Engineering for Bridge Demolition

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According to the American Society of Civil Engineers (ASCE) *2021 Report Card for America's Infrastructure*,[1] the average age of bridge structures in the United States was 44 years; 42% of all bridges are more than 50 years old. Updating, repairing, and replacing the bridges in the National Bridge Inventory will require significant bridge demolition operations.

Poorly planned bridge demolition operations have caused property damage, unexpected road closures, injuries, and fatalities. Demolition problems can result in additional costs, project delays, impacts to public traffic, and adverse publicity for the contractor and owner. A properly engineered demolition plan includes the analysis of the bridge structure during the operation stages and provides work sequences that reduce risks and potentially negative outcomes.

Bridge demolition operations can be either complete or partial demolition of existing structures. In complete demolition operations, the entire bridge structure is permanently removed and the demolition sequences can be analyzed—assuming that the remaining service life is finite and known—without considering future use. Partial bridge demolition may involve limited removal of the bridge structure as required for repairs or partial bridge replacement. The remaining structure remains in service and must be protected to ensure that the service life of the rehabilitated bridge is not adversely affected by demolition activities. Although analyses of complete and partial demolition are similar, the design limits and criteria vary. The load factors used for strength-level limit state checks of bridges under complete demolition can be lower than the load factors for bridges under partial demolition. The difference in load factors is comparable to operating-level design limits for complete demolition and inventory-level limits for partial demolition.[2]

Engineering analysis used for bridge demolition operations must be appropriate for the type and configuration of the structure being analyzed. The analysis must take into consideration the condition of the concrete, changes to the structure during each stage of the demolition operation, and the equipment used. Complex bridge demolition analyses require an experienced engineer.

Ultimately, it is up to the contractor and their engineer to determine the most effective demolition method and to develop a plan for the work to be performed safely, within the constraints of the project contract documents.

Equipment Loading for Bridge Demolition

In general, bridge demolition has three phases: deck removal, superstructure removal, and substructure removal. The equipment used for each phase is selected based on the structure type, site conditions, contractor preferences, and project schedule. In many cases, when bridges are being demolished or rehabilitated, construction equipment must be supported by the bridge structure being removed. In these cases, the actual equipment loads and their locations, including moving load effects, should be used to evaluate the structure's adequacy at each stage of partial removal.

While knowing the weight of specific demolition equipment is straightforward, understanding the weight distribution and dynamic effects of the equipment during demolition activities becomes complicated. It is the engineer's responsibility to determine the wheel, track, or outrigger loading based on the machine weight, attachments, operating radius, and dynamic impact from the work being performed. For some types of equipment, such as cranes, bearing-pressure calculation software may be available. For other types of equipment,

Figure 1. The top flange of this concrete girder was damaged during demolition. If the girder is to remain, it must be repaired. Photo: Collins Engineers.

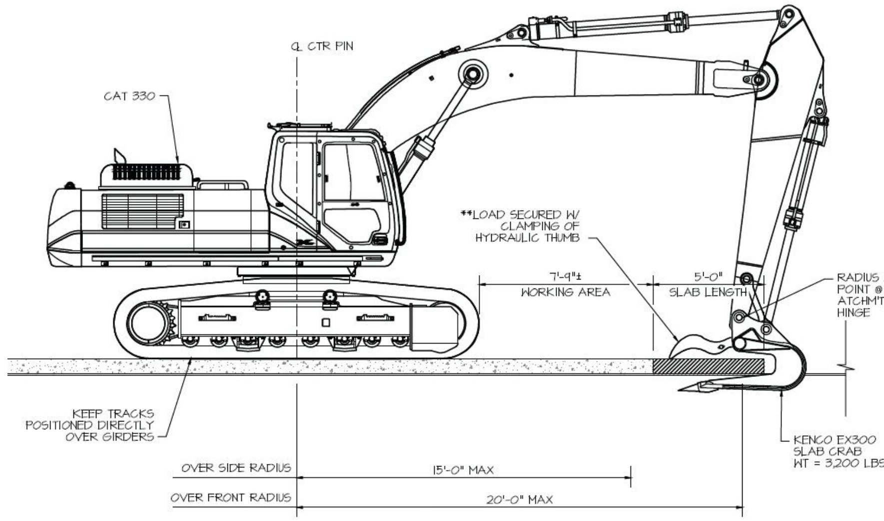

Figure 2. Schematic of an excavator removing precut deck panels using the "slabbing" technique, which minimizes falling debris. Figure: Steamboat Structures.

the engineer must determine the loading based on hand calculations or finite element modeling of the equipment. The level of conservatism or need to accurately determine the applied equipment loading will vary depending on the project and structure's capacity.

Deck Removal

Deck removal is typically performed with an excavator equipped with an attachment specific to the selected removal method. Two common removal methods are (a) cutting and removing the deck in panels and (b) breaking and dropping the deck out with a hammer. When choosing a method for deck removal, contractors must consider what the bridge is spanning and whether the girders are to be reused. If the existing girders are to be reused, the demolition contractor must take additional care during deck demolition to minimize damage to them. If the top flange of the girder is damaged, typical concrete patch repairs on spalls or epoxy injection in saw cuts may be adequate to restore the structural integrity of the girder (**Fig. 1**). However, the location, severity, and depth of the damage must be analyzed in correlation with possible prestressing or post-tensioning strand or bar locations to ensure that the primary load-carrying reinforcement was not compromised. In such cases, analysis may indicate that strengthening or replacing the damaged girder is required.

When demolition activities take place over live traffic, a railroad, environmentally sensitive areas, or a waterway, controlled removal methods are typically preferred. The most common removal method is to precut panels and remove them using a slab crab or grapple attachment (slabbing). Slabbing helps minimize the amount of falling debris and reduces the effects of the dynamic impact that the equipment induces on the structure (**Fig. 2**). Once the deck panels are removed with the excavator, they are then transported off the bridge using support equipment, such as flatbed trucks, front-end loaders, or skid steers; then the panel pieces can be processed using a pulverizer/muncher or other specialty excavator attachment.

Demolition contractors generally prefer to saw cut a grid of manageable-sized deck pieces in advance to speed up the removal process. Most concrete girder bridges were designed to act compositely with the reinforced deck, and saw cutting longitudinally along the girder edges disengages a significant portion of the composite deck. The capacity of the superstructure with a saw-cut deck must be analyzed for the weight of the deck in combination with equipment removing the cut pieces.

The most efficient deck removal method is using a hammer or shear attachment to break the deck to the ground or shielding below. When demolitions occur over a finite outage period, these methods are often used for partial deck removal to separate the girders (**Fig. 3**). The deck over the girder flanges remains and can either be hoisted out with the girders or removed later using smaller handheld tools if the girders are to be reused.

Superstructure and Substructure Removal

Superstructure and substructure removal are performed by either saw cutting to lift components out with a crane or pulling portions of the structure over with an excavator from the ground. When dealing with a concrete superstructure, components are generally very heavy, and it is critical to correctly size equipment to handle these large loads. It is also important to remember that in demolition, a component that is being removed often cannot be set back down, so accurate estimates of component weight and center of gravity are crucial to safe removal operations. If detailed plans are not available to adequately determine component weights, field measurements or additional factors of safety, or both, are recommended.

Figure 3. Excavator with a shear attachment breaks the deck to separate the girders. Shear attachments are hydraulically controlled jaws used to cut reinforcement, concrete, and structural steel members. The thickness of steel that shears can cut is dependent on the specific shear attachment and size of excavator. Photo: D. H. Griffin.

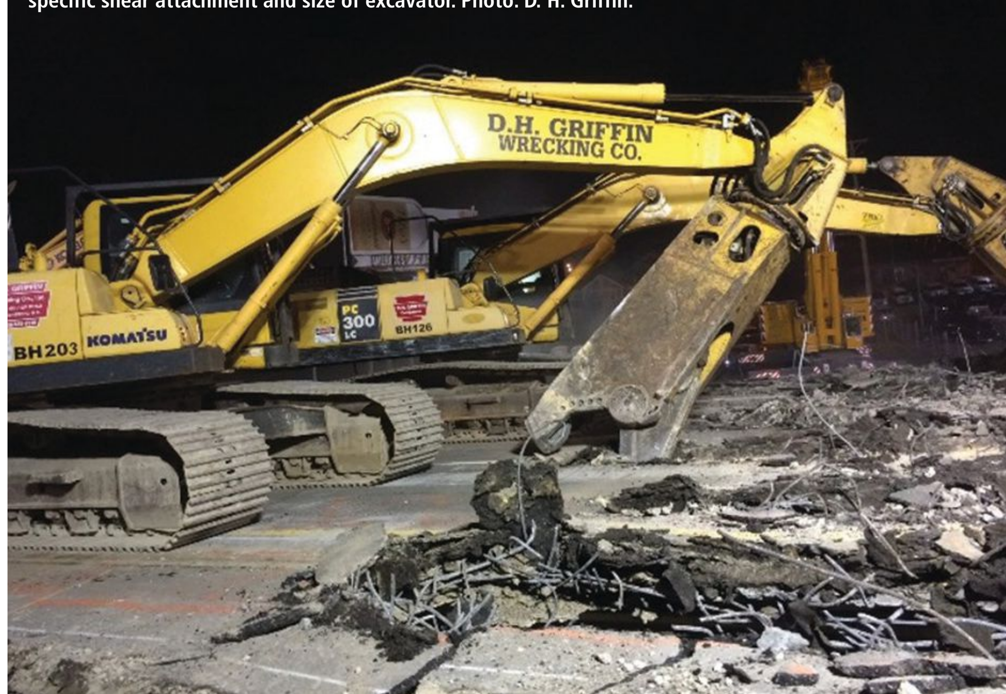

Figure 4. During demolition of a bridge superstructure, a prestressed concrete girder is removed using a single-crane pick. The demolition engineer should verify the proposed lifting configuration to ensure stability of the girder during its removal. Photo: Collins Engineers.

With the deck removed and the excavators no longer loading the structure, additional engineering effort is required to ensure the safe and stable removal of the superstructure. During initial construction, prestressed concrete girders generally need to be lifted at or near the ends of the girder to ensure that the tensile stresses in the top flange are within limits. Demolition contractors often prefer to use a single crane for girder removal to avoid the additional cost and site logistics of positioning a second crane. The demolition engineer should verify the proposed lifting configuration to ensure girder stability and to avoid failure of the girder due to the combined negative moments from the prestressing strands and the self-weight of the cantilevers beyond the proposed lifting points (**Fig. 4**).

Demolition of post-tensioned (PT) structures can result in unexpected behavior if the PT strand or bar configuration, grouted or ungrouted conduit condition, and sequencing of PT disengagement during demolition are not thoroughly analyzed. Ungrouted PT strands can be as dangerous as a flying projectile when severed and the tensile stress is released. Detensioning PT strands and losing the continuity over multiple spans can result in significant capacity reductions; various PT structure types may not have the capacity to support the self-weight of the concrete superstructure without the continuity of the PT engaged.

Deck removals or replacements on PT structures must also be carefully planned. The engineer cannot simply assume that the deck can be removed without an understanding of the composite behavior of the PT strands in combination with the superstructure and the deck. Partial or full removal of the deck could affect the composite properties of the primary post-tensioned sections, compromise the integrity of the PT strands, or inadvertently cut or damage PT strands relied upon to support the dead load of the structure. An understanding of the type of post-tensioning and the design intent is essential to appropriately analyze the demolition sequence. Conservative methods of shoring for the structure self-weight should be considered.

Conclusion

Evaluation of the capacity of existing structures should take into account the current condition of the structure, and the limit states for evaluation should be based on something similar to "operating-level" evaluations as presented by the American Association of State Highway and Transportation Officials' *Manual for Bridge Evaluation*.[2] Ultimately, however, capacity determination is at the discretion of a qualified structural engineer.

Proper consideration of the demolition sequence is as important as the evaluation of bridge structures during the various stages of construction. Structural engineers evaluating demolition sequences must be aware of the loads, the load paths, and the structure's changing stiffness and response as a bridge is being dismantled. Failure to account for all of these factors can lead to unexpected results in the field.

Owners and stakeholders can further enhance project safety and mitigate project risk by adopting bridge demolition guidance, requirements, and oversight. The Bridge Demolition Subcommittee of the American Society of Civil Engineers (ASCE) Construction Institute Temporary Works Committee is currently working on the first edition of a bridge demolition best-practice document to be published by ASCE in the spring of 2024.

References

1. American Society of Civil Engineers. 2021. *2021 Report Card for America's Infrastructure*. https://infrastructurereportcard.org/wp-content/uploads/2020/12/National_IRC_2021-report.pdf.
2. American Association of State Highway and Transportation Officials (AASHTO). 2017. *Manual for Bridge Evaluation*. 3rd ed. Washington, DC: AASHTO.

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