Application of Deflection Bowl Parameters for Assessing Different Structures of Road Pavement

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Introduction

- At present, highway agencies have been encouraged to use more non-destructive testing (NDT) methods to evaluate the structural conditions of pavement.
- Two established NDT methods so far, seismic method (SASW method) and deflection method (using backcalculation program) need **specialist with in-depth knowledge about materials and also information about layer thicknesses**.
- These could prevent a wider acceptance of the NDT method.

Introduction

- In 1987, Horak introduced **the use of deflection bowl parameters**, as an alternative evaluation of the structures of the road pavement.
- The use of these parameters is quite simple and does not require the layer thicknesses.
- The use of this parameter will not produce detailed results, but **only an indication of the structural conditions** of a pavement, and this is sufficient for field evaluation of structural damage of road pavement.

Objectives

- To evaluate **the usefulness of the parameters at present** when the pavement structure may have fewer or more number of layers compared to the number of layers at the time the method is developed (i.e. 4 layers)
- To evaluate whether the use of sensors within the parameters is **completely thickness-free**.

Deflection Bowl Parameters

- Horak and Emery (2006) suggested four deflection bowl parameters that have correlations with the condition of certain pavement structural layer.

Parameters	Which layer?
Max. deflection (D_0)	All layers, 70% contributed by subgrade
Base layer index (BLI) = $D_0 - D_{300}$	Base layer
Middle layer index (MLI) = $D_{300} - D_{600}$	Subbase layer
Lower layer index (LLI) = $D_{600} - D_{900}$	Subgrade

Deflection Bowl Parameters

- The use of parameters to indicate behaviour state for flexible pavement with granular base

Deflection Bowl Parameters (mm)				Behaviour State
D_0	$BLI = D_0 - D_{300}$	$MLI = D_{300} - D_{600}$	$LLI = D_{600} - D_{900}$	
< 0.3	< 0.08	< 0.05	< 0.04	Very Stiff
0.3 – 0.5	0.08 – 0.25	0.05 – 0.15	0.04 – 0.08	Stiff
0.5 – 0.75	0.25 – 0.50	0.15 – 0.20	0.08 – 0.10	Flexible
> 0.75	> 0.50	> 0.20	> 0.10	Very Flexible

Deflection Bowl Parameters

- The use of parameters to indicate condition of the pavement structure with different base layer materials

Type of Base	Deflection Bowl Parameters (mm)				Structural condition rating
	D_0	$BLI = D_0 - D_{300}$	$MLI = D_{300} - D_{600}$	$LLI = D_{600} - D_{900}$	
Granular base	< 0.50	< 0.20	< 0.10	< 0.05	Sound
	0.50 – 0.75	0.20 – 0.40	0.10 – 0.20	0.05 – 0.10	Warning
	> 0.75	> 0.40	> 0.20	> 0.10	Severe
Asphaltic treated base	< 0.40	< 0.20	< 0.10	< 0.05	Sound
	0.40 – 0.60	0.20 – 0.40	0.10 – 0.15	0.05 – 0.08	Warning
	> 0.60	> 0.40	> 0.15	> 0.08	Severe

The criteria should be used with caution and adjustments might be required if **different material behavior is encountered**.

Research Methodology

- **Evaluation of existing deflection bowl parameters** on different structures of road segments.
  - the possibility to use the parameters on different structures of the segments.
  - the possibility to use different sensors on the parameters.
- **Proposed recommendation** for improving the usefulness of deflection bowl parameters.

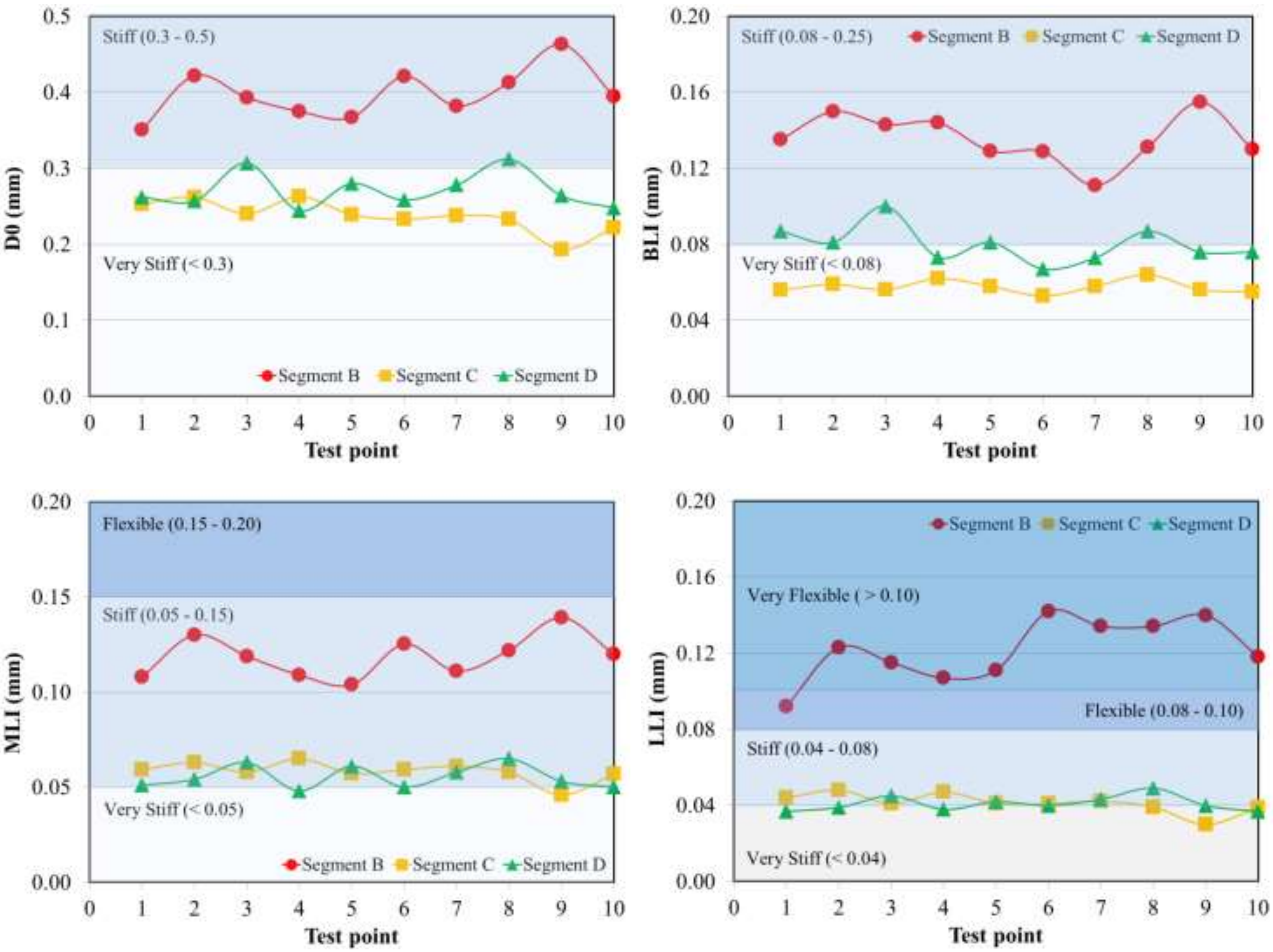
Research Methodology

- Different pavement structures used in this study and all data were extracted from Long-term Pavement Performance (LTPP) database.

Road segments	No. of layers/ total thickness	Layer details
A	3 / 7.5 in.	Subgrade (infinite), unbound granular base (3 in.), AC layer (4.5 in.)
B	3 / 11.9 in.	Subgrade (204 in.), unbound granular base (9.6 in.), AC layer (2.3 in.)
C	4 / 24.3 in.	Subgrade (infinite), unbound granular base (16.2 in.), AC layer (6.6 in.), AC layer (1.5 in.)
D	4 / 31.5 in.	Subgrade (132 in.), unbound granular base (18.4 in.), AC layer (11.7 in.), AC layer (1.4 in.)
E	5 / 16 in.	Subgrade (infinite), unbound granular subbase (4.7 in.), unbound granular suubase (5.3 in.), bound treated base (5.0 in.), AC layer (1.0 in.)
F	5 / 28.3 in.	Subgrade (infinite), unbound granular subbase (19.5 in.), bound treated base (4.6 in.), AC layer (2.7 in.), AC layer (1.5 in.)

Results and Discussions:

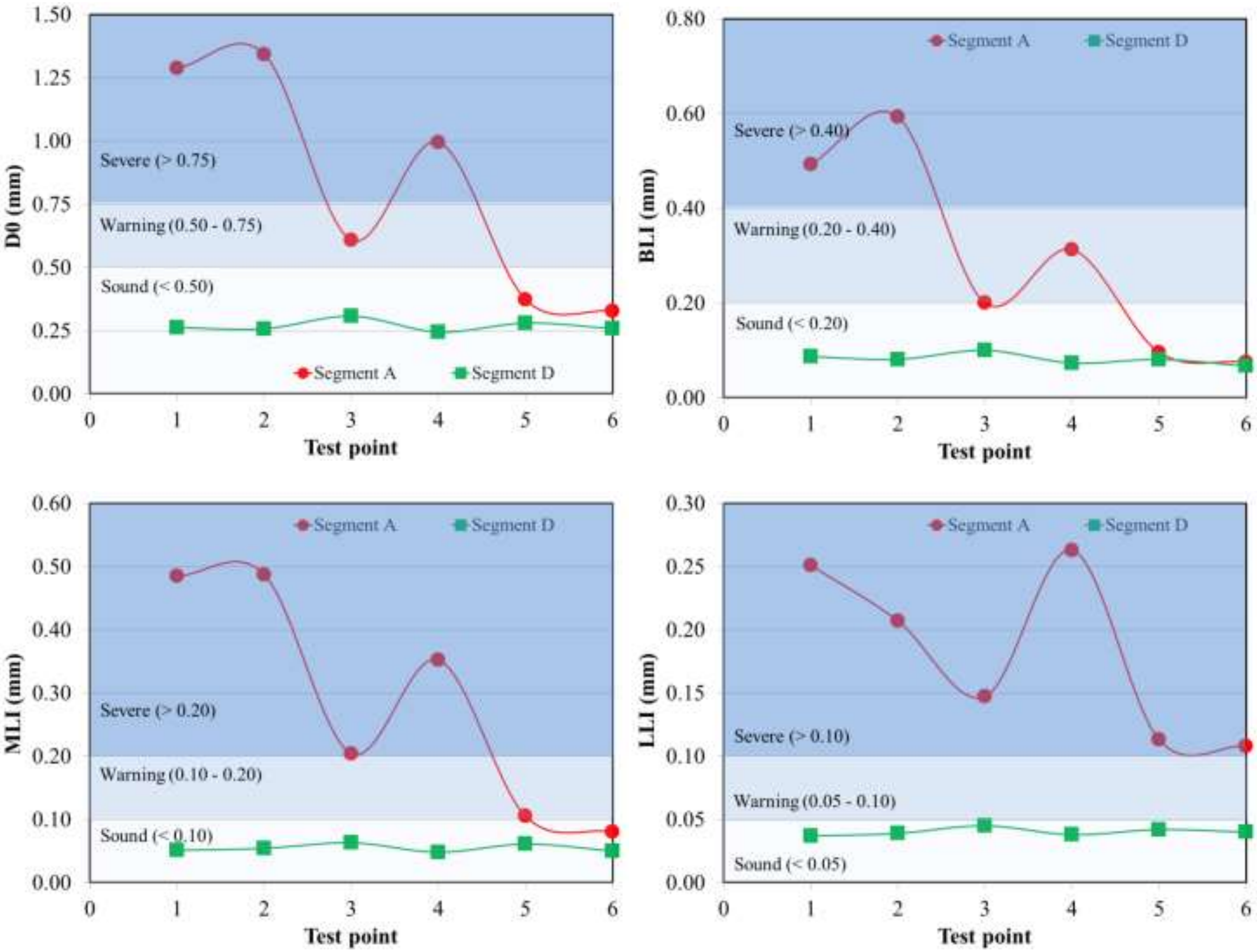
Behavior states of road segments with different structures



- This figure is very useful to **indicate the elastic response** of the layers.
- **A strict range of behavior states** could complicate the evaluation of the structure.
- From the figure, it seems that the road segments **have shown inconsistency** in terms of behavior states due to some factors.

Results and Discussions:

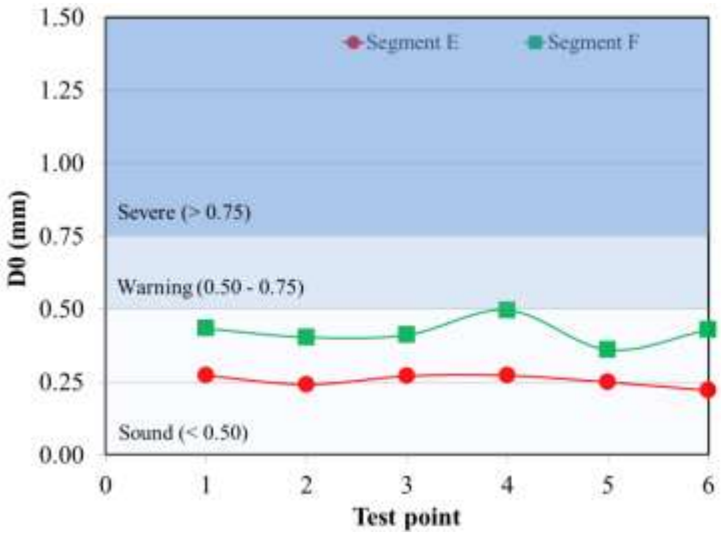
Structural condition of a granular-base pavement structure

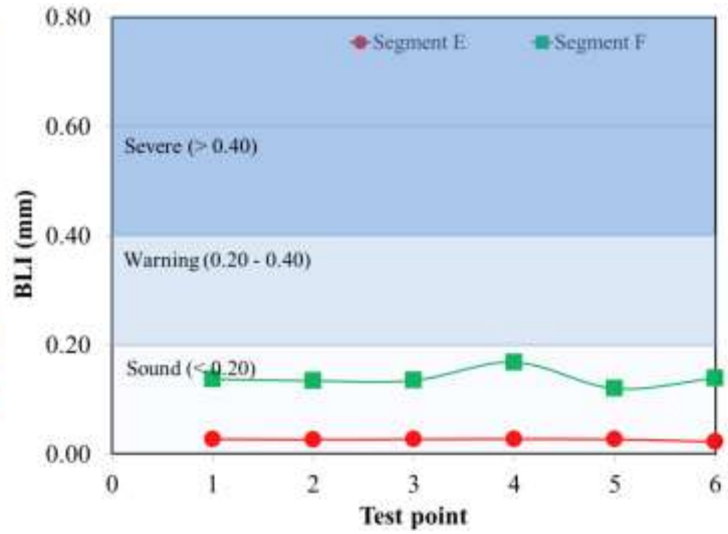


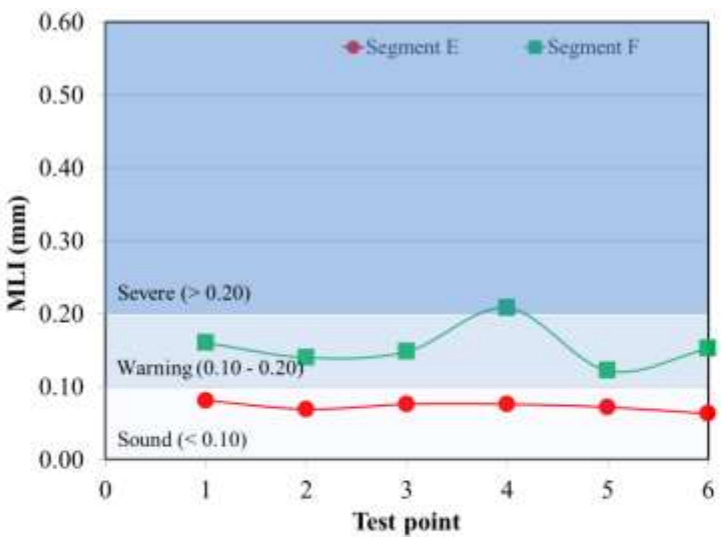
- Two segments **show different conditions**: segment D is in good condition, while segment A shows different condition along the segment.
- Parameters D_0, *BLI* and *MLI* have similar trends, while *LLI* trend may lead a misinterpretation. This is due to the segment **does not have subbase layer.**

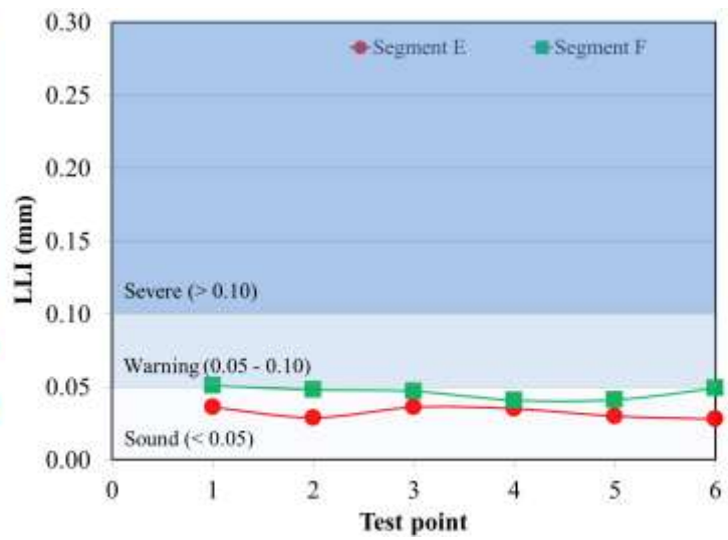
Results and Discussions:

Structural condition of a asphalt-treated base pavement structure









- Parameters D_0, *BLI* and *LLI* have similar trends. The warning condition of *MLI* (segment E) due to **imprecise selection of the sensors** or **improper determination of rating criteria.**

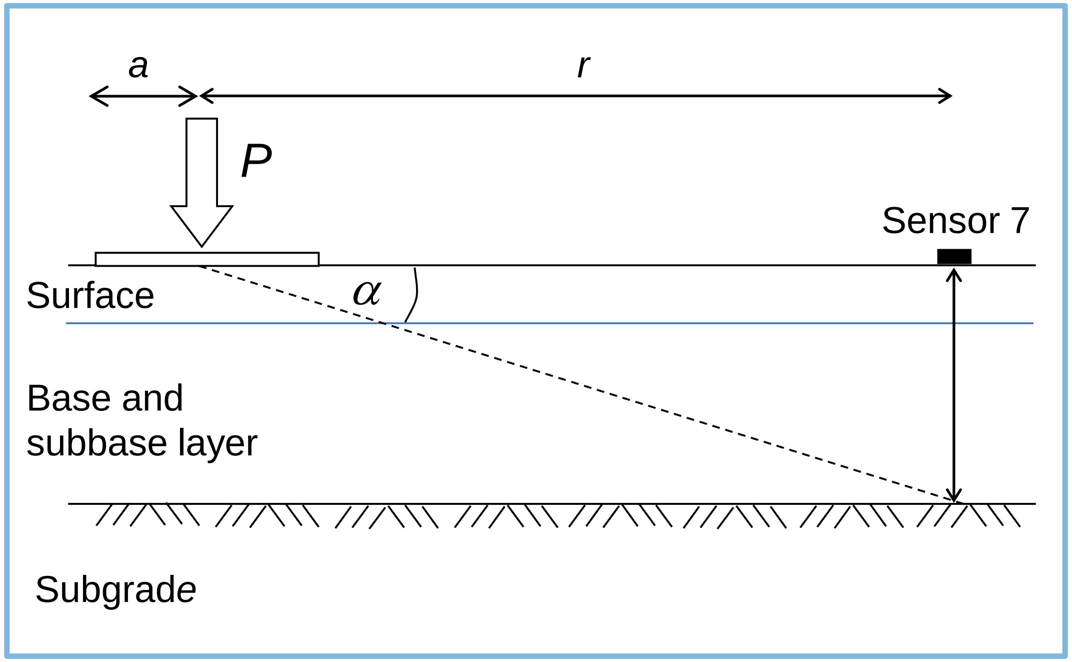
Results and Discussions:

Evaluation on the use of parameters on different structures

- It is recommended to simplify the parameters into only 3 parameters (D_0, *MLI* and *LLI*). The first and last parameters are very important to indicate the **sufficiency capability of the structures to reduce susceptibility to cracking and rutting**.
- MLI is very important to indicate:
  - **the condition of middle layers in providing sufficient support to the surface layer**;
  - whether the middle layer is affected in case of damage to the surface layer or subgrade.

Results and Discussions:

Effect of different sensors usage on deflection bowl parameters



$$M_r = \frac{0,24P}{d_r r}$$

M_r is considered valid if $r > a_e$

$$a_e = \sqrt{a^2 + \left[D\left(\frac{E_p}{M_r}\right)^{1/3}\right]^2}$$

$$d_0 = 1,5pa\left\{\frac{1}{M_r\sqrt{1+\left(\frac{D}{a}\sqrt[3]{\frac{E_p}{M_r}}\right)}} + \frac{\left(1 - \frac{1}{\sqrt{1+\left(\frac{D}{a}\right)^2}}\right)}{E_p}\right\}$$

Results and Discussions:

Effect of different sensors usage on deflection bowl parameters

Road segment	Pavement thickness (in.) /no. of layers	Min. outer sensor offset for subgrade measurement (in./mm)
A	7.5 / 3	18 / 457
B	11.9 / 3	18 / 457
C	24.3 / 4	36 / 914
D	31.5 / 4	60 / 1524
E	16 /5	24 / 610
F	28.3 / 5	36 / 914

- From the table, for road segments with many layers (i.e. C, E an F), it is not possible to use LLI equation: $LLI = D_{600} - D_{900}$
- To measure subgrade support, **it requires outermost sensors**, therefore, the following LLI equation is recommended:

$$LLI = D_{914} - D_{1524}$$

Results and Discussions:

Effect of different sensors usage on deflection bowl parameters

- For middle layer, it is proposed to use the following equation:

$$MLI = D_{305} - D_{457}$$

- This is because:
  - these sensors (at r = 305 mm and 457 mm) are **located at a considerable distance from the load center *P***;
  - both sensors can cover the response of the base or subbase layers of a three-layer pavement structure

Conclusions

- The sensor offsets used in the parameters should be in accordance with those used by the falling-weight deflectometer (FWD) device.
- **A simplification of the parameters** to only 3 parameters (D0, MLI, LLI) was proposed for the sake of ease in practice.
- **Reformulation of MLI and LLI** were required by taking into account the accuracy of the subgrade modulus determination and the possibility to evaluate pavement structures with a layer number less than four

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End of Presentation.

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