LIGHTWEIGHT MODULAR ACCELERATED BRIDGE SYSTEM FOR MANAGED CAR LANES

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INTRODUCTION

There is a widening infrastructure investment gap globally. In emerging economies majority of infrastructure investments are tied to greenfield projects while in developed countries investments are earmarked for brownfield projects. To keep up with urbanization trends and population growth, investments in infrastructure need to increase by more than 60% globally. In United States, $2.75 trillion of infrastructure investments were estimated between 2016 and 2020 with the investments on roads representing about 25% of the total investments as shown by Arezki et al (1).

The Eisenhower era infrastructure is over 54 years old and way past the 50-year bridge design life. Aging infrastructure requires high maintenance. On the other hand, severe congestion on important urban interstate corridors is leading to prohibitive economic costs. Top 10 highway interchange bottlenecks in the country cause an average of several million truck hours of delay as documented in AASHTO Report (2).

This paper proposes managed car lanes and combines metal grid deck systems with Simple for Dead Load - Continuous for Live Load (SDCL) approach to create a rapidly scalable installation system for highway bridges. The high initial cost of metal grid decks is offset by quicker installation, lower cost of construction, and longer service life. The modular approach makes for easy construction, which is further enhanced by the lightweight superstructure.

CONGESTION AND DIFFERENT LANE MANAGEMENT STRATEGIES

In 1960's, Eisenhower interstate highways were public goods – non-exclusive and non-rivalrous in economics terms. With increased urbanization, interstate highways have transformed into common goods or private goods (in case of tolled roads) during rush hours. It is estimated that 40% of congestion is attributed to inadequate infrastructure and 10% to construction necessary to fix it as per FHWA (3).

Congestion is measured by Levels of Service (LOS) (4), which indicates the level of traffic flow based on performance measure like vehicle speed, density, etc. LOS is denoted using letter A to F, with A being the free flow condition and F being the breakdown flow. LOS D indicates a high density flow in which speed and freedom to maneuver are severely restricted and comfort has declined even though flow remains stable. The 2018 Federal Highway Administration (FHWA) annual report for congestion trends (3) indicates that the freeways in 52 biggest US urban centers on an average day operated 4 hours 16 minutes under free flow speeds, registered a trip delay of 33% and provided a trip reliability of 212% for a day each month.

Different lane management strategies have been used by the operators to combat congestion as detailed by Dowling et al (5). These are primarily based on three levers – access control to highways, user eligibility, and pricing. The goal is to optimize explicit qualities such as freeway efficiency, throughput and implicit qualities such as travel time reliability, higher speeds, etc. Historically, the most widely used form of managed lanes have been the High Occupancy Vehicles (HOV) lanes, which restrict the use of lanes to busses and carpool vehicles. More recently, High Occupancy Tolled (HOT) lanes with or without variable congestion pricing have been used successfully to maintain high level of service during peak use hours. Similarly, truck lanes are used to move freight at high levels of service as determined by Truck LOS Index.

The 2014 United States Census Bureau surveys data indicates that on a typical day 76% of the 143M commuters travelled to work alone. With rising costs of building infrastructure and funding crunch there is need to build and utilize infrastructure more efficiently. The use of managed car lanes is proposed in this study as a subset of HOV lanes to cater to carpool vehicles under FHWA vehicle classes 1, 2 and 3 only as a means to address the very high percentage of car traffic on urban roads during rush hour.

AASHTO DESIGN LIVE LOADS VERSUS CONTEMPORARY CAR LOADS

FHWA classifies vehicles into 13 classes. Class 1 includes motorcycles, class 2 includes passenger cars while class 3 includes other two-axle, four-tire single unit vehicles. Classes 2 and 3 also include vehicles pulling other 1- or 2-axle trailers. The upper bound for Gross Vehicle Weight Rating (GVWR) of class 1, 2, and 3 vehicles is 6 kips, 10 kips and 14 kips respectively.

The light and medium duty trucks of FHWA classes 2 and 3 can be simulated effectively by the notional H-10 design truck with a total gross vehicle weight of 20 kips (4 kips front axle and 16 kips rear axle spaced 14-ft apart). A corresponding lane loading of 480 lbs/ft is used in conjunction to follow AASHTO (6) LRFD reliability standards as well as to ensure that the live loads applied are comparable to pedestrian loads as used by different design codes and researched by Nowak (7).

A research of contemporary 2-axle cars and trucks found the maximum GVWR of a two-axle, four-tire single unit heavy duty truck (such as Ford 350, RAM 3500, Chevy Silverado) to be 11.5 kips. The design loading of H10 truck and lane is, thus, appropriate for managed car lane bridges.

PROPOSED BRIDGE SYSTEM

The girder design utilizes SDCL detail to forgo field splicing and accelerate bridge construction. A literature review revealed that different states use varying details to achieve connection continuity at the pier but all involve use of a load transfer mechanisms from girder flanges to a pier diaphragm. The pier diaphragm is poured monolithically with the pier diaphragms after deck is set over the spans. The diaphragm is designed to provide lateral support at the ends and resist shear at the girder compression flange. Long-term monitoring of results from Sprague street over I-680 Bridge and 262nd street bridge over I-80 by Yakel and Azizinamini (8), showed no performance issues for SDCL construction detail. The Sprague bridge used W40x249 rolled section for two 97-ft spans, while 262nd street bridge used steel pre-topped box girders.

Several deck systems were evaluated – SPS deck system, Fiber Reinforced Polymer decks, full depth grid reinforced concrete deck, partial depth grid reinforced concrete deck, and exodermic deck. Among the metal grid decks, precast partial depth gird deck offers a modular deck system that can be installed at a rapid pace (up to 2000 sf/day). For this analysis, the proprietary precast exodermic deck system was chosen due to its rapid installation, durability, and the best strength to weight ratio among metal grid decks. The deck design for two girder spacings (10' and 14' c/c girder) using the above notional loads were used in the analysis. The 10-ft and 14-ft spacings yield a 7" and an 8" thick deck that weigh 65 lbs/ft^2 and 68 lbs/ft^2 respectively. The panels can be prefabricated in size of 8-6" wide by up to 45' long panels.

Analysis and design of bridges is performed for various span layouts per AASHTO using Finite Element Analysis software LARSA 4D (Melville, New York) (Figure 1). The design vehicular live loads are applied as per AASHTO 3.6. The negative moments at supports are taken at 90% of two H10 trucks fifty feet apart in each span and combined with a 480 lbs/ft uniform lane load. The models use the following assumptions:

- Exodermic deck: concrete: f_c' = 4.0 kips/in^2, w_c = 0.145 kips/ft^3; Grid Steel - f_y = 50.0 kips/in^2; Rebar Steel, f_y = 60 kips/in^2; concrete cover over steel - 2 in.; Sacrificial wearing surface – 0.5 in.
- Haunch thickness = 1 in.; future wearing surface – 50 lbs/ft^2; Barrier weight – 650 lbs/ft
- Girder spacing – 12 ft; Overhang cantilever - 3.4167 ft; structural steel – A588

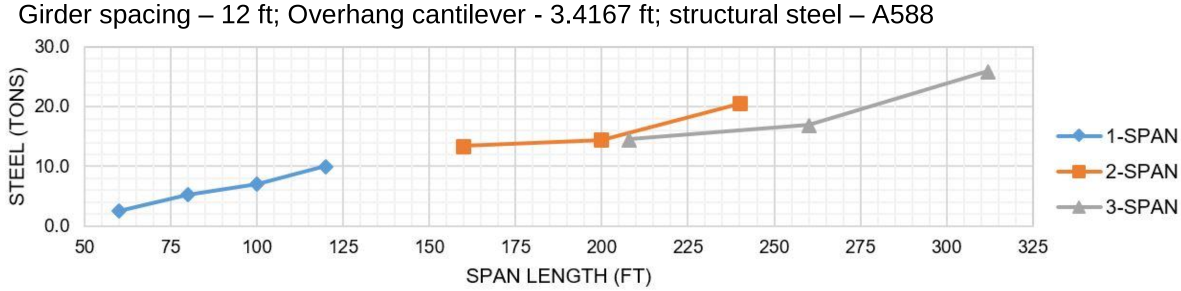

Figure 1 – Girder steel weight as a function of span length for 12'-0" girder spacing.

This Bridge System provides the many advantages of a typical ABC technique –

1. Modular installation - The bridge system can be installed in two different sequences. In sequence 1, the girders and cross-frames are placed on the substructure, the modular deck is installed next and the pier SDCL connection is achieved in the end by using rapid setting concrete. In sequence 2, the girders, cross-frames and the deck are constructed for each span off-site. In this case, the weight of the exodermic deck is kept to 50-55 lbs/ft^2 by using light weight concrete. The bridge is then installed span wise and the diaphragms at pier locations are poured in the end to achieve SDCL connection.
2. Low life cycle costs – Apart from cost savings owed to reduced construction impact on traffic flow and project delivery time, the system provides material savings. For one span bridges, superstructure steel uses an estimated 50% less structural steel than conventional bridges as calculated by Morgan (9). Due to light weight superstructure and lower live loads, substantial cost savings would be achieved in substructure construction considering that deep foundations are usually one of the most expensive pay-item on the project.
3. Durability – exodermic decks have an average life span of 70 years almost matching the substructure life span resulting in a long-lasting structure with no future re-decking required.

The proposed Bridge system is applicable under the following circumstances –

- Owners looking for inexpensive temporary Maintenance of Traffic as part of a larger project.
- Agencies looking to stretch dollars for new bridges with very low Average Daily Truck Traffic.
- Agencies looking to augment highway capacity in urban built-up environments to combat congestion and functional obsolesce of existing bridges.

CONCLUSIONS

This paper proposes use of managed car lanes to relieve pressure on existing infrastructure by giving policy planners a tool to effectively augment and manage existing bridge infrastructure network. The proposed bridge superstructure is 50% lighter, incorporating light weight characteristics of structural components (deck and girders) with lower live loads and SDCL connection details, resulting in a very efficient structure.

ACKNOWLEDGEMENTS

The author would like to thank Michael Riley of LB Foster Company, Eduardo Flores and Mohamad Faraj of Illinois Tollway, and Michael Banashek of Horner & Shifrin for support to perform this study.

DISCLAIMER

The paper in an independent research work by the author and not supported or owed to any organization.

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