NATIONAL TRANSPORT RESEARCH CENTRE

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FAILURE CAUSES

OF N-35

(SARAI - SALEH TO MUSLIMABAD)

NTRC-226

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EXECUTIVE SUMMARY

The National Highway (N-35) provides a vital link between the north and the rest of the country. It is 806 km long and off-takes from N-5 near Hassanabdal and ends at Khunjrab pass at Chinese border. It is an ancient route known all over the world as "Silk Route". Presently, it is called "Karakoram Highway".

The section between Sarai-Saleh (km 38) and Muslim Abad (km 59) which was laid in 1991-93 with 6 cm thick wearing course and 7 cm thick base course (to be overlaid in the year 2000) has failed.

Visual examination of the section revealed high severity alligator (fatigue) cracking with depressions varying from 1-3 cm at few places. The cracked pieces were found more severely spalled at edges & loosened. Medium to severe stripping/ravelling was also observed.

As part of the remedial measures, asphalt concrete layers were scarified at different places and re-laid either as "Double Surface Treatment" or "Asphalt Concrete". The concerned NHA officials were however not able to explain the rationale for choice of "Double Surface Treatment" and "Asphalt Concrete".

Samples were collected by NTRC which were found dry and brittle. NTRC also extracted asphalt concrete cores from the cracked as well as un-failed sections. The laboratory analysis showed the following probable causes of failure:

a) Cracked sections have a bitumen content of 2.40% as compared with un-failed sections of 3.35%.

b) The asphalt concrete in cracked cores was found fully decomposed (Oxidized), with very little flexural strength.

c) The density of failed cores was found low, having high voids in the mix, resulting in high permeability of the mix.

d) The aggregates being used for "Double Surface Treatment" as remedial measure were found to be dirty, which retards adhesion to binder, ultimately resulting in stripping of aggregates.

e) The Abrasion value of coarse aggregates was in the acceptable range of 35 - 40%.

f) The aggregates used for resurfacing were twice (38mm) the specified size (18 mm - first course) and were being spread by twirling baskets, as against the specified mechanized method.

Conclusions

1) The low bitumen content could be due to less quantity of bitumen at the time of batching or due to oxidation of bitumen with age.

2) The deformation of pavement indicate seepage of water in the underlying layers.

3) The remedial measures (Asphalt Concrete or DST) were not based on any scientific criteria.

4) Laying of asphaltic wearing course on severely cracked base course would be shear wastage of funds as reflection cracking would reappear soon after opening to traffic.

Recommendations

1. Full care must be observed in mix design and strict quality control should be exercised while laying the asphaltic concrete.

2. The remedial measures should be based on scientific rationale. The choice between the asphaltic concrete mix or double surface treatment should be made very carefully depending on the need and thorough engineering and economic analysis.

3. The efforts should be made to provide efficient surface and side drainage in order to prevent ingress of water. Was it observed

4. The layers showing cracking should be removed before applying any remedial treatment. (General)

Clear ORDER of Abstract

I Observations by lab Testing

II Conclusions

III Causes of Failure

IV Recommendations

1 : INTRODUCTION

Highway pavements are designed and constructed to last a certain period having several physical, structural, and functional properties. These properties in terms of pavement performance are assessed to determine that how well the pavement served the users. The engineers associate these pavement properties with quantifiable values relating to pavement roughness, pavement distress or pavement strength. Performance is then measured as a change in properties with passage of time.

A team of NTRC engineers carried out the pavement condition survey of a section of N-35 near Sarai - Saleh to Muslimabad to observe the pavement performance and determine the types, severity, and extent of distress and their causes. The team made two visits and thoroughly inspected the road pavement and road environment, and made various qualitative and quantitative measurements as well as took photographs to augment the report. Dynamic cone penetration tests were carried out to determine the strength of underlying layers. Samples from basecourse were taken up to determine laboratory CBR and field moisture content. Cores were extracted from the distressed and controlled sections (un-failed) to evaluate the mix properties in NTRC's laboratories.

2 : SCOPE OF THE STUDY

The scope of the study was to find out the possible causes of failure of this national highway (N-35) which included following:-

i) To observe and assess the surface distresses and their severity and estimate the riding quality.

ii) To compare the bitumen content of cores drilled out from distressed section with those taken from the control (un-failed) sections.

iii) To determine the voids content, specific gravity and density of cores, including maximum specific gravity.

iv) To compare the stability and flow of distressed & control sections.

v) To determine the strength of base/subbase layer, through DCP tests.

vi) To inspect drainage & shoulder conditions.

3 : METHODOLOGY

The team comprising of NTRC Engineers and Laboratory Technicians visited the National Highway (N-35) from Hassan Abdal to Abbottabad. Particular attention was made to the failed Section between Sarai Saleh and Muslimabad and following methodology was adopted.

a) Visual inspection of the Section for
   i) Depressions, ruts, corrugation, etc
   ii) Cracking (fracture in pavement)
   iii) Disintegration, ravelling, stripping potholing, etc
b) Photography showing state of the art at site.
c) Core extraction.
d) In-situ testing (Dynamic cone penetration test).
e) Sample collection from pits.
f) Laboratory analysis/testing of drilled cores for:-
   i) Determination of bitumen content
   ii) Determination of Marshall stability & flow
   iii) Specific gravity & density of cores, including maximum specific gravity by Rice Method
   iv) Size and gradation of aggregates
g) Analysis and discussion on results and report writing.

4 : NATIONAL HIGHWAY N-35

The national highway N-35 is an ancient route called Silk Route and is 806 km long from Hassanabdal to Khunjrab pass near China border. Presently, it is called Karakoram highway which provides a direct link between the north and the rest of the country, and a vital link with China. This is a two lane undivided highway with 24 ft width and with varying shoulder width on each side.

The highway section upto Abbotabad is lined with Eucalyptus trees which provide good soil evaporation besides esthetic view and sunshade for users.

4.1 Cross-Section of the Highway

According to NHA offices at Abbotabad, highway pavement having following thicknesses was re-constructed in 1991-93.

x-Section of Pavement

AC Wearing Course	:	60mm
AC Base Course	:	70mm
Granular Subbase Course	:	250mm-350mm

However, during field visit, thicknesses were found somewhat different than the reported.

5 : VISUAL INSPECTION/CONDITION SURVEY

Condition survey of the highway was conducted, right from its start i.e. Hassanabdal to Abbottabad to locate and assess the visible signs of distress like surface irregularities, type and extent of cracking, rut depth under wheel paths, stripping, lane or shoulder stepping etc. These important indicators allow pavement engineers to depict the functional condition of highway facility. The following features were recorded.

a) The section of N-35 from Hassanabdal to Sarai Saleh is in good condition with no serious pavement damage. However, some signs of cracking and secondary compaction were observed at scattered locations. Signs of stripping, ravelling and potholes were also observed at some places. On this section the pavement shoulders and drains were also in reasonably good condition. At some places patch work carried out in the past was also visible.

b) The section between Sarai Saleh to Muslimabad is extensively cracked and repair works were in progress. At some places, asphalt wearing course was being scarified while at other places double surface treatment work was in progress.

c) Asphaltic base course surface was closely observed, which showed extensive cracking. The wearing course mix removed was carefully examined and its was observed that the bitumen was fully decomposed and its appearance was dry/oxidized.

6 : FIELD SAMPLING

During field sampling the aim was to obtain samples representing the true nature and condition of the pavement. It was ensured that distribution of sampling should be such that variability, quality and quantity requirements are adequately met. The asphalt concrete samples were obtained in accordance with AASHTO T 168, "Sampling Bituminous paving Mixtures" as under:

i) Asphalt concrete wearing course samples were taken from the scarified layer thrown on sides.

ii) A total of seven cores were cut. The asphalt pavement samples were obtained in the following manner.

a) In the vergeside wheelpath.
b) In the off-side wheelpath.

iii) At two Locations, pits; one each at cracked and controlled section, were dug to obtain the base/subbase material. The pits were dug very close to the pavement edge.

7 : FIELD TESTING

After coring, dynamic cone penetration (DCP) test to determine in-situ strength of the underlying layers was carried out. Field results of each test were recorded and in-situ California Bearing Ratio (CBR) was determined using computer software developed by TRL for the purpose.

The road examined has a base course layer of 250-350 mm crushed aggregates

8 : IDENTIFICATION OF CAUSES & MECHANISM/MODE OF PAVEMENT FAILURE

Generally highways fail because of insufficient structural strength, poor quality of construction through lack of quality control and insufficient or no maintenance. It is therefore necessary to identify the causes of failure before appropriate choice can be made between maintenance, overlay, partial or complete reconstruction. The determination of failure cause would help prevent or retard its happening again due to same cause. This will result in time & money saving. The various forms of distress are closely inter-connected. Once deterioration has been allowed to continue unchecked for some time it is often very difficult to identify the primary causes. For example, if the surfacing of a road which is structurally adequate cracks because the quality of the surfacing is poor, water will enter the pavement thereby weakening underneath layers and leading to substantial rutting and deformation. The same end result could have arisen if the pavement structure rather than the surfacing was inadequate for the traffic loading, leading first of all to rutting in the subgrade and base followed by cracking of the surface through the inability of the surface to accommodate the deformations. In this example the remedial treatment for the failed areas will be the same, namely deep patching, but the treatment for adjacent sections of road not showing complete failure will be very different. In the first case the problem is simply one of repairing the surface whereas in the second it is one of adding sufficient structural strength to reduce the stresses on the layers at risk in other words an overlay is appropriate.

8.1 Identification of Distress type

It is often difficult to identify the primary mode of failure of a road but the task is made considerably easier if the condition of the road has been monitored regularly since construction so that signs of distress can be identified in the early stages.

Signs of alligator (fatigue) cracking, a series of interconnecting cracks caused by asphalt concrete failure, were readily observed and easily identified during a close inspection of the highway between Sarai Saleh & Muslimabad. There were high severity cracks throughout the length of the section and were spread over the entire pavement with concentration under wheel paths.

8.2 Mechanism

The form of cracking is traffic related and therefore occurs first under the wheelpaths. It usually starts as small, random cracks which progress until they are linked together in the familiar crocodile skin pattern. It is a manifestation of fatigue in the bituminous layer caused by repetitions of the stress at the underside of the stiff surface layer. The cracks therefore begin at this point and propagate upwards.

8.3 Causes

These cracks have most probably developed because of poor quality of mix. The poor quality of mix has resulted either due to less bitumen content in the mix than the optimum at the time of mixing or due to high voids which allowed air entrance in the mix and accelerating the oxidation/decomposition of the mix.

9 : LABORATORY ANALYSIS

For laboratory analysis field sampling was carried out and photographs were taken to supplement the laboratory results. In all seven cores, three from failed (cracked) section and three from control (un-failed) section and one from patched section were extracted from the pavement. In addition to the cores, three large chunks of scarified wearing and base course were also obtained.

Similarly at two locations pits, one each at cracked & control sections respectively, were dug to obtain subbase/base samples to determine laboratory CBR & moisture content. The cores were secured in premarked containers and their raw and sawed measurements were taken. The extracted cores are of various lengths due to the effect of cracking and patching. Two cores did not have wearing course which had been scarified. Close examination was made to determine the overall features of the cores. Following tests were carried out on the bituminous cores:-

i) Bulk specific gravity and density determination of compacted bituminous mixture using saturated surface dry specimens as per ASTM D272689/AASHTO T 166-88

ii) Maximum specific gravity ASTM D2041 AASHTO T 209/90

iii) Quantitative extraction of bitumen as per ASTM D2172-88/AASHTO T 16- 490

iv) Gradation of material as per AASHTO T 30-87

v) Marshall stability ASTM D1559-76/AASHTO T 245-90

9.1 Discussion on Results

By analyzing specific gravity, density, air voids and asphalt content, an insight into failure causes can be made.

9.1.1 Bulk Specific Gravity and Density

The bulk specific gravity and density of cores was determined using standard surface-dry specimens. The average bulk specific gravity of cores extracted from the distressed sections of the highway was 2.30 while that of control (un-failed) sections was 2.4.

The average density of asphalt cores extracted from the distressed sections of the highway was 2.25 while that of control sections was 2.35.

It can be concluded that the average bulk specific gravity and density of the distressed sections is considerably low (4%) than the control sections because of low compaction and decomposition of asphalt.

9.1.2 Maximum Specific Gravity & Voids Ratio

The average maximum specific gravity determined for the distressed and control sections was found to be 2.51. Therefore, the average voids in distressed cores were calculated to be 9.03%, while in un-failed section were 1.78%, a difference of more than 7%. Such a high percentage of voids is undesirable and it increased permeability and caused rapid age hardening, making the mix brittle. Although the allowable voids percentage ranges between 2-7% & 3-6% but usually voids are maintained around 4-5% in the initial mix. This high percentage of voids even after secondary compaction, is most probably the result of low bitumen content accompanied with poor or cold compaction. This deficiency in the mix caused rapid age hardening.

9.1.3 Gradation

After extraction of bitumen, the aggregates were graded in accordance with the standard procedures as already mentioned. The laboratory results showed that the percentage of aggregates passing 25 mm (1 inch) and 19 mm (3/4") sieve size on the average is 100 per cent for distressed and control sections as well. A close examination of gradation values reveal the following:

a) There is hardly any significant difference in the wearing and base course gradation curves.

b) The gradation values for wearing course satisfy the class 'B' specification of NHA, but the gradation values for base course do not satisfy either class 'A' or 'B'.

c) The gradations are on the "too finer" side as shown in the typical graph.

d) There is hardly any significant difference in the passing percentages of aggregates from distressed & control sections.

e) The percentage of filler (below # 200) is also quite higher (7%) than the normal practice of 4-5%. This high percentage of filler might be due to attrition of aggregates rather than a design proposition.

f) As regards the quality of filler is concerned, clay like sticky material was found in two distressed cores, which is detrimental to adhesion.

g) A high percentage of fines decreased the filler-binder ratio and therefore the pavement performed poorly.

9.1.4 Particle Shape

The particle shape was closely examined. The particles were of very suitable shape for an asphalt mix, providing good interlocking/ stability to the mix. No rounded, flaky or elongated particles were found.

9.1.5 Surface Texture and Resistance to Skidding

Aggregates were separated from the extracted cores after washing and were found of suitable quality to increase resistance to skidding.

9.1.6 Bitumen Content

The bitumen content in asphalt concrete mix should provide a balance of stability and durability. Asphalt film thickness in a pavement is in the order of 0.005-0.010 mm. It has been shown that significant amount of asphalt retards aging process.

The bitumen content of cores extracted from the distress sections and those from the control sections (un-failed) was determined.

The average bitumen content in the asphalt courses of the distressed sections of the highway was found to be 2.40% by mix, while that from control section was found to be 3.35% by mix.

The abnormally low percentage of bitumen content in the distressed (cracked) sections, clearly point out the fact that lowering of asphalt content increased the void content & reduced the film thickness, which ultimately decreased the durability of the pavement. It is well known that too great reduction in film thickness leads to accelerated oxidation, increased permeability and ultimately to brittleness. This low asphalt content is the primary cause of pavement failure. Secondly, age hardening (bitumen quality) and heavy vehicle loads exasperated the problem.

9.1.7 Marshall Stability

The two principal features of the Marshall method of mix design are density-voids analysis and stability-flow test.

9.1.7.1 Density-voids

The first principal relationship of density-voids analysis could not be carried out and compared with that determined in NTRC's laboratory as NHA did not provide the design data. This key relationship would have provided an insight in the determination of degree of pavement compaction (AASHTO T 230-68 (1986) and per cent air voids in compacted pavement (AASHTO T 3203-75). Though, another test maximum dry density AASHTO T 209-90' was carried out.

9.1.7-2 Stability-Flow

Marshall stability tests were carried out on the extracted cores. The results clearly showed that the average Marshall stability of distressed cores was significantly lower (37%) than those from the controlled sections, because of following reasons.

i. Interparticle binder friction (oxidized binder hardened) was present and the cohesive forces were least in cracked cores.

ii. Secondly, high voids ratio also helped reduce the interparticle roughness.

iii. Thirdly aging of asphalt (oxidation) made the asphalt brittle i,e less flexible.

Expectedly average Marshall flow of distressed sections was comparatively lower than those of cores obtained from the controlled section primarily because of following reasons.

i) The flow value decreases with decreasing asphalt content.

ii) The flow value increases with decreasing density or otherwise increasing voids.

It can be seen that the stability values, both for distressed and un-failed sections are significantly higher than the minimum required value of 10.0 KN (8.0 KN by MS-2 Standards) for such mixes. While flow values for both the distressed and control sections are quite low, i.e. 4.75 & 6.57 for distress and control sections respectively; which is lower than the minimum required value of 2 mm or 8 flow value. The higher values of stability in this case can be attributed to interparticle friction of the aggregates and hardened binder contents as said earlier. While the low flow values in both the cases is because of oxidation and aging of binder and it can be reasonably assumed that the flow values at the time of construction were within the limits of 8-14 (2 mm to 3.5 mm). The lower flow values and comparatively high stability values tend to make the pavement brittle and hence prone to cracking.

10 : PRESENT REMEDIAL MEASURES

Many types of failures that occur in asphaltic concrete pavements are result of the inherent properties of asphaltic concrete mixtures, and/or due to improper choice of design method, inadequate quality control or lack of proper control in construction.

The maintenance work while providing a comfortable riding surface, should aim at the elongation of the service life of the pavement. This is possible only through elimination of the causes of failure. If the causes are not well identified and eliminated during the maintenance work, it is obvious that the same causes will result in the same failures under the same circumstances.

The present maintenance works being carried out consists of two methods.

i) Scarification of existing wearing course & laying of new mix.

ii) Sealing of existing cracks through double surface treatment.

Scarification of existing wearing course and laying of new mix

Wearing course was being scarified from two sections of approximately 2.5 km and 1.75 km out of a total damaged road length of 10 kms. These sections were to be re-laid with asphaltic concrete mix. Since the highway is heavily trafficked therefore, the depth of this wearing course would be kept around 6-7 cm, as per original design.

Since this solution is not based on eliminating the fault, cracks would reflect through the wearing course as was observed on a patched section. It would simply be waste of resources. Since asphalt concrete costs 4-5 times more than simple double surface treatment, the later being most appropriate should have been preferred.

Double Surface Treatment

Surface treatment is a thin layer of bituminous binder covered with double application of aggregates. There are many usages of surface treatment. It is most suited to asphalt pavements which show signs of cracking or substantial failure. The surface treatment not only prevents further deterioration but also improves riding quality.

Samples of aggregate and bitumen were taken from the construction site and spray rate of bitumen was measured, through site observations and laboratory testing. Following conclusions were drawn.

i) Aggregates being spread over bitumen were found dirty, as shown in photographs.

ii) The percentage of wear by Los Angles test was found close to 40%.

iii) The size of aggregates was found much larger than specified and were not of uniform quality.

iv) The rate of bitumen application to the surface was around 1.56 liters/m^2 which is less than the specified 1.90 liters/m^2 for first layer.

v) The aggregates were being manually distributed through twirling baskets instead of mechanical method as laid down in the specification and therefore the rate of spread of aggregates was not uniform.

11 : MINUTES OF THE MEETING

After detailed inspection of the works at site, office of the Deputy Director, NHA at Abbottabad was contacted to get further information about the section. The NTRC engineers met Mr. Jamal Abdul Nasir, Deputy Director (Maintenance), NHA, Mr. Ibrahim Khan, Assistant Director, NHA and Mr. Malik, Assistant Engineer. Various points were discussed with them and the following information was obtained:-

i) The work under progress was a maintenance activity and not a capital work. The DST was being carried out as per NHA's General specifications. 60-70 penetration grade bitumen was being used. Coarse aggregates of 18 mm & 12 mm size were being used for the treatment.

ii) The Asphalt concrete wearing course having extensive cracks which was being removed. It was about 6 to 7 cm thick. According to NHA, the wearing course was laid in 1991 to 1993 and the design consultant had recommended to overlay section by the year 2000.

iii) The maintenance works were being carried out without any evaluation of causes of failure or consultant's recommendations & it was being done as decision of G.M. & D.D.(Maint.), NHA.

iv) The maintenance of section between Hassanabdal-Thakot is responsibility of NHA while section above Thakot is maintained by FWO.

v) According to D.D. NHA, the criteria for their choice between asphalt concrete and DST was availability of funds. The maintenance team was in favor of DST due to their experience of laying DST on N-5 near Nowshera which performed well.

vi) Some job mix formula (JMF) was being adopted as on Barian - Nathiagali road.

vii) The DST was being laid on the climbing lanes.

viii) The NHA staff was not fully clear of cross section of the existing road.

12 : CONCLUSION & RECOMMENDATIONS

The National Highway (N-35) provides a vital link between the north and the rest of the country. The Highway off-takes from near Hassan-Abdal and ends at Khunjrab pass, it is also called as Karakoram Highway. The over all condition of the pavement upto Sirai-Saleh is good, with scattered patch-work and interspersed cracking signs. The section between Sirai-Saleh and Muslimabad has failed.

NTRC evaluated functional and structural characteristics of the highway to determine the possible causes of failure.

Visual examination of the Highway section revealed high severity alligator (fatigue) cracking with depressions varying from 1 cm to 3 cm at few places. The cracked pieces were found more severely spelled at the edge and loosened. Medium to extensive Stipping/ravelling was also observed.

The asphalt concrete Layer being scarified at three places was found dry and brittle, as shown in the photographs. Asphalt concrete cores were extracted from the cracked and un-failed sections as well as from the asphaltic base of the scarified wearing course. Samples from base course were picked up from the edge of the pavement and from beneath the scarified pavement.

The Laboratory analysis of samples showed that most probable causes of failure are as under:-

a) Cracked sections have a bitumen content of 2.40% by mix which is quite less than that of un-failed sections having 3.5% by mix. The reduction in asphalt film thickness led to brittleness & accelerated oxidation.

b) The deformation of pavement surface suggest that water had entered the pavement, thereby weakening water susceptible layers of the pavement and that lead to substantial deformation, and these deformations did not occur because of weak underlying layers.

c) The asphalt concrete in cracked cores was found fully decomposed (Oxidized) which led to loss of strength.

d) A greater proportion of clay or clay-like minerals was found in the extracted cores.

e) The Specific gravity of distressed cores was extremely low and voids were extremely high (approximately 10%), that resulted in high permeability and lower durability.

f) Measurement of cores extracted from the various sections showed variably of pavement thickness due to patch work & poor quality control.

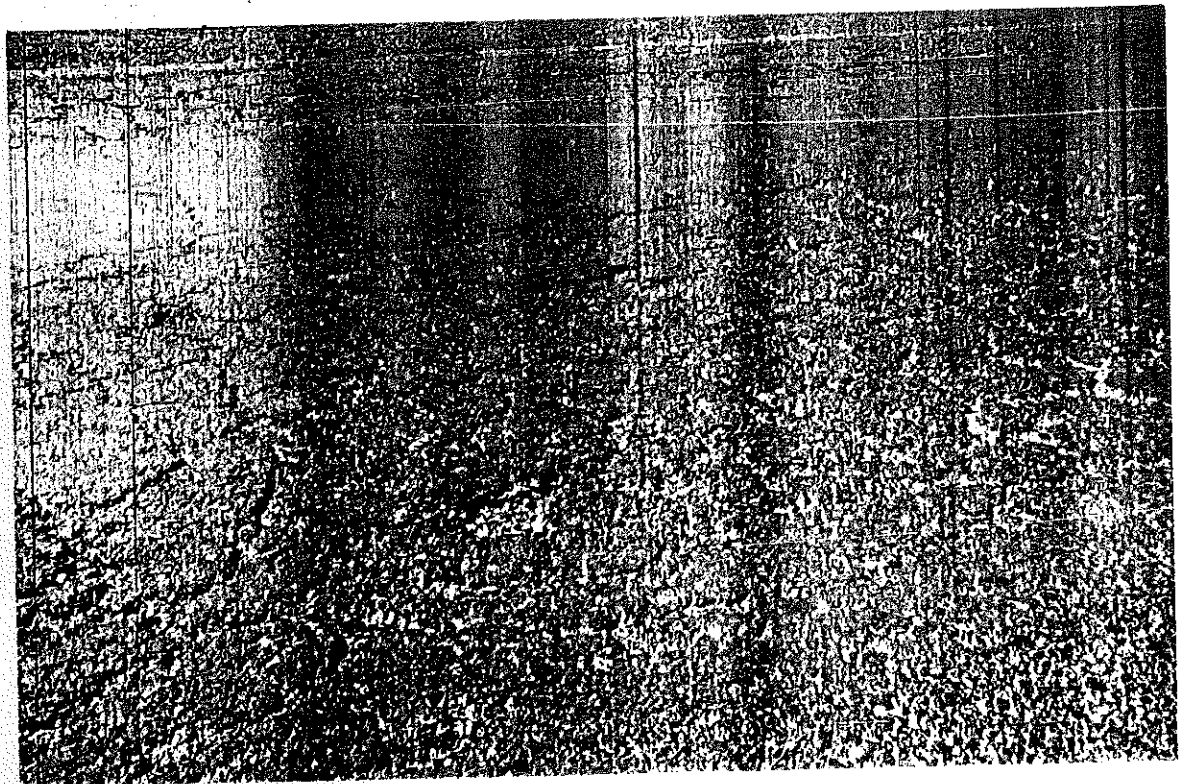
g) The moisture content in the subbase has stabilized while the moisture content in the subgrade needs determination through pits. The gradation of both distressed and control sections do not follow NHA's gradation specification for class A or B.

h) The aggregates used for double surface treatment were found dirty which retards adhesion to binder. Later on this action results in reduced riding quality due to stripping of aggregates.

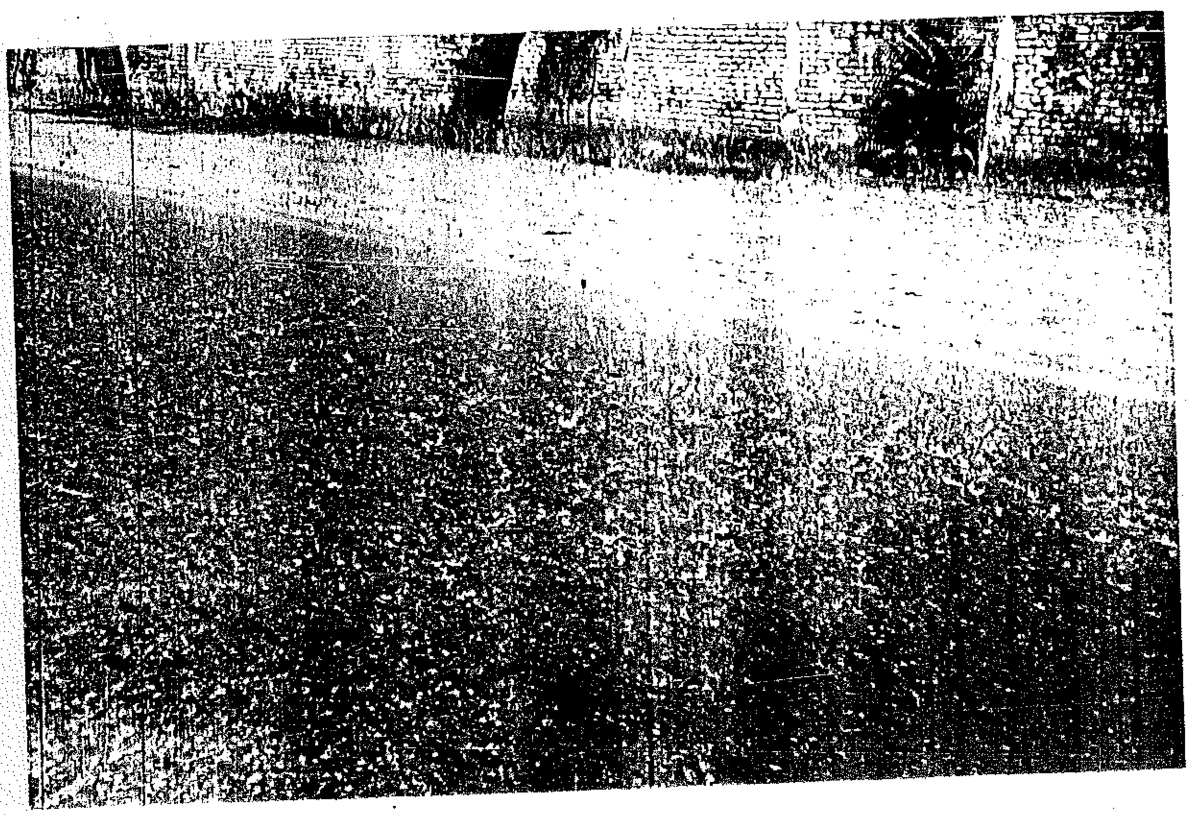
i) The aggregates used for double surface treatment were having Los Angeles abrasion values of 35 - 40 %.

Where are Recommendations?

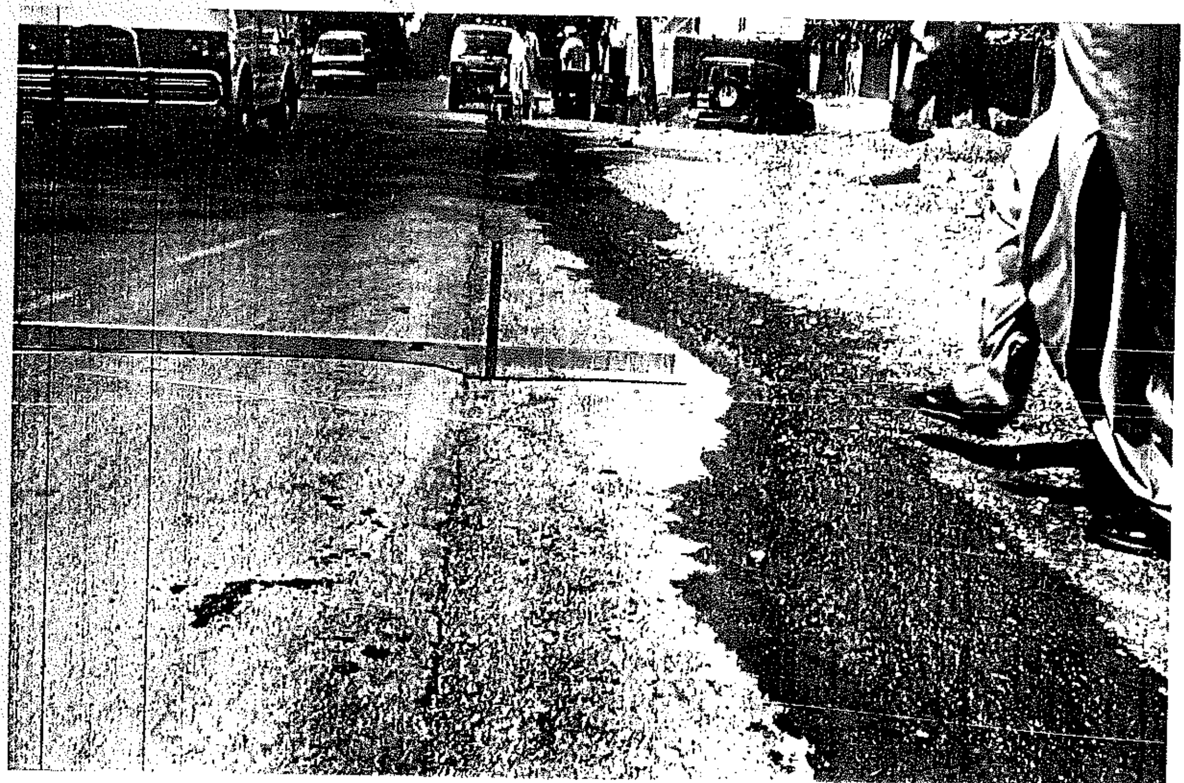
PHOTOGRAPHS



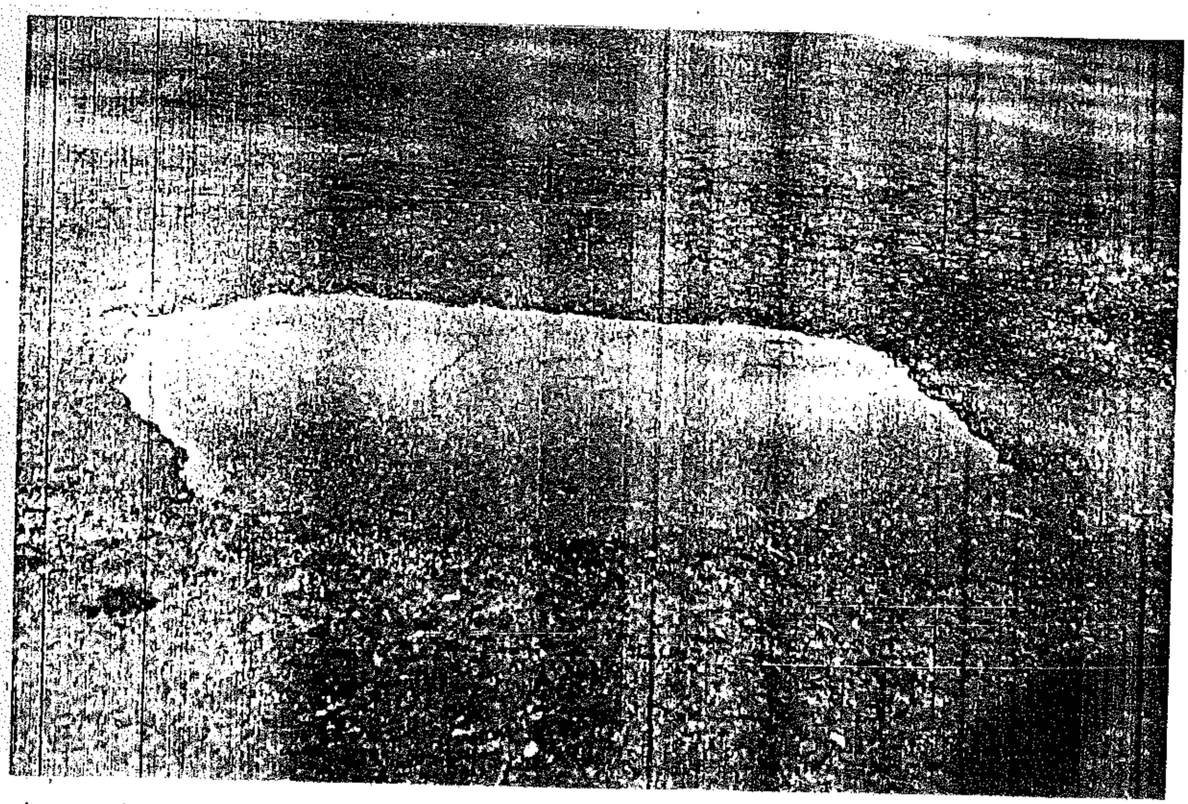
1. High severeity cracking and potholing. Spalled and loosened pieces are clearly visible



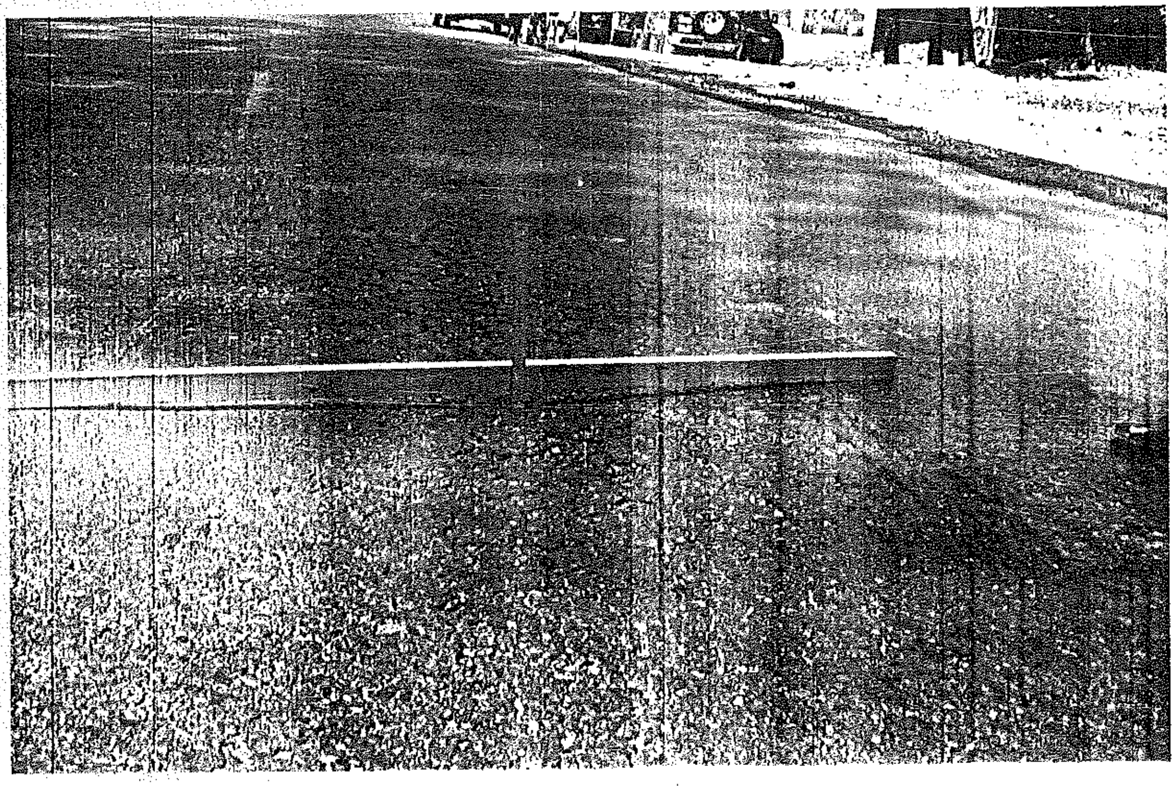
2. A view of extensive cracking of the pavement



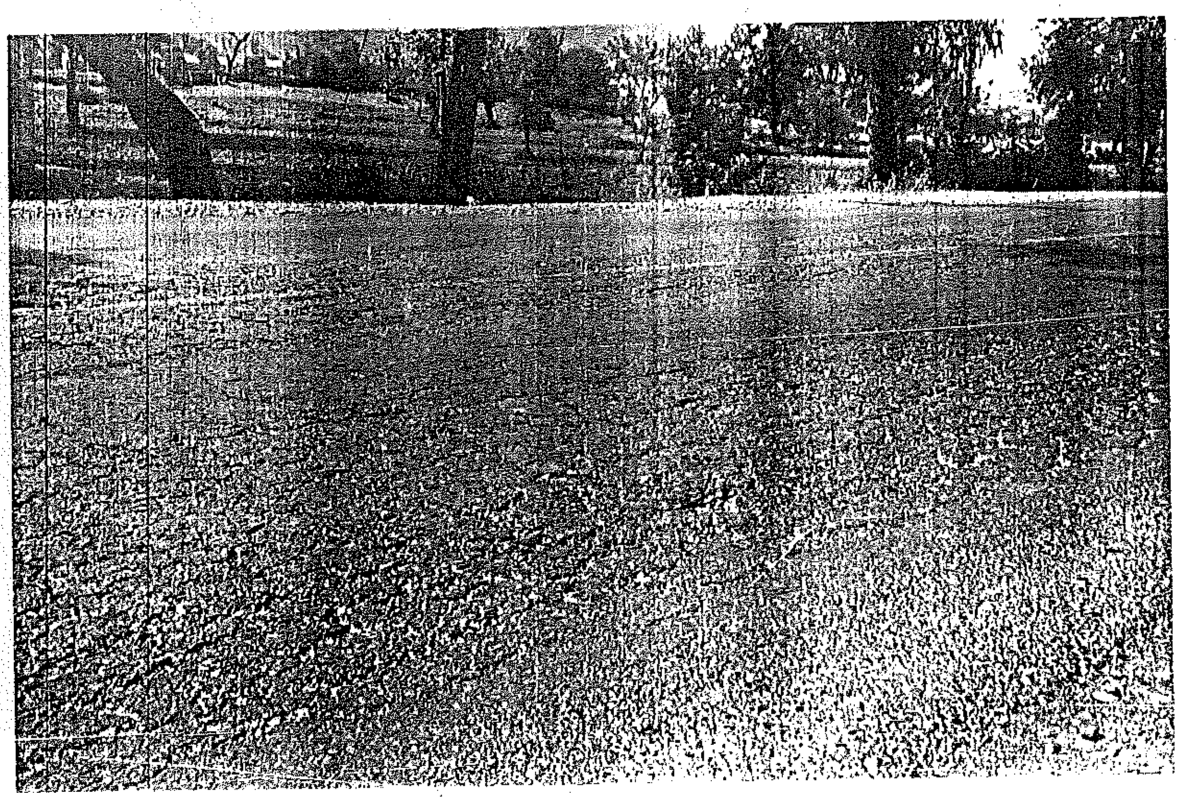
3. A view of overlayed section (done in the past)



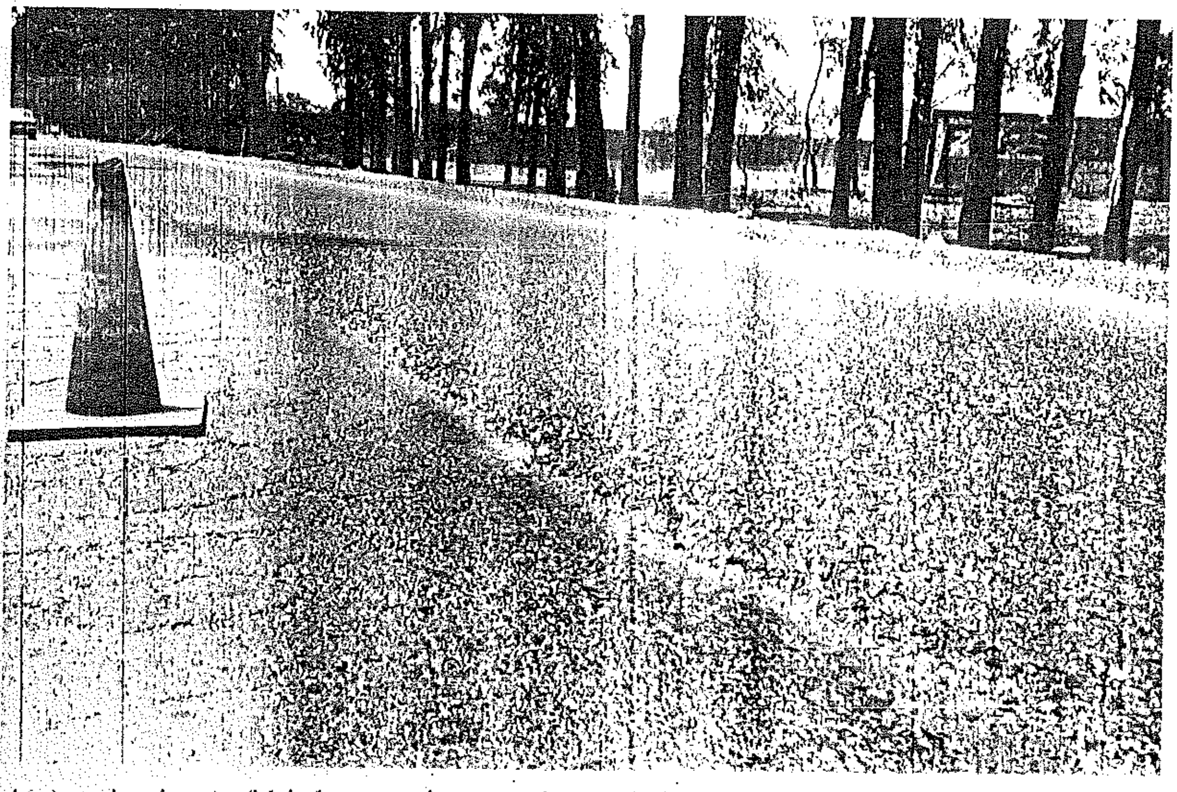
4. A view of deteriorated overlayed section



4(a). High severity/Extensive cracking and settlement / depressions



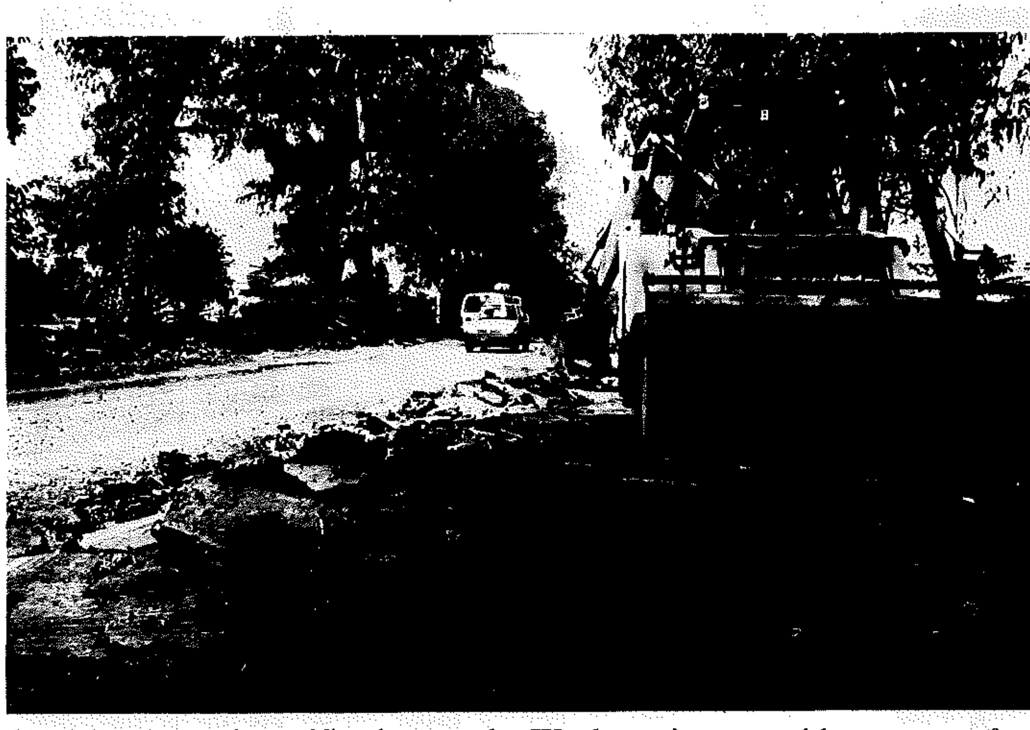
4(b). High severity cracking & potholing



4(c). A view of high severity cracks and double surface treated lane

5. Pavement wearing course layer being scarified using 'un-specified' technique. The base course is prone to damage

6. A view of coring works in progress



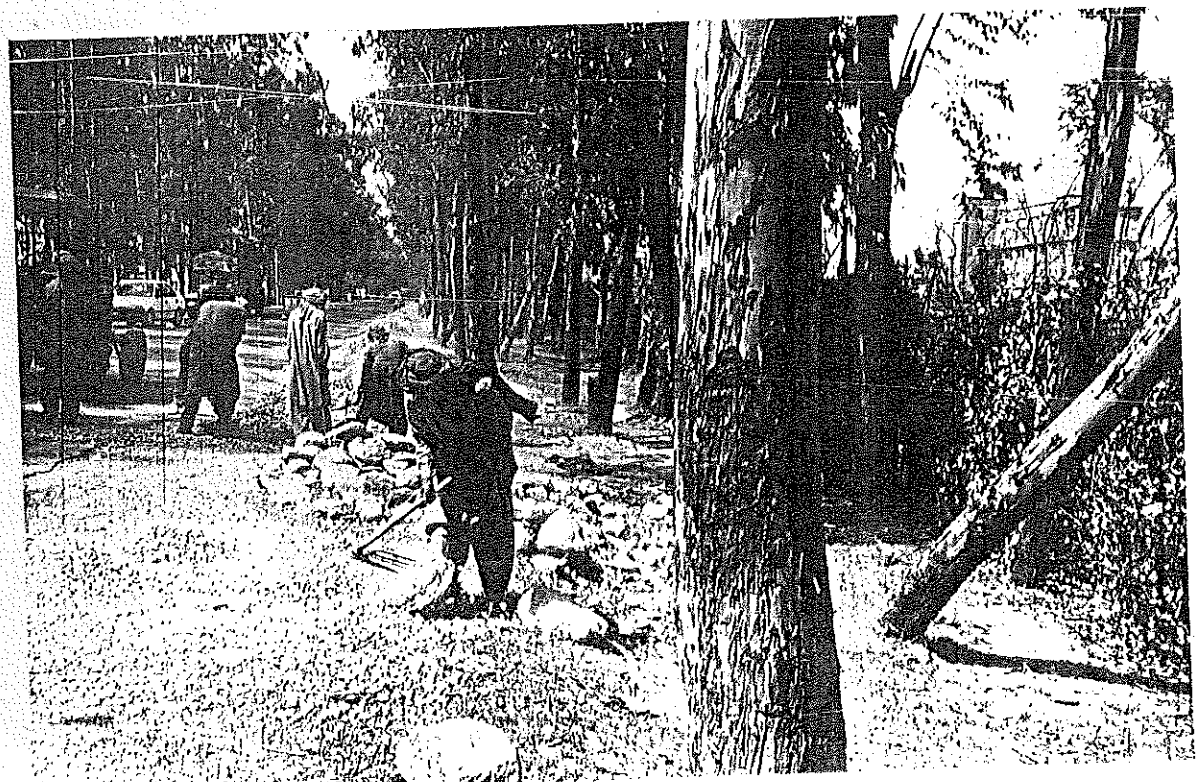
6(a). A view of scarification work. Works going on without any safety precautions

7. A view of coring works in progress. Dynamic cone penetration

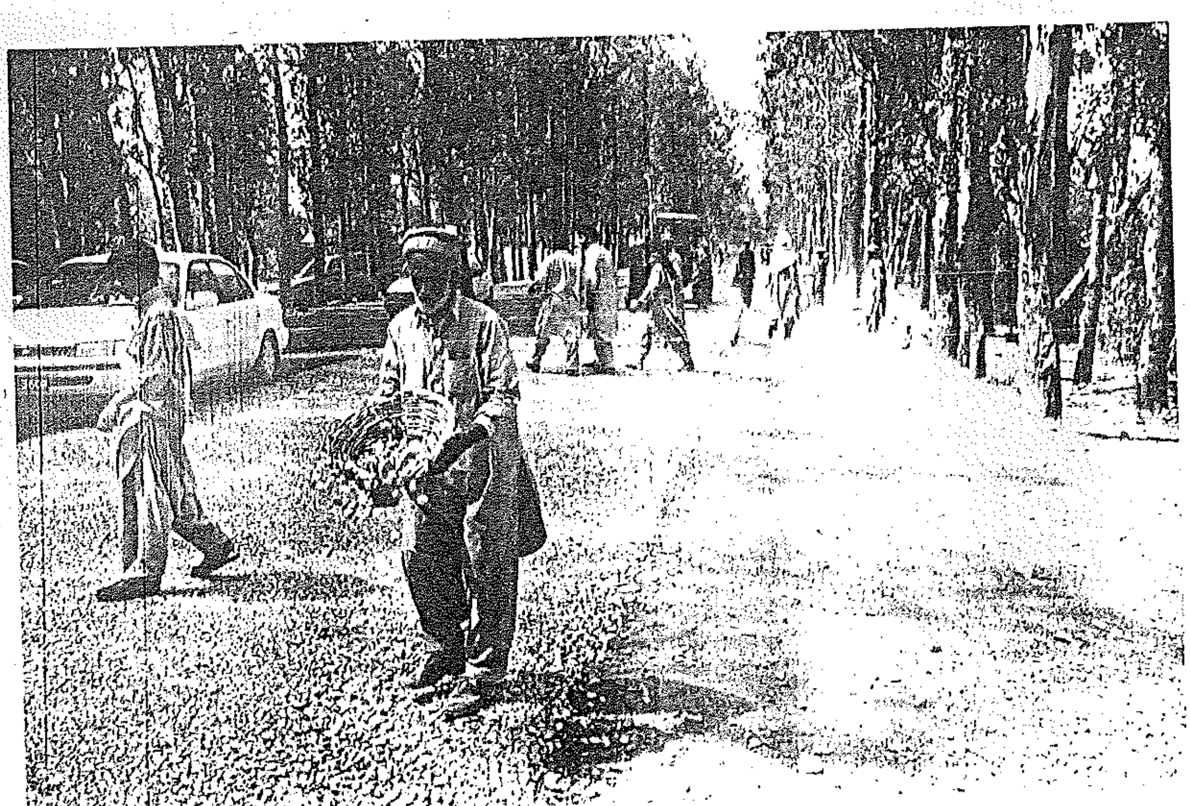
8. A view of scarified wearing course layer. Also visible is the 'dry appearance' of debris lying alongside the pavement

9. A view of excavated pit alongside the highway

10. A view of double surface treatment works and also visible is blowing dirt

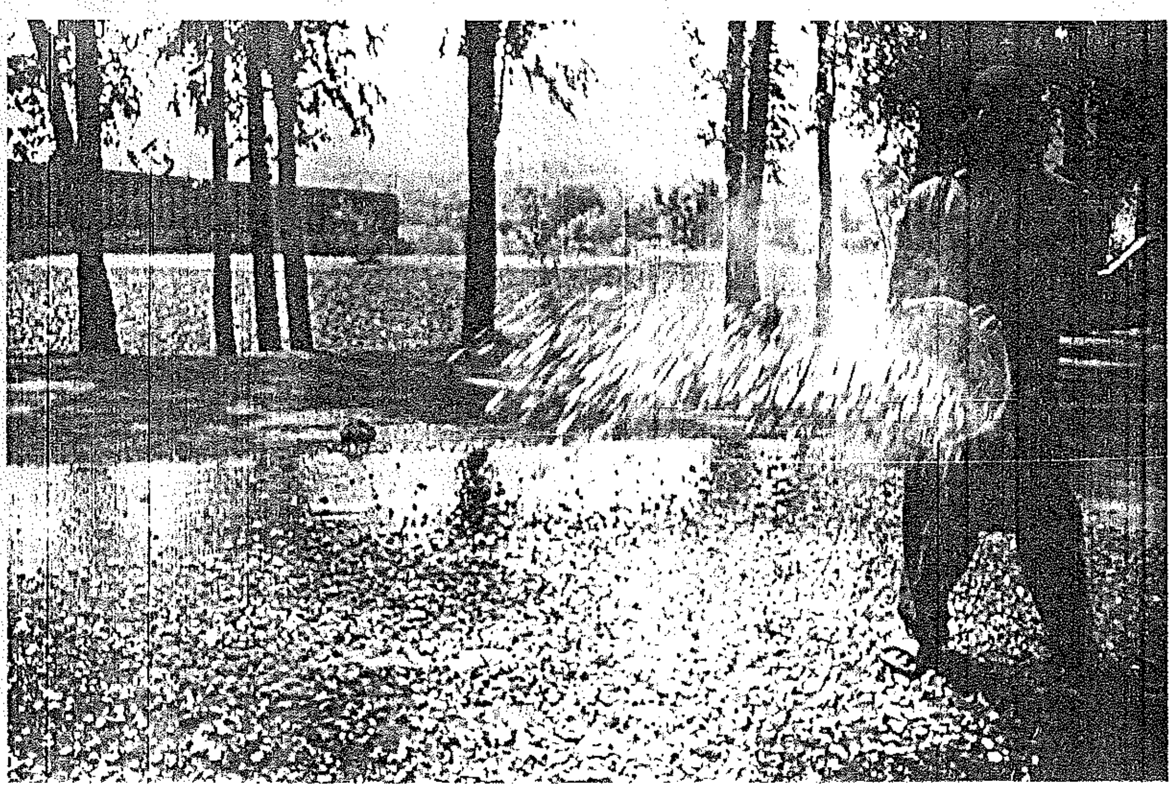


11. Dirty aggregates being are clearly visible



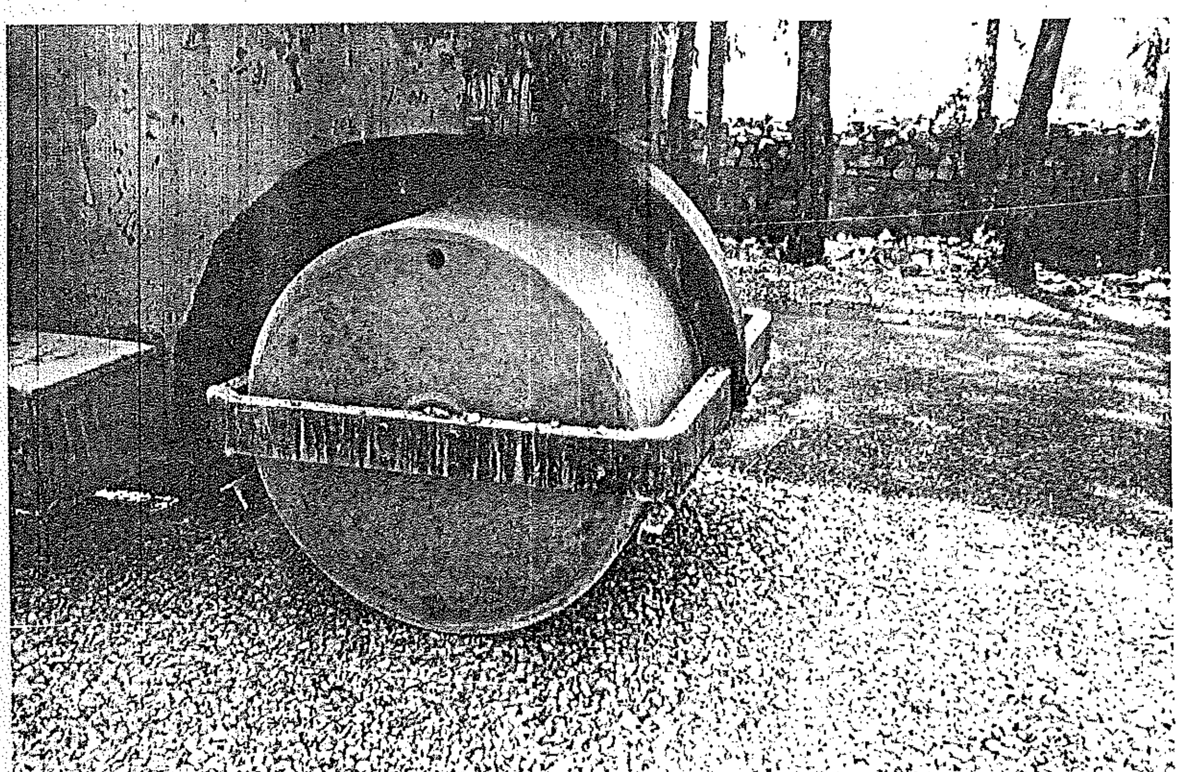
12. A view of double surface treatment works

13. A view of double surface treatment works

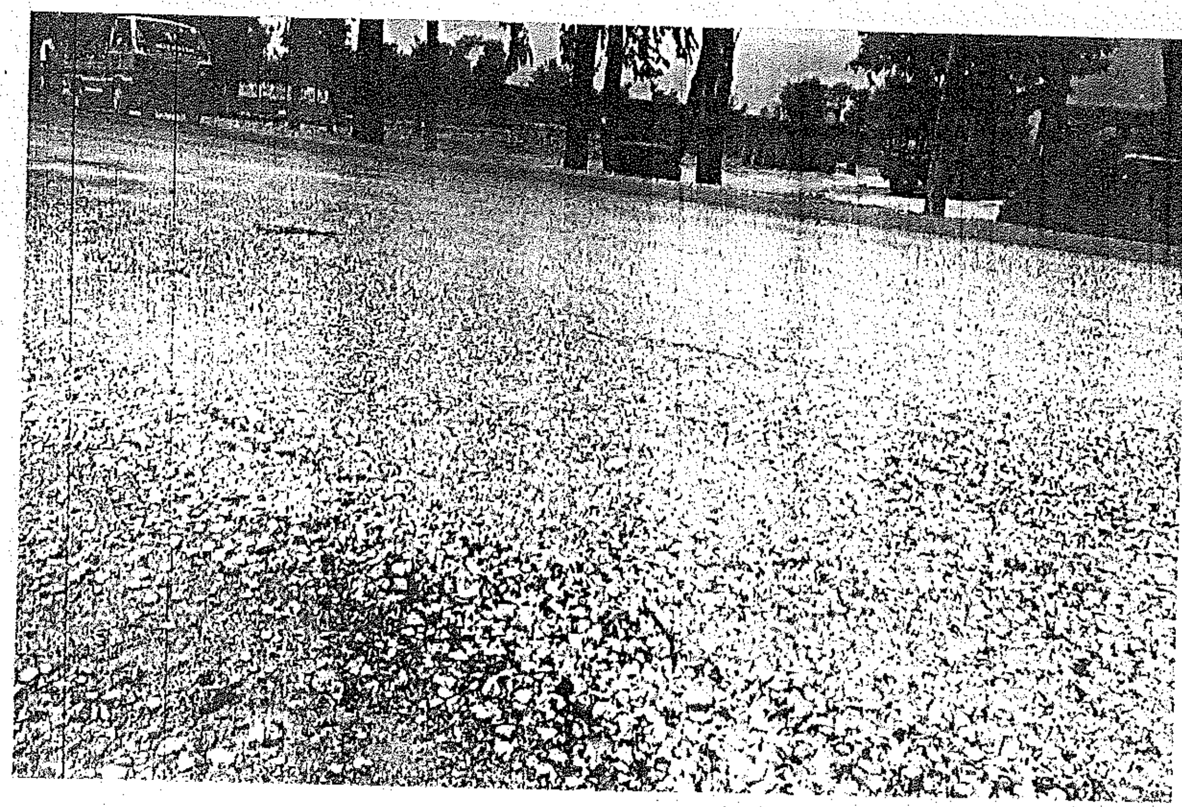


14. A view of DST work using out-dated bucket throughing technique ?

15. A view of DST work



16. Double surface treatment works in progress rolling being carried out



17. Double surface treatment works in progress