A Field Assessment of Timber Highway Bridge Durability in the United States

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Abstract

This paper summarizes a cooperative project to assess the current condition and life expectancy of 132 timber highway bridge superstructures at locations throughout the United States. Several superstructure types were included in this comprehensive effort, of which two-thirds were sawn timber stringer systems. In-depth inspections were conducted by the project team using visual, probing, and nondestructive evaluation (NDE) techniques to characterize the condition of the primary bridge superstructure components. The condition of the bridges was satisfactory and better for large percentages of the superstructure subsets, even within those regions of the country that have higher hazard ratings for exposed wood structures. Inspection results show that timber is a viable option for primary structural members in highway bridges with satisfactory service-life estimation of 70 years or more. These results shall provide the basis for the development of life-cycle cost analyses and bridge deterioration rate modeling for timber bridge superstructures in the future.

INTRODUCTION

A recent analysis of the National Bridge Inventory (FHWA 2010) indicated more than one-third of the states have more than 500 timber bridges in their inventories (see Figure 1). As many engineers begin to implement life cycle cost analyses within the preliminary bridge design phase, there is a significant need for more reliable data on the expected service life of highway bridges. Many claims are being made about the expected longevity of concrete and steel bridges being 75 years or more, but often these are not based on actual performance data. Because engineers are least familiar with timber bridges, their expected longevity is typically estimated at only 20-30 years. Limited data exists about timber bridge service life, and studies only report on the regional performance attributes. Additional research is needed on a national scale that provides more reliable data about the longevity of timber bridges.

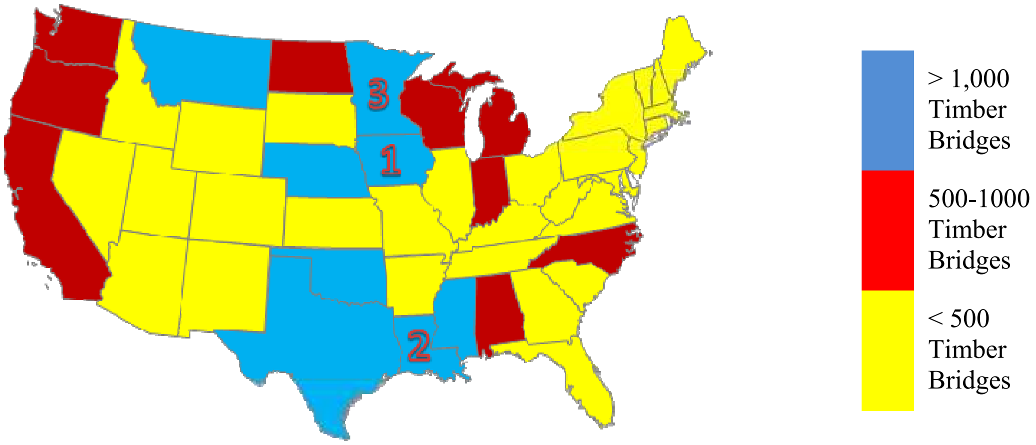

Figure 1. Graphical representation of state timber bridge inventories in the contiguous USA. Iowa, Louisiana, and Minnesota have the most timber bridges.

In order to generate more quantitative and unbiased data on timber bridge durability, the Forest Products Laboratory (FPL) in conjunction with the Federal Highway Administration (FHWA) designed a nationwide study. The goal of this multi-year, team effort was to assess the condition of more than 100 timber bridge superstructures located throughout the United States under various service conditions. The results will provide a better understanding of the design, performance, and durability characteristics of timber bridge structures, and shall provide the basis for the development of life-cycle cost analyses and bridge deterioration rate modeling for timber bridge superstructures in the future.

PROJECT TEAMS

The project was conducted by a team approach, with six different inspection teams with members from various organizations. Each team represented their specific U.S. region and was responsible for selecting and inspecting several timber bridges. These organizations included Iowa State University, Laminated Concepts Inc., Louisiana Transportation Research Center, Mississippi State University, Rogue River-Siskiyou National Forest, Tom Williamson Timber Engineering LLC, the University of Minnesota Duluth, University of New Orleans, and the USDA Forest Service.

BRIDGE SELECTION AND LOCATIONS

The timber bridges selected for this study were from states that have significant timber bridge inventories greater than 500 bridges. Many of them were located in the central and eastern regions of the country. In conducting field inspections, safe and economical access to the bridge underside was a top priority. Selected timber bridges for inspection were required to be located along a public roadway and been in-service for at least 16 years in order to be considered for inclusion in this study. Lastly, bridge inspection, maintenance, and repair records had to be made available for review by the inspection teams, in order to identify previous bridge component

Figure 2. Location of all 132 bridges inspected within this study.

Table 1. Summary of bridge superstructure types and state breakdown.

		Deck type	Total	AL	CA	GA	IA	LA	MD	MN	MS	NC	NY	OR	TN	WA	WI
Girder Systems	Sawn	Timber plank	46	5	1	5	10	9		1	8	2		2	3		
		Nail-laminated	19		1					3				5		10	
		Plank/ Tr. Beam	5		1												4
		Concrete	15	4				2				4			4	1	
	Glulam	Nail-laminated	6		1					5							
		Concrete	3		3												
		Glulam transverse	5			1							4				
	Steel	Timber plank	2			2											
		Nail-laminated	5							5							
Slab Systems		**Deck type**															
	Sawn	Spike-Laminated	17				5		5	4				3			
	Conc. Sawn	Spike-Laminated	1			1											
	Glulam	Long. glulam	8										6	2			

Note: AL-Alabama, CA-California, GA-Georgia, IA-Iowa, LA-Louisiana, MD-Maryland, MN-Minnesota, MS-Mississippi, NC-North Carolina, NY-New York, OR-Oregon, TN-Tennessee, WA-Washington, WI-Wisconsin.

upgrades or replacement activities. See Figure 2 and Table 1 for a summary of bridges evaluated.

A total of 132 timber bridges had field assessments performed during the two year period ending in the fall of 2013. Bridges were located in several different climate regions of the U.S., with a large majority located in the central and eastern regions of the country. Girder systems and slab-deck superstructure types were evaluated. These superstructures were constructed of sawn lumber and glued laminated timber (glulam) materials. Nearly all bridges were built with either Douglas fir or Southern pine species, and were pressure-treated with creosote or pentachlorophenol oil-type preservatives. Bridge locations within their AWPA hazard decay zones are depicted in Figure 3. The American Wood Protection Association originally developed this hazard decay map for wood utility poles, and we adopted it for use in this study.

INSPECTION PROCEDURES

Each team conducted bridge inspection work using the protocol that was demonstrated during the initial project meeting and described in the detailed study plan. This ensured that a reliable dataset was produced regarding the performance of timber bridges. All data was documented through onsite sketches, high-resolution digital photos and videos.

Pre-Inspection Protocol. Prior to inspection, a careful review of design plans and any prior inspection and maintenance work was recommended. This review identified bridge areas that have had problems or been noted in the past. These areas were then a focus area during the in-depth bridge inspection. Teams were encouraged to interview the bridge owner about the bridge and any previous problems noted and to obtain previous inspection and/or repair records. A spreadsheet template was provided for all inspection teams to assist with creating data consistency.

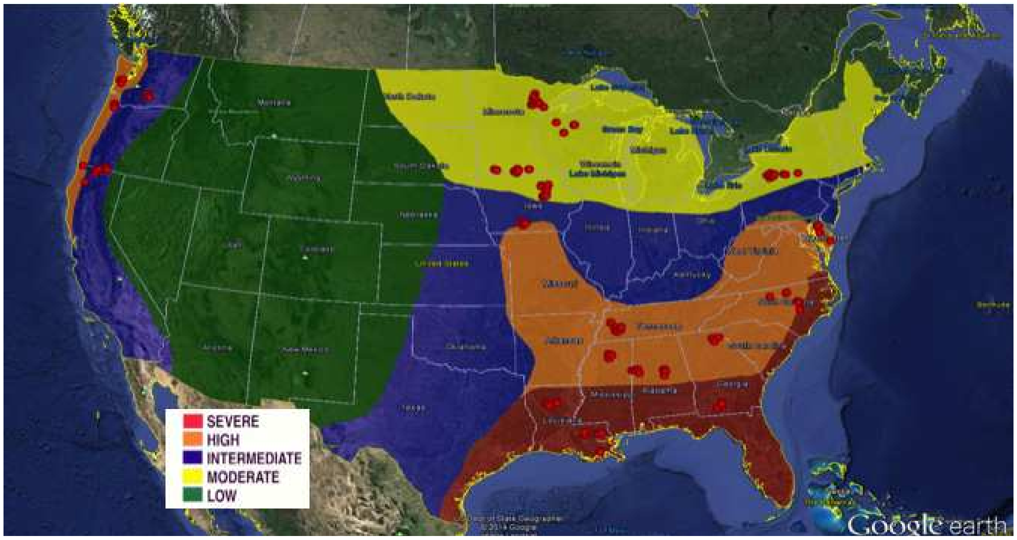

Figure 3. Bridge locations within the five AWPA-defined hazard decay zones.

Inspection Protocol. Inspection procedures included visual observations and supplementary nondestructive evaluation (NDE) tools including hammer sounding, moisture meters, stress wave timer, and a resistance microdrilling tool. Detailed information about these procedures is also available (White and Ross 2014).

Comprehensive inspection protocols for timber bridges include a wide variety of techniques to assess the condition of wood in service. The simplest method for locating deterioration is visual inspection. An inspector observes the bridge elements for signs of actual or potential deterioration, noting areas that require further investigation. However, visual inspection should never be the only method used.

One of the most commonly used techniques for detecting deterioration is to hit the surface of a member with a hammer or other object. Based on the sound quality or surface condition, an inspector can identify areas of concern for further investigation using advanced tools like a stress wave timer or resistance microdrill. Deteriorated areas typically have a hollow or dull sound that may indicate internal decay.

Moisture meters can effectively be used in conducting inspections of timber bridge elements. It is well documented that the presence of moisture is required for decay to occur in timber. Typically, moisture conditions in timber of less than 20 percent will not allow decay to occur. However, as the moisture increases above 20 percent, the potential for decay increases. Serious decay occurs only when the moisture content of the wood is above 28-30 percent. Pin style moisture meters determine the electrical resistance between two metal pins that are driven into the member, using this information to determine actual moisture content values. A hammer slide is used to drive the pins into the member.

Stress wave timing is an effective method for locating and defining areas of decay in timber bridges. Stress wave propagation in wood is a dynamic process that is directly related to the physical and mechanical properties of wood. In general, stress waves travel faster in sound and high quality wood than in deteriorated and low quality wood. By measuring wave transmission time through a timber bridge stringer, pile cap or piling in the radial direction, the internal condition of the structural element can be fairly accurately evaluated.

The resistance drill system measures the resistance of wood members to a 1.5-mm drill bit with a 3.0-mm head that passes through them. The drill bit is fed at a fixed movement rate allowing the inspector to determine the exact location and extent of the damaged area. This system produces a chart showing the relative resistance over its travel path. This technique is now the preferred drilling and coring technique for timber bridge members. Areas of sound wood have varying levels of resistance depending on the density of the species and voids show no resistance.

Based upon the collective dataset from bridge inspections, each team was required to assign numerical ratings for the bridge deck and the superstructure according to the NBI bridge condition code rating description shown in Table 2.

Table 2. Rating scale used for timber bridge inspections.

Condition Rating Code	FHWA/NBI Condition Rating Description
N	NOT APPLICABLE
9	EXCELLENT CONDITION - New or like new condition.
8	VERY GOOD CONDITION - No problems noted.
7	GOOD CONDITION - Some minor problems but no structural defects at critical locations (wood decay is a defect).
6	SATISFACTORY CONDITION - Structural elements show some minor defects and/or deterioration at critical locations. No measureable section loss.
5	FAIR CONDITION - All primary structural elements are sound but may have minor to moderate defects and/or deterioration with measurable section loss at critical locations. No significant reduction in primary structural member load carrying capacity.
4	POOR CONDITION - Primary structural elements show moderate to serious defects, deterioration, corrosion, cracking, crushing, and/or scour. Advanced section loss at critical locations. Diminished load carrying capacity of members is evident.
3	SERIOUS CONDITION - Serious and widespread defects have substantially reduced load carrying capacity of primary structural members. Local failures may be evident. Deflection/misalignment of members may be evident. Signs of severe structural stress are visible. Fatigue cracks in steel, shear cracks in concrete, and severe decay, checking, splitting, and crushing of beams or stringers in wood elements may be present.
2	CRITICAL CONDITION - Advanced deterioration of primary structural elements. Defects have now resulted in significant local failures. Scour may have removed substructure support. Unless closely monitored it may be necessary to close the bridge until corrective action is taken.
1	IMMINENT FAILURE CONDITION - Major deterioration or section loss present in critical structural components and/or obvious vertical or horizontal movements affecting structure stability. Bridge is/should be closed. However, correction action may put bridge back in light service.
0	FAILED CONDITION - Out of service. Beyond corrective action.

FHWA/NBI–Federal Highway Administration/National Bridge Inventory

RESULTS

Summary results are provided herein based upon the superstructure type and its hazard decay zone location. Detailed results are also available for several U.S. hazard decay zones (see Brashaw et al 2013; Hosteng et al 2013; Jones et al 2013; Gopu and Wacker 2013; and Williamson et al 2013).

The sawn girder superstructure type represented 64 percent (85) of the 132 bridges evaluated. The sawn girder bridge clusters were located in four of five wood hazard zones as defined by the AWPA. 61 percent of the sawn girder bridges supported a plank deck system. This system proved to have a good record on longevity in many wood hazard (climate) zones. About 75 percent of the bridge decks and superstructures in the moderate and intermediate wood hazard zones were rated at satisfactory and better condition with NBI ratings between 6 and 9. Nearly 83 percent of the bridge decks and superstructures inspected in the high wood hazard zone were rated at satisfactory and better condition with NBI ratings between 6 and 9. Only 41 percent of the bridge decks and 29 percent of the superstructures in the severe wood hazard zone were rated satisfactory and better with NBI ratings between 6 and 9 . The advantage of this superstructure type may lie in its member redundancy (i.e., closely spaced girders) that enhances the overall resiliency of the structural system.

The glulam girder superstructure type represented 10 percent of the 132 bridges evaluated. No glulam girder bridges were inspected in the low or severe hazard zones. For the moderate, intermediate and high zones, 100 percent of the decks and 100 percent of the girder superstructure had NBI ratings of 6-9 (satisfactory and better). However, due to a relatively low number of glulam girder bridges (13 total) inspected within this study, it will prove difficult to draw substantive conclusions about their durability performance in the various wood hazard (climate) zones, or any potential role that the deck type may contribute to bridge longevity.

Steel beam with timber deck superstructure type represented 6 percent of the 132 bridges evaluated. No steel beam timber deck bridges were inspected in the low, intermediate or severe hazard zones. For the moderate zone, 100 percent of the decks and 100 percent of the beam superstructure had NBI ratings of 6-9 (satisfactory and better). In the high zone, 100 percent of the deck system had NBI ratings of 6-9 (satisfactory and better), and 50 percent of the steel superstructure had NBI ratings of 1-4 (poor and worse) and 50 percent had NBI ratings of 5 (fair). However, due to a relatively low number of steel beam bridges (7 total) inspected within this study, it will prove difficult to draw substantive conclusions about their durability performance in the various wood hazard (climate) zones, or any potential role that the deck type may contribute to bridge longevity.

The sawn lumber spike laminated superstructure type represented 18 bridges (13.6 percent) of the 132 bridges evaluated. These sawn slab-deck bridge clusters were located in three of five possible wood hazard zones. For the moderate zone, none of the decks and 75 percent of the slab-deck superstructure had NBI ratings of 6-9 (satisfactory and better). In the intermediate zone, 40 percent of the decks and 62.5 percent of the slab-deck superstructure had NBI ratings of 6-9 (satisfactory and better). For the high zone, 83.3 percent of the decks and 83.3 percent of the girder superstructure had NBI ratings of 6-9 (satisfactory and better). However, due to a relatively low number of steel beam bridges (18 total) inspected within this study, it will prove difficult to draw substantive conclusions about their durability performance in the various wood hazard (climate) zones, or any potential role that the deck type may contribute to bridge longevity.

The longitudinal glulam superstructure type represented 8 bridges (6.1 percent) of the 132 bridges evaluated. For the moderate zone, 67 percent of the decks and the slab-deck superstructures had NBI ratings of 6-9 (satisfactory and better). For the high zone, 100 percent of the girder superstructure had NBI ratings of 6-9 (satisfactory and better). However, due to a relatively low number of longitudinal glulam bridges (8 total) inspected within this study, it will prove difficult to draw substantive conclusions about their durability performance in the various wood hazard (climate) zones, or any potential role that the deck type may contribute to bridge longevity.

Bridge inspectors noted several inadequate deck drainage issues. These poor design details promote moisture accumulation and accelerated deterioration of bridge components. Remedial actions to alleviate these deck drainage issues will undoubtedly help to further extend bridge service life. It appeared through the data review that the slab-deck systems are potentially more affected by deteriorated and poorly maintained wear layers. Elevated moisture contents in the 20-30 percent range were identified in these superstructures, all resulting from moisture infiltration from the roadway surface.

CONCLUSIONS

A total of 132 timber highway bridges were inspected by a diverse team of bridge inspectors as part of a national program aimed at determining their durability characteristics. Nearly all of these bridges were built with either Douglas fir or southern yellow pine wood species, and were pressure-treated with creosote or pentachlorophenol oil-type preservatives. The following conclusions are based upon our findings:

1. Timber is a durable option for primary structural members in highway bridge superstructures and can perform adequately for more than 70 years when properly pressure-treated with preservatives. Bridge durability can be enhanced by effective deck drainage detailing and preventative maintenance practices focused on eliminating moisture traps. We found numerous examples of long service life bridges in all five AWPA hazard zones in the 48 contiguous Unites States.

2. The sawn girder superstructure type represented 64 percent (85) of the 132 bridges evaluated. The sawn girder bridge clusters were located in four of five possible wood hazard zones as defined by the AWPA. 61 percent of the sawn girder bridges supported a plank deck system. This system proved to have a good record on longevity in many wood hazard (climate) zones.

3. The use of combined visual and NDE technologies allowed project inspectors to fully and accurately assess the condition of the timber bridges inspected. The use of visual inspection, sounding, probes, and moisture meters allowed teams to determine where advanced technologies like stress wave timing and resistance microdrilling could be used to locate and quantify internal deterioration.

A comprehensive technical report (currently under review) will include more detailed information about all the timber bridges evaluated in this study. Finally, t is recommended that additional bridges be evaluated in order to increase the datasets and allow for improved service life estimates in the future.

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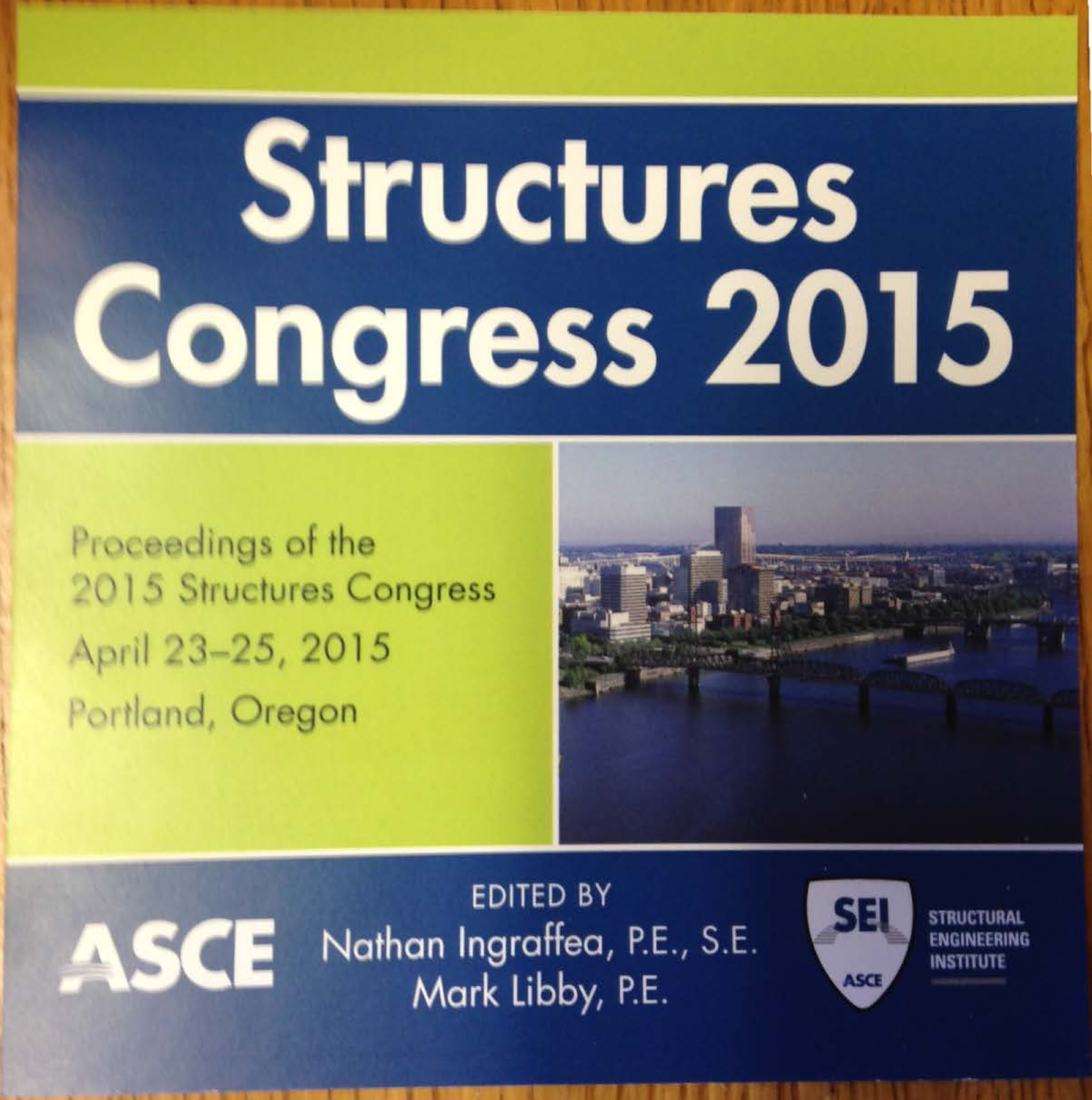

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