and 2) the cold joint between the deck pour and the member pour was not at a location beneath the failure interface.

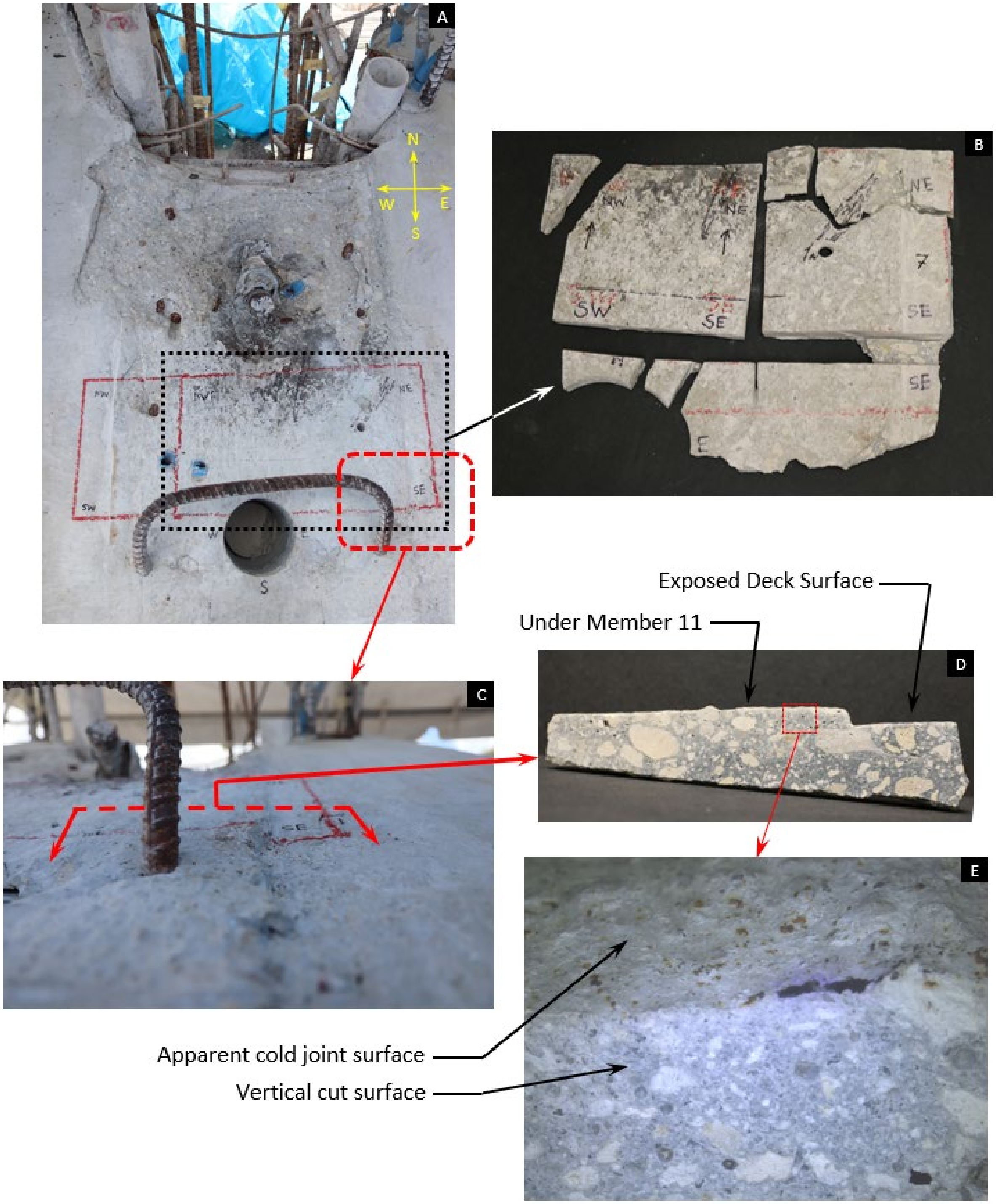

Figure 10. Interface surface under Member 11.

Figure 11. Annotated image of core extracted from south end of interface surface under Member 11.

SUMMARY

The failure interface between the bases of Members 11 and 12 and the bridge deck was investigated. Evidence was collected to assess the location of the cold joint between the deck concrete pour and the truss member pour, and also to assess the apparent roughness of the interface created at the cold joint. Photographs captured prior to the collapse provide an indication of the location of the failure interface and the apparent smoothness thereof. Evidence collected after the collapse provide an indication of the location of the cold joint within the structure and the original roughness of the cold joint. The evidence indicates that a portion of the failure interface coincides with the original cold joint and that the cold joint was not intentionally roughened.