PAVEMENT FAILURE STUDY

PHASE - II

NATIONAL TRANSPORT RESEARCH CENTRE

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Not for Issuance
Only for Reference

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CONTENTS

EXECUTIVE SUMMARY

The roads and bridges constructed by NHA/NHB during last thirty years have suffered all kinds of premature failures and have been subjected to several inquiries at various levels. The primary aim of such inquiries has been to pin point the person(s) responsible for act of omission/ commission and impose appropriate penalty. Whereas this is an essential exercise, there is no institutional arrangement for learning lessons from the technical mistakes made, which resulted in failure. Determining the cause(s) of failure is absolutely imperative for future appropriate counter measures. In developed countries such findings are widely disseminated to all concerned to ensure that the same problem does not re-occur.

With a view to achieve this objective, 10 investigation reports pertaining to NHA were examined. The main technical findings of the reports are as follows :-

a) The quality control was found below the required levels on all the projects investigated.

b) In all investigations, the failure has been found to occur in the asphaltic concrete layer.

c) On half of the projects investigated, the failures has been attributed to the under designing of the pavements, mainly on account of incorrect estimation of the Equivalent Standard Axle Load (ESALs).

d) Heavy axle loads and extreme environmental conditions are also indicated to be the cause of failures in most of the cases.

In addition to the common causes identified above, some of other factors have been identified in the reports which have also contributed to the failures in some individual cases:-

e) Inadequate compaction of the underlying layers i.e. subgrade, sub-base and aggregate base course has been identified as the major reason for failure of road structure on Karachi-Hyderabad highway.

f) Improper mix design has also indicated to the cause of rutting on Lahore-Islamabad Motorway.

g) Quality of aggregate materials used in the asphaltic mix and the quality of bitumen material used are also indicated as factors responsible for failures of Rawalpindi-Kharian Section of National Highway N-5.

Remedial Measures

To overcome the failures, following remedial measures have been suggested in the reports :-

a) There is a need to establish detailed procedures for quality control and its implementations. This needs institutional change in the selection of personal and particular training be given to the specified personal in carrying out the duties required of them.

b) Research work should be carried out to derive an asphaltic mix capable of performing well at high temperatures & under heavy loads.

c) Much tighter and comprehensive specifications be introduced with reference to material quality of aggregates and bitumen and procedures for the design of asphalt mixes.

d) To design a rut resistant asphalt mix (a problem on very heavy trafficked roads in Pakistan), Percentage Refusal Density (PRD) test should be introduced.

e) Design engineer must correctly assess the traffic loads (ESALs) to which the pavement would be subjected to during its design life.

f) On two lane single carriageways, design lane factor used should be based on actual ESAL estimated rather than assuming a value of 50/50.

d) Laws should be introduced for strict implementation of the load controlling measures.

h) There is a need for controlling the loading of the trucks by introducing weighbridges. Very high axle loads in excess of 20 tones should not be allowed on roads under any circumstances.

CHAPTER - 1

1.1 General

The pace of highway construction in our country has increased tremendously during the last two decades. The budget allocation for the highways alone now constitute about 20% of the country's total development outlay. As a result, pavements now represent one of the most costly of all the public investments. These highway pavements are designed and constructed to last for a certain life period having several physical, structural & functional properties. Unfortunately, in our country, most of these highways fail prematurely either because of poor quality control, inadequate estimation of axle loads, extreme environment and loading conditions and poor analysis of material properties. As a result the investment made is mostly wasted.

1.2 The Problem

There is little doubt that socio-economic benefits rendered by the improved highway system are prodigious but it is the dilemma of this country that these gains are lost when the highway pavements fail prematurely. Sections of National Highways such as Nowshera - Chablat, Mian Channu - Sahiwal (N-5), Sarai Gambila - Karak (N-55), Karachi - Hyderabad (N-5) are some examples where pavements have failed prematurely. These premature pavement failures not only result in wastage of investment made but also inflates operational costs of the vehicles and cause considerable delays in freight movements. As a result millions of rupees are being lost daily. This situation calls for immediate remedial steps in this regard. There is an immediate need to identify causes of pavement failures in the country and to suggest remedial measures to mitigate the prevailing problems.

1.3 Methodology

The roads and bridges constructed by NHA/NHB during last 30 years have suffered all kinds of failures and have been subject to inquiries at various levels. The primary aim of such inquiries has been to pin-point the person(s) responsible for act of omission/commission and impose appropriate penalty. Whereas this is an essential exercise but because of the disciplinary nature of the proceeding, it is always treated as "Confidential". As a result, hardly any lesson has been learnt todate and the same mistakes are repeated again and again.

Since such failures are world-wide phenomenon, in most developed countries, learning lessons from technical mistakes is regarded as a very important goal. This is aimed at determining the cause (s) of failure and recommending appropriate counter measures. Such findings are widely disseminated to all concerned to ensure that the same problem does not re-occur.

With a view to achieve the objective, NHA was approached to provide copies of the investigation reports so that these could be compiled as "Case Studies" and disseminated to all relevant government agencies.

The following reports were received from NHA :-

1. Evaluation of Additional Carriageway (N-5) Mian Channu - Sahiwal Section (NTRC)

2. Rehabilitation of Mian Channu - Sahiwal ACW (N-5) (Condition survey report (Engineering Associates)

3. Investigation and material test report of Karachi Hyderabad Motorway (Nooriabad - Jamshoro Section) South bound carriageway) KM81+000 to KM 148+000 (Sampak).

4. Karachi - Hyderabad Motorway (M-9) Project soil investigation report (02.12.99)

5. Karachi - Hyderabad (M-9) project Final Soil Investigation and Materials Report, (Part-II Appendices (Nov.1999), Nespak.

6. IHP Phase-II Contract - 12A, Sarai Gambila-Karak Flexible Pavement investigation report-contract-12A (PCI) 17.04.1999

7. IHP Phase-II Contract-12B, Karak-Krappa Chowk Pavement investigation report for IHP C-12B (PCI) 07.09.1999.

8. Report on pavement failure (Kampsax) 23.04.1996

9. Kharian Rawalpindi ACW (Report on pavement failure) Vol-I (April 1996)

10. Lahore - Islamabad Motorway (M-2) causes of rutting

It has been tried to extract all possible causes of failures and remedial measures given in these reports so that these findings could be made/use of for design and construction of roads in future.

CHAPTER - II

CASE STUDIES

2.1 General

Premature failure of road pavement is a common phenomenon in Pakistan these days. The pavements are designed and constructed to last for a certain period of life. Unfortunately in most cases the pavements do not last for the period for which they are designed and fail prematurely. The pavement failure occurs much earlier than the design life of the pavements. As a result, in most cases, the inquiries are set up to probe the matter. The primary aim of such inquiries has been to pin-point the person(s) responsible for act of omission/commission and impose appropriate penalty. However, there is a technical aspect of such reports also, which is aimed at determining the cause (s) responsible for these failures and recommending appropriate counter measures. It is this technical aspect of these reports in which roads engineers are mainly interested in. However, due to disciplinary nature of the proceeding, in most cases, the reports are treated as confidential and not circulated.

In order to study the technical aspects of the investigations, NHA was approached to provide the copies of the investigation reports. About 10 number of reports were received from NHA. A brief background, conclusions and recommendations given in these reports have been extracted and are given in this chapter.

2.2 Summaries from Case Studies

2.2.1 Evaluation of Additional Carriageway N-5 (Mian Channu - Sahiwal Section)

2.2.1.1 Back Ground

National Transport Research Centre (NTRC) on the request of Accountability and Co-ordination Cell, has evaluated the

Mian Channu-Sahiwal Section on the additional carriageway of National Highway N-5 to ascertain the possible causes of structural failure of the road pavement.

The 81 km long additional carriageway consisting of two lanes (about 2 meter embankment) was constructed by the National Highway Authority (NHA) during 1990-93 as contract 6, under the Fourth Highway Project financed by the World Bank at a cost of Rs. 1.015 billion. The road was opened to traffic in May, 1993. The pavement (reportedly in the 3rd year after opening) has shown sign of distresses in the form of cracking and rutting on the surface.

2.2.1.2 Observations

The road evaluation was carried out as per AASHTO methodology duly approved by the World Bank. The sallient observations are as follows:-

i) During last five years (1993-98) nearly 140 million Equivalent Standard Axles (ESAL's) have passed over the road.

ii) Extensive surface distresses in the form of alligator cracks and rut in the wheel tracks on left lane of additional carriaegway were observed.

iii) The cracks penetrated to full depth in the asphaltic layers.

iv) Under lying layers i.e. granular base and sub-base were found to be intact.

v) The air voids in the asphalt mix were found to be very high (initially more than 6%).

2.2.1.3 Conclusions

Based on the preceedings, the following conclusions are drawn from the study:-

i) Lack of quality control in laying and compaction of the bituminous mix as obvious by very high air voids in the body of mix which has produced rather brittle mixture, prone to excessive cracking and rutting.

ii) The traffic was under estimated and as a result, the road was under designed. Even the traffic in terms of the Equivalent Standard Axles passed so far, require greater thickness.

iii) Pavement has been found structurally weak, as full depth cracks in the asphaltic layers were confirmed.

iv) Pavement has been found under-design for the traffic plying on the road section.

2.2.2 Rehabilitation of Mian Channu - Sahiwal Additional Carriageway (N-5), Condition Survey Report

2.2.2.1 Project Background

National Highway Authority (NHA) had planned to overlay the sections, 6-A Mian Channu to Chak Behni (39.2 kms) and 6-B Chak Behni to Sahiwal (41.4 kms), of additional carriageway (N-5). The project road sections were opened to traffic in mid of year 1993. The pavement (reportedly in the 3rd year after opening) has shown signs of distresses in the form of cracking and rutting on the surface. To enhance service life of the road sections, National Highway Authority intends to overlay and strengthen the pavement. In this regard NHA assigned Engineering Associates (Pvt) Ltd, the task of field investigations and detailed design for rehabilitation of Mian Channu - Sahiwal additional carriageway of N-5 (80.6 km). The project brief is as under:

Section 6-A

Consultant	:	M/s Freeman Fox/ACE
Contractor	:	M/s Husnain Construction Co. Ltd.
Length	:	39.2 km
Date of Start	:	August 1989
Date of Completion	:	August 1993

Section 6-B

Consultant	: M/s Freeman Fox/ACE
Contractor	: M/s Saadullah Khan & Bros.
Length	: 41.4 km
Date of Start	: August 1989
Date of Completion	: September 1993

The scope of consultancy services to be provided by Engineering Associates (Pvt) Ltd, included necessary studies for pavement evaluation and rehabilitation, carry out surveys, soil investigation, prepare PC-1, detailed design and drawings, tender documents and bill of quantities.

This report pertains to 'Condition Survey' conducted from 9 to 17 August 1998, on the project road of Mian Channu - Sahiwal additional carriageway.

2.2.2.2 Observations

i) Visual survey of the road indicates high severity block cracking which is increased due to overloaded vehicles and also probably due to settlement of the fine grained soil used in the embankment.

ii) Alligator cracks were found at the tracks of the wheels of loaded vehicles, which may be due to consolidation of the earthen layers underneath bituminous material.

iii) High severity rutting was observed on most of the sample units, which is apparently due to fatigue failure in the bituminous bound layers and permanent vertical deformation of the underlying layers which reflects through the flexible pavement. This type of distress is due to vehicles carrying load being more than the design axle load and settlement in the underneath layers of the top bituminous materials.

iv) Some sample units exhibit low to medium severity reveling, which usually occur as a result of aged asphalt, poor mixture quality, segregation, or insufficient compaction.

v) Slippage cracks are observed on some of the sample units, which are due to poor bonding between the underlying bituminous pavement layer and low strength surface mix.

vi) Lane-shoulder drop off is present at several locations along the project road, as the shoulders have neither been properly constructed nor compacted.

vii) The other distresses associated with the sample units as observed are bleeding, depressions, longitudinal and transverse cracking, and potholes.

viii) The cracks are more predominant and of higher severity in the lanes on which traffic moves towards Sahiwal. This is, in our opinion, due to more loaded vehicles travelling to Sahiwal from Multan and Mian Channu, carrying oil and other commodities from Karachi. On the return journey, these vehicles either go empty or are not as heavily loaded.

ix) Double surface treatment (DST) has been done at the stretches of major failure on the roadway by NHA. It was observed that DST has been overlaid on about 25% of the project road. In some stretches it was seen that DST work was in progress/being carried out by NHA.

2.2.2.3 Results of Condition Survey

Data collected during the inspection was used to calculate the PCI of each sample unit and for the entire project.

The results of condition survey are summarized as under :-

2.2.2.4 Section 6-A (39.2 km)

The results of the evaluation indicate that the PCI of this section is 42.41, which apparently means the road in the section is in fair condition.

However, it is relevant to mention that above overall indicated PCI value of 42.41 for Section 6-A indicating the road in fair condition is due to the fact that a stretch of approximately 11 km out of 39.3 km is constructed on the right side of the existing carriageway is used by Multan bound traffic which is comparatively lightly loaded and therefore the condition of this stretch is good. Whereas, the remaining 28.2 km stretch of additional carriageway is being used by heavily loaded Lahore/Sahiwal bound traffic and the road condition is poor. It is only due to this reason that in weighted average the pavement condition comes to be 'fair'. This in our opinion is a false indication. Therefore we shall rate the entire section as poor.

2.2.2.5 Section 6-B (41.4 km)

The PCI of section 6-B is 16.05, which indicates the road in this section is in very poor condition.

The PCI (avg.) of the project road (Section 6A + 6B) is 29.23, which means the overall condition is poor. Further, for evaluation purposes, distresses have been classified into three groups based on cause. These groups are load associated, climate/ durability associated, and other factors. The results indicate that load associated distresses and settlement in the underneath layers of the bituminous pavement are the major causes of deterioration for the pavement of the project road. Contribution of this factor alone on failure of overall project has been calculated to be 66.1%. The contribution of climatic/durability associated distresses is calculated as 23.4% while other/drainage associated distresses are 10.5%.

2.2.2.6 Remedial Measures/Improvement Options

Condition Survey and Evaluation of road indicate that the road needs rehabilitation. A comprehensive solution to restore the structural strength and integrity for continued serviceability of the road will be provided after detailed study of the existing pavement deterioration. As a preventive measure at this initial stage, it is suggested that the road should be covered by a seal coat in the form of double surface treatment (DST) to stop further deterioration.

The rate of deterioration is high for the project road as indicated by the PCI values. The present alarming situation requires the proper design and provision of overlay with additional asphalt layers. Load associated cracks, which are the predominating distresses are progressing towards a higher intensity level at a rapid pace. The serviceability as well as riding conditions are fair at present, but will deteriorate rapidly if no corrective maintenance activities are carried out soon.

2.2.3 Rehabilitation of Mianchannu - Sahiwal Additional Carriageway (N-5), Soil and Materials Investigation Report

2.2.3.1 Project Background

National Highway Authority (NHA) planned to rehabilitate the sections, 6-A Mian Channu to Chak Behni (39.2 kms) and 6-B Chak Behni to Sahiwal (41.4 kms), of additional carriageway (N-5). The project road sections were opened to traffic in mid of year 1993. The pavement (reportedly in the 3rd year after opening) has shown signs of distress in the form of cracking and rutting on the surface. To enhance service life of the road sections, National Highway Authority intends to overlay and strengthen the pavement. In this regard NHA has assigned Engineering Associates the task of field investigations and detailed design for rehabilitation of Mian Channu - Sahiwal additional carriageway of N-5 (Length = 80.6 km).

The scope of consultancy services by Engineering Associates included necessary studies for pavement evaluation and rehabilitation, carry out surveys, soil investigation, prepare PC-1, detailed design and drawings, tender documents and bill of quantities.

This report pertained to investigations and study of soil and materials used in existing pavement including destructive testing on pavement layers on the site and on collected samples in laboratory. Field investigations/testing were conducted from 30 September to 12 October 1998, on the project road of Mianchannu-Sahiwal additional carriageway.

2.2.3.2 Conclusions

Based on the field inspection and investigations, in-situ density testing of subgrade, subbase and aggregate layers at site, taking cores and cut-outs (blocks) for asphaltic layers, laboratory testing on the collected representative samples and analysis of their results, the following conclusion have been drawn:

(a) Subgrade

i) Subgrade according to AASHTO classification is A-4 silty clay and clayey silt soils. 75% samples indicate low to medium plasticity (PI from 01 to 09) whereas 25% samples show non-plastic behaviour. 3-point soaked CBR values at 95% of Max. Dry Density (MDD) vary from 6% to 11%.

ii) In-situ compaction at only 20% test locations is 95% (minimum required), whereas at the remaining 80% test locations, the compaction is in the range from 79.05% to 94.31% much below the requirement.

(b) Subbase

i) Subbase material according to AASHTO classification is generally A-1-a except for 3 samples which fall into A-1-b group. About 50% samples indicate PI from 01 to 05 and remaining 50% samples show non-plastic behaviour. Three point soaked CBR values at 98% of Maximum Dry Density (MDD) vary from 80% to 93%.

ii) In-situ compaction at only 10% test locations is 98% (minimum required), whereas at the remaining 90% test locations, compaction is in the range from 74.44% - 97.16% i.e. below the minimum requirement.

(c) Aggregate Base

i) Aggregate Base material as per gradation is generally A-1-a except one sample which falls into A-1-b group. About 50% samples indicate PI from 01 to 04 and remaining 50% samples show non-plastic behaviour. Soaked CBR values at 100% of Maximum Dry Density (MDD) vary from 81% to 97% except one sample which shows 67%, which is less than the required 80% value.

ii) In-situ compaction at only 15% test locations is 100% (required) whereas the remaining 85% test locations indicate compaction in the range from 82.76% to 99.43%, which is below the requirement.

(d) Asphaltic Base Course

i) In-situ thicknesses at 75% test locations are found to be 7 cm whereas at the remaining 25% test locations it ranges from 5 cm to 6.5 cm. The required thickness is 7 cm.

ii) Asphalt content is generally in the range from 3.95% to 4.82% and one sample indicates 2.23% which is way below the requirement.

iii) Stability test results are in the range from 1828 to 2460 kg, which is very high indicating that the asphaltic base has been hardened.

iv) Air voids are generally in the range from 1.23% to 4.87% and even one sample shows only 0.89% air voids.

v) Compactions are in the range from 97.8% to 102.7% showing over-compacted asphaltic base course due to prolonged use by heavy traffic.

(e) Asphaltic Wearing Course

i) In-situ thickness at 50% test locations is found to be around 5 cm whereas on the remaining 50% test locations, thickness is in the range form 3.5 cm to 4.5 cm against the required thickness of 5 cm.

ii) Asphalt content is generally in the range from 3.99% to 5.52% and one sample indicates 3.13% which is way below the requirement.

iii) Stability test results are in the range from 1408 to 2562, which is very high indicating that the asphaltic wearing course has been hardened due to oxidation of asphalt.

iv) Air voids are generally in the range from 1.08% to 3.48% and even one sample shows only 0.36% air voids.

v) Compactions are in the range from 98.0% to 105.4% showing over-compacted asphaltic w.c. due to prolonged use by heavy traffic.

2.2.4 Investigation and Material Test Report of Karachi - Hyderabad Highway (Nooriabad - Jamshoro Section) (South Bound Carriageway)

2.2.4.1 Back Ground

Nooriabad - Jamshoro section of Karachi-Hyderabad highway has a length of 67 kms. The pavement design used for the section consisted of sub-grade, granular sub-base, crushed aggregate base course, asphaltic base and wearing course over the embankment.

The road developed different types of cracks, upheavals, after it was opened to traffic. The Contractor started the repairs in patches. But due to heavy traffic road has deteriorated gradually. General Manager Inspection directed M/S Sampak to investigate the causes of failure and prepare a formal report.

To ascertain the diagnostic investigation, samples of asphalt wearing course, aggregate base course, granular subbase, subgrade and 30 cm below subgrade were obtained at 30 different locations. For this purpose test pits were made. The samples collected from each test pits were tested in the central laboratory. In addition to test pits, asphalt concrete cores of wearing course were also drilled.

2.2.4.2 Summary of Findings and Recommendations

a) Although there may be certain variations in some of the qualitative tests of asphalt, yet such types of variations are common during construction. Hence failure of road structure due to asphalt is of the secondary nature.

The major reason of the failure of the road structure is due to inadequate compaction of sub-grade, sub-base and aggregate base course. Another cause of failure is the use of plastic material in aggregate base and sub-base added with deficient thickness of these layers.

b) This investigation is of preliminary nature carried out at an interval of 3 km generally, where as in bad areas the frequency was reduced to 1.5 km. However, it is suggested to carry out full scale investigation at 500 M interval as recommended by AASHTO, for deciding about any rehabilitation works.

2.2.5 Flexible Pavement Investigation Report (Contract 12A) (Sarai Gambila - Karrapa Chowk (N-55)

2.2.5.1 Back Ground

The section Karrapa Chowk-Sarai Gambila is part of the National Highway N-55. The contract-12A starts at Ch: 93+000 at Sarai Gambila and ends at Ch:34+000 at Karappa Chowk (total length of section is 59 km). The asphaltic layers were completed at various stages from January 1995 to October 1997.

In April 1998, the pavement showed signs of distress in the form of depressions in the wheel track of the slow lane, particularly in the Northbound direction (note: Northbound direction, according to the records, is trafficked by loaded vehicles (90%)) and the Southbound is trafficked by unloaded vehicle (90%), and isolated locations with "alligator" cracking. The affected areas were estimated at about 320 m in length. In May, 1998, the affected areas deteriorated both in severity and magnitude. It was noticeable that rutting was taking place on the Northbound direction. Other failures such as "shoving" were also noticed.

In June 1998, the failed areas deteriorated further, with the ruts developing under both wheel tracks and measuring upto 50 mm in the nearside wheel track and upto 30 mm in the offside wheel track, in the Northbound direction. The affected area was estimated to be around 1.2 Km.

In July 1998, deterioration increased, in the same fashion as in June 1998 and more areas being witnessed to be failing in the form of cracking and rutting. The affected areas extended to about 2 Km (very conservative). A short site investigation was undertaken in order to establish the causes of failures.

2.2.5.2 Conclusions

The investigation carried out for this report identified five areas of concern which needed to be addressed.

i) General

From the analysis of the test results it became evident that the results of the preliminary report must be considered applicable only to the limited locations tested for the preliminary report and that they do not represent the pavement as a whole. The present test results from Ch.93+000 to Ch.49+000 indicate that the materials and the workmanship comply with the specification and contract documents, except for the non compliances of certain asphalt tests, which are considered to have influenced the rate of deterioration of the pavement but the non compliances themselves were not the cause of the failures.

Substantiating this statement further, attention must be drawn to the fact that the rutting occurring on C-12A is not confined only to areas which have shown failures in the test results.

ii) Marshal design and revised specification

During the course of the investigations certain parameters in Marshall testing were found to have been determined using unspecified test methods. It is not stated by Marshall how to achieve "refusal", however, whichever means are used, if compaction is involved, then compaction must be performed at the compacting temperature corresponding to the respective penetration bitumen that was used.

The purpose of introducing hydrated lime to the mix was to increase the stiffness of the mix and render it more suitable to withstand deformation at higher temperatures. The proportions of hydrated lime and the overall total fines with respect to bitumen had to satisfy certain criteria in order that the stiffness would increase to acceptable limits.

iii) QC procedures and QC implementation

The lack of initiative in taking rectifying corrective actions also became apparent during the course of this investigation. The inert attitude in responding to the needs of the Quality Control requirements, whether inherited or induced, must be rectified. This needs institutional change in the selection of personnel and particular training be given to specified personnel in carrying out the duties required of them.

iv) Pavement design

The results of this investigation into the pavement design revealed the causes of the failures in the pavement in Contract-12A.

Firstly the design of the pavement indicated that a cumulative ESAL of 5.81 x 10^6 would occur over 10 years (ACE 1988 report for IHP by NHA). Actual traffic count analysis indicated that the pavement has been receiving 1.549 x 10^6 ESAL per year nett. Assuming a 7% rate of increase per year, the design period is reduced to 3.7 years.

Irrespective of which design or modified design was used, the multi-layered system thicknesses determined at the original design stage, would not be able to sustain the damage inflicted to the pavement, corresponding to a cumulative number of 19.6 x 10^6 ESAL over 10 years (ESAL in Northbound direction).

Secondly, the method of calculating ESAL has been found not to satisfy the conditions prevailing in Pakistan. Because of the lack of controlling the loading of trucks, particularly the 2-axle and 3-axle trucks, the differential loading within the same class of vehicle makes it impossible to standardize the truck factor corresponding to that class. This means that averaging the loads and calculating one average truck factor is grossly in error, inferring that the derived ESAL would be in error. The results show that, using this method of calculation, which is also used by BS; RN31 and NTRC (1995, AASHTO), would lead to only 50% of the real value in Pakistan.

In Pakistan, due to the large differential loading within the same class of vehicle, it is important to calculate the actual truck factor for each vehicle based on its actual load and then calculate the ESAL corresponding to each vehicle.

Thirdly, in a two lane single carriageway, when actual ESAL's in each direction are similar, it is reasonable to assume a design lane factor of 50/50. It is not the number of trucks in the lanes that is important, but the ESAL. When actual ESAL's in each direction differ substantially, it is not reasonable to assume a Design Lane Factor of 50/50. In C-12A the ESAL calculated for the Northbound Lane was 19.26×10^6 whilst for the Southbound Lane was 2.14×10^6, making the total ESAL equal to 21.4×10^6. If a Design Lane Factor of 50/50 is chosen, it would follow that the design ESAL for both directions would be 10.7×10^6. This is nearly 50% of the actual ESAL for the Northbound direction, inferring that the design period of the pavement would be reduced by nearly 50%.

2.2.5.3 Recommendations

a) To control pavement rutting caused by overloading

i) Accurate traffic counts to be taken over a period of time on all IHP Contracts. One such count was taken and used in this report. Another is being carried out during the course of this investigation & will be published separately.

ii) Adopt an accurate method of calculating ESAL by calculating truck factor for each truck.

iii) Control loading of trucks by introducing weighbridges throughout IHP Contracts.

iv) Introduce laws for the strict implementation of the load controlling measures.

v) Calculate ESAL using actual truck factor for each vehicle.

vi) Choose design lane factor based on the actual ESAL estimated.

b) To control pavement rutting caused by high temperatures

i) Further research work to be carried out to derive a mix containing hydrated lime, at proportions required for the mix to have a Softening Point of greater than 70 C, stability greater than 1000 Kg for AWC and 1200 Kg for ABC, when measured at 70 C, and VIM at refusal, (400 blows at 145 C), greater than 3%.

General

i) Establish detailed procedures for QC and its implementation.

2.2.6 Flexible Pavement Investigation Report (Contract - 12B) Karak - Karappa Chowk

2.2.6.1 Back Ground

The Karak - Karappa Chowk section of the Indus Highway has a length of 34 Kms. The Contractor of Contract IHP-12B, M/s CPECC, was awarded a "Substantial Completion" certificate for Contract IHP-12B, on 17 March, 1999. A comprehensive "snag" list was attached to the certificate for all completed items of work. During the following two months, up to the origination of this investigative report, the number of pavement failures increased. This prompted PCI, the Engineer, to launch a site investigation procedure in an endeavour to ascertain and evaluate the failures as well as establish the possible causes and subsequently recommended remedial measures to be taken.

The deficiencies encountered were described as a) "Slippage cracks", b) "Localized transverse depressions", c) Longitudinal depressions", d) Alligator cracks", e) minor form of "Rutting" and f) "Shoving". In June, 1999, a number of test pits were opened and testing was performed using testing procedures as contained in the standard IHP specifications.

2.2.6.2 Conclusions

i) The Contractor had used materials of acceptable quality and each material complied with the specifications for the intended use of the material.

ii) The Contractor had followed the Quality Control procedures as specified in the specifications. The QC records also indicate that compliance was achieved. Notwithstanding any of the requirements that the Contractor achieved, and without prejudice to the

Contractor, the Contractor must be held liable to the fact that deficiencies were identified in the Southbound lane which were not attributed to heavy repeated loads. On this basis, and the fact, that the Northbound lane was constructed simultaneously with the Southbound lane, the Contractor must be held responsible for the repair of all defective locations in the Northbound lane.

All defects hereinunder, such as Alligator cracks, Shoving, Slippage, Transverse and Longitudinal depressions, and as they may progressively appear during the maintenance period, are required to be repaired with a permanent repair method by the Contractor.

2.2.6.3 Recommendations

i) Accurate traffic counts to be taken, at frequent intervals of time, on all IHP contracts.

ii) Adopt an accurate method of calculating ESAL, by calculating truck factor for each individual truck.

iii) Control loading of trucks by introducing weighbridges throughout IHP contracts.

iv) Control high tyre inflation pressures.

iv) Introduce laws for the strict implementation of the load and tyre inflation control measures.

v) In a single two-way carriageway, when the ESAL in one direction differs from the ESAL in the other direction, it is recommended that:

a) The higher ESAL be used in the design, or
b) Carry out individual designs for each direction using the arrived corresponding ESAL.

vi) In order that the air voids, in the mix in the newly constructed pavement, be kept nearer the median of the specified envelope, it is recommended that the minimum degree of relative compaction of the bituminous mixes be raised to 98.5% instead of 97%, presently specified.

vii) It is recommended that in the formation of embankment and subgrade, in fill areas, the materials used shall have a CBR value of 15% min at 90% compaction, while the percentage of compaction in zone A shall be 98% and in zone B shall be 95%.

viii) In order that there is no ambiguity or confusion in the interpretation of the specification, it is recommended that, any amendments or special provisions given in the specification, be rewritten in the original appropriate paragraphs and they should not be featured again in another section of the specification.

2.2.7 Kharian - Rawalpindi Additional Carriageway Report on Pavement Failure

2.2.7.1 Project Back Ground

Kharian - Rawalpindi section is a part of the National Highway N-5. Two separate sub-sections of the Kharian - Rawalpindi Additional Carriageway were fully opened to traffic as follows:-

Section 1 - Jhelum - Dina (Km.1442-1452): 10 Km. on 4 July '95

Section 2 - Mandra - Islamabad More (Km.00 -19): 19 Km. on 2 March '95

Cracking of the asphalt wearing course was initially reported in July 1995 (during the monsoon season) at several locations on the Mandra section and subsequently, in September, on an uphill section near Dina. Further deterioration appeared minimal during the dry season (October - December, 1995) but during the winter rains (January - March, 1996), further cracking was observed.

Initial site investigations indicated that the cracking of asphalt was limited to the wearing course (top down cracking) but that water had penetrated through the cracks to both wearing course and base course layers - causing deterioration in the performance of the asphalt layers. However investigations have also revealed that it, under hydraulic pressure, water has been pressed through the voids in the mix which led to weakening of the layer matric and further cracking. The investigations revealed presence of water between the asphalt/aggregate base layers. There was no evidence of water ingress into the lower unbound granular layers or subgrade and asphalt base and wearing course (Section 4.2).

Initial material tests carried out on the site revealed that the pavement layers had been constructed in compliance with the Specifications (Section 4.3.2).

A limited reach of 4Km was opened to two way traffic north of Mandra in June 1994 for a period of 4 months during which the pavement was subject to full traffic loading and monsoon climatic conditions. No deterioration was observed during this period and full confidence was placed on the asphalt design mixes. This section of road remains in generally good condition with only limited signs of distress. Based on petrographic tests on the aggregate, it appears that the subsequent increase in percentage of quartzite could be a major contributor to the fact that the asphalt laid later, in 1995, suffered failure more rapidly.

Samples of asphalt (cores) and bitumen were sent to both UK and Denmark for exhaustive material testing using laboratory facilities not available in Pakistan. The investigation on asphalt centered around the material assessment of the asphalt mix together with rigorous testing for stiffness, creep and fatigue using the Nottingham Asphalt Tester.

2.2.7.2 <u>Conclusions</u>

The main conclusions of the material investigations are as follows:-

i) During the period of rains, water ingressed into the layers either through the voids in the mix or through surface hairline cracks and under high pressure of the heavy wheel loads was subjected to a pumping suction (hydraulic pressure) which caused the water to penetrate the air voids throughout the full depth of the asphalt layers resulting in migration of fines.

ii) The support capability of the asphalt mixes suffered under high temperatures, whereby the stiffness was reduced significantly during the summer months.

iii) This reduction in strength was accelerated by the type of aggregate, a crushed gravel containing a high but acceptable percentage (46%) of quartzite, creating poor adherence of bitumen to the stone. This allowed stripping in the asphalt layers rendering the supporting properties of the asphalt to be severely reduced.

Latest petrographic tests on the aggregate revealed that the percentage of quartzite had increased from an initial 46% in 1993 to 69% as recorded in asphalt laid in 1995. The latest sample tested in March 1996 showed an average of 75%.

iv) A combination of factors stated above could probably have led to some overstressing of the lower unbound granular layers which explains the evidence of shallow rutting on some sections, but which could also be caused by an associated residual compaction of the asphalt materials.

(v) The reason why the surface initially suffered cracking is thought to be a combination of events, which is submitted as follows:-

(a) Overstressing on the top surface of the asphalt wearing course resulting in micro-strain cracking caused by overloaded axles. It is considered that damage could be caused by a few excessively loaded vehicles rather than cumulative numbers of standard axles. Overstressing could have been further facilitated by reduced strength caused by water being pressed into the mix and stripping the bitumen from the aggregate surfaces.

(b) The tests carried out on the bitumen show that the material is 'temperature susceptible' and thus prone to rapid "age hardening". The mechanism is initiated by sunlight (a worsening problem with the continuing reduction in the ozone layer) and rapidly becoming a major problem on highways constructed in tropical countries. This micro-cracking is evident on exposed surfaces not subject to traffic for prolonged periods.

(c) The expansion and contraction of the surface during the hot summer months (temperature range between day and night) causes tensile stress at the bitumen/aggregate interfaces. With the poor adhesion properties of the quartzite gravels, the bitumen becomes separated from the aggregate surface causing 'micro' breakdown in the matrix.

(vi) Reference is also made to workmanship, especially in the areas of aggregate cleanliness, tack coat application, level control necessitating thin regulating layers and segregation within asphalt mixes. However, these items are not considered to be main causes of failure.

(vii) Action already taken to correct the problem includes the suspension of the use of crushed gravel (Pandory) aggregates in the asphalt mix (in August 1995) and substitution with limestone aggregate from Margalla Hills. It is imported to point out that the gravel aggregate was initially incorporated in favour of limestone due to its stronger properties in producing a rut resistant asphalt. Concern is conveyed that the limestone based asphalt could deform under heavy traffic loadings. Development of rut resistant asphalt mixes using limestone remains an ongoing exercise.

In addition, the previously used "emulsified bitumen" tack coat has been replaced by a 'cut-back' bitumen in an attempt to improve the adhesion between layers.

It is quite clear that most of the damage to the pavement takes place during the wet seasons. For this reason, it is necessary that the total length of pavement laid with the crushed gravel be either replaced or sealed before the onset of the summer rains (monsoon) which are expected to start at the end of June.

2.2.7.2 Proposed Remedial Measures

Proposals are submitted for the following remedial works along the 29 Km of asphalt laid using the gravel aggregates. These include:-

- Replacement of all badly cracked or damaged asphalt (restore to original design) - 4.7 Km
- Deep Patching of isolated cracked sections followed by Surface Treatment of complete road width- 1.0 km
- Overlay on up-hill section (Km. 1450 - South of Dina) - 9 cm thick using base course mix and surface treated
- Surface treatment (Double/Triple Surface Dressing) of all remaining wearing course already constructed with Pandory gravel aggregate - 22.6 Km.

The Consultants do not consider that the above remedial works constitute a repair to bring the pavement back to the original 10 year design life. However, it is recommended that this interim measure, especially in respect of surface treatment, should be taken for the following reasons:-

i) The proposed remedial works should provide an acceptable road surface for 2-3 years. A 15 km section of N-5 south of Gujranwala was treated similarly 3 years ago and is still performing well.

ii) During this time the future traffic demand on this section of N-5 (Kharian - Rawalpindi) can be reassessed on the basis of future transfer of traffic to the Motorway (50%) for an appropriate pavement design.

iii) The latest Axle Load Studies (1995) reveal a continuing increase in loads being carried by truck axles which must be incorporated in any new pavement design.

iv) The development of a rut resistant mix using limestone (or other aggregates) is still ongoing. Trials using modified bitumens are presently in hand. Up hill grades remain a particular problem.

v) The incorporation of a stiff, non-deformable asphalt pavement sealed with a Surface Treatment is a subject of considerable study in countries with similar conditions to Pakistan and the above Surface Treatment proposal is one of the recommendations in the TRL & DRI Reports.

The fixing of responsibility has not been addressed in this Report.

It is recommended that much tighter and comprehensive specifications are introduced with reference to material quality of aggregates and bitumen and the procedures for the design of asphalt mixes.

2.2.8 Construction of the Enquiry Committee to determine the Causes of Rutting on M-2

2.2.8.1 Back Ground

In pursuance of the decision of the NHA's Executive Board in its meeting of dated 23-7-1998, a 3-members Enquiry Committee was constituted with Mr. Sadiq Swati, Senior Chief, NTRC, as its Chairman. The other two members designated were Mr. Abdul Rauf Ch., P.D., Kharian-Rawalpindi (N-5) Project & the Director, Road Research Laboratory, Lahore.
The terms of reference comprised of the followings:

a) To determine the causes of failure of M-2, due to rutting.

b) To estimate the loss to public on this account.

c) To fix responsibility for the lapse/failure and to apportion the loss incurred.

The work assigned comprised of determining the adequacy of the pavement design, Standard Specifications, Job Mix Formula for the asphalt concrete and testing of the samples to be supplied by and preparation of the report with comments.

Initially, two samples of asphaltic cores, with a chunk of asphaltic material alongwith a sample of aggregate base course material, were supplied for necessary testing and evaluation. These samples were analyzed. However, in the meeting of dated 1-2-99, it was brought to the notice of the Chairman of the Committee that the report can not be based on the results of such a small number of samples so testing of large number of samples would be required for evaluation.

It was also emphasized that the analysis of the underlying layers, i.e. aggregate base, sub-base and subgrade would also be required to be carried out in order to arrive at a rational conclusions.

In pursuance of the above meeting of dated 1-2-99, 14 Nos. asphaltic concrete core samples were supplied by the General Manager, LIMP, which were tested in Road Research & Material Testing Institute, Research Campus, Lahore for the following.

1. Bitumen extraction
2. Gradation

2.2.8.2 Review of Specifications

A copy of the specifications book entitled "General Specification (March 1991), prepared by M/S Sampak (Pvt) Ltd. for the National Highway Authority, was supplied by the General Manager (M-2) vide Memo No.2(20)/GM(M-2)/NHA/99/79 dated 30-04-1999. These specifications had been followed in the construction of Motorway.

As a result of review of the specifications, it has been found to meet with the requirements and general, standards for the construction of Highways except in the case of a few of the specifications for asphaltic mixes. Particularly, with regard to the general requirements for the gradation for the combined aggregates for asphaltic wearing and base course, wherein, the finer limits having been reduced by 7 to 15% for different aggregate sizes from the recommended specification of the Asphalt Institute.

The criteria for VIM for A.C. wearing and base courses and for VFA for base course differs from MS-2 series of Asphalt Institute standards. However, the specifications attached with JMF show that for VIM and VFA the criteria set forth by Asphalt Institute was followed.

2.2.8.3 Conclusions

The quality control unsigned record provided by General Manager (M-2) for the 14 Nos test cores samples for wearing and base courses, sent to R.R.& M.T.I., Lahore, shows that the criteria for VIM, VMA and VFA and compaction achieved in the field meets with the general requirements. The bitumen extraction test and gradation tests on the retrieved materials show that in the case of more than half the samples, the quantity of bitumen used in the mix was beyond the permissible limits and gradation of aggregates was found slightly out of limits on two to three sieves in each case.

However, from the quality control record supplied for A.C. wearing and base courses by the General Manager, for Kms 205 to 214 to 245, 254 to 255 shows that :-

i) The voids in mineral aggregates (VMA) which has a criteria of 13% minimum for wearing course, could not be maintained in the field to the desired level. From the quality control record, it is evident that the value of this factor ranged between 8-9% in most of the cases. Due to the low voids in the mineral aggregates, the air voids left after bitumen filling were very low in value in the mix. The quality control calculation sheets show that this figure was near about 3% or in some cases even below this figure. As per Asphalt Institute series MS-2 standards, the mixtures that ultimately consolidate to less than 3% air voids, can be expected to rut and shove if placed in heavy traffic locations. Several factors may contribute to this occurrence, such as, arbitrary on accidental increase in the asphalt content at a mixing facility or an increase of extra fine particles passing the 75 from (No.200) sieve beyond that used in the laboratory, which will act as asphalt extender.

From the extraction test on the samples supplied, the filler/binder ratio is ranging between 0.95 to 1.6 and in 75% of the cases this is higher than 1.2 i.e the mix recommended permissible limit. The filler content in the aggregates should have been restricted to 5% which has been used upto to 8% as is evident from the gradation of the retrieved aggregates.

ii) According to Asphalt Institute, MS-series -2. "Mix durability has also been related to amount of the fine dust or dirt particles in the mixture. Excessive fines can lower the quality of the asphalt film on the aggregates Depending upon the size of these particles, the mix may be stiffer or more tender. The Federal Highway Administration of U.S.A. has recommended that mixes especially in higher traffic locations be designed with dust to asphalt ratios between 0.6 to 1.2.

iii) The section of Motorway where rutting has been observed is located in salt range where the road has steeper gradient. Due to the higher gradient the speeds on the climbing lanes are low. The properties of the asphaltic mixes are time and temperature dependent. Due to lower speeds of the vehicles and slow loading, the time of loading increases resulting high stresses in the asphaltic and underlying layers. Further, due to the extremely heavy loaded vehicles than the normal are causing secondary compaction resulting plastic flow in the asphaltic layers.

Apparently, the distress has occurred in the upper layer, but nothing can be said about the lower layers as no testing of the lower unbound materials and the subgrade was carried out.

Though rutting phenomenon can not be totally eliminated, but it can be minimized by proper design of the asphaltic mixes. In the case of the motorway, the mix design for the wearing course was not proper and adequate and was on the finer side, having approximately 50% stone dust in the combination of aggregates. This has led to a tender mix. The phenomenon has accelerated on slow speed reach on steeper gradient due to very heavily loaded vehicles.

CHAPTER - 3

CONCLUSIONS:

The roads and bridges constructed by NHA/NHB during last 30 years have suffered all kinds of failures and have been subject to various kinds of inquiries at various levels. Since such failures are world-wide phenomenon, in most developed countries, one of the important goal of such inquiries is to learn lesson from the technical mistakes. This is aimed at determining the cause (s) of failure and recommending appropriate counter measures. Such findings are widely disseminated to all concerned to ensure that the same problem does not reoccur.

With a view to achieve this objective, investigation and material test reports pertaining to NHA were reviewed and the main technical findings of the reports are as follows:-

I : Construction Quality

The quality of construction was found to lack the required levels on all the projects investigated as;

i) The compaction of subgrade, subbase and aggregate base course layers were found inadequate in many cases.

ii) Thickness of asphaltic concrete layers was found less than the specified thickness in some cases.

iii) Quantity of the bitumen used in the mix was found outside the permissible limits in several cases.

iv) The gradation of aggregates in the mix was found out of limits on different sieves

v) The bitumen material was found temperature susceptible and thus prone to rapid "age hardening" on one project.

vi) For subgrade, although the gradation is not generally specified, it is normal practice that the maximum aggregate size should not exceed 50% of the layer thickness, as this would pose difficult in achiving the required compaction. In many cases over size materials were used in the subgrade material.

vii) Crushed gravel containing a high but acceptable %age of quartzite was found used on one project which created poor adherence of bitumen to the stone. This allowed stripping within the asphalt layers rendering the supporting properties of the asphalt to be severely reduced.

viii) Workmanship such as in the areas of aggregate cleanliness, tack coat application, level control, etc. also contribute to pavement failures.

II : Pavement Design Factors

ix) The estimated cumulative number of axles for which the pavements are designed were found much less than the actual ESA that surpassed the pavement. As a result, the life of the pavement was exhausted much earlier than its design life resulting in early deterioration of the pavement.

x) The method of calculating ESAL has been found not to satisfy the conditions prevailing in Pakistan. Because of the lack of controlling the loading of the trucks, particularly the 2-axle and 3-axle trucks, the differential loading within the same class of vehicles makes it impossible to standardize the truck factor corresponding to that class. This means that averaging the loads and calculating one average truck factor is grossly in error, inferring that design ESAL would be in error.

xi) In Pakistan, on a two lane single carriageway, assumption of a design lane factor of 50/50 is not correct in most cases. The actual lane factor could be as variable as 90/10.

III : Other Factors

xii) The damage to the pavement could be caused by a few excessively loaded vehicles rather than cumulative number of standard axles.

xii) Very high axle loads (in excess of 25 tonnes per axle) impose exceedingly high streses on the asphalt surface. The premise that a pavement is designed to withstand a cumulative number of equivalent standard axles (8.2 tonnes) is valid only until the imposed load does not create stresses in the layer in excess of the limiting tensile strength. In case when the applied load cretaes stresses in excess of the limiting tensile strength, the matrix undergoes plastic deformation. Same phenomenon is expected to occur under the equivalent of point loads caused by axles of heavy trucks loaded in excess 25 tonnes with tyre pressure in excess of 150 psi.

xiii) During the summer months, the stiffness of the mixes reduces significantly under high temperatures causing considerable reduction in the support capability of mixes resulting in pavement failures.

Remedial Measures

To improve the situation, some remedial measures have been proposed in the reports by the consultants which are as follows :-

i) Research work is required to derive a mix capable of rut resistant at high temperatures under heavy loads.

ii) A satisfactory mix may be achieved by preparing a mix containing hydrated lime at proportions required for the mix to have a softening point of greater than 70^0 C, stability greater than 1000 kg for ACW and 1200 kg for ABC when measured at 70^0 C and VIM at refusal (400 blows at 145^0 C) greater than 3%.

iii) In order to design the mix to resist rutting (a problem on very heavy trafficked roads in Pakistan), the Percentage Refusal Density test should be introduced. This test, now part of UK Standard specifications, measures the residual air voids of the mix after compaction to refusal. If the residual voids are reduced to zero, then flushing of the mix takes place and rutting results.

iii) Much tighter and comprehensive specifications are required to be introduced with reference to material quality of aggregates and bitumen and procedures for the design of asphalt mixes.

iv) There is a need to establish detailed procedures for quality control and its implementations. The inert attitude in responding to the needs of the quality control requirements, whether inherited or induced, must be rectified. This needs institutional change in the selection of personal and particular training be given to the specified personal in carrying out the duties required of them.

v) There is a need for taking accurate traffic counts at the design stage.

vi) An accurate method of calculating ESAL should be used and it should be done by preferably calculating actual truck factor for each vehicle. On two lane single carriageways, design lane factor used should be based on actual ESAL estimated rather than assuming a value of 50/50.

vii) There is a need for controlling the loading of the trucks by introducing weighbridges. Laws should be introduced for strict implementation of the load controlling measures.

ix) The latest axle load studies reveal a continuing increase in loads being carried by truck axles which must be incorporated in any new pavement design.