Designing Bridges for Inspectability

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ABSTRACT

Bridge inspection is essential for public safety and effective bridge management. Bridge inspection and bridge inspectors are the first line of defense against bridge failures. Most highway bridges in the United States and the rest of the world are predominantly inspected using visual methods by bridge inspectors manually assessing the condition of various elements. Thus, whenever possible, it is the responsibility of bridge designers to make sure that bridge details are designed such a way that the inspection of all the bridge components is visually possible. This paper highlights some of these issues and recommendations for designers based on the input from bridge inspectors working for the New York State Department of Transportation.

INTRODUCTION

Highway bridge inspections in the United States are mandated by the Federal Highway Administration (FHWA), as well as individual states, with procedures detailing inspection procedures, organization responsibilities, inspector qualifications, inspection frequency, reporting, and documentation. The original Highway Act passed by the United States Congress in 1916 that provided for federal aid to highways and subsequent highway acts include the requirements for maintenance of bridges as well as highways. Since about 1916, inspection of highway structures has been a part of maintenance work, although often a relatively minor part, by the states and other jurisdictions (White et al. 1992). More detailed inspections currently in place can be attributed to the Silver Bridge Collapse in 1967 and subsequent major failures.

The present federal requirements can be found and are detailed in the FHWA National Bridge Inspection Standards (NBIS), last revised in 2004 and becoming effective in January 2005, sets minimum standards for the inspection of all publicly owned highway bridges (National 2004). These standards were set to ensure public safety by assuring that bridges have enough capacity to carry loads allowed on them. Inventory and certain condition data are also collected (Recording 1995) for assessing the condition of the entire bridge network in the nation and for determining allocations of federal highway bridge program funds (Alampalli and Jalinoos 2009). Many states and owners, including the New York State Department of Transportation (NYSDOT), collect more data for effective bridge management, i.e., decisions taken to support planning, design, maintenance, replacement, and rehabilitation activities. Some states also have more stringent requirements on personnel qualifications than those mandated by the NBIS. The current status of highway bridge inspections and use of NDE/NDT methodologies can be found in literature (e.g., Alampalli and Jalinoos 2009 and ASCE 2009).

ROLE OF BRIDGE DESIGN IN BRIDGE INSPECTION

Bridge life cycle is composed of several phases. These include planning, preliminary design, final design, construction, initial inspection following the construction, routine inspections throughout the service life of the bridge, maintenance, rehabilitation, and finally replacement. Many decisions taken during the planning and design may significantly influence the bridge service life as well as costs of inspection and maintenance. As noted earlier, the NBIS requires a full inspection of most highway bridges every twenty-four months and hands-on inspection of fracture critical components. New York State requirements are more stringent requiring hands-on inspection for all bridges and include component level inspection on a span basis. When certain conditions exist, New York State inspects bridges every twelve months or more often. New York State also specifies all Team Leaders to be
Professional Engineers. Underwater inspections, generally performed by divers, are also required at least once every 60 months. Thus, these inspections do cost a considerable amount during the service life of the bridge. Inspectors also document the section loss and other deterioration so that critical findings can be documented and accurate load capacity of the structure can be evaluated to assure public safety (Alampalli and McCowan 2008). Thus, designers of new bridges or bridge rehabilitation must be cognizant of those requirements and take into consideration accessibility and costs of future bridge inspections.

Inspection costs include, but are not limited to, personnel costs, access costs, work zone control costs, documentation costs, and evaluation costs. In some cases, the access and work zone control costs can be significantly higher than other costs due to heavy traffic volumes in urban areas. Thus, making access as easy as possible should be an important consideration in the bridge design process and has often been overlooked in the past. In addition, the use of details that make visual observation of critical components of primary members difficult should be avoided. The design codes have been relatively silent on these aspects even though AASHTO LRFR Bridge Design Specifications (AASHTO 2010) contain some requirements for bridge inspection that the designer needs to consider. The recent AASHTO Manual for Condition Evaluation of Bridges documents these requirements in more detail (The Manual 2008). Both of these manuals contain criteria for determining primary and secondary members and also contain criteria for further determining whether primary members are redundant or non-redundant and whether they are fracture critical or not. The NYSDOT Bridge Manual (Bridge 2010) also needs to be consulted for recommended design practices and details. The Bridge Manual contains suggested details for a variety of bridge types.

Several aspects that can be considered during the design phase that can minimize inspection costs and improve inspection quality include: 1) bridge type selection, 2) type of details, and 3) access. These are discussed in the next sections. Some of the comments are based on responses received to a survey questionnaire that was sent in early 2010 to all inspection personnel within NYSDOT.

**Inspection Issues: Bridge Type Selection**

The most important element in designing for inspectability is the initial choice of a bridge type. In designing for inspectability, the first preference is to choose a structure that is load path redundant. This is an important consideration that affects inspection costs. The other types of redundancies are internally redundant and structurally redundant, but at present, the NYSDOT only recognizes load path redundancy in determining inspection requirements. A non-redundant structure that contains fracture critical members raises the level of necessary inspection even higher.

Thus, a designer’s first choice, from an inspection standpoint, should always be to choose a load path redundant structure. This is usually achieved by the selection of multi-girder bridges, irrespective of material used. By federal standards, any bridge with more than two girders is considered redundant. But, in New York State, to be considered load path redundant (Bridge Inspection Manual 1997), four or more girders are required. However, recent analytical studies indicate, that in specific cases, three and even two girder bridges can be load path redundant. Thus, in such cases, a designer documenting this on bridge plans and providing guidance to bridge inspectors can be very helpful. More documented guidance is needed in this area so that inspection costs can be reduced in the future. Other types of structures, such as multi-ribbed arches and concrete slab bridges, can also be considered load path redundant.

However, sometimes load path redundant type structures cannot be used due to factors beyond the designer’s control. These factors include site conditions and aesthetic concerns. One such example is the use of through trusses and through girders with limited vertical clearances or very long spans. In such circumstances, it is important for the designer to provide as much redundancy as possible, and furthermore, to include inspectable details and provisions in the design. Internal redundancy can be added to non-load path redundant structures. This is most important for fracture critical tension members. The tie girder in a tied arch can be made internally redundant by the use of multiple structural components connected by bolting rather than welding. Similar details can be used for truss chords or two girder bridges. In order for this internal redundancy to be effective, the designer must ensure that the remaining components of a fracture critical member have sufficient capacity to prevent collapse of the structure after the failure of an individual component.
Steel box or tub girders can be attractive structural types and are especially efficient for curved structures because of their high torsional strength. They are, however, inherently more difficult to inspect than I-shaped girders. The designer can improve the inspectability by making them large enough for access. A minimum depth of 5 feet 6 inches is recommended. In addition, the diaphragm openings need to be large enough for an inspector to pass through. Inspectability can also be enhanced by painting the interior white and providing interior lighting (see Figure 1).

Adjacent prestressed concrete box girders have been a common and favored structural choice. They are an economical structure and have the advantage of a small structure depth where vertical clearance is an issue and having a smooth underside that helps to prevent the snagging of debris carried by waterways. They do, however, present inspection challenges. Prestressed girders, by their nature, are harder to assess visually. In addition, adjacent box girder design prevents the bridge inspector from making a visual assessment of the sides of the girder.

**Inspection Issues: Bridge Details for Inspection Access**

Bridge details play a major role in ensuring bridge safety as accessibility to all components of a bridge is important. If a component cannot be reached or is hidden to the inspector, the inspector cannot examine the component and cannot determine its condition to assure that it is behaving as designed. Sometimes it is not possible to make all components directly visible to the inspector, but provisions should be made that simple devices available to the inspector (e.g., mirror) can be used to assess their condition.

**Abutments and Piers**

One of the common issues faced by bridge inspectors is accessibility to the abutments and piers. In most cases, these can be dealt with relatively easily during the bridge design. Some details that can assist inspectors include the following:

- When the exposed face of the abutment stem is four feet or higher, providing a flat spot or berm in front of the abutment stem will allow a ladder to be placed for easy access to the bridge seat and bearings.
- During bridge replacement projects, new abutments are often built behind the old abutments with old abutments left in place for slope/scour protection. In such cases, removing enough of the old abutment to provide at least a three feet clearance to the new superstructure above will give bridge inspectors access to the new abutments.
- When it is anticipated that access to the piers will be by boat, provisions for tying off the inspection boat to the pier will be of use to bridge inspectors.
If it is anticipated that use of the Under Bridge Inspection Unit (UBIU) is not possible to inspect piers in water due to the deep superstructure or other design details, a provision for inspection access ladders on the piers should be considered.

**Trusses and Arches**
Truss chords and arches commonly use box sections to minimize debris accumulation. However, their closed section makes visual inspection difficult and thus, providing periodic access ports of sufficient size on the underside of the box should be considered to provide inspection access. Removable screens should be provided with these access ports to prevent the ingress of nesting birds.

Large through and deck trusses are normally used over waterways to accommodate required long spans. In such cases, UBIUs are commonly used for inspection. Hence, openings between the truss verticals and diagonals should be large enough to accommodate the passage of the UBIU bucket. Designers should consult with bridge inspection personnel to determine the size of the equipment typically used. The openings between the verticals and diagonals are most easily controlled by setting the panel length as long as possible to maximize the opening. Similarly, an effort should be made to accommodate sidewalks inside the trusses to make inspection access by UBIU relatively easier (see Figure 2). Utilities should be provided inside the truss whenever possible to make access with the UBIU easier for inspection of the bridge’s underside (see Figure 3).

![Figure 2. Bridge with sidewalks outside the truss](image1)

![Figure 3. Bridge with utilities outside the truss](image2)
Girder Bridges

I-girder bridges are commonly used and are also the easiest type of bridge to inspect since most elements are visually accessible to the inspector. But, whenever possible, Class D, E, and E’ fatigue details should be avoided (AASHTO 2010) as these necessitate special emphasis inspection. In such cases, use of bolted connections of all cross frame and laterals is recommended while, in general, avoiding complex details.

Stay-in-place forms are more economical than removable forms from a construction perspective and thus are commonly used in New York State. However, their use makes the visual inspection of the bridge deck more difficult as illustrated in the Figure 4. In such cases, removal of some panels should be considered for deck inspection.

![Figure 4. Stay-in-place forms](image)

Inspection hand rails are commonly provided on girder bridges even though their use is debated by several inspectors (see Figure 5). When hand rails are provided, they must be robust enough to safely support a bridge inspector. Current NYSDOT practice is to provide inspection hand rails on girders having a web depth of 5 feet or greater on both sides of interior girders and on the inside of fascia girders (Bridge Manual 2010).

![Figure 5. Use of handrail in deep sections](image)
End Diaphragms
Almost all girder bridges have a line of end diaphragms to support the deck slab at joints and to convey lateral loads to the bearings and substructure. If solid diaphragms are used at the abutments, a sufficient opening should be provided to permit the bridge inspector access to the bearings and abutment backwall.

Bridge Railing and Fencing
Fencing is frequently provided on bridges over roadways and railroad tracks to discourage vandalism to traffic beneath the bridge. However, fencing can make inspection access by UBIU difficult. Although not commonly used, it should be possible to provide sections of fence with swing down details to accommodate UBIU access. Of course, any such detail should be provided with secure locking mechanisms.

Bridge Inspection and Security
Bridge security is becoming a very important aspect and consideration of a bridge’s security is now part of the bridge design process in most states. Thus, protecting critical components of bridges is routinely undertaken by bridge owners, especially in urban areas. One popular method used is to make sure the critical components are concealed by protective coverings, but this can make inspection operations and access very difficult. This can also increase the inspection costs if the protective coverings have to be dismantled and reassembled during inspection. Careful consideration for inspection of concealed components should be given before such protective measures are undertaken.

Recent and Other Ongoing Activities at NYSDOT
The current NBIS (2004) requires that specialized inspection procedures be identified for “complex bridges.” It defines potentially complex bridges as “moveable, suspension, cable stayed, and other bridges with unusual characteristics.” In order to address this requirement as well as to provide guidance to bridge inspectors when uncommon or unique details are used by the designers, a recent update of the Bridge Manual (2010) included the following language to alert designers. Note that every bridge in New York State has a unique bridge identification number (BIN) and all inspection related documentation for each bridge is placed in the appropriate BIN folder.

The designer of innovative or complex bridges, or of bridges that incorporate innovative or unusual elements or details, shall identify those bridge elements or details that warrant specialized inspection attention. A “Special Emphasis Inspection Procedure (SEIP)” shall be assembled, submitted with the “Final Bridge Plans,” and stored in the BIN file. The contents of the SEIP shall be as follows: A brief statement of purpose presenting an explanation of why the SEIP is required. Characterization of the complex of unusual elements or details to be given special attention; a description of the element or detail and the reason(s) it is considered complex or unusual. A description of how the element or detail should function or behave along with a description of the physical conditions that can be observed that would indicate that the element or detail is functioning appropriately. A description of the observable physical characteristics that would indicate that the element or detail is not functioning appropriately along with direction relative to how to assess the degree to which the element or detail is faulty in its performance.

When new materials (such as fiber reinforced polymers) or new design details are used, the designer should provide guidance to bridge inspection personnel by incorporating appropriate comments on the final plans. This could also include suggestions for periodic load testing or the use of instrumentation for periodic structural health monitoring based on cost-benefit analysis. In such cases, the designer should identify on the plans the properties that should be measured, locations for measuring, what items should be given attention during routine inspections, etc.

The bridge selection and detailing is mostly done by experience. Cost-effectiveness is given a priority during the design and is taught at colleges in design courses. In most cases, inspectability is not discussed unless designers have some inspection experience. No written guidelines exist for designers. Hence, NYSDOT is considering preparing guidelines on designing for inspectability and providing this to all the designers.
SUMMARY
A properly designed bridge is one that accounts for bridge inspection and maintenance. Bridge inspection is not routinely considered during the bridge design process and this paper discusses designing bridges for inspectability. Selection of bridge type, component details, access requirements, effect of considering security in recent years, and other aspects are discussed based on the input received from bridge inspectors working for the New York State Department of Transportation.

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REFERENCES