TECHNICAL PROPOSAL for
DEVELOPMENT OF JSLAB 2007

ESCINC will undertake this effort in coordination with the Center for Transportation Infrastructure Systems, The University of Texas at El Paso (UTEP) and Ohio Research Institute for Transportation and the Environment (ORITE). The project is specified as two tasks. Task A is to be performed by UTEP team and Task B by ORITE.

Expected Completion Date: May 2009

TASK A

The team of Cesar Carrasco, Parisa Shokouhi, and Soheil Nazarian from the Center for Transportation Infrastructure Systems at The University of Texas at El Paso (UTEP), will work on enhancing the JSLAB2004 functionality to include the use of multiple foundation models and a base or subbase layer. The following paragraphs summarize the proposal.

BACKGROUND

JSLAB-2004 can be used to analyze jointed pavement responses under self-weight, traffic load, and/or any combination thereof. JSLAB-2004 can process six types of foundations for a single slab analysis:

- Spring foundation (SP)
- Winkler foundation (Dense Liquid [DL] model)
- Boussinesq foundation (Elastic Solid [ES] model)
- Vlasov Two-Parameter (TP) foundation
- Kerr Three-Parameter (K3) foundation
- Zhemochkin-Sinisyn-Shtaerman (ZSS) foundation

Responses of a single slab under a temperature gradient or any combination of temperature gradient and traffic load can also be calculated. A two-layer system of up to nine slabs can be analyzed. The two layers can be fully bonded or unbonded. The joints can be doweled, tie bar, keyed, or aggregate interlocked. Uniformly or non-uniformly spaced, circular, or non-circular dowels can be used in numerical analysis. Variable support conditions, including partial loss of support, variable material properties and slab thicknesses can be considered. JSLAB2004 also provides the capability to calculate the pavement response time history under a load moving from one end of a multiple-slab pavement to the other.

JSLAB is based on early version of ILLI-SLAB, a finite element code developed by the University of Illinois and has gone through several updates. Some of the most resent improvements were added to JSLAB 92 under the direction of the 2(203) Pooled Fund Study team through an FHWA contract with Galaxy Inc. that resulted first in JSLAB 2002 and then JSLAB 2004. The effort that resulted in JSLAB 2002 accomplished the following:

- Programmed options for six different subgrade types: Spring, Winkler, Elastic, Valsov two-parameter, Kerr three-parameter, and ZSS foundations.
- Developed a user friendly graphical interface consisting of pre and post processors
- Tested the software theoretically and by comparisons with BISAR, the FAA's H5I and JSLAB 92 and with pavement test data from the Ohio Test Road.
- Provided a users manual.

The Pooled Fund Study (PFS) review team determined that, although the JSLAB program must be able to handle complicated cases, it was determined that an "express method" option be implemented to accommodate the more frequent of user needs. The effort that resulted in JSLAB 2004 accomplished the following:

- Installed an axel configuration library that includes single, dual, and super single tires and tandem, triple and quad axle configurations.
- Added capability to allow the user to easily change the loading areas, axle spacing for multiple axles, and to move the axle groups to any position on the slabs.
- Added the capability to directly calculate the response time history at specified locations within the pavement under a moving axle and/or vehicle in order to simulate responses in the field.
- Provided an "Express" interface (option) that generates input data for most common needs including the pavement mesh plan.

In the earliest version of JSLAB, FHWA/RD-86/041 (page 27), it is stated that the curling analysis was done for a single slab only. In another FHWA report (1992), May Dong found an error in the curling formula and appropriate corrections were immediately made and results verified by theoretical and numerical comparisons. The current program also handles multiple-slab curling for response distribution, however, no verification has been seriously attempted for proving the accuracy of multiple slab curling.

OBJECTIVES

Under the direction of the National Pool Fund Study (205), UTEP is currently developing a software with the capacity to estimate the damage caused by super heavy trucks on flexible as well as rigid pavements. For the rigid pavements option, the engine (processor) of JSLAB-2004 is being used to estimate the state of stress and deformation caused by the super heavy loads.

The objectives of the work proposed in this document seek to improve the functionality of JSLAB-2004 by incorporating the processor in the software currently being developed under Pool Fund (205). In addition, several modeling issues will be addressed to improve the capabilities of the processor. Specifically, the work proposed will improve the modeling of the foundation for multiple slabs allowing for the selection of several foundation models as well as the addition of a base/subbase layer. In addition, several improvements to the “Express Mode” as well as general results-display and reporting issues will be implemented to address the specific needs of the NYDOT.

It is important to note that the final product will be the development of an improved JSLAB processor that will be coupled with the interface currently being developed under Pool Fund (205). This will result in a software tool with the capacity for analysis of flexible and rigid pavements that currently has no parallel.

STATEMENT OF WORK

Subtask 1: Foundation and Base

1. Upgrade the current JSLAB 2004 to enable the user to select different types of foundation when analyzing multiple slabs. Currently, the software limits multiple slabs analysis to only the dense liquid foundation model.
2. Modify the current ZSS foundation model to improve the accuracy of the slab response when a load is applied at the edge or comer of a slab. Currently, JSLAB 2004 only considers the contribution of a portion of the elastic semi-infinite space under the slab.
3. Expand the applicability of the current JSLAB 2004 to allow incorporating at least one base/subbase layer between the concrete slab and subgrade. Currently, JSLAB 2004 allows the analysis of a slab (could be composed on two concrete layers) over a subgrade.

Subtask 2: Time History of Multiple Slabs

1. Expand the capability of the current JSLAB 2004 to predict the response time history of a pavement with three curled slabs in each direction. Note that the current analysis is for a pavement with multiple flat slabs (i.e., zero thermal gradient). The program shall be modified to automatically eliminate the effects of tires that fall outside of the pavement area when the loading assembly is moved. Note that if the total number of slabs in one direction needs to be increased to six or seven to address the item described above, the program engine may need to be replaced. If so, the current engine of the JSLAB 2004 program (processor) may need to be replaced with a more effective one and modification of existing subroutines to fit the needs of the new engine will be needed, e,g., response time history of a curled pavement with multiple slabs, increase the number of slabs for handling very long vehicles, back-calculate the pavement for insitu material properties, predict the response of slabs under nonlinear temperature and/or moisture gradient.

Subtask 3: Enhance Functionality of "Express Way" Interface

1. Add the capability to the current "Express Way" of JSLAB 2004 software to handle non-uniform support (under one or several slabs) to mainly account for utilities, such as catch basins and manholes, which are typical cases for urban PCC pavements. Currently, only the expanded input interface allows specifying non-uniform support conditions.
2. Add the capability to the current "Express Way" to allow running time history analysis. Currently, only the expanded input interface allows running such analysis.
3. Modify "Express Way" option in the current JSLAB 2004 to allow cursor-viewing of definition of each of the input variables in the input menus and instruction to users (only available in expanded input version of JSLAB 2004).

Subtask 4: Development of User Interface

1. As already explained, the interface to the modeling capabilities of the improved JSLAB code will be embedded in the interface currently being developed under Pool Fund (205). This interface will be expanded to accommodate all the options of the current JSLAB and in addition, implement the necessary interface improvements to accommodate the new proposed modeling options.
2. The user interface will have the capacity to present the magnitude of the various responses in graphical color form in terms of contours of the pavement being analyzed (in both the Express Way and Extended Interfaces). The interface will be designed so

that the user can extract critical information with simple mouse operations. The user will also be given the option to generate “user defined” reports with the information that he/she considers important or critical.

Subtask 5: Documentation

1. All modifications to the current JSLAB 2004 will be documented in a report.
2. A user manual will be produced explaining the functionality of the JSLAB simulation capabilities within the more general pavement analysis software in which the new processor will be embedded.
3. At least one TRB (or a similar conference or technical journal as agreed to by FHWA) paper shall be prepared, as directed by the NYDOT, to report on the various upgrades the JSLAB has undergone lately, findings, and supporting applications, and comparisons with other available software. A Power Point Presentation shall also be prepared.

<u>TASK B</u>

Dr. Shad Sargand of Ohio Research Institute for Transportation and the Environment will perform the validation of the modified JSLAB 2004. ORITE at Ohio University will conduct the validation and verification of this software independently of the UTEP development team using data gathered on a variety of rigid pavements and bases used on instrumented test roads such as the Ohio Strategic Highway Research Program (SHRP) Test Road on US Route 23 in Delaware County (DEL23) and the long-life pavement on the US Route 30 bypass of Wooster, Ohio in Wayne County (WAY30).

Validation of Modified JSLAB2004

Introduction

The finite element analysis program JSLAB was created and refined through the pooled fund program specifically to model the response of rigid pavement systems under stresses, whether from the weight of the concrete slab itself, under heavy traffic loads, or temperature gradients. It was most recently modified in 2004. This latest version can model a single slab under one of six different foundation models: spring, Winkler (dense liquid), Boussinesq (elastic solid), two-parameter Vlasov, three-parameter Kerr, or Zhemochkin-Sinisyn-Shtaerman. For modeling multiple slab jointed concrete pavements, JSLAB2004 can model a two-layer system with up to nine slabs. The program can account for such conditions as non-uniform joint spacings, dowels with non-circular cross-sections, partial loss of support such as that due to curling and warping, varying slab thicknesses, and varying material properties. JSLAB2002 included a user-friendly GUI and a user’s manual. JSLAB2004, the latest version added an “express” interface to handle the most common situations, an axle configuration library that included single, super single, and dual tires in single, tandem, triple, and quad axle groupings, the capability for the user to modify loading areas, axle spacings, and load positions, and the ability to simulate the history of a load moving along the entire length of the pavement. JSLAB2004 can also simulate multiple-slab curling, but no verification of this function exists; all verification has been restricted to single slab curling as simulated in earlier versions of the program.

The improved JSLAB model will be incorporated into a larger project under National Pooled Fund Study (205) to develop software to estimate the damage caused by superheavy trucks on rigid and flexible pavements.

A more extensive background on the history of finite element modeling of PCC pavements and the evaluation of these programs against test pavement data is given in the draft report *Truck/Pavement/Economic Modeling and In-Situ Field Test Data Analysis Applications Volume 2: Verification and Validation of Finite Element Models for Rigid Pavement Using In Situ Data – Selection of Joint Spacing*, which will be published in a final version in the next few months.

Test Pavements

ORITE has been the leader of two major instrumented test pavement research efforts involving PCC pavements on DEL23 and WAY30. The extensive data collected during these projects can be used to validate and verify the new JSLAB program. Below are specifics of the test pavements.

<u>The DEL23 test road</u>

The Ohio SHRP Test Road has been providing excellent data for comparing realistic pavements and loadings to finite element models and to examining the effects of varying properties on the pavement response since its opening in 1996. As part of its support for the Strategic Highway Research Program (SHRP), the Ohio Department of Transportation, in conjunction with the Federal Highway Administration, developed a comprehensive test road encompassing four of nine experiments in the Specific Pavement Studies (SPS). This three-mile long project is located on U.S. 23 approximately 25 miles north of Columbus in Delaware County, and an overhead view is shown in Figure 1. To enhance the value of this test road, seasonal and dynamic response instrumentations were installed in 33 of the 38 test sections. The northbound lanes contain the SPS-2 experiment, while the southbound lanes contain the SPS-1 and SPS-9 experiments. The SPS-2 sections are presented in
Figure 2. The variations of geometric and material properties between the slabs display the key roles that each property plays in the stress and deflection characteristics of the slabs. The different base types and number of layers determine the influence of the base stiffness on the load response of rigid pavements. Dimensions, composition and strength values for the Portand Cement Concrete (PCC) sections are presented in Table 1. Almost ten years after its opening, valuable data are still being collected on DEL23.

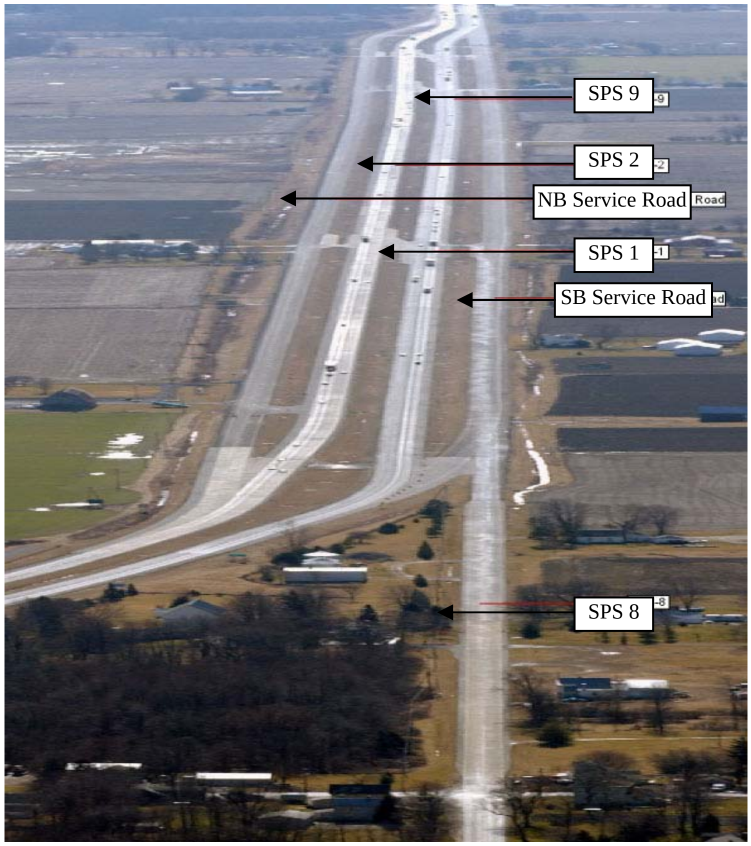

Figure 1. Layout of Ohio SHRP Test Road (Sargand, 1994).

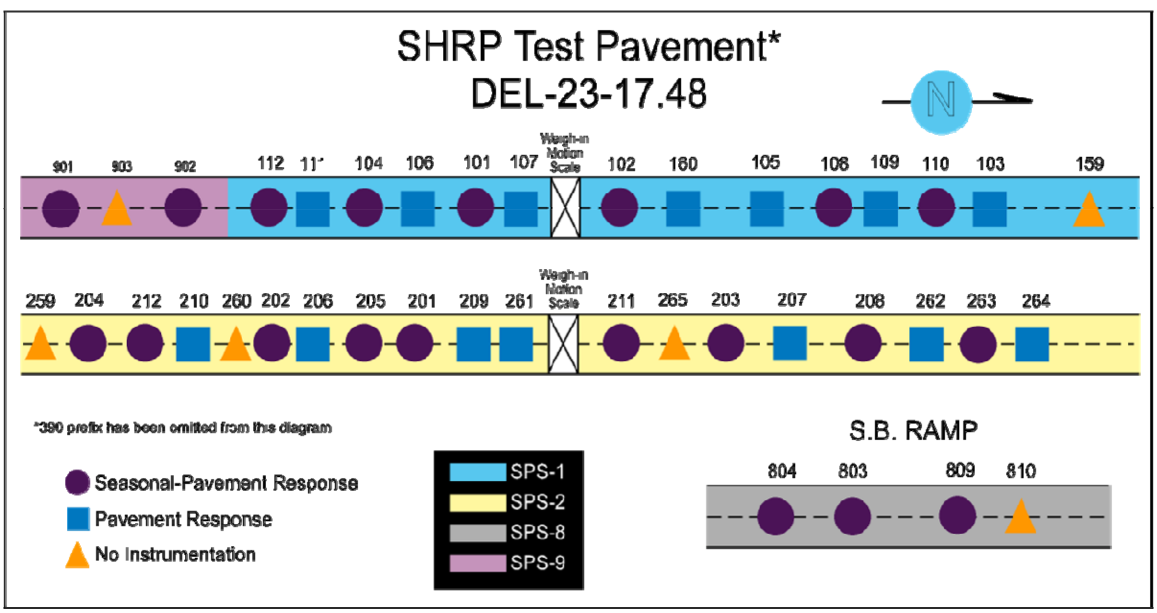

Figure 2. Sections of SPS1, SPS2, SPS8, and SPS9 in Ohio SHRP Test Road (Sargand, 1994).

Table 1. Portland Cement Concrete Sections in Ohio SHRP Test Road (adapted from Sargand, 1994).

Portland Cement Concrete Studies on Ohio SHRP Test Road										
SPS-2										
	Lane Width		Strength		PCC Thickness		Base thickness			
Section	(ft)	(m)	(psi)	(MPa)	(in)	(cm)	(in)	(cm)	Base Type	Drainage
390201	12	3.66	ODOT	ODOT	8	20.3	6	15.2	DGAB	No
390202	14	4.27	900	6.21	8	20.3	6	15.2	DGAB	No
390203	14	4.27	ODOT	ODOT	11	27.9	6	15.2	DGAB	No
390204	12	3.66	900	6.21	11	27.9	6	15.2	DGAB	No
390205	12	3.66	ODOT	ODOT	8	20.3	6	15.2	LCB	No
390206	14	4.27	900	6.21	8	20.3	6	15.2	LCB	No
390207	14	4.27	ODOT	ODOT	11	27.9	6	15.2	LCB	No
390208	12	3.66	900	6.21	11	27.9	6	15.2	LCB	No
390209	12	3.66	ODOT	ODOT	8	20.3	8	20.3	half PATB/half DGAB	Yes
390210	14	4.27	900	6.21	8	20.3	8	20.3	half PATB/half DGAB	Yes
390211	14	4.27	ODOT	ODOT	11	27.9	8	20.3	half PATB/half DGAB	Yes
390212	12	3.66	900	6.21	11	27.9	8	20.3	half PATB/half DGAB	Yes
390259	12	3.66	900	6.21	11	27.9	6	15.2	DGAB	Yes
390260	12	3.66	ODOT	ODOT	11	27.9	8	20.3	half PATB/half DGAB	Yes
390261	14	4.27	ODOT	ODOT	11	27.9	8	20.3	half PCTB/half DGAB	Yes
390262	12	3.66	ODOT	ODOT	11	27.9	8	20.3	half PCTB/half DGAB	Yes
390263	14	4.27	ODOT	ODOT	11	27.9	6	15.2	DGAB	Yes
390264	12	3.66	ODOT	ODOT	11	27.9	6	15.2	DGAB	Yes
390265	12	3.66	ODOT	ODOT	11	27.9	8	20.3	half PATB/half DGAB	Yes
SPS-8										
390809	11	3.35	550	3.79	8	20.3	6	15.2	DGAB	No
390810	11	3.35	550	3.79	11	27.9	6	15.2	DGAB	No

The WAY30 Test Road

The WAY30 test road was constructed in 2005 to showcase long-lived rigid pavement techniques and durability on the eastbound lanes of the Wooster bypass on US Route 30 as shown in the map in Figure 3 and the aerial view in Figure 4. The construction of the road includes a 10" (25.4 cm) layer of Portland cement concrete (PCC), a 3" (7.6 cm) layer of ODOT 301 asphalt concrete (AC) base, and 4" (10.2 cm) of dense graded aggregate base (DGAB) on the existing subgrade. The test road opened to traffic in November 2005 and data collection and load testing has begun. Data will be collected from the road for at least three years.

Instrumentation of Test Roads

Both the DEL23 and WAY30 test roads have been extensively instrumented to measure both environmental and traffic load impacts. Environmental data collected include temperature of the pavement, base, and subgrade during and after curing and moisture data in the base and subgrade. Load response data collected include pressure from pressure cells and displacement from linear variable displacement transducers (LVDTs). Traffic data, including traffic load amounts, are collected from Weigh-in-Motion (WIM) sensors. The instrumentation plan on WAY30 is shown in Figure 5. Curling and warping data are also collected by performing surface profiles using a laser profilometer.

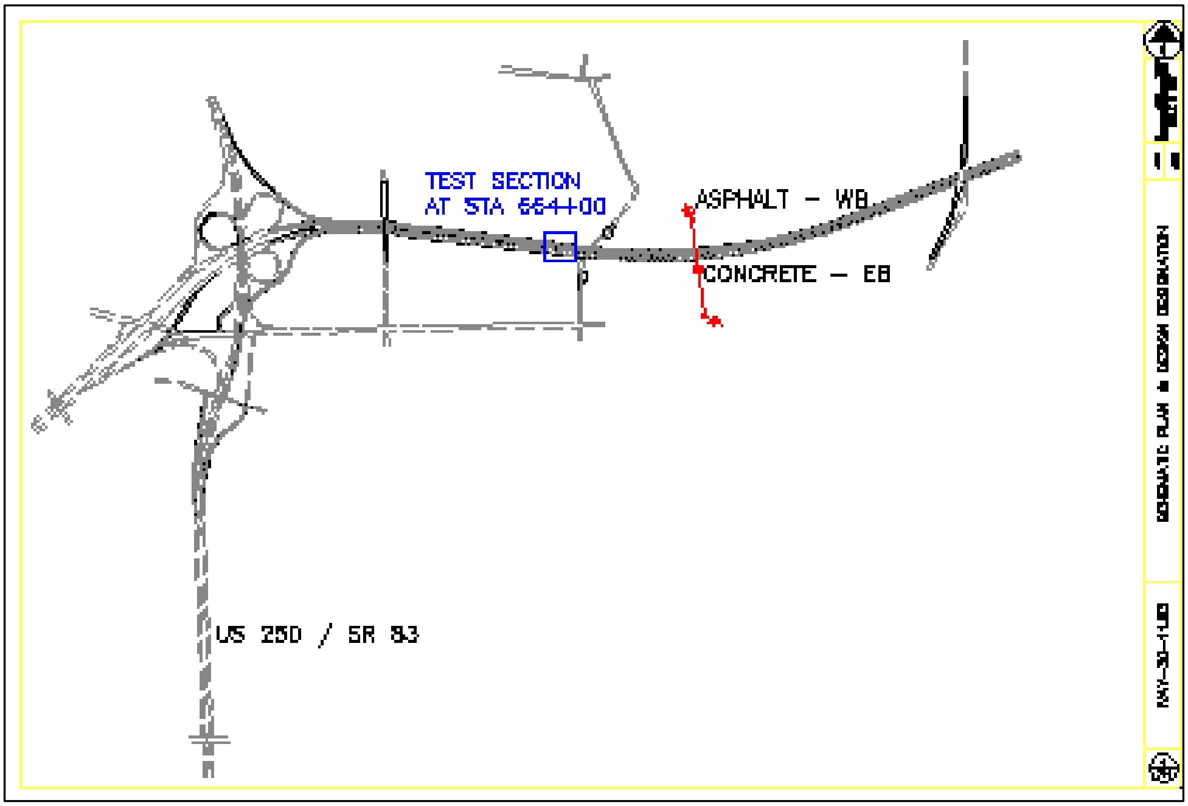

Figure 3. Map of WAY30 test road.

Figure 4. Aerial view of WAY30 test section location under construction.

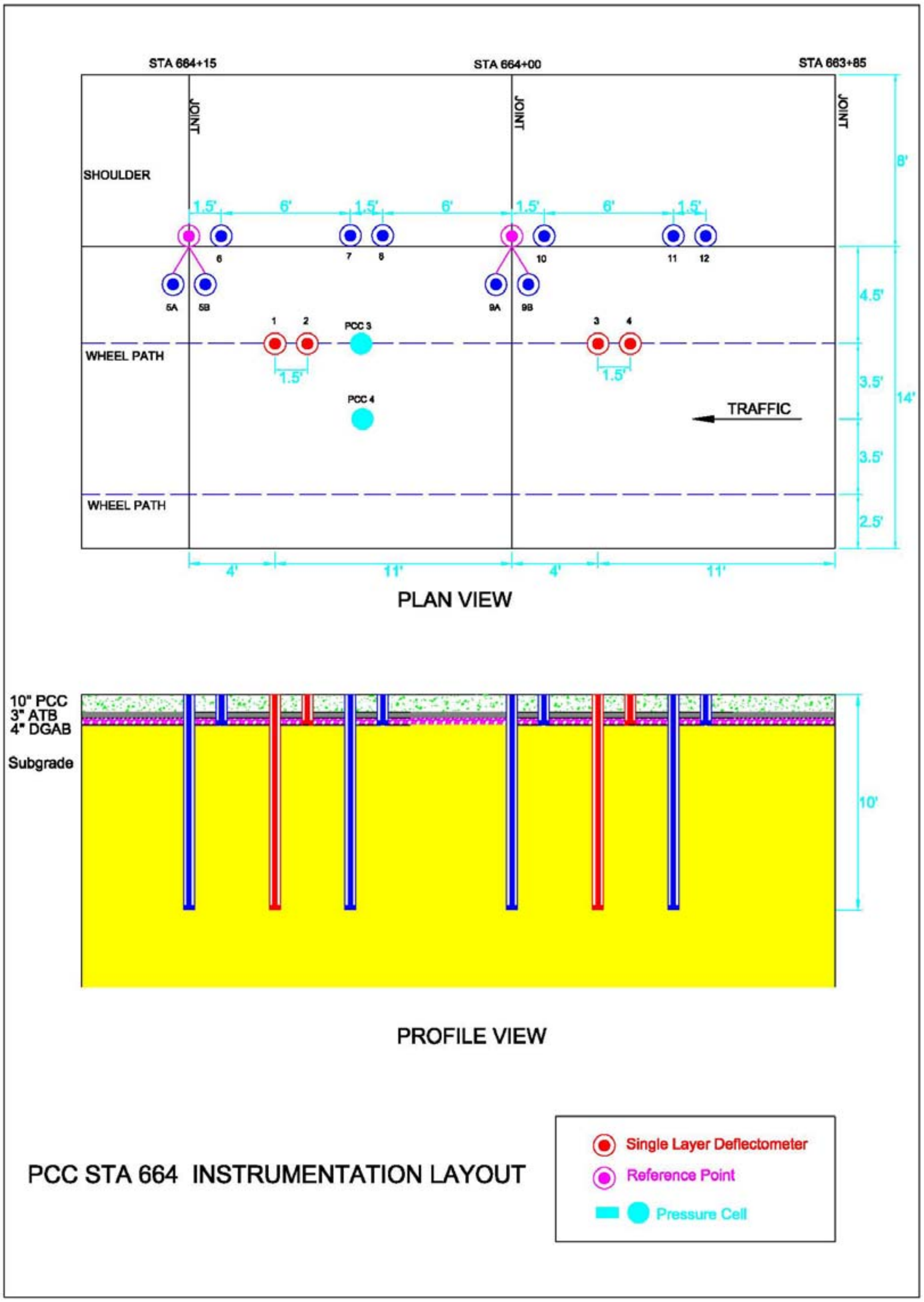

Figure 5. Instrumentation plan for PCC section on WAY30.

Validation procedure

The validation of the UTEP-modified JSLAB2004 software will consist of ORITE personnel using the software to model PCC sections of the DEL23 and WAY30 test roads and comparing the results to data collected in the field. As a secondary objective, ORITE personnel can also evaluate the programming interface for suitability to the modeling task and ease of use.

If needed, the ORITE research team can help the UTEP personnel by providing results or other information regarding the accuracy of the results, usability of the software, etc, that they may use in their development efforts.

Previous FEM software validation efforts have focused exclusively on the comparison of simulated and measured deflections only, yielding results of limited accuracy. This validation will include measurements and simulations of strain and pressure in addition to deflection.

Subtasks

1. Select test road data for comparison, focusing on but not necessarily limited to DEL23 and WAY30 test roads. Examine databases and select test events to model. Include at least four different types of bases and two different pavement thicknesses for analysis.

2. Obtain, install, and run JSLAB software to simulate selected test events on selected pavement sections.

3. Compare simulation results to test data. This comparison includes deflection, strain, and pressure experienced in all layers of the pavement.

4. Conduct a sensitivity analysis to determine stability of results against perturbations in input parameters.

5. Provide validation results as feedback to UTEP development team. As UTEP refine JSLAB software in response, repeat validation in steps 1-3 to verify revised software works as promised.

6. Write draft report chapter(s) on validation process and results.

7. Revise appropriate parts of final report after review.

Estimated duration of project: 24 months including review of report and corrections. Efforts will be coordinated with UTEP efforts to match their schedule.

References

Cesar Carrasco, Parisa Shokouhi and Soheil Nazarian, “Development of JSLAB 2007: Enhancements to JSLAB 2004”, proposal submitted to the New York State Department of Transportation March 13, 2006.

Shad Sargand and Basel Abdalla, Truck/Pavement/Economic Modeling and In-Situ Field Test Data Analysis Applications Volume 2: Verification and Validation of Finite Element Models for Rigid Pavement Using In Situ Data – Selection of Joint Spacing, Draft Report FHWA/OH-2006/3B, submitted February 2006, ORITE, Ohio University, Athens OH.