

**VISVESVARAYA TECHNOLOGICAL UNIVERSITY
BELGAUM**



PAVEMENT DESIGN

(Subject Code: 18CV825)

LECTURE NOTES

(MODULE-3)

VIII-SEMESTER

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Module - 3

Flexible Pavement Failures, Maintenance and Evaluation

General Causes of Pavement Failures:

- Defects in the quality of materials used.
- Defects in construction method and quality control during construction.
- Inadequate surface or subsurface drainage.
- Increase in the no. of vehicles and magnitude of wheel load repetitions.
- Settlement of foundation of embankment of the filled materials.
- Environmental factors- heavy rainfall, soil erosion, high water table, frost action, snow fall.

Pavement Failures:

1. General:

- Due to formation of pot holes, ruts, cracks, localised depressions.
- Aging and oxidation of bituminous films lead to the deterioration of bituminous pavements.
- Entry of water through cracks.
- Settlement of component layers.
- Failure in sub grade, base course, wearing course.

2. Failure in Soil Subgrade:

- Excessive deformations in subgrade soil results in undulations or waves and corrugations.
- Insufficient bearing capacity or shear failure in subgrade soil results lateral shoving (push or thrust) of pavement near the edges.
- Due to inadequate stability.
- Due to excessive stress application
- Due to inadequate compaction.

3. Failure in Sub Base or Base Course:

- Inadequate stability or strength- poor mix proportions, use of soft stone aggregates, improper quality control during construction.
- Loss of binding action- due to internal movement of aggregates under repeated stress, poor load transmitting property of pavement layer.
 - Loss of base course materials- occurs when not covered with a wearing course or the wearing course is completely worn out.

- Inadequate wearing course- this will damage the base course due to rain, frost action, traffic.
- Use of inferior quality materials.
- Crushing of base course materials due to less strength
- Lack of lateral confinement for the granular base course.

Types of Flexible Pavement Failures:

1. Alligator (map) cracking
2. Consolidation of pavement layers
3. Shear failure
4. Longitudinal cracking
5. Frost heaving
6. Lack of binding to the lower course
7. Reflection cracking
8. Formation of waves and corrugations

1. Alligator (map) Cracking:

- Cracking of bituminous surface.
- Most common type of failure due to relative movement of pavement materials.
- Due to repeated application of heavy wheel loads resulting in fatigue.
- Due to moisture variations resulting in swelling and shrinkage of subgrade and pavement materials.

2. Consolidation of Pavement Layers:

- Formation of ruts will cause consolidation.
- Due to repeated wheel load consolidation occurs.

3. Shear Failure and Cracking:

- Occurs due to lower shear resistance when loaded heavily.
- Upheaval of pavement is followed with a depression and results in cracks.

4. Longitudinal Cracking:

- Due to frost action.
- Due to volume change in the longitudinal direction.
- Due to settlement of fill or sliding of slide slopes.

5. Frost Heaving:

- Heaving up of pavement due to ground water and climatic conditions.

6. Lack of binding to the lower course:

- Due to weak bond between layers.
- Results in slipping of materials and opening up and loss of materials.
- Results in pot holes and patches.

7. Reflection Cracking:

- Observed in bituminous overlays provided over existing CC pavements.
- Allows surface water to seep through and damage the soil subgrade.
- Results in mud pumping.

8. Formation of waves and corrugations:

- Due to excessive load
- Increased traffic
- Poor quality of work and materials used
- Failure of component layers
- Moisture content and ground water table.

Classification of Maintenance Works:

- 1. Routine Maintenance Works:** Filling up of pot holes, patch works, maintenance of shoulders and cross slope, side drains, road side drains, clearing choked culverts, road signs etc.
- 2. Periodic Maintenance:** Renewal of wearing course of pavement surface, preventive maintenance of different layers.
- 3. Special Repairs:** Strengthening of pavement structure overlay construction, widening of roads, repair work of damage due to floods, providing additional safety measures.

Factors to be included in the road Maintenance Management System:

1. Minimum acceptable serviceability standards for the maintenance of different categories of roads.
2. Field surveys for the evaluation of maintenance requirements.
3. Factors influencing the needs of maintenance- subgrade soil, drainage, climate, traffic, environmental condition.
4. Estimation of rate of deterioration of the pavement for the above conditions.
5. Type and extent of maintenance requirements.
6. Possible alternatives and their economic evaluation

7. Source and availability of funds.
8. Availability of materials, machines and man power.
9. Optimum utilization of inputs and fixing priorities for maintenance.

Maintenance of Earth Roads:

Damages will take place due to formation of:

- Dust in dry weather
- Longitudinal ruts along wheel path
- Cross ruts along the surface after monsoons due to surface water.

Remedial Measures:

- Frequent sprinkling of water.
- Treatment with Calcium Chloride- will retain water due to hygroscopic nature of mix.
- Use of other dust palliatives (i.e., calming or retarders)

Maintenance of Water Bound Macadam Roads:

- Replace the soil binder periodically to prevent the aggregate from getting loosened from surface course.
- Provide bituminous surface dressing course over WBM pavement to prevent dust nuisance.
- Patch up pot holes and ruts.
- Do the resurfacing after the useful life of WBM gets over.
- Increase the thickness of WBM pavement during the resurfacing.

Maintenance of Bituminous Surfaces:

- 1. Patch repairs:** For pot holes and depressions formed due to poor quality of materials and construction work.
- 2. Surface treatment:**
 - a) Excess of bitumen bleeds and the pavement becomes slippery. Aggregates of 10mm size will be spread over bitumen. Rolling is done for good bond between existing pavement and new materials spread.
 - b) Renewal coat such as surface dressing or seal coat is applied for oxidized surfaces due to aging and heavy rain.
- 3. Resurfacing:** To strengthen the totally worn-out pavement surface due to increased traffic. Extra thickness may be designed for increased traffic.

Special Repairs in Flexible Pavement:**1. Waves and Corrugations due to:**

- Defective rolling
- Poor subgrade conditions
- Poor gradation or Mix
- Unstable underlying layers

Remedial Measures:

- If the failure is due to excessive moisture conditions, suitable subsurface drainage system should be provided.
- If the failure is due to improper construction, reconstruct the road again.
- If the failure is due to sub grade soil due to highly plastic expansive clay (E.g. Black soil), do the treatment by using a modifying agent for stabilization (lime, lime-fly ash, bituminous emulsion, etc).

2. Skidding of Pavement Surfaces due to:

40% of the accidents are due to poor skid resistance offered by pavement surface.

There are 3 types of skidding:

1. Straight Skidding – occurs in the direction of travel when sudden breaks are applied.
2. Impending Skidding - occurs when the braking is gradual and wheel continues to revolve.
3. Sideway Skidding – occurs on curves where sufficient super elevation is not provided, or when coefficient of friction is inadequate.

Remedial Measures: Make the surface rough by using stone aggregates rolled on pavement.

Pavement Evaluation:

Pavement evaluation is a technique of assessing the condition of a pavement, both structurally and from the point of view of functional aspects, i.e., surface characteristics.

Evaluation involves thorough study depends on factors like:

- Subgrade support
- Pavement composition
- Pavement thickness
- Traffic loading and
- Environmental conditions.

Pavement Evaluation studies the investigation of structural adequacy of pavements and also the functional requirements for providing safe and comfortable traffic operations.

Methods of Pavement Evaluation:

- Visual Inspection
- Benkelman Beam Deflection Method
- Falling Weight Deflectometer

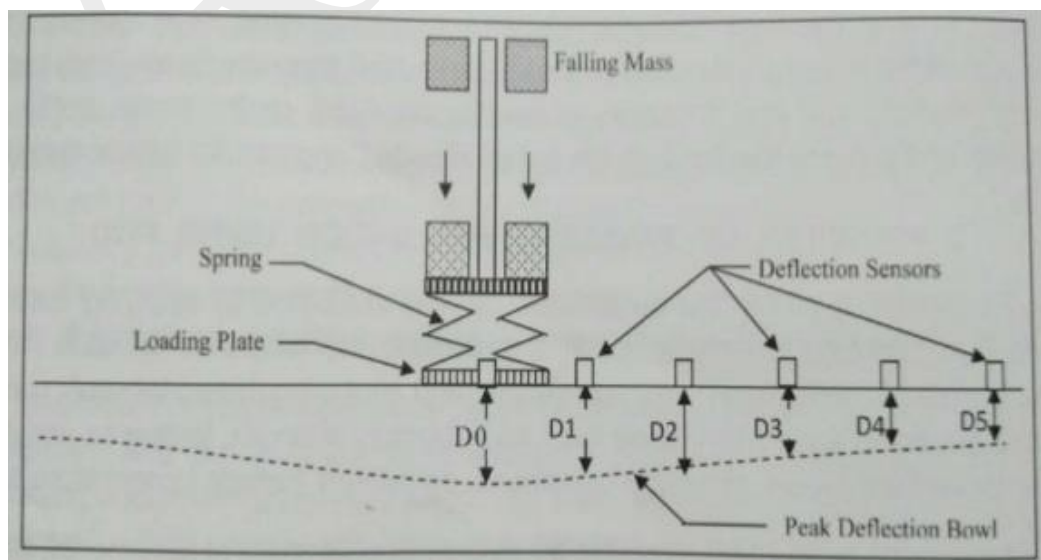
Visual Inspection Method:

This is a simple method of inspecting the pavement surface for detecting and assessing the amount and severity of various types of damage in the form of:

- Rutting
- Corrugation
- Flushing
- Alligator cracking
- Pot holes
- Longitudinal cracking
- Transverse cracking

Falling Weight Deflectometer Method:

In falling weight deflectometer (FWD) method, an impulse load is applied on the pavement surface by means of a falling weight and the deflected shape of the pavement surface is recorded using velocity transducers or geophones placed at different radial distances from the centre of the falling weight. Different magnitudes of falling weight are dropped from different heights of fall. Velocity sensors are used for collecting and storing the surface deflection data. The values of pavement layer thickness, Poisson's ratio, etc. are fed in and the values of elastic moduli of different pavement layers of existing pavement are determined by 'back calculation' method. Effective modulus of the existing pavement is made use of to assess the structural condition of the pavement and for estimation of overlay thickness required to provide the desired service life of the pavement.



Falling Weight Deflectometer

Principle of FWD:

- The working principle of the FWD is a mass of weights is dropped from a pre-determined height onto a series of springs placed on top of a loading plate.
- The corresponding peak load and peak vertical surface deflections at different radial locations are measured.
- In FWD 6-9 geophones are generally adequate for measuring surface deflections of flexible pavement and these geophones have reading resolution of at least 1 micron.

Steps involved in measuring the deflection:

- 1) Mark the test point on the pavement.
- 2) Raise the mass to a pre-determined height required for producing a target load of 40kN.
- 3) Raise the mass and drop. Record load and deflection data into the computer through data acquisition system.
- 4) Record air and pavement temperature at hourly interval.
- 5) Measure pavement temperature by drilling holes of 40mm depth into the pavement surface layer.
- 6) Deflection measurements should not be made when the pavement temperature is more than 45°C.

Purpose of Pavement Evaluation:

1. Structural Evaluation of Pavements
2. Evaluation of pavement surface condition

1. Structural Evaluation of Pavements:

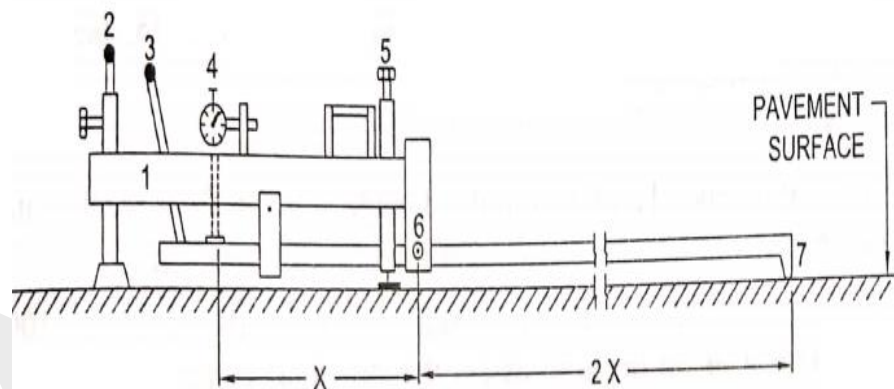
- Carried out by Plate Bearing Test.
- Structural capacity of the pavement is assessed by the load carried at a specified deflection of the plate or by the amount of deflection at a specified load on the plate.
- Benkelman Beam method is widely used- it is a rating survey of the road where the road will be divided into homogenous section of approximately similar serviceability.

2. Evaluation of pavement surface condition:

- Service conditions will be evaluated by the unevenness, ruts, patches and cracks.
- Pavement unevenness is measured by unevenness indicator, profilograph, profilometer or roughometer to get unevenness index in cm/km of the road.

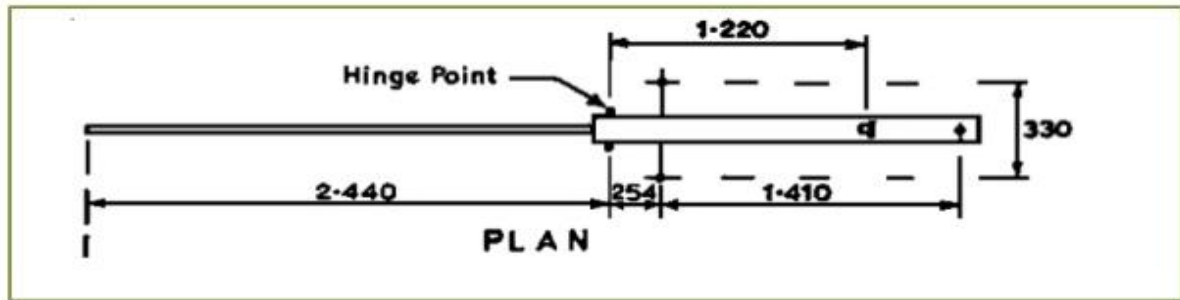
Benkelman Beam Deflection Method:

1. It is a device to measure the deflection of pavement due to a dual wheel load assembly or the design wheel load.
2. Equipment consists of a slender beam of length 3.66m pivoted to a datum frame at a distance 2.44m from the probe end.
3. Datum frame rests on a pair of front leveling legs and a rear leg with adjustable height.
4. The probe end of the beam is inserted between the dual rear wheels of a truck and rests on the pavement surface at the centre of loaded area of dual wheel assembly.
5. A dial gauge is fixed on the datum frame with its spindle in contact with other end of the beam so that distance between probe end & fulcrum of beam is twice the distance between the fulcrum & dial gauge spindle.
6. Rebound deflection reading measured at the dial gauge is to be multiplied by two to get the actual movement of the probe end.
7. In this case, a loaded truck with rear axle load of 8170 kg is used for the deflection study
8. The design wheel load is 4085 kg.
9. Inflation pressure will be 5.6 kg/cm².



- | | |
|-----------------------------------|-------------------------------------|
| 1. DATUM FRAME | 4. DIAL GUAGE |
| 2. REAR LEG WITH QUICK ADJUSTMENT | 5. FONT LEGS WITH ADJUSTMENT SCREWS |
| 3. CLAMP | 6. HINGE OF PROBE BEAM |
| | 7. PROBE END OF BEAM |

Benkelman Beam



Plan of Benkelman Beam

Steps:

1. Initial dial gauge reading D_o is noted.
2. The truck is moved forward slowly for 2.7m & reading dial gauge D_i is noted when the rate of recovery of the pavement is less than 0.025mm per minute.
3. Then the truck is driven for another 9m and the final dial gauge reading D_f is recorded.

The Deflection Value “D” at any point is calculated by any one of the 2 conditions:

1. If $D_i - D_f$ less than or equal to 2.5 divisions of the dial gauge or 0.025mm, then

$$D = 2 (D_o - D_f) \text{ divisions of } 0.01 \text{ mm units.}$$

$$D = 0.02 (D_o - D_f) \text{ mm}$$

2. If $D_i - D_f$ is greater than or equal to 2.5 divisions, then it will indicate that correction is needed for the vertical movement of the front legs. Therefore,

$$D = 2 (D_o - D_f) + 2K (D_i - D_f) \text{ divisions}$$

The value of K of Benkelman Beam is 2.91

Hence, Deflection Value in the 2nd case will be,

$$D = 0.02 (D_o - D_f) + 0.0582 (D_i - D_f) \text{ mm}$$

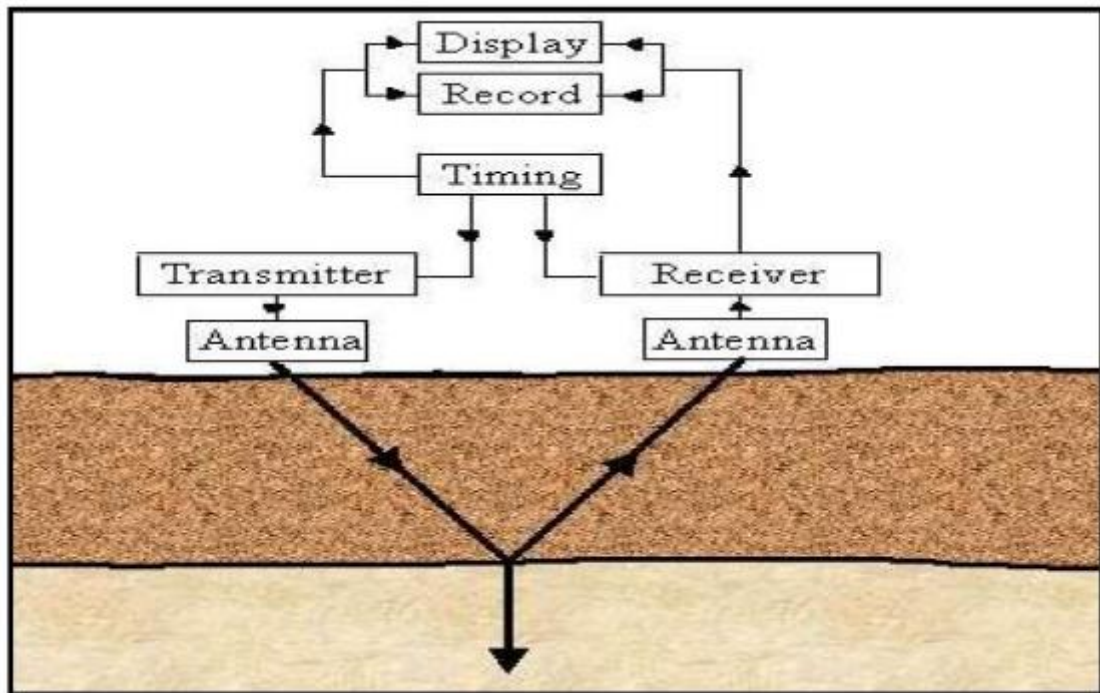
Ground Penetrating Radar (GPR) Method:

- Ground Penetrating Radar is a geophysical method that uses radar pulses to image the subsurface.
- GPR is used for finding and detecting buried object.
- GPR have a co-located transmitter and receiver.
- GPR is a short-range pulse system for remote sensing applications.
- Monostatic GPR operates by transmitting electromagnetic energy down into the ground through an antenna.

Components of GPR:

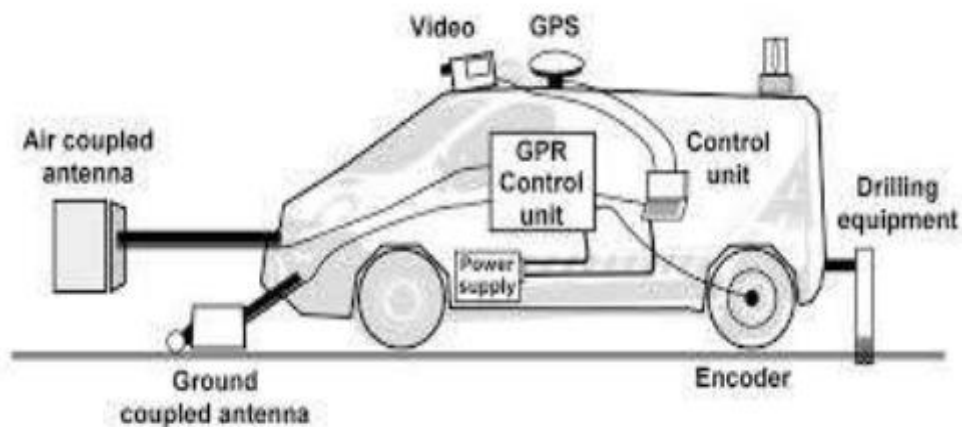
- 1) Transmitting and receiving unit
- 2) Control unit
- 3) Display unit
- 4) Power supplies

GPR Working Principle:



Data Acquisition:

- GPR uses high frequency radio waves and transmits into the ground.
- When the waves hit the buried object or a boundary with different dielectric constants, the receiving antenna records variations in the reflected return signal.
- The depth range of GPR is limited by electrical conductivity of the ground, the transmitted frequency and the radiated power.
- As conductivity increases the penetration depth decreases.



GPR Technology

Data Model and Layer-Stripping Inversion:

- In pavement, each layer of asphalt or concrete is basically a mixture of particles embedded in a homogenous matrix.
- Since particle size is considered to be small if compared to the waveform resolution of the GPR system, each system can be model as a homogeneous medium with effective complex dielectric permittivity values.
- Layer-stripping inversion is used to estimate the permittivity profile as well as the location in depth of those interfaces estimated in time.

Detection/Tracking in pavement profiling:

- Layer-stripping inversion with monostatic GPR is rather complicated since the echo amplitude decreases with time due to waveform attenuation.
- Moreover, the estimate of the echo amplitude is biased due to propagation through random media.
- Consequently, in pavement profiling, the SNR decreases with depth.

Multiple-Interface D/T:

- In the presence of more than one interface, the multimode and the D/T components tracks the echo delay with the largest SNR.
- In principle, this tracking ambiguity could be avoided by processing subsequence of time samples.
- In practice, errors are difficult to avoid when two interfaces are close to each other, when one interface splits into two interfaces, or even when two or more interfaces merge into one.

Application:

- In the Earth sciences it is used to study bedrock, soils, groundwater and ice.
- Military uses including detection of mines, unexploded ordnance detection and tunnels.
- Locating clandestine graves and buried evidence.
- The other main application is to locate underground utilities.

Advantages:

- Low cost
- Extremely accurate
- Fast
- No need of drilling and digging selected area
- Real time targeting
- Non-destructive
- Digital media storage
- Easy to operate
- Safe

Limitations:

- Site specifics.
- Limitations if dielectric properties are similar.
- Difficult in thin layer.
- Compromise between penetration depths and target resolutions.
- Requires fairly uniform soil for moisture estimation.

Problems

1. A Benkelman beam was used to measure the deflection. The readings obtained on the dial gauge at positions of wheels indicated below are:

Wheel Positions	Dial Reading
1. 1.2m behind selected point	0.06mm
2. At selected point	0.46mm
3. 3m in front of selected point	0.08mm

Calculate the (1) maximum deflection (2) rebound deflection (3) residual deflection

Solution:

$$\begin{aligned}\text{Maximum deflection} &= 2 \times (\text{maximum deflection} - \text{initial deflection}) \\ &= 2 \times (0.46 - 0.06) = 0.80\text{mm}\end{aligned}$$

$$\begin{aligned}\text{Rebound deflection} &= 2 \times (\text{maximum deflection} - \text{final deflection}) \\ &= 2 \times (0.46 - 0.08) = 0.76\text{mm}\end{aligned}$$

$$\begin{aligned}\text{Residual deflection} &= 2 \times (\text{final deflection} - \text{initial deflection}) \\ &= 2 \times (0.08 - 0.06) = 0.04\text{mm}\end{aligned}$$