Lecture 5

Pavement Roughness Evaluation

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Pavement Condition Survey

Condition Category	Pavement Condition Parameter
1. Safety	• Skid resistance measurements • Accident rate
2. Structural capacity	• Cores • Deflection measurements
3. Serviceability	• **Surface roughness measurements** • Panel rating
4. Distress	• Distress condition survey (automated nondestructive survey; manual measurements; visual inspection; photo-logging)

CONCEPT OF PAVEMENT PERFORMANCE AND PAVEMENT SERVICEABILITY

Concept was proposed for AASHO Road Test (1958 – 1960)

Pavement Performance

Ability to serve its function of providing a comfortable, safe and 'smooth' ride to road users.

Pavement performance $\neq$ Structural condition of pavement

PAVMENT PERFORMANCE & SERVICEABILITY

THE CONCEPT OF SERVICEABILITY

Pavements are provided for motorists. It is logical to use some measure of user response in assessing the condition of pavements. User response is useful in determining what is an **acceptable pavement** and the level of **acceptable ride quality** of a pavement. It provides an indication of the level of service, or serviceability, provided by the pavement.

Evaluating Pavement Serviceability

Pavement Serviceability, a measure of riding quality, is determined by a panel of individuals who rate a pavement on a rating scale from 0 - 5 as they drive over selected pavements. The average of ratings is known as **PSR** (present serviceability rating).

PAVMENT PERFORMANCE & SERVICEABILITY

AASHO Serviceability Performance Equations

By correlation analysis, AASHO Road Tests produced the following serviceability equations in terms of pavement conditions:

Flexible Pavements

$$PSI = 5.03 - 1.9 \log (1+SV) - 0.01\ C + P - 1.33\ (RD)^2$$

Rigid Pavements

$$PSI = 5.41 - 1.80 \log (1+SV) - 0.09\ C + P$$

These equations provide a way to determine PSI from physical measurements using standard procedures.

Roughness Characteristics of Road Surface

Wavelength & amplitude of surface unevenness are important.

Flexible Pavements -- Longitudinal unevenness are mostly associated with pavement damage, structural or surface defects.

Rigid Pavements -- Unevenness usually arises from joint defects, construction faults, movement between slabs.

Effect of Wavelength (French)

Speed (km/h)	Wavelength with adverse effect	
	Road Safety (m)	Riding Comfort (m)
40 – 60	0.6 – 1.6	3.7 – 16.6
90	1.25 – 2.5	8.3 – 25
130	1.8 – 3.5	12 - 25

Effect of Amplitude (French)

User Response	Wavelength		
	Very Short 1 – 3.3 m	Short 3.3 – 13 m	Long 13 – 40 m
Acceptable	2 mm	4 mm	14 mm
Unacceptable	3 mm	8.5 mm	27 mm

Human Perception of Vibration

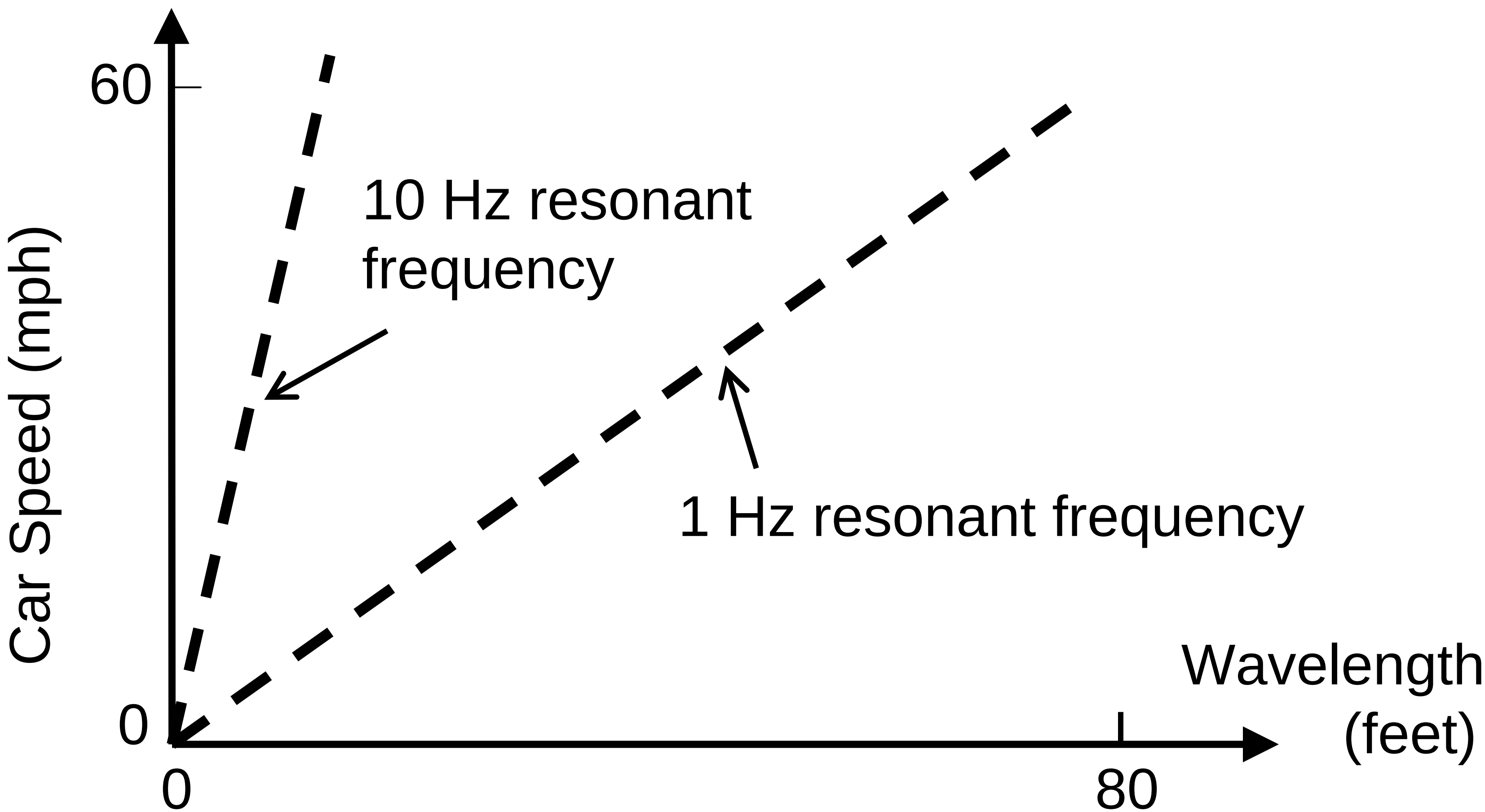
People are sensitive to frequency and amplitude of excitation. Max sensitivity usually 1 ~ 10 Hz in which range various internal organs vibrate in resonance with the excitation.

Vibration = f (Veh dynamic characteristics, veh speed
surface wavelength & amplitude)

Most cars possess similar characteristics, if driven at about the same speed, user response (ride quality) becomes ~ f (surface wavelength & amplitude)

Normal Veh = Mechanical vibrating system
(mass + springs + shock absorbers)

Resonant freq. of typical car = 1 ~ 10 Hz



Roughness Measuring Devices

Desirable profile features to be measured :

Wavelength 0.03 m ~ 150 m (0.1' ~ 500')

Amplitude down to 0.25 mm

Two Types of Equipment :

1. Response type
2. Profiling equipment

Response Type

– measures vehicle response to roughness

-- gives a relative measurement of road roughness

-- f(road profile, equipment mechanical system, speed)

Profiling Equipment

– gives scaled reproduction of pavement profile along a straight line.

Response Type Roughness Measuring Devices

(UK)	Bump Integrator	20 ~ 65 km/h
(US)	PCA Road meters	~ 80 km/h
	Mays meter	~ 80 km/h
(Can)	ARAN (Automatic Road Analyser)	50 - 80 km/h
(Sweden)	Road Surface Tester	30 – 120 km/h
(Australia)	NAASRA Roughness meter	50 – 80 km/h

Limitations:

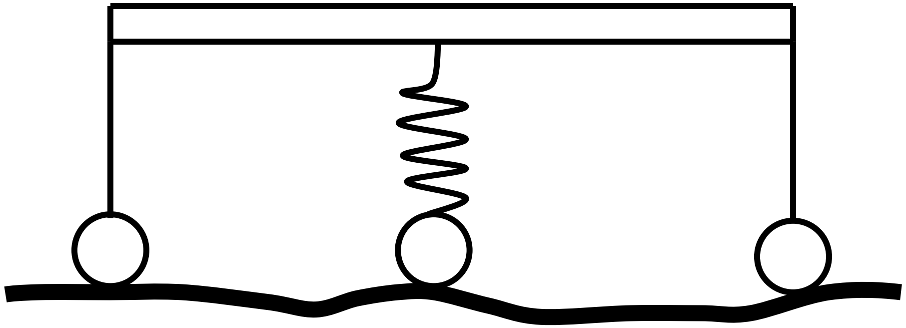
- Time-unstable
- Frequent calibration
- Limited wavelength range (up to ~ 7.0 m)

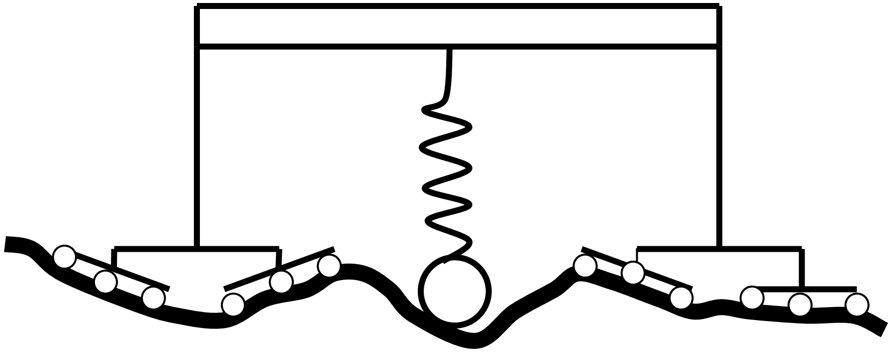
Profiling Equipment for Roughness Measurement

<u>Rolling Straightedge</u> (or profilograph)

- Only for wavelength < span
- Distort wavelength = span harmonics
- Low speed

Usual span 10’, 12’, 15’, 30’





Profiling Equipment for Roughness Measurement *(cont'd)*

Rod and Level Survey

Discrete point levels
Tedious, time consuming

CHLOE Profilometer

Developed at AASHO Road Test
Measures change in angle between 2 reference lines

Other Profilometers

GM Profilometer (Surface Dynamic Profilometer SDP)
UK TRRL High-Speed Profilometer

Profiling Equipment for Roughness Measurement *(cont'd)*

Non-Contact Profilometer Using Laser Sensors

e.g. TRRL High-speed Road Monitor (Trailer mounted)

- 4 laser sensors mounted on a rigid beam to compute longitudinal profile
- An additional sensor positioned along wheel path to determine rut depths
- Inclinometers mounted both along and perpendicular to the trailer axle together with a distance transducer to calculate gradient, cross-fall and horizontal curvature of the road continuously.
- Operating at traffic speed

Interpretation of Road Roughness by Roughness Index

(A) Deviations in Elevation

Accumulation of Vertical Deviations

Roughness represented by cumulative displacement relative to a fixed reference.

Roughness = $\sum |d|$ (in/mile or mm/km)

(e.g. cumulative displacement of an axle w.r.t. vehicle body)

Example: Bump Integrator – records counts of displacement in inches (Downward only or both directions)

PCA Road meter – records counts of displacement in 1/8 inch

(A) Deviations in Elevation *(cont'd)*

Squares of Deviations

Roughness = $\sum d^2$

Roughness represented by sum squared displacements relative to a fixed reference.

Slope Variance (AASHO Road Test)

$$SV = \frac{\sum Y^2 - \frac{1}{N}\left(\sum Y\right)^2}{N-1}$$

where Y = Difference in elevation of 2 successive points at a constant distance apart (1ft for AASHO Road Test)

N = number of readings

(B) Roughness Indices

RMSVA (Root Mean Square Vertical Acceleration)

Root mean square of change in elevation with distance

$$\mathbf{RMSVA_d} = \sqrt{\sum_{i=2}^{n-1}\left(\frac{I_{i+1} - 2I_i + I_{i-1}}{d^2}\right)^2 / (n-2)} \qquad (1/mm)$$

where I = level measurement

d = interval of level measurement

May be computed for one wheel path or as average of both wheel paths.

MAVA (Mean Absolute Vertical Acceleration)

Mean change in grade with distance

$$\mathbf{MAVA_d} = \frac{1}{n-2}\sum_{i=2}^{n-1}\left|\frac{I_{i+1} - 2I_i + I_{i-1}}{d^2}\right| \qquad (1/mm)$$

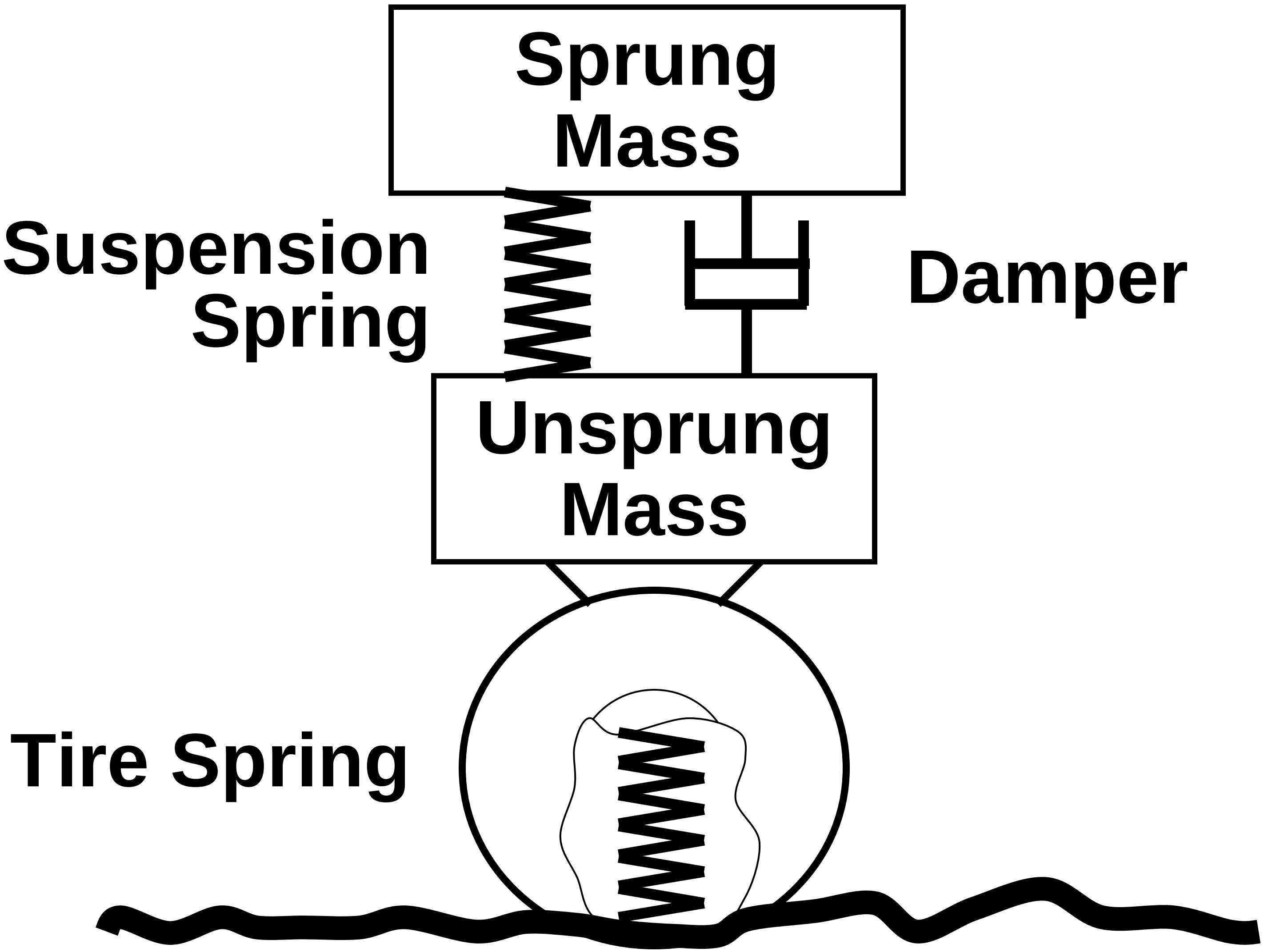
(C) Quarter-Car Simulation

Refers to mathematical models that simulate the response of one fourth of a vehicle ‘travelling’ over known input pavement profile data.

$$M_1 \ddot{Z}_1 + C_1(\dot{Z}_1 - \dot{Z}_2) + K_1 + (Z_1 - Z_2) = 0$$
$$M_1 \ddot{Z}_1 + M_2 \ddot{Z}_2 + K_2(Z_2 - Z) = 0$$

(Linear 2nd-order differential equations, exact solutions can be calculated)

(C) Quarter-Car Simulation *(cont'd)*



(C) Quarter-Car Simulation *(cont'd)*

Two common QCS statistics for describing road surface roughness :

$$QCS_1 = \frac{1}{T}\int_0^T \left|\dot{Z}_1 - \dot{Z}_2\right| dt$$

(m/sec) T = total time

$$QCS_2 = \frac{1}{L}\int_0^T \left|\dot{Z}_1 - \dot{Z}_2\right| dt$$

(mm/m) L = total distance

(i) **Average Rectified Slope (ARS)**, similar to response-type roughness device output in mm/m, measures the axle motion relative to car body normalized by distance. The relation of this index with road serviceability is confounded with travelling speed.

(ii) **Average Rectified Velocity (ARV)** measures axle motion relative to car body normalized by time.

Travelling speed is usually specified, e.g. ARS_v, ARV_v.
Note: $(QCS_1/QCS_2) = (ARV/ARS) = V$

(C) Quarter-Car Simulation *(cont'd)*

(iii) IRI (International Roughness Index)

- QCS_2 on single wheel track profile
- Simulation travelling speed = **80 km/h**

Class 1 IRI

– Index obtained with highest quality profile measurements.
– Suitable for all applications.
– On smooth roads, precision 0.5 mm
– On rough roads, precision 3 mm
– Measurement interval < 250 mm
(e.g. TRRL Beam; GM Inertial Profilometer, Rod and Level)

Class 2 IRI

– Index obtained with less accurate profile
e.g. lower precision measurement or longer sampling interval

(C) Quarter-Car Simulation *(cont'd)*

(iii) IRI (International Roughness Index) *(cont'd)*

Class 3 **IRI**

– Index measurement from response type road meters directly.

For developing aggregate data on the condition of a highway network, Class 3 IRI is satisfactory. When incremental deterioration of special test sections is to be tracked, Class 1 IRI is desired.

(iii) **IRI (International Roughness Index)** *(cont'd)*

The differential equations can be solved for road profile input Z to give values of z_1', z_2', z_1 and z_2 at fixed time intervals (i.e. at fixed distance intervals since speed of travel is constant at 80 km/h)

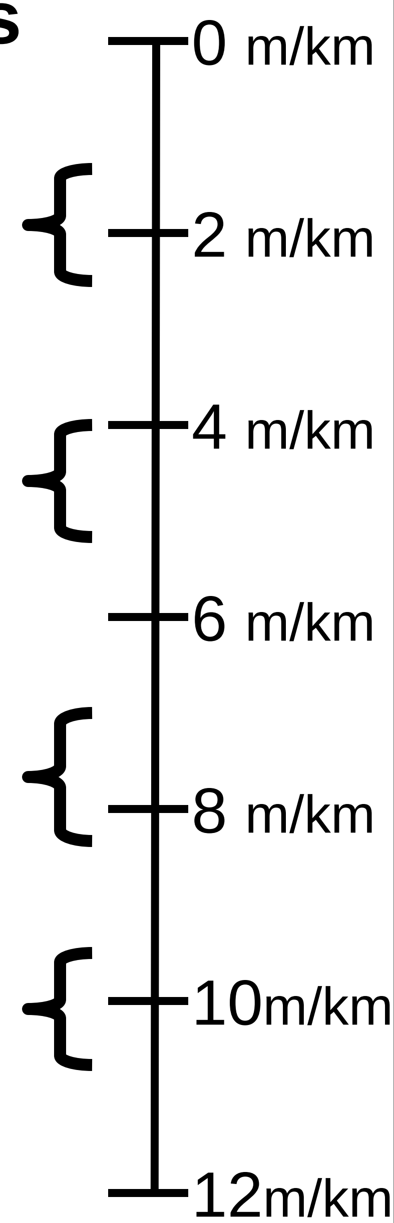
where z_1' = vertical velocity of sprung mass
z_2' = vertical velocity of unsprung mass
z_1 = vertical displacement of sprung mass
z_2 = vertical displacement of unsprung mass

If the total number of constant time intervals is n, then

$$\mathbf{IRI} = \frac{\mathbf{1}}{\mathbf{L}}\int_0^T \left|\dot{z}_1 - \dot{z}_2\right| dt = \frac{\mathbf{1}}{\mathbf{L}}\sum_{i=1}^{n}\left|\dot{z}_1 - \dot{z}_2\right|_i \Delta t$$
$$= \frac{1}{n\,\Delta t\,V}\sum_{i=1}^{n}\left|\dot{z}_1 - \dot{z}_2\right|_i \Delta t$$
$$= \frac{1}{nV}\sum_{i=1}^{n}\left|\dot{z}_1 - \dot{z}_2\right|_i$$

Alternatively, IRI can also be computed from output z_1 and z_2 (see tutorial)

IRI Roughness Scale for Paved AC Roads



Ride comfortable over 120 km/h. Undulations barely perceptible at 80 km/h. Depressions < 2mm/3m

Ride comfortable at 100-120 km/h. At 80 km/h moderately sharp movements or large undulations may be felt. Occasion depressions (e.g. 12-25/3m or 20-40/5m with freq. 3-1 per 50m), or many shallow potholes.

Ride comfortable at 70-90 km/h. Frequent sharp movements & swaying. Frequent deep & uneven or large depressions (e.g. 20-40/3m or 40-50/5m with freq. 5-3 per 50m), or frequent potholes (e.g. 4-6 per 50m).

Necessary to reduce velocity below 50km/h. Many deep potholes and severe disintegration (e.g. 40-80mm deep with freq. 10-20 per 50m)

References

- Chapter 19 “Highway Condition Surveys and Serviceability Evaluation” in The Handbook of Highway Engineering, edited by T. F. Fwa. (2006)
- Lui W. and Fwa T. F. (2005) Characterizing Road Roughness by Wavelet Transform. Transportation Research Record, No. 1869, pp. 152-158.