TRAINING NOTE ON PAVEMENT EVALUATION TECHNIQUES AND THEIR APPLICATIONS FOR MAINTENANCE AND REHABILITATION

AT

CENTRAL ROAD RESEARCH INSTITUTE

NEW DELHI

FROM 12.12.2011 TO 16.12.2011

By

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Training Programme on

Pavement Evaluation Techniques and their Applications for Maintenance & Rehabilitation

From 12th – 16th December, 2011 at Central Road Research Institute (CRRI), Mathura Road, New Delhi

The following three officers from the Project Management Unit of Orissa State Roads Project attended the Training Programme on Pavement Evaluation Techniques and their Application for Maintenance & Rehabilitation from 12th – 16th December, 2011 at Central Road Research Institute (CRRI), Mathura Road, New Delhi vide Works Department Letter No-EAP (Cell)-121/ 2011-9733 Dt-22.09.2011 and Memo No- 50280 Dt- 15.11.2011 of Chief Engineer, World Bank Projects, Odisha.

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BRIEF NOTE by Delegates

The Central Road Research Institute (CRRI) is a constituent's laboratory of the Council of Scientific & Industrial Research (CSIR) of Govt. of India. The Institute provides high quality & globally acceptable research and consultancy services to the profession in the major areas of highway and road transportation technology.For capacity building in human resources in the area of Highway Engineering to undertake and execute roads and runway projects, CSIR-CRRI has been organizing regular training programmes/ continuing education courses for in-service Highway, Traffic & Transportation Engineers and Planner since 1962.

As a part of its numerous training programmes, CRRI had organized this programmes from 12th – 16th December, 2011 at New Delhi, which was attended by 22 delegates from different states of India.

The course contentsof this training course is listed below.

Date	Topic	Name of the Lecturer
12.12.2011		
First Session	Registration & Inauguration of Programme	ILT Division & Dr. S Gangopadhyay, Director
Second Session	An Introduction to Pavement Maintenance Management System	Mr. K Sitaramanjaneyulu
	Road Asset Inventory using Automated Road Survey System (Network Survey Vehicle)	Mr. Pradeep Kumar
Third Session	Structural Evaluation of Pavement by Benkelman Beam Deflection Method	Mr. R K Srivastava
Fourth Session	Structural Evaluation of Pavement by Falling Weight Deflectometer (FWD) Method	Mr. S P Pokhriyal

13.12.2011		
First Session	Pavement Surface Distress on Flexible Pavements	Mr. Sunil Jain
Second Session	Repair Techniques for Maintenance of Flexible Pavements	Dr. Devesh Tiwari
	Pavement Surface Distress on Rigid Pavements	Mr. Binod Kumar
Third Session	Practical Demonstration of Benkelman Beam Deflection Method and Analysis of Data	Mr. R K Srivastava, Mr. Rampal, Mr. Atar Singh & Mr. Shanta Kumar
Fourth Session	Practical Demonstration of FWD and Analysis of Data	Mr. S P Pokhriyal, Mr. R K Srivastava, Mr. Pradeep Kumar & Mr. Prithvi Raj Singh
14.12.2011		
First Session	Repair Techniques for Maintenance of Rigid Pavements	Mr. Binod Kumar
Second Session	Road Roughness including its Standardization	Mr. Pradeep Kumar
	Surface Characteristics of Pavements (Skid Resistance and Texture) and its importance and Measurements	Mr. Sudesh Kumar
Third Session & Fourth Session	Demonstration of various Equipments/ Devices (Dipstick, Walking Profiler, Roughometer-II, Bump Integrator, Static Weigh Pads and ATCC)	Mr. Pradeep Kumar, Mr. Y V Rao, Mr. Y C Pradeshi, Mrs. Shanta Kumar & Mr. P R Singh
15.12.2011		
First Session	Investigation of Pre-mature Distress and Failures on Bituminous Pavements	Mr. M N Nagabhusan
Second Session	Road User Cost Study in India	Dr. S Velmurugan
Third Session & Fourth Session	Visit to Road Projects for demonstration of Bituminous Technologies	Mr. Sunil Jain, Mr. Y V Rao, Mr. Rampal & Mr. A P Singh
16.12.2011		
First Session	Economic Evaluation of Highway Projects	Dr. S Velmurugan
Second Session	Introduction to HDM-4 and its Application in Management of Roads	Mr. R K Srivastava

	An Overview of RIS and HDM-4 software and their live demonstration	Dr. Devesh Tiwari
Third Session	Discussions with the Participants	HOD (PED) & Faculty
Fourth Session	Concluding Session & Distribution of Certificates.	Director, HOD (PED), HOD (ILT) & Faculty

TRAINING NOTE

It is well known fact that good roads are asset to the nation and bad roads are debt to the nation. Hence, pavement issue is a matter of concern for the engineers. The different issues relating to pavement are (i) Planning, Scheduling and Budgeting , (ii) Design and Cost Estimating, (iii) Construction and Quality Control (iv) Traffic Control (v) Maintenance & Repair, (vi) Material Quality and Specifications, (vii) Pavement Type Selection, (viii) Public Safety, (ix) Traffic Forecasting, (x) User Costs, (xi) Land Acquisition, (xii) Highway Signs, (xiii) Environment Problems, (xiv) Drainage, Etc.

The various factors affecting the pavement performance are (i) Road factors, (ii) Traffic factors and (iii) Climate and other factors. Thus, it is a need to evaluate the pavement for its performance and stability during the entire period of service life. The pavement can be evaluated on the basis of structural and functional point of view.

The Structural evaluation is made to assess the structural ability of the pavement and the Functional evaluation is made to assess the riding comfort & safety of the pavement.

The structural requirements of flexible pavements are

- The total thickness of the pavement and the thickness of individual layers should be such that they are not subjected to stresses or strains exceeding the allowable values.

- The pavement layers should be able to withstand repeated applications of wheel loads of different magnitudes without causing excessive distress/deformation.

EVALUATION OF STRUCTURAL CONDITION OF PAVEMENTS

Pavement deteriorates with passage of time through their design life. Due to excessive traffic loads than anticipated and being unattended for proper maintenance, the rate of deterioration will be rapid to result in early failure of the structure. Thus, Structural evaluation becomes necessary to provide the technical data for pavement management systems or maintenance planning. One of the most important aspects of the evaluation is the determination of the structural properties of the existing pavements

The test methods for structural evaluation may be classified into two groups, viz.,

- Destructive testing
- Non-destructive testing

1. Destructive

- CBR for evaluating sub grade strength
- Plate bearing tests for determining modulus of elasticity and modulus of sub grade reaction
- Marshal Stability
- Flow Index
- Modulus of rupture
- Indirect Tensile strength test
- Laboratory testing for quality of the pavements (Grain size distribution, density, moisture content, cores testing for CS and other lab. Tests)
- Extraction of cores from the in-service pavements

2. Non Destructive Evaluation Techniques

- Structural performance of the pavements can best and faster be evaluated by deflection methods.
- Non-destructive methods have the advantages of high speed and ease of operation.

Non-destructive are preferred over destructive testing since the structure's integrity is not disturbed at the test location. Most of the non-destructive test methods resort to measurement of pavement surface deflection or rebound deflection under the application of specified load. The deflection method is used as a criterion since the determination of such deflections is relatively simple. A pavement is regarded as having insufficient strength if the deflection measured under a test load exceeds an empirical determined value related to the traffic expected. In case where the structure has to be strengthened the required deflection reduction often serves as the basis for determining the thickness of the overlay to be applied.

The use of the maximum deflection under a load as a criterion for structure quality of the pavement may not always be appropriate since the relation between deflection and critical strain in the structure is dependent on the dimensions of the structure and the properties of materials therein.

To overcome this problem, the methods evaluating the shape of deflection bowl or profile are preferred over the methods that can measure only maximum deflection under the load.

PRINCIPLE OF DEFLECTION METHOD

Performance of flexible pavements is closely related to the elastic deflection of pavement under the wheel loads. The rebound deflection method of pavement evaluation is based on the concept that stretches of flexible pavements that are in service and have been conditioned by traffic, would deform elastically under a wheel load and when the load is removed or is moved forward, the deflected pavement surface would rebound. Rebound deflection is related to pavement performance. The residual deflection is due to non-recoverable deflection of the pavement or because of the influence of the deflection bowl on the front legs of the beam. Rebound deflection is used for overlay design.

STRUCTURAL BEHAVIOUR OF FLEXIBLE PAVEMENTS

- Phenomenon of repeated load applications over a certain time period.
- The surface deflection of the pavement under the load is recovered at each point soon after the load advances further.
- The magnitude of this 'rebound deflection' is an index of the structural ability of the pavement.
- Due to easy and quick measurements of rebound deflection, it is preferred for structural evaluation of flexible pavements.

The various factors on which the rebound deflection of a pavement depends are (a) sub-grade soil type, (b) moisture content of the sub-grade soil and compaction, (c) type and thickness of the pavement component layer, (d) temperature of the bituminous layers, (e) previous loading history of traffic load on the pavement and on the wheel path under consideration, (f) magnitude, contact pressure and configuration of the applied load, (g) drainage conditions and (h) other environmental factors.

The Structural evaluation of the pavement can be made either by Benkelman Beam Deflection (BBD) Method or by Falling Weight Deflection (FWD) Method.

METHODS OF DEFLECTION MEASUREMENTS

There are two methods for deflection measurements

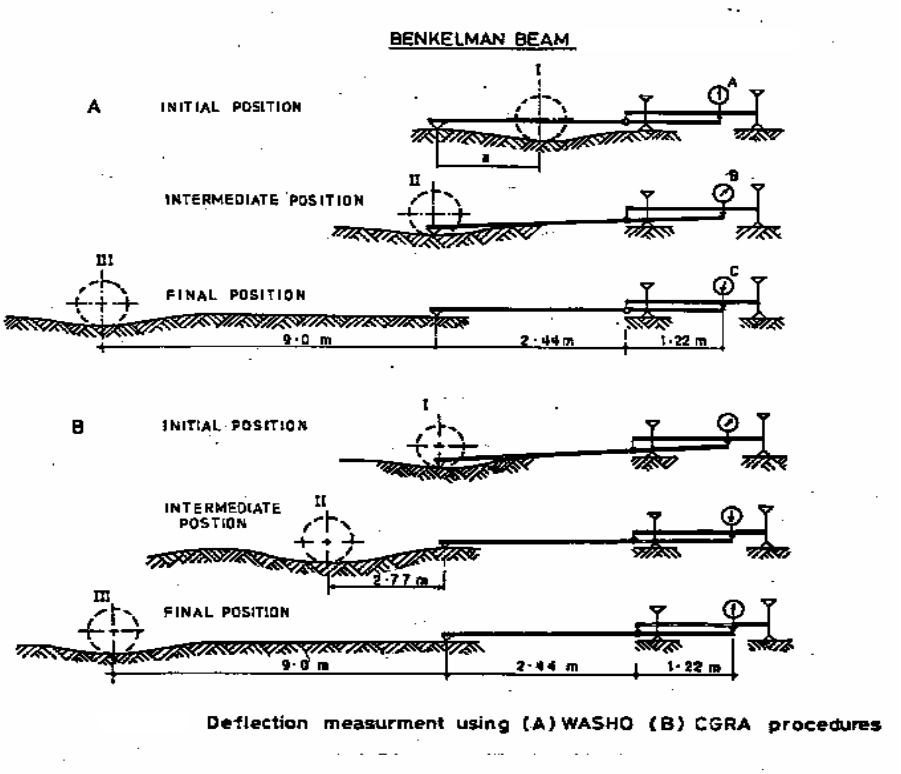
CGRA – Testing under static load

WASHO – Testing under creep load

However, CGRA method for deflection measurement is commonly used in our country.

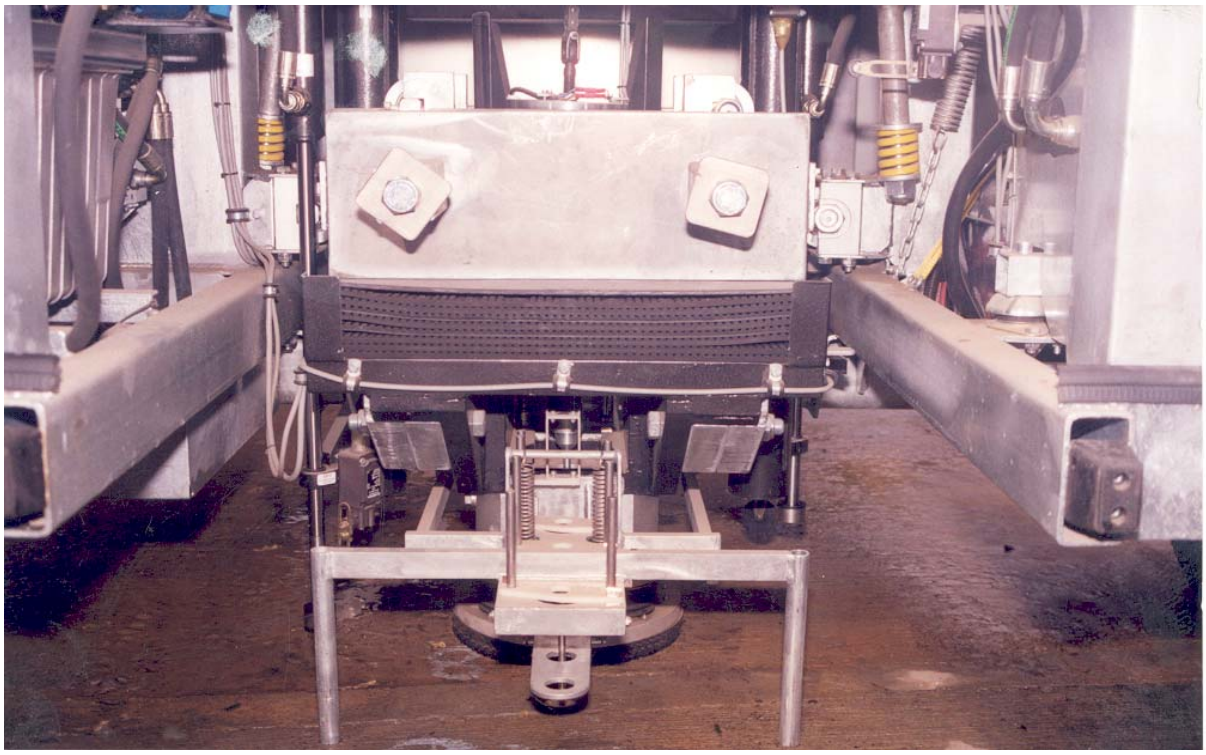
Benkelman Beam Deflection Technique

CRRI-2011-Pavement Evaluation



Deflection measurment using (A) WASHO (B) CGRA procedures

Falling Weight Deflectometer (FWD) in use



Sensor Bar in Contact with Pavement Surface

Advantages of FWD

- Fast in operation
- State- of- the- art equipments
- Use of mechanistic-imperial approach
- Applicable for any material/ pavement structure and climatic condition
- Enables design/ evaluation based on fundamental material properties
- Impulsive load to pavement
- Follows largely mechanistic approach
- Loads pavements dynamically at actual traffic loads and durations
- Cover long distances per day
- Very accurate deflection measurements

EVALUATION OF FUNCTIONAL CONDITION OF PAVEMENTS

Roughness is the measure of functional performance of the pavement. It is defined as the longitudinal deviation of a pavement surface from a true planar surface. Increase in roughness produces (i) Discomfort in riding, (ii) Decrease in the speed of vehicle, (iii) increase of accident, (iv) increase in vehicle damage and (v) increase in the vehicle operating cost.

Roughness Measurement Method

- Pavement surface roughness is measured in terms of Roughness Index (RI) in mm/km.
- International practice for measurement of roughness in terms of International Roughness Index (IRI) in m/km

- As per the Indian Codes/ Standards, Pavement surface roughness is expressed as the unevenness or Roughness Index in mm/km measured through fifth wheel Bump Integrator or vehicle mounted Bump Integrator.

Roughness norms as per IRC-SP-16: 2004

Type of Surface	Condition of Road Surface		
	Good	Average	Poor
Bituminous Concrete	< 2000	2000-3000	>3000
Cement Concrete	< 2200	2200-3000	>3000

Conversion between RI & IRI

$$RI = 630(IRI)^{1.12}$$
$$IRI = 0.0032(RI)^{0.89}$$

Where, IRI is in m/km or mm/m and RI is in mm/km

Types of Roughness Measuring Equipments

- Fifth Wheel Bump Integrator
- Vehicle Mounted Bump Integrator
- Laser Profilometer
- Ultrasonic Profilometer
- ARRB Roughometer- II/ III
- ROMDAS Bump Integrator
- Dip Stick Auto Read Road Profiler
- Walking Profiler

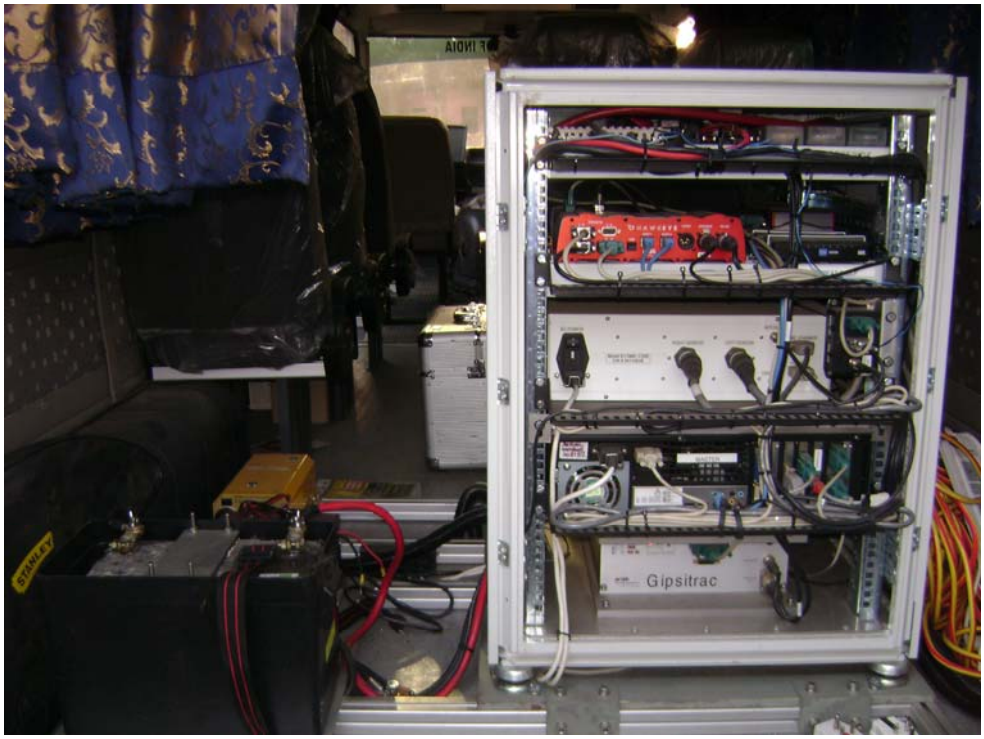
CRRI Pavement Condition Survey Vehicle

Dipstick Auto Read Road Profiler

Walking Profiler

Vehicle Mounted Bump Integrator

ARRB Roughometer



Inside View of CRRI Survey Vehicle

Pavement Distress

It is the physical manifestation of internal damage which may be due to inadequacy of structural or functional system.

Flexible Pavement Distresses

Types of premature Distress

1. Cracks
    - Hairline cracks
    - Alligator cracks
    - Longitudinal cracks
    - Edge cracks
    - Shrinkage cracks
    - Reflection cracks
2. Deformation
    - Slippage
    - Rutting
    - Corrugations
    - Shoving
    - Shallow Depressions
    - Settlements and Upheavals
3. Disintegration
    - Stripping
    - Loss of Aggregates
    - Raveling
    - Pot holes
    - Edge Breaking
4. Miscellaneous
    - Lane to Shoulder Drop off
    - Lane to Shoulder Separation

Why flexible pavements fail prematurely?

Factors attributable for premature failure of flexible pavements in India are follows

- Inadequate Structural design; poor or improper data/ information and unscientific approach
- Reduction in design life; significant and rampant over loading of heavy commercial vehicles
- Inadequate compliance to material/ mix specifications; poor or inferior material and mixes
- Improper/ poor construction practice; inadequate compaction, less attention to moisture and temperature, missing interface treatments, improper cleaning of layer surfaces, not treating defects in existing pavement
- Lack of modern planning, management tools and the needed construction machinery
- Deficiencies in maintenance practices
- Poor or missing drainage
- Adverse climatic and environmental factors

Rigid Pavement Distresses

Type of premature distresses

- Uncontrolled Transverse Cracks

- Longitudinal cracks
- Settlement Cracks
- Transverse Cracks Over Culverts
- Longitudinal Joint Failure
- Cracks Over Dowel Bars
- Misplaced Saw Cuts at Transverse Joints
- Blow Ups
- Plastic Shrinkage Cracks

Causes and recommended repairs of premature distresses

Uncontrolled Transverse Cracks
Causes:

- Incorrect joint spacing (working crack)
- Shallow or Delayed joint sawing(working crack)
- Locked Joints on both sides (working crack)
- Passage of very heavy load especially during day time

Recommended Repair

Saw & seal, dowel bar retrofit, full depth repair

Longitudinal Cracks
Causes:

- Incorrect joint spacing (working crack)
- Shallow or delayed joint sawing (working crack)
- Differential settlement of old and widened portion
- Incorrect placement of longitudinal joint
- Sub-grade settlement or movement

Recommended Repair

- Saw & Seal (W.C)
- cross-stitching and slot stitching (non-WC low severity)
- full depth repair (high severity, wheel path)

Settlement Cracks
Causes:

- Embankment settlement
- Backfill settling over culverts or underground utility structures

Recommended Repair

- Slab replacement with sub-grade repair & sub-base repair
- Cross -stitching

Longitudinal Joint Failure
Causes:

- Faulty tie bar design esp. length & spacing
- Wrong placement of lane markings vis-à-vis longitudinal joint
- Improper installation (manual construction)

Recommended Repair

- Staple Pinning or re-installation of tie bars

Cracks over Dowels

Causes:

- Settlement around dowels due to high slump and delayed setting
- Shallow depth of dowels
- Stiff concrete
- Improper functioning of DBI or TBI Unit

Recommended Repair

- Seal with neat epoxy

Misplaced Saw Cut at Transverse Joint

Causes:

- Dislocation of dowel baskets if not firmly anchored to the base
- Incorrect marking of dowel location along pavement edge

Recommended Repair

- Dowel retrofit if several feet away
- FDR if saw cut over dowels or immobilize the joint by stitching & saw cut with retrofit at different location

Blow-ups

Causes:

- Elevated temperatures in afternoon
- Restricted joint movement
- Longer slabs
- Joint less DLC

Recommended Repair

- Full depth repair or slab replacement

Plastic Shrinkage Cracks

Causes:

- Hot weather with low humidity
- Strong winds
- Evaporation greater than bleeding

Recommended Repair

- Brush dry cement and then moist (if noticed early)
- Tight hairline cracks - no treatment
- Wider cracks - pour HMW Methacrylate and sprinkle sand

Economic Evaluation of Highway Projects

Scope of transportation planning

- All man-made projects should start with a plan
- The more significant the project, the more intensive and long term the planning
- For large transportation projects, planning should starts 5 years before construction

Planning Process

- Situation Definition
- Problem Definition

- Search for Solutions
- Analysis of Performance
- Evaluation of Alternatives
- Choice of Projects
- Design & Construct

Functional Classification of Highway Systems

- Primary System
  - Expressways
  - National Highways (Multilane highways)
- Secondary System
  - State Highways
  - Major District Roads
- Tertiary System
  - Other district Roads
  - Village Roads

Steps in Highway Planning

- Situation Definition
  - Inventory of existing facilities
  - Current conditions and issues
    - Congestion, very high travel time, very high road user costs
  - Identification of other planning studies
    - Earlier plans at National, regional and local level to arrive at a solution
- Problem Definition
  - After understanding the present problems the problem could be defined
  - To achieve reasonable journey speeds, vehicle operation costs, comfort and convenience for travel

- Search for Solutions
  - Develop alternative concepts and solutions to reasonably satisfy the future needs considering their impact on environment, safety , economy and fiscal resources of the area
  - Examination of alternative alignments and development concepts is essential for the proper identification of viable alternatives

- Analysis of Performance
  - Demand forecasting
    - Demand forecasting includes determination of daily volume of different classes of vehicles.
    - The forecast must also give the traffic volume during the busiest hour of the day
    - If the facility is tolled a relation between the volume levels and the toll levels should be established
  - Analysis of the interaction between demand and capacity of the facility
  - Use performance measures to shortlist the alternatives

- Evaluation of Alternatives – Economic Feasibility
  - Conduct economic evaluation for the short-listed alternatives

- Each of the alternative may be compared with the do nothing alternative
- The benefits and cost for all the alternatives need to be worked out
- Benefits include savings in travel time, reduction in operating cost, reduction in accidents, etc.
- Cost includes capital cost of construction, maintenance cost, environmental costs, etc.
- Economic Internal Rate of Return (IRR) is worked out for all the alternatives
- The alternatives can be ranked based on the IRR

- Evaluation of Alternatives – Financial Feasibility
  - Financial feasibility analysis is conducted - Sponsor's Perspective
  - If the project is completely funded by the government, the sponsor is The Government
  - If the project is being implemented under Public - Private participation or purely by private agencies, then the sponsor is the concerned private agency
  - A Financial Internal Rate of Return is worked out for each alternative by computing the cash flows in the hands of the sponsor
  - This financial analysis is also used to arrive at the best financial strategy for the project

- Environmental Impact Assessment
  - The environmental impact of alternative concepts and recommended solutions must be considered and incorporated into the cost effectiveness analysis
  - The probable impacts like Traffic, Pollution, Noise, Ecological and Social should be studied and a proper environment management plan mitigating the impacts should be prepared

- Choice of project and Implementation
  - Prepare a Detailed Project Report (DPR) for the selected alternative
  - DPR includes all the technical design details, schedules for implementation, sources of revenue for the implementation of various phases of the proposed project
  - Construction, Maintenance and Operation

PROJECT BENEFITS

Benefit from road projects can be classified as direct and indirect benefits.

Direct Benefits

- Savings in Vehicle Operating Costs
- Savings in travel time
- Savings due to reduction in accidents

Indirect Benefits

- Improved accessibility resulting in more travel and convenience
- Increased land value

Vehicle Operating Costs (VOC)

- Fixed Costs
- Variable Costs

Fixed costs are those costs, which will have to be incurred by virtue of owning a vehicle. These are:

- Interest on the investment
- Insurance Costs
- Road Taxes.

Variable costs are those associated with the running of the vehicle. These are:

- Fuel Costs
- Lubricants Cost
- Tyre Costs
- Spares Costs
- Maintenance Labor Costs
- Depreciation
- Crew costs

ECONOMIC ANALYSIS

Net Present Value (NPV)

It is defined as the net worth of the project as of today. This is the difference between total present worth of benefits and total present worth of costs. This is obtained by discounting the future benefits and costs at a given rate.

Cost-Benefit Ratio (CBR)

It is the ratio of total present worth of costs to the total present worth of benefits. If the CBR is less than unity the project is acceptable. CBR is generally employed in ranking of the projects.

Internal Rate of Return (IRR)

The rate at which the net benefits are discounted so as to arrive at the cost of the project is called the IRR.

$$C = \sum_{i=1}^{n} \frac{B_i - C_i}{(1 + r)^i}$$

Where C = total initial investment cost in a year.
Bi = Total Benefit in year i
Ci = Total cost incurred in year i.
n = project life in years.

The widely used and most trusted software for economic analysis of Highway Projects is HDM-4. This tool not only analyses the economic viability of the projects but also helps the Engineers in selection of projects on priority basis. It also gives timely requirement of future maintenance and budgeting for Highway Projects.

Experience & Lesson Learnt

The experience in the above programme was quite exiting for all of us. The lecture delivered by eminent scientists of the institute through demonstration, site visits and inter actions with participants of different states helped us to know about structural, functional & economic evaluation of pavements. The training also helped us to know about different causes and remedy of premature distresses of pavements.

Kashinath Patra	**B Bhaskar Rao**	**Digambar Biswal**
Junior Engineer (Civil)	Junior Engineer (Civil)	Executive Engineer
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