Figure 3. Close-up views of the components of the bridge.
Photos by A. Astaneh-Asl.

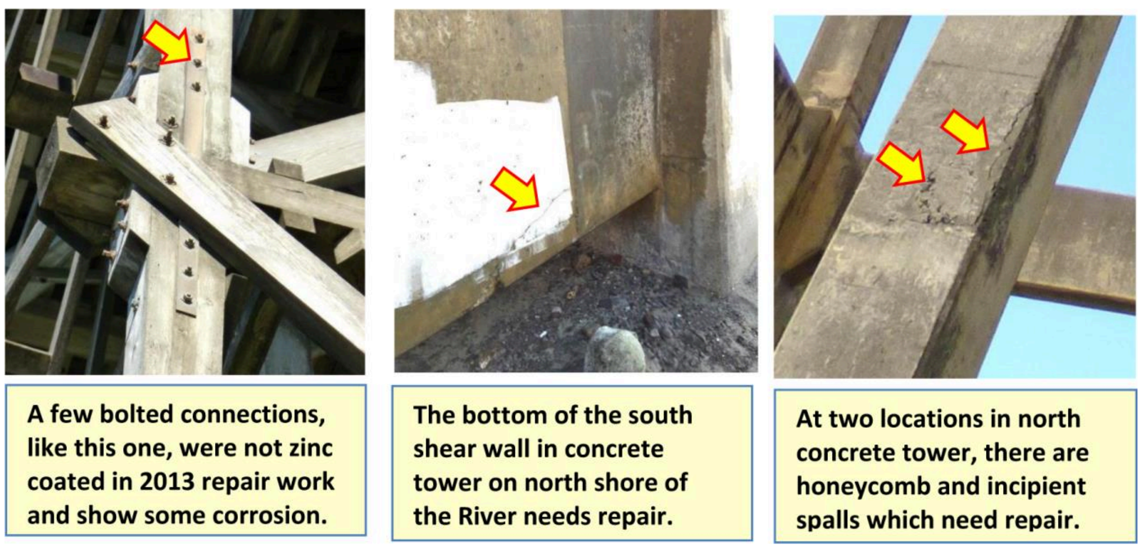

Figure 4. Areas of the bridge that need repair.
Photos by A. Astaneh-Asl.

Although much of the bridge is structurally sound, as Figure 4 suggests, a few areas require repair or maintenance. However, none of these areas currently affect the integrity or safety of the bridge.

CONDITION RATINGS OF THE ELEMENTS OF THE ALBION RIVER BRIDGE

Table 1 summarizes the current condition ratings of elements of the Albion River Bridge. Some of these, especially the timber elements, were incorrectly assigned lower condition states in the 2015 Routine Inspection Report (Caltrans, 2016), or their condition has improved due to repairs conducted since the report was issued. In the table below, these changes are identified by the superscript letters "a, b, …" and are explained in the footnotes. The author used AASHTO (2013) for the condition ratings.

Table 1. Inspection Ratings of All Albion River Bridge Elements

El. No.n	Element Description	Total Quantity	Units	GOOD	FAIR	POOR	SEVERE
31	Deck-Timber	2,549	Sq. meter	**2,549**	**0**	**0**	**0**
117	Stringer-Timber	4,332	meter	**4,332**	**0**	**0**	**0**
120	Truss-Steel	79	meter	**79**	**0**	**0**	**0**
135	Truss-Timber	254	meter	**254**	**0**	**0**	**0**
156	Floor Beam-	868	meter	**867**	**0**	**0**	**0**
205	Column-Reinf.	8	each	**7**	**1**[a]	**0**	**0**
206	Column-Timber	214	each	**214**	**0**	**0**	**0**
208	Trestle-Timber	716	meter	**716**	**0**	**0**	**0**
210	Pier Wall-Reinf.	58	meter	**48**	**10**[b & c]	**0**	**0**
215	Abutment-Reinf.	22	meter	**22**	**0**	**0**	**0**
227	Pile-Reinf. Conc.	1	each	**1**	**0**	**0**	**0**
228	Pile-Timber	1	each	**1**	**0**	**0**	**0**
234	Pier Cap-Reinf.	33	meter	**33**	**0**	**0**	**0**
235	Pier Cap-Timber	69	meter	**69**	**0**	**0**	**0**
304	Joint Open	17	meter	**17**	**0**	**0**	**0**
311	Bearing Movable	2	each	**2**	**0**	**0**	**0**
313	Bearing Fixed	2	each	**2**	**0**	**0**	**0**
332	Railing-Timber	949	meter	**949**	**0**	**0**	**0**
510	Wearing Surface-Asphalt	2,340	Sq. meter	**2,340**	**0**	**0**	**0**

Footnotes:
[a] One of the reinforced concrete columns in Bent 14 has an incipient spall as shown in the right side photo in Figure 4. The damage must be investigated for structural ramifications and be repaired.
[b] One of the reinforced concrete pier walls in Bent 13 has a crack at the bottom as shown in the middle photo in Figure 4. This defect is not mentioned in the Caltrans 2015 Routine Inspection Report and is noted by the author. The damage must be repaired.
[c] One of the reinforced concrete pier walls in Bent 13 has an incipient spall at the corner, which is not mentioned in the Caltrans 2015 Routine Inspection Report. The damage must be investigated for structural ramifications and be repaired.

Table 1 demonstrates that all the timber and steel elements of the Albion River Bridge are in "State 1: Good" condition. The only minor areas of damage are a reinforced concrete column and pier wall, which show a crack at one location and incipient spalls at two others. All three damaged areas must be investigated structurally and appropriate repair plans must be developed and implemented. After these repairs, all elements of the Albion River Bridge will have a current condition rating of good.

This assessment would not be complete without summarizing the condition of the threaded rods (i.e., bolts) and nuts in the connections of the timber elements. Currently, thanks to Caltrans and its contractor's efforts during the 2013 maintenance operations, almost all the threaded rods, and their nuts are in "good" condition. However, due to environmental corrosion and water dropping from above, a small number of nuts show deterioration and loss of sections. It is suggested that Caltrans, in consultation with the bolt manufacturers, use galvanized threaded rods, washers, and nuts and protect the bolt heads and nuts by using plastic or metallic non-corroding caps and covers, which are commonly utilized in bolted structures subjected to corrosion.

STRUCTURE INVENTORY AND APPRAISAL REPORT

**************** IDENTIFICATION ***************

(1) STATE NAME- CALIFORNIA 069
(8) STRUCTURE NUMBER 10 0136
(5) INVENTORY ROUTE(ON/UNDER)- ON 131000010
(2) HIGHWAY AGENCY DISTRICT 01
(3) COUNTY CODE 045 (4) PLACE CODE 00000
(6) FEATURE INTERSECTED- ALBION RIVER
(7) FACILITY CARRIED- STATE ROUTE 1
(9) LOCATION- 01-MEN-001-43.74
(11) MILEPOINT/KILOMETERPOINT 43.74
(12) BASE HIGHWAY NETWORK- PART OF NET 1
(13) LRS INVENTORY ROUTE & SUBROUTE 000000000101
(16) LATITUDE 39 DEG 13 MIN 30.32 SEC
(17) LONGITUDE 123 DEG 46 MIN 09.83 SEC
(98) BORDER BRIDGE STATE CODE % SHARE %
(99) BORDER BRIDGE STRUCTURE NUMBER

******** STRUCTURE TYPE AND MATERIAL *********

(43) STRUCTURE TYPE MAIN:MATERIAL- STEEL
TYPE- TRUSS - DECK CODE 309
(44) STRUCTURE TYPE APPR:MATERIAL- WOOD OR TIMBER
TYPE- STRINGER/MULTI-BEAM OR GDR CODE 702
(45) NUMBER OF SPANS IN MAIN UNIT 1
(46) NUMBER OF APPROACH SPANS 33
(107) DECK STRUCTURE TYPE- TIMBER CODE 8
(108) WEARING SURFACE / PROTECTIVE SYSTEM:
A) TYPE OF WEARING SURFACE- BITUMINOUS CODE 6
B) TYPE OF MEMBRANE- NONE CODE 0
C) TYPE OF DECK PROTECTION- NONE CODE 0

*************** AGE AND SERVICE ***************

(27) YEAR BUILT 1944
(106) YEAR RECONSTRUCTED 0000
(42) TYPE OF SERVICE: ON- HIGHWAY 1
UNDER- WATERWAY 5
(28) LANES:ON STRUCTURE 02 UNDER STRUCTURE 00
(29) AVERAGE DAILY TRAFFIC 2100
(30) YEAR OF ADT 2009 (109) TRUCK ADT 6 %
(19) BYPASS, DETOUR LENGTH 51 KM

*************** GEOMETRIC DATA ***************

(48) LENGTH OF MAXIMUM SPAN 39.6 M
(49) STRUCTURE LENGTH 295.4 M
(50) CURB OR SIDEWALK: LEFT 0.0 M RIGHT 0.0 M
(51) BRIDGE ROADWAY WIDTH CURB TO CURB 7.9 M
(52) DECK WIDTH OUT TO OUT 8.6 M
(32) APPROACH ROADWAY WIDTH (W/SHOULDERS) 7.3 M
(33) BRIDGE MEDIAN- NO MEDIAN 0
(34) SKEW 0 DEG (35) STRUCTURE FLARED NO
(10) INVENTORY ROUTE MIN VERT CLEAR 99.99 M
(47) INVENTORY ROUTE TOTAL HORIZ CLEAR 7.9 M
(53) MIN VERT CLEAR OVER BRIDGE RDWY 99.99 M
(54) MIN VERT UNDERCLEAR REF- NOT H/RR 0.00 M
(55) MIN LAT UNDERCLEAR RT REF- NOT H/RR 0.0 M
(56) MIN LAT UNDERCLEAR LT 0.0 M

*************** NAVIGATION DATA ***************

(38) NAVIGATION CONTROL- BR PERMIT REQ CODE 1
(111) PIER PROTECTION- NOT REQUIRED CODE 1
(39) NAVIGATION VERTICAL CLEARANCE 50.0 M
(116) VERT-LIFT BRIDGE NAV MIN VERT CLEAR M
(40) NAVIGATION HORIZONTAL CLEARANCE 35.7 M

SUFFICIENCY RATING = 15.3
STATUS STRUCTURALLY DEFICIENT
HEALTH INDEX 81.7
PAINT CONDITION INDEX = 100.0

*************** CLASSIFICATION *************** CODE

(112) NBIS BRIDGE LENGTH- YES Y
(104) HIGHWAY SYSTEM- NOT ON NHS 0
(26) FUNCTIONAL CLASS- MINOR ARTERIAL RURAL 06
(100) DEFENSE HIGHWAY- NOT STRAHNET 0
(101) PARALLEL STRUCTURE- NONE EXISTS N
(102) DIRECTION OF TRAFFIC- 2 WAY 2
(103) TEMPORARY STRUCTURE-
(105) FED.LANDS HWY- NOT APPLICABLE 0
(110) DESIGNATED NATIONAL NETWORK - NOT ON NET 0
(20) TOLL- ON FREE ROAD 3
(21) MAINTAIN- STATE HIGHWAY AGENCY 01
(22) OWNER- STATE HIGHWAY AGENCY 01
(37) HISTORICAL SIGNIFICANCE- ELIGIBLE 2

***************** CONDITION ***************** CODE

(58) DECK 7
(59) SUPERSTRUCTURE 7
(60) SUBSTRUCTURE 3
(61) CHANNEL & CHANNEL PROTECTION 8
(62) CULVERTS N

********** LOAD RATING AND POSTING ********** CODE

(31) DESIGN LOAD- M-13.5 OR H-15 2
(63) OPERATING RATING METHOD- LOAD FACTOR 1
(64) OPERATING RATING- 30.8
(65) INVENTORY RATING METHOD- LOAD FACTOR 1
(66) INVENTORY RATING- 22.7
(70) BRIDGE POSTING- EQUAL TO OR ABOVE LEGAL LOADS 5
(41) STRUCTURE OPEN, POSTED OR CLOSED- A
DESCRIPTION- OPEN, NO RESTRICTION

*************** APPRAISAL *************** CODE

(67) STRUCTURAL EVALUATION 3
(68) DECK GEOMETRY 3
(69) UNDERCLEARANCES, VERTICAL & HORIZONTAL N
(71) WATER ADEQUACY 9
(72) APPROACH ROADWAY ALIGNMENT 8
(36) TRAFFIC SAFETY FEATURES 0010
(113) SCOUR CRITICAL BRIDGES 5

********** PROPOSED IMPROVEMENTS **********

(75) TYPE OF WORK- DECK REPLACEMENT CODE 37
(76) LENGTH OF STRUCTURE IMPROVEMENT 295.4 M
(94) BRIDGE IMPROVEMENT COST $2,540,000
(95) ROADWAY IMPROVEMENT COST $508,000
(96) TOTAL PROJECT COST $4,267,200
(97) YEAR OF IMPROVEMENT COST ESTIMATE 2010
(114) FUTURE ADT 5182
(115) YEAR OF FUTURE ADT 2037

*************** INSPECTIONS ***************

(90) INSPECTION DATE 10/15 (91) FREQUENCY 24 MO
(92) CRITICAL FEATURE INSPECTION: (93) CFI DATE
A) FRACTURE CRIT DETAIL- YES 24 MO A) 03/14
B) UNDERWATER INSP- NO MO B)
C) OTHER SPECIAL INSP- NO MO C)

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Figure 5. The latest (2015) Structure Inventory and Appraisal Report for the Albion River Bridge (Source: Caltrans Albion River Bridge 2015 Routine Inspection Report).

Table 2. Caltrans Condition Rating Numbers for the Albion River Bridge, 2001 to 2015

Line No.	Item No.	Item in the Structure Inventory & Appraisal Report	Year of Routine Inspection							
			2001	2003	2005	2007	2009	2011	2013	2015
1	HI	California Health Index	91.05	82.4	82.4	78.6	79.4	79.4	93.5	81.7
2	58	Deck Condition Rating	6	6	6	5	6	5	5	7
3	59	Superstructure Condition Rating	7	6	6	6	6	6	7	7
4	60	Substructure Condition Rating	6	6	6	6	6	6	7	3
5	67	Structural Evaluation Appraisal Rating	6	6	6	6	6	6	6	3
6	SR	Sufficiency Rating	71.5	70.3	69.3	68.2	69.0	74.8	63.9	15.3
7	-	Status	Structurally Not Deficient	Structurally Not Deficient	Structurally Not Deficient	Structurally Not Deficient	Structurally Not Deficient	Structurally Not Deficient	Structurally Not Deficient	Structurally Deficient

STRUCTURE INVENTORY AND APPRAISAL REPORT

The FHWA National Bridge Inspection Standards (NBIS, 2004) require that all bridges on public roads with a length of more than 20 ft be inspected every 24 months. The findings of these inspections are summarized in the Routine Bridge Inspection Report (BIR). At the end of the BIR is a single page named the Structural Inventory and Appraisal (SI&A) Report sheet, which provides the key documentation on the current condition of a bridge. Updated every two years, this report sheet is prepared by the states' Departments of Transportation (DOTs), such as Caltrans, and is submitted to the FHWA and its National Bridge Inventory (NBI) Database (NBI, 2016.) By law, all the information on a SI&A Report sheet must be accurate and be based only on the bridge's current condition, as assessed during the latest routine inspection and in other inspection reports. Figure 5 shows the latest SI&A report for the Albion River Bridge (Caltrans, 2016.)

The SI&A Report sheet describes the bridge's location and structure, details its condition, and makes suggestions for improvement. All bridge management decisions, such as funding for repair, rehabilitation, or replacement, are based primarily on the information in the SI&A Report sheet. The FHWA assumes that this sheet contains only the most current and accurate data resulting from actual inspections. Table 2 shows the main items in the SI&A Report sheet for the Albion River Bridge since 2001.

Based on a review of the 2011–2015 SI&A Report sheets for the Albion River Bridge, as summarized in Tables 1 and 2, the author reached the following conclusions:

1. The California Health Index (CHI), expressed as a percentage, is a measure of the condition of bridges in the state. It is the most important parameter that Caltrans uses in deciding whether these structures should be repaired, rehabilitated, or replaced.

According to Figure 6, from 2001 to 2015, the California Health Index for the Albion River Bridge varied from a minimum of 78.6% in 2007 to a maximum of 93.5% in 2013. In 2015, when the latest inspection was performed, the CHI was 81.7%. The stated goal of Caltrans (TRB, 2001) is to have no more than 5% of the state's bridges with a CHI below 80%. This is done by allocating funding for repair and rehabilitation. Currently, more than 15% of bridges in Caltrans's District 1, where the Albion River Bridge is located, fall below this level (TRB, 2001). Given that the bridge has a CHI of 81.7%, it is impossible for this author to understand the justification for spending more than $66 million on its rehabilitation or replacement when others with a CHI below 80% demand the state's attention.

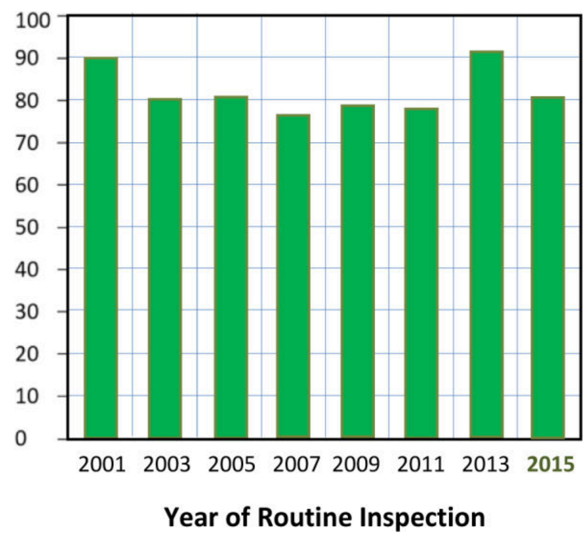

Figure 6. Variation of the "California Health Index" for the Albion River Bridge between 2001 and 2015

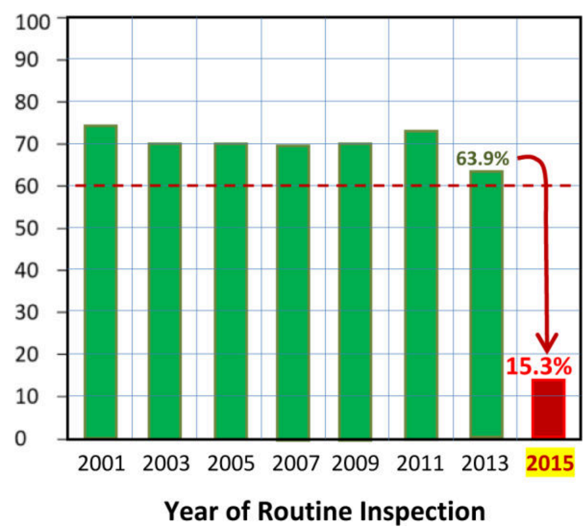

Figure 7. Variation of the "FHWA Sufficiency Rating" for the Albion River Bridge between 2001 and 2015

2. Figure 7 shows the variation of the sufficiency rating. The FHWA uses this measure of the current condition of a bridge in allocating federal funding for its rehabilitation and

replacement. If a bridge's sufficiency rating is less than 60%, it is eligible for financial support. From 2001 to 2013, the sufficiency rating for the Albion River Bridge ranged from a minimum of 63.9% in 2013 to a maximum of 71.5% in 2001. However, in 2015, its rating suddenly dropped to 15.3%. The sufficiency rating is calculated using equations and guidelines provided by the FHWA (1995). Using the values and parameters in the equations based on the current condition of the bridge, the sufficiency rating should be more than 60%, not 15.3% as Caltrans reports. The drop in the sufficiency rating from 63.9% in 2013 to 15.3% in 2015 is clearly erroneous and does not reflect the actual condition of the bridge. A recalculation correctly results in a sufficiency rating of more than 60%. According to the FHWA, this value makes the Albion River Bridge ineligible for federal funding for rehabilitation or replacement.

CONCLUSIONS

Based on the Routine Inspection Reports and the Structure Inventory and Appraisal Reports filed with the FHWA National Bridge Inventory Database from 2001through 2013, the Albion River Bridge was not considered "structurally deficient." However, the 2015 Routine Inspection Report and the SI&A Report sheet submitted by Caltrans to the FHWA National Bridge Inventory in 2016 reversed these findings, designating it as "structurally deficient" (Caltrans, 2016; Pogash, 2015) without the data required to justify such a conclusion. It appears that the substructure of the bridge, which was rated as "7: Good condition" in 2013, has been downgraded to a rating of "3: Serious condition." It is difficult to understand how Caltrans came to this decision, given that the actual condition rating of the substructure is still a 7 and that the conclusion of the bridge's structural integrity based on actual inspection data remains "structurally not deficient."

The following is an excerpt from the website of the FHWA National Bridge Inspection Standards, which govern how inspections are conducted and reported to the National Bridge Inventory Database. It outlines the quality assurance and quality control (QA/QC) processes that state Departments of Transportation such as Caltrans should implement to ensure that the data reported to the FHWA are *current* and *accurate*. It appears that in this case, Caltrans has not satisfied the QA/QC requirements and has reported erroneous inspection data by unjustifiably changing the condition of the substructure from "7: Good" to "3: Serious," and then incorrectly claiming that the bridge is "structurally deficient."

> 23 CFR 650.313(g) Quality Control and Quality Assurance requires each state to assure that systematic Quality Control (QC) and Quality Assurance (QA) procedures are being used to maintain a high degree of accuracy and consistency in the inspection program. Accuracy and consistency of the data is important since the bridge inspection process is the foundation of the entire bridge management operation and bridge management systems. Information obtained during the inspection is used for determining needed maintenance and repairs, for prioritizing rehabilitations and replacements, for allocating resources, and for evaluating and improving design for new bridges. The accuracy and consistency of the inspection and documentation is vital because it not only impacts programming and funding appropriations, it also affects public
>
> (Excerpts from FHWA, 2017

According to the 2016 Annual Bridge Report by the American Road & Transportation Builders Association (ARTBA, 2016), California has 25,318 bridges on public roads, roughly half of them under the jurisdiction of Caltrans. Of this total, 7.9%, or 2,009, are considered structurally deficient. From a bridge management, as well as an engineering and economic, point of view, bridges that are considered structurally deficient should receive priority in the allocation of public transportation funds. Such funds should not be spent on bridges that have previously been deemed structurally sound. In 2015, the Albion River Bridge was, for the first time in years, labeled as structurally deficient based on a faulty condition rating assessment, not on actual inspection data.

The author, after spending more than three years studying the actual condition of the Albion River Bridge and reviewing numerous documents and inspection reports, recommends that Caltrans correct the inaccurate designation of the bridge as structurally deficient and that it reclassify it as structurally not deficient. In addition, instead of spending more than $66 million to rehabilitate or replace a bridge that has a California Health Index of 82% and whose deck, superstructure and substructure all have a rating of "7: Good condition," it is highly recommended that scarce public funds be spent on the more than 1,000 bridges in California that are correctly and legitimately rated as structurally deficient.

ACKNOWLEDGEMENTS

The author performed this study as a consulting project for Mr. John Danhakl, a property owner in Albion. His support is sincerely appreciated. The opinions expressed in this document are those of the author and do not necessarily represent the views of the University of California, Berkeley, where he is a professor, nor those of the individuals and agencies cited therein.

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Timber Bridge Inspection Using UAV

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ABSTRACT

Unmanned aerial vehicle (UAV)-enabled bridge inspection has gained more interest over recent years among bridge owners, researchers, and stakeholders due to inefficiency and high cost of conventional access inspection techniques. A large number of deteriorating bridges can be efficiently inspected using UAVs equipped with various sensors. In fact, some departments of transportation (DOTs) (e.g., Minnesota DOT) in cooperation with research institutions have investigated the effectiveness of UAVs as a cost-efficient bridge inspection alternative. Based on the findings from the projects done by the DOTs in their states, this paper is intended to demonstrate the effectiveness of a UAV by inspecting a timber arch bridge in the State of South Dakota (SD). The bridge inspection using UAV was completed based on multiple analyses of high-resolution images and videos recorded from the UAV. Further, the use of a pixel-based damage quantification methodology provided a quantifiable value for the observed damage. The visual results obtained from the UAV-based bridge inspection were compared to those from the past inspection reports from SDDOT. The comparison of results demonstrated the ability of the UAV to identify damage. It is expected that this emerging technology will supplement routine bridge inspections conducted with conventional methods.

INTRODUCTION

For over a decade, the American Society of Civil Engineers (ASCE) has evaluated the structural integrity of the United States' infrastructure. Every four years, the ASCE releases a report card summarizing the results for different infrastructure, including bridges. The last issue revealed that approximately 9.1% of the 614,387 in-service bridges were classified as structurally deficient (ASCE 2016). A significant decrease in deficient bridges from over 12% in 2007 to 9.1% in 2016 demonstrates the commitment of ASCE to repair and enhance their structural integrity. Although some progress has been made over recent years, it was reported that the bridge rehabilitation backlog exceeds $123 billion USD. Additionally, over 44% of the 614,387 in-service bridges are over 40 years old and are approaching the end of their service life. Due to the increasing costs and limited accessibility of bridge inspection with current inspection technology, the use of remote-controlled drones equipped with high-resolution cameras may shed light on efficient and effective bridge inspection (Hallermann and Morgenthal 2014).

In recent years, the field of civil engineering has observed a significant increase in the use of drone technology to inspect and monitor infrastructure, especially bridges (Khaloo et al. 2017; Lovelace and Zink 2015; Moller 2008; Otero 2015). The interest of different state Departments of Transportation (DOTs) and other governmental organizations, such as the United States Department of Agriculture – Forest Service (USDA – FS), has provided significant findings on the drone technology. For instance, Moller (2008) developed a drone prototype during the early stages of the technology growth for bridge inspection for the Caltrans project. The drone prototype was a twin-motor, single-duct, electric-powered system designed to carry cameras and other sensors to observe damage on bridges.

The Florida DOT (FDOT) in junction with Otero (2015) utilized a multi-rotor drone coupled with high-definition cameras to inspect different types of bridges. During the inspection, stress cracks on the timber stringers were observed with the aid of the high-quality imagery data from the drone. Additionally, a more comprehensive evaluation of the drone capabilities to investigate bridges was conducted by the Minnesota DOT (MnDOT) in partnership with Lovelance and Zink (2015). Four different types of bridges were inspected in the state of Minnesota including a long single span prestressed concrete bridge, an open spandrel concrete arch bridge, a five-span steel underdeck truss bridge, and an arch truss bridge. The research project demonstrated the capability and advantages of the drone to efficiently observe damage the considered bridge types. The USDA – FS and Khaloo et al. (2017) developed an aerial platform based on the DJI S800 airframe with Gyrostabilized Sony Nex7 and GoPro cameras to inspect the Placer River Trail Bridge in the Alaskan Kenai Peninsula. It was found that the drone was able to gather sufficient data to recreate the bridge in 3D virtual space to observe damage on the structure.

The main objective of this study was to identify the capabilities of drones as supplemental tools for the inspection of bridges. The efficiency of the structural damage identification was studied by executing drone-enabled inspection of an identified bridge in South Dakota (SD). The inspection of the bridge considered state and federal regulations (e.g., SDDOT and Federal Aviation Administration (FAA)). This study is subdivided into six different section, including this section. The second section details the selected drone and bridge to perform this study. The third section shows the bridge inspection approach, including a damage quantification method used to evaluate the damage on the bridge. The fourth section presents the results gathered from the damage identification and its comparison with historical inspection reports from SDDOT. The final section presents conclusions derived from this inspection work.

DRONE AND BRIDGE SELECTION

Prior to conducting the bridge inspection, a suitable drone and bridge structure were first selected. A drone platform capable of safely flying near a target structure with high-resolution cameras was needed, while the bridge having accessibility limitations was required to check the effectiveness of the drone inspection. The following subsections detail the drone and bridge selection.

Drone Selection

A variety of considerations were analyzed prior to selecting a drone. Specifically, the study done by Otero (2015) recommended that various drone specifications, including user-controls/interface, maneuverability, software capability, adaptability, size, and payload, be considered when selecting a drone for the bridge inspection. It can be noted that the conclusion of the Otero's study considered the DJI Phantom 2 (the latest DJI Phantom series drone on 2015) as a suitable drone. Based upon the recommendation from the study, the DJI Phantom 4, which is the latest version of DJI drones, was considered an appropriate drone for this study. The drone contains obstacle avoidance technology and capability to fly without Global Positioning System (GPS) signal for the underside of deck observation, enabling it to conduct the bridge inspection safely. The drone (see Fig. 1) was also satisfactory with additional criteria, including fly time,