Bridge Rideability
- Louisiana’s Perspective

Zhongjie “Doc” Zhang, PhD, PE

Columbus, Ohio
March, 2011
Outline

- Some facts about Louisiana bridge rideability
- Review of Louisiana Quality Initiative (LQI) and its products
- Research work sponsored by LADOTD
- Closing comments
Louisiana has

- 1,775 roadway miles of Interstate highway
- 17,175 roadway miles of state-maintained non-Interstate highway
- 1,546 Bridges on Interstate highway
- 7,984 on-system Bridges
- 5,182 off-system Bridges
# Bridge Rideability Compared to Roadway Rideability

<table>
<thead>
<tr>
<th>Pavement type</th>
<th>IRI</th>
<th>Roadway Miles</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Bridge</strong></td>
<td>150</td>
<td>363</td>
</tr>
<tr>
<td>Asphalt</td>
<td>149</td>
<td>9,320</td>
</tr>
<tr>
<td>Composite</td>
<td>129</td>
<td>2,487</td>
</tr>
<tr>
<td>CRCP</td>
<td>106</td>
<td>58</td>
</tr>
<tr>
<td>JCP</td>
<td>163</td>
<td>1,440</td>
</tr>
<tr>
<td>New Asphalt</td>
<td>65</td>
<td></td>
</tr>
<tr>
<td>New concrete</td>
<td>75</td>
<td></td>
</tr>
</tbody>
</table>

*Note: on system mileage*
Bridge Rideability over Ages
1,004 bridges

Average IRI By Age Groups

Note: Over 50% of tenth Bridge
Example of Bridge Rideability

Average IRI for Longest On-System Bridge: 148
Structure Number 62484520100002
Length: 76,714 ft or about 14.53 miles
I-55 from I-10 & US 51 & Swamp shown on map
Major Bridge Rideability Problem

- Rough riding of Bridge deck faulting for some long bridges, due to deteriorated joints
- Bridge end bump, due to deteriorated bridge approach slabs
DOTD Maintenance Solutions
– a case by case approach

- Maintenance Overlay
- Slab Jacking
  - Mud Jacking
  - Uretech
- Replacement
  - Deck bearings/cushions, not rideability based
  - Approach slabs, rarely done
DOTD Design Solutions

- Excessive subgrade settlement
  - Longer bridges / reduced fill heights
  - Accelerated settlement
    - Surcharges with wick drains
    - Piles supported approach slabs
    - Lightweight fills (cost?)
  - Better settlement prediction
Loss of material from around abutment
- Various abutment configurations
- Gravel backfills
- Extensive drainage components
- Higher quality materials near abutment
DOTD Design Solutions cont.

- Poor quality of fill materials
  - Restrictive specification
    - PI 10 – 20 within 1000 ft of abutment
- Abutment lateral deformation/rotational movement
  - Battered piles
  - Semi-integral abutments
- Compression of embankment material
  - Use modified proctor? difficult to implement
A Pile-Supported Approach Slab System
- a costly design
LTRC research indicated that if using drivers’ rideability as the evaluation criterion, out of 90 bridges in southern Louisiana,

- Only 4% was in very good condition (peak IRI < 228)
- 22% in good condition (228 - 455)
- 33% in fair condition (455 - 683)
- 22% in poor condition (683 - 910)
- 19% in very poor condition (peak IRI > 910)
Preservation of Bridge Approach Rideability

Louisiana Quality Initiative (LQI)
Proposal

August, 2002

Louisiana Transportation Research Center

August, 2002
Problem: The “Bump” at Bridge Ends

The “bump” felt when driving on or off a bridge approach slab is caused by:

- faulting of approach slab joints;
- a sudden change in slope grades of slabs.

![Diagram showing faulting and abrupt slope change before and after embankment settles.]

3 - a. Before Embankment Settles
3 - b. After Embankment Settles
Reason:
Concrete approach slabs lose their underneath contact supports due to various causes. Therefore:

- Slabs will bend in a concave manner
- The weight of slabs will be redistributed to the ends of slabs, i.e., the end bents and subgrade near R/S joints
- Faulting occurs at S/D and R/S joints
Causes

(NCHRP Synthesis: Design and Construction of Bridge Approaches)

- Settlement of the embankment foundation
- Compression of embankment in fill material
- Loss of material from or around the abutment and approach slab due to erosion
- Poor quality of fill material
- Poor compaction of the approach embankment
- Poor drainage
- Poor construction joints
- Lateral deformation of the bridge approach embankment
- Longitudinal or rotational movement of the abutments
Suggested Solution

Allow approach slabs to lose their contact supports to a certain extent without approach slab deflection by

- Increasing the flexural rigidity EI of approach slabs
- Controlling embankment settlement
Purpose of LQI

- Find out
  - a new structure design for approach slabs that can tolerate contact support loss
  - how much support loss that the new structure can tolerate without losing the rideability of approach slabs
- Give
  - Extra attention to the S/D and R/S joints
Basic Idea

Design a bridge span, but build the span on an embankment.
Bridge approach slab structure and foundation design

- Determine the correlation between ride quality and the deflection of approach slabs
- Correlation between allowable faulting, deflection and embankment settlement
- Allowable faulting and deflection
- Embankment settlement prediction and control
- Cost analysis
- Repair existing problematic approach slabs
“The successful design, construction, and maintenance of bridge approaches require collaboration among engineers with expertise in geotechnical, pavement, and bridge design and in construction and maintenance.”
Proposed Tasks / Responsibility

- Determine the correlation of the ride quality with the deflection of approach slabs (1) (LTRC, Bridge Management) preliminary results
- Develop alternate approach slab designs (2) (Bridge Design, LTRC, University) completed
- Conduct a finite element analysis on the newly designed approach slabs (3) (University, LTRC, Bridge Design) completed
Proposed Tasks / Responsibility

- Establish a design guideline for approach slabs (4) (Bridge Design, LTRC, University) on going
- Develop an adequate foundation design for approach slabs at R/S joint (5) (Geotech Design, LTRC) on going
- Monitoring the performance of existing approach embankments (6) (LTRC, Geotech Design, Maintenance) on going
- Develop more reliable procedures to predict embankment settlements (7) (LTRC, University, Geotech Design) on going
Proposed Tasks / Responsibility

- Explore techniques to control approach embankment settlement (8) (Geotech Design, LTRC,) on going
- Build experimental approach slabs and monitor their performance (9) (LTRC, Geotech & Bridge Design, Construction, Maintenance) on going
- Determine effective techniques to repair existing problematic approach slabs (10) (Maintenance, LTRC, Construction) not start
- Cost analysis (11) (LTRC, Bridge Design, Maintenance, Construction) not start
LADOTD Sponsored Research Projects in Response to LQI
Determination of Interaction between Bridge Concrete Approach Slab and Embankment Settlement

(LTRC 03-4GT, Report # 403, 2005)

- The objective is to establish the correlations of the faulting and deflection of the approach slab with the approach embankment settlement and the approach slab structural performance

- 3-D finite element analysis with the variation of input and statistical analysis of results
Physical Model
(partially supported slab)

\[ \theta_1 \text{ (change of slope)} \]

Original slab position

\[ \Delta_1 = \text{faulting} \]

\[ \Delta_2 = \text{slab deflection} \]

Abutment

Given Soil Settlement

Fig. Illustration of Slab Interaction with Soil
Geometry

Fig. Sketch of Abutment
Modeling Approach

- Eight-node hexahedron elements for Soil and slab
- Contact surface element for Interface between Slab and Soil
Loads on Slab

- Dead load of the slab
- Live Load: AASHTO truck loads

Fig. Characteristics of the Design Truck
Conclusions

- System Performance
  - With the increase of differential settlement
    - Contact area between embankment soil and slab decreases, and contact stress of soil increases
    - Maximum vertical stress of soil under sleeper slab increases
    - Magnitude of the slab’s maximum deflections and internal forces increase
    - When the settlement increases to some large value, it no longer affects the performance of slab since the approach slab almost completely loses its contact with the soil and becomes a simply supported slab
Approach Slab Design & Performance

- Reinforcement for both 20 and 40 ft slabs were insufficient
- Insufficient reinforcement results in slab cracking or breaking, which corresponds to large deflection
- 20 ft long slab has about 0.9 inches deflection and 0.55 degree of rotation angle
- 40 ft long slab could have about 15 inches deflection and 5.5 degree of rotation angle
- The field observed failures indirectly confirm these predictions
A simple design and deflection prediction procedure has been developed through parametric studies of finite element analysis.

- Engineers can use simple beam theory to design partially supported approach slab without doing Finite Element Analysis.

- A well designed 40 ft long slab with thickness of 18 inches has a long-term deflection of about 3 inches and rotation angle of about 1.0 degree.
Conclusions cont.

- Ribbed approach slab is introduced for approach span with a length of 60 ft and longer
  - A well designed ribbed slab has small deflection
  - For three girder option with 60 ft long approach slab, the elastic instantaneous deflection is about 0.8 inches and the rotation angle is about 0.2 degrees
Recommendation of Implementation

- LA DOTD should consider to change the design procedure for approach slab
- For 20 ft long slab with 12” thickness, increase reinforcement from current #6@6” to #7@6”
- For 40 ft long slab, increase thickness if settlement is to be considered
- For approach slab with length of 60 ft and longer, ribbed slab is recommended
LTRC Report # 403, published in 2005
Available at http://www.ltrc.lsu.edu/pubs_final_reports_4.html
Control of Embankment Settlement: Field Verification of PCPT Prediction Methods
(LTRC 04-5GT, Report #474, in print)

- Compare settlements predicted from PCPT and laboratory-tests data with measured field settlements of embankments
- Develop a visual basic program to determine the consolidation settlement of symmetric and un-symmetric embankments from PCPT data or input of users.
Juban Road-I12 Embankment Site

Typical roadway embankment section at Juban Road - I12 Interchange

- Geotextile Fabric (Class C)
- 30.5 m (100 ft)
- Horizontal Inclinometer
- Vertical Extensometer
- Soil Surcharge
- Flat Grade
- 61 cm (2') Nonpastic Drainage Layer
- 10 cm (4'') PVC Drain Pipe
- Limits of wicks
Field Instrumentations – J uban Road

- Settlement plate
- Horizontal inclinometer

vertical magnet extensometers  

Horizontal inclinometer
PCPT and Dissipation Tests: Juban Road North Embankment

Dissipation test

PCPT test

Normalized excess pore pressure (\(\Delta u/\Delta u_i\))
Development of Computer Software
Development of Computer Software

[Image of a software interface showing settlement calculation parameters and results.]

- **Fill characteristics**
  - Embankment Type: [Symmetric, Asymmetric]
  - Embankment Width (B1): [100 ft]
  - Height of Fill (H): [10 ft]
  - Height of Surcharge 1: [5 ft]
  - Height of Surcharge 2: [5 ft]
  - Unit weight of Fill (gamma): [122 kN/m³]
  - Width along the slope (B2): [110 ft]

- **Check to enter Expansion Characteristics**
  - Left Expansion Width: [10 ft]
  - Right Expansion Width: [40 ft]

- **Point for Computation of Settlement**
  - Coordinates of Point A:
    - X1: [160 ft]

- **Check to enter the PVD Parameters**
  - Width of the Vertical Drain (a): [1.5 in.]
  - Thickness of the Vertical Drain (b): [1.5 in.]
  - Spacing (s): [1 ft]
  - Permeability: [k_h = 1.5, k_v = 0.5]
  - Diameter of disturbed zone: [1 ft, 5 ft]
  - Discharge capacity of drains (q): [107 ft³/yr]
  - PVD Depth: [7 ft]

**Results**
- Total Estimated Settlement at the point (without Surcharges): 15.135516 inches
- Total Estimated Settlement at the point (with Surcharge 1): 19.41558 inches
- Total Estimated Settlement at the point (with Surcharge 2): 21.369828 inches
- Total Estimated Settlement at Center point due to Expansion: 15.1884 inches

[Buttons for Back, View Settlement Profile, View Time Rate of Settlement]
Development of Computer Software
Development of Computer Software
Development of Computer Software
Development of Computer Software

[Image of graph showing time rate of settlement with options for surcharge and PVD parameters, including graph axes and data points for settlement over time with and without PVD parameters.]
Conclusions

- PCPT method has comparable accuracy similar to the traditional laboratory method in predicting the magnitude and time-rate of consolidation settlement.
- PCPT method has the advantage of providing continuous profile of constrained modulus, $M$, and coefficient of consolidation, $C_v$.
- The PCPT based settlement calculation can substitute the traditional settlement calculation which is laboratory-based with extensive labor and time consuming.
Recommendations

- LA DOTD engineers start implementing the PCPT technology to estimate the consolidation settlement of cohesive soils, in conjunction with traditional laboratory calculations.
- Continue the comparison of the consolidation settlements predicted from the PCPT method, laboratory method, and field measurements until engineers build enough confidence on the PCPT prediction method.
Field Demonstration of New Bridge Approach Slab Designs and Performance (LTRC 05-1GT, on going)
Objective

- Validate the findings and design recommendations developed in the previous research projects for bridge approach slabs to mitigate bridge end bump problem.
Potential Solution

- Approach Slab: increase the slab flexural rigidity (EI) through increasing slab thickness and reinforcement.

- Sleeper Slab (Strip Footing): build a reinforced soil foundation at the pavement/approach slab joint to support slab and traffic loads.
Potential Solution

- Strip footing
- Reinforcement
- Soft soil
- Induced stress increment
- Unreinforced stress zone
- Reinforced stress zone
- Approach slab
- Footing size to produce same influence as the reinforced
Bayou Courtableau Bridge Site
Approach Slab System Design

**BRIDGE**

**APPROACH SLAB**

**PAVEMENT**

**EMBANKMENT FILL**

- **STRAIN GAUGES**
- **PRESSURE CELLS**
- **SISTER BAR**

- **BEDDING MATERIAL**

- **GEOGRID**

- **WEST EMBANKMENT SIDE**

- **EAST EMBANKMENT SIDE**

* = 1'-0" (TYP.)
Instrumentation

(a) Geogrid with strain gages

(b) Pressure cells

(c) “Sister bar” strain gages

(d) Data acquisition system
Static Load Testing (October, 2009)

3, 400 lbs

3, 700 lbs

3, 700 lbs

3, 700 lbs

5,000 lbs

5,000 lbs

5,000 lbs
West Approach Slab
East Approach Slab
Conclusions

- The west approach slab remained its supports from the soil while the east approach slab (regular) started partially losing its contacts from the soil at the time when they were ready for traffic.
- Now the approach slabs at both ends partially lost underneath supports.
- Long term performance of the new approach slab system will be monitored and evaluated.
- Another demonstration project (Lacassine Bridge) is scheduled by LADOTD bridge design engineers.
Closing Comment

- Determine possible changes to existing specifications, design procedures, maintenance processes, etc. that can be incorporated now to improve rideability performance.
- Provide a coordinated effort within the department for the evaluation and/or development of new technologies and concepts.
- Determine priorities for future research effort.
- Oversee implementation of research findings and recommendations.
- Develop assessment program to monitor improvements in bridge system rideability.
Thanks!