Implements of Husbandry (Farm Loop) Instrumentation Plan

The object of this Plan is to solicit response from the researcher such that an appropriate instrumentation design may be developed.

Background

The Farm Loop, a roadway for testing pavement section response to large implements of husbandry, will be constructed in the existing "stock pile area". There is no existing cell structure to modify. The roadway proposal is for two, HMA paved, instrumented, 300-foot test sections with a connecting gravel loop. The two, 300-foot test sections are separated by a 50-foot long transition area. The transition area will be the temporary home for a tire stress distribution device. It is not likely that the gravel loop will be instrumented, at least for the present.

The instrumented sections of the Farm Loop will be constructed on a raised grade. It is unlikely that the entire "loop" will be on a raised grade. That is, topsoil will be stripped from the existing grade and stockpiled subgrade material will be shaped and compacted to a one or two-foot high embankment.

Each of the test sections will have a different pavement/base structure. There will be a thin and a thick section. The thin section, Cell 55, will consist of eight inches of gravel base with three and one half inches of Hot Mix Asphalt (HMA) for a total of 11½ inches of pavement/base. The thick section, Cell 56, will consist of nine inches of gravel base and five and one half inches of HMA for a total of 14½ inches of pavement/base. Both test sections will have 12-foot lanes. The thick section will have 6-foot paved shoulders; the thin section will have 3 foot gravel shoulders.

Proposal

The proposal is to construct the test sections described above to assess the impact of larger/heavier farm equipment on the various pavement/base thicknesses.

Research Objectives

Compare pavement responses to farm implements with those responses of a typical heavy vehicle (e.g. 5-axle tractor/trailer). Measure normal and shear stresses at the pavement surface.

Variables

There are environmental variables that will have to be accounted for (e.g. temperature gradient throughout the roadway section and moisture content of the base and subgrade). Strain due to changes in environment will have to be documented..

Strain due to dynamic loading must be measured and stored. The base also will be affected by dynamic loading. Normal stresses at the pavement/base and base/subgrade interfaces may be of interest.

Methods of Analysis

Are there specific methods of analysis that you anticipate using that might require data in a particular format, that might require specific frequencies of data collection, or that might require special data collection methods?

We expect to provide regular distress surveys.

Researcher's Assessment of Instrumentation Needs

The Researcher would like sensing to include strain in the base materials. Horizontal strain, both longitudinal and transverse to the centerline (to the axis of dynamic loading), and vertical strain are required.

Strain in the pavement is to be measured in both of the "wheel paths" and in both directions of travel.

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A specialized tool for analyzing normal and shear stresses, due to off-road tire designs, at the pavement surface is needed. There are two alternatives for this device. Currently, a South African device is preferred.

Proposed Instrumentation

The instrumentation proposed in the following section is an initial proposal bases on the writers interpretation of available descriptions of the proposed research and an estimation of other potential research opportunities.

Static Sensors

Static mode sensing represents a variable's value at a specific point in time. The mode of sensing suggests the change in the variables value is small over small time intervals and therefore should be measured less often. Static sensing can be accomplished with less sophisticated equipments and is therefore less expensive to accomplish reliably.

Environmental sensing is generally thought of as requiring a static sensing approach. Temperature, moisture, and water table levels within all roadway test sections will be measured in the static mode. Strains due to environmental conditions may be captured with a static sensing approach. The present strain sensing approach in asphalt test sections is to capture strain due to environmental conditions as part of sensing for dynamic loading.

Static sensors for the farm loop study will include thermocouples and time domain reflectometers (TDRs) for temperature and moisture sensing respectively. The current configuration of the temperature and moisture sensors is a vertical sensor "tree".

The temperature thermocouple tree is eight feet long with sensing beginning at ½-inch below the pavement surface and extending downward at variable increments; starting at one-inch increments and increasing to one-foot increments. For the proposed "Thin" section, the increments proposed are one-inch, one inch, one inch, three inches, six inches, and one foot for the remaining seven feet. For the proposed "thick" section, the increments proposed are one inch, one inch, three inches, six inches, six inches, and one foot for the remaining six feet.

The moisture TDR tree starts at the bottom of the pavement and begins with two six-inch increments and extends eight feet downward, from the pavements surface at one-foot intervals. Given the upper portion of the tree is in granular materials, the researcher may opt to choose another moisture sensing approach as TDR sensing precision in granular materials is lessened at lower moisture contents. The traditional TDR used at MnROAD is the Campbell Scientific CS 616. Temperature and moisture trees (one each) are proposed for every paved test cell.

There are no ground water monitoring wells in the vicinity of the proposed Farm Loop construction area. Verification is to take place prior to detailed sensor design.

Dynamic Sensors

Strains and pressures associated with dynamic loading will be measured in the pavement, base, and subgrade. CTL asphalt strain gauges will be used in the pavement; alternatives are available. Strain gauges will be oriented longitudinal and transverse to the direction of loading. Vertical strain gauges, for asphalt embedment, are available as an alternative. Soil Strain Deformation Transducers, by Dynatest, will be used to measure both horizontal and vertical strains in the base; alternatives are available.

Strain gauges will be placed in both wheel paths of both directions of travel. Strain gauges will be placed in pairs; one in the longitudinal direction, one in the transverse direction.

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Geokon Model 3500 pressure cells are proposed for use at the pavement-base and base-subgrade interfaces; alternatives are available.

Activating (triggering) dynamic sensors will be accomplished with an induction loop(s) buried upstream of sensor arrays; alternatives are available.

Sensor Locations

Horizontal

All sensors, within the sensor array, will be within 60 feet of the data collection cabinet. For detail with regard to sensor locations, see the attached sketch. 24 strain sensors will be used in each cell's HMA pavement. There will be three base strain locations and three pressure measurement locations.

Given the expected size of the farm equipment to be tested and the width of the tires that support them, strain sensors will be placed in two locations relative to the center and edge lines. Twelve pavement strain sensors will be placed one-foot from the edge/centerline. Eight pavement strain sensors will be placed 1-½ feet from the edge/centerline The three strain locations in the base unit and the three pressure cells will be centered on the same offsets from the edge/centerline.

All distances for location documentation are measured from the centerline of the proposed pavement.

Vertical

Vertical placement of static sensors is discussed in that section. Dynamic strain sensors are to be placed at the bottom of the HMA layer. Base strain sensors, or displacement sensors, are placed in the middle of the base and pressure cells at the base/subgrade interface.

Alternatives

I am not sure that measuring temperature and moisture to eight feet below the surface is necessary. As a compromise, I would propose measuring to six-feet below the surface. Part of the reason for proposing this is that the excavation and installation of an eight-foot tree is significantly harder to accomplish than that of a six-foot tree. Also, a higher density of thermocouples may be necessary in the upper portion (pavement/base portion) of the roadway section.

An alternative for the Campbell Scientific TDR is Decagon's ECH2O volumetric moisture sensor.

Devices for gathering horizontal strains in unbound materials are not easily found. CTL has a displacement sensor that may be applicable to measurement of horizontal deflections in the base and subgrade.

Triggering for gathering dynamic sensor data may be accomplished in a number of ways. Using non-intrusive detection is a viable alternative. Pneumatic tubes are also an alternative but require added labor to implement.

Infrastructure

Data Loggers

Campbell Scientific data loggers will be used for the static sensors.

Pavement responses to dynamic loadings require a measurement approach consistent with the speed at which the load is applied. Point measurements of these responses require a large number of consecutive measurements to detail the maxima/minima of interest. A minimum of ten data points while the load is over the sensor is required. At a vehicle speed of 40 mph, measurements at a frequency of approximately 1000 Hz are needed.

National Instruments multifunction data acquisition tools are to be used. Detail on the specific model and capabilities is yet to be decided.

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Triggers for the dynamic data acquisition are to be induction loops. Four-channel 3-M detectors are available. Never-Fail induction loops will be placed up and down-stream of dynamic sensing locations.

Cabinets

NEMA 3 cabinets are to be used to house data acquisition equipment. Cabinets will need to be sufficiently large to accommodate insulation and environmental control, as some data acquisition equipment will not stand up to extreme cold.

Some small NEMA 4 enclosures may be used as satellite control cabinets to minimize sensor lead wire lengths. Humidity control is an issue in these cabinets.

Construction Sequence

Considering that this project will be constructed as one of many similarly small projects, it is important that there be a minimum of 10 days available for instrumentation installation after the subgrade is at final grade and again after the base is at final elevation.

Once the subgrade is at final elevation we will begin installing conduit for lead wire. Four transverse trenches will be cut across the subgrade to a depth of one-foot. A 1.5- inch PE conduit will be installed in each trench. Long-radius bends and tees will be used to bring the conduit to the top of the subgrade. The conduit is capped and marked at the base/subgrade interface. Instrumentation will be placed on the base/subgrade interface prior to installation of the base. Lead wire will be protected with plastic coated FMC to the conduit opening. Trenches are backfilled with subgrade material and compacted to the prescribed density.

Once the base is placed and compacted, conduits stubbed at the base/subgrade interface are located and extended to the top of the base. Instrumentation in and on top of the base is placed and protected leads pulled through conduits to the control cabinet.

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Instrumentation Estimate

Sensor Code	Sensor Type	Manufacturer	Measure Type	Cell 55	Cell 56	Cost per sensor	Instrument Estimate
LE/TE	Embedded Strain Gauge	CTL	Dynamic Strain	24	24	600	28,800***
MH	Moisture-Humidity	Campbell Scientific, CS-635	Volumetric Moisture Content	10	10	80	3200**
TC	Thermocouple Tree	Campbell Scientific TC Wire	Temperature	1	1	500	2000*
PK	Pressure Cell	CTL	Normal Stress	3	3	1000	6000
PL/PT	Pressure Cell		Horizontal Stress	9	9	500	9000
							0
MDD	Multi –Depth Deflectometer	CTL	Vertical Deflections	1	1	3500	7000
							$55,000 [1]

***** Dynamic Data Collection for strain data is accomplished with high-speed polling data loggers; a minimum of 1000 hz. A National Instruments PXI based chassis and applicable PXI modules for 84 dynamic data sensors is required. Costs are not yet available.**

**** Requires a dedicated data logger (CR 1000 shared with TC Tree) and two multiplexers per data collection station; One data reader (TDR 100) per 10 sensors. Estimate an additional $5000 per Cell.**

*** Requires a dedicated data logger and two 8-channel multiplexers (CR 1000 shared with MH). Add an additional $2500 per cell.**

[1] Does not include the costs of data loggers and other necessary infrastructure (e.g. control cabinets, conduit, splice vaults, electrical power, communications, etc.)

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Instrumentation Infrastructure Estimate

Item	Manufacturer	Description	Cell 55	Cell 56	Cell 57	Cell 58	Unit Cost	Cost per Item
Power Cable		1-C # 4,	1200	1200	1800		2.25/ft.	9450
Fiber Optic Cable		6-SM	500	300	400		3.00/ft.	3600
Control Cabinet		NEMA 334	1	1	1		4000	12000
Pull Vault	Quasite	24 by 36 by 42 deep		1			1000	1000
Power Dist. Cabinet			1	1	1		600	1800
PVC Hand Hole		24 by 42 w/lid	2	2	3		300	2100
PE Conduit		1-inch	300	300	300		1.25	1125
PE Conduit		2-inch	300	300	600		2.25	2700
PE Conduit		3-inch	300	300	300		3.00	2700
Foundation		Combination, Control/Power	1	1	1		1000	3000
Cabinet Components								
NI Chassis	National Instruments	Dynamic Data Management	1	1	1		14000	42000
NI Chassis Extension	National Instruments		1	1	1		5000	15000
NI Modules	Universal Strain	Strain or Displacement	7	7	7		3000	63000
Multiplexer	CS?		4	4	4		500	6000
TDR100	CS		1	1	1		4000	12000
CR 1000	CS		1	1	1		1500	4500

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