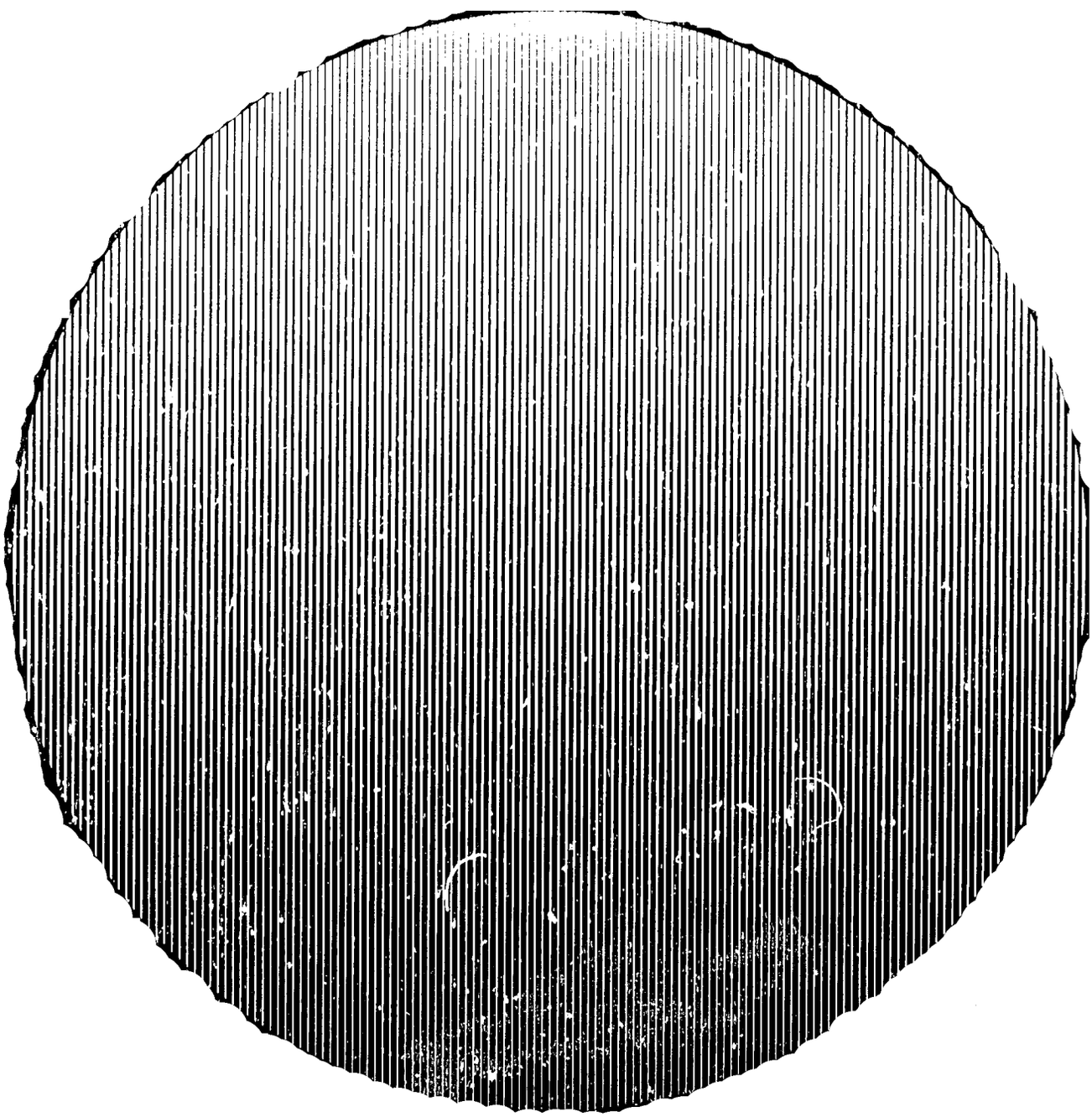
Cairo University/Massachusetts Institute of Technology Technological Planning Program

Performance of Paraffinic-Waxy Asphalt Cements in Egyptian Road Construction
Volume III
Field and Laboratory Evaluation of In-Service Roadway Pavements

By
Abdel Moneim Osman
and Mohsen M. Baligh

Prepared by
Technology Adaptation Program
Massachusetts Institute
of Technology
Cambridge, Massachusetts
02139

Sponsored by
United States Agency for
International Development



TAP Report 81-4 June 1981

PERFORMANCE OF PARAFFINIC-WAXY ASPHALT CEMENTS IN EGYPTIAN ROAD CONSTRUCTION

VOLUME III

FIELD AND LABORATORY EVALUATION OF IN-SERVICE ROADWAY PAVEMENTS

SUPERVISED BY

ABDEL MONEIM OSMAN
MOHSEN M. BALIGH

TAP Report 81-4

June 1981

PREFACE

This report is one of a series of publications which describe various studies undertaken under the sponsorship of the Technology Adaptation Program at the Massachusetts Institute of Technology.

The United States Department of State, through the Agency for International Development, awarded the Massachusetts Institute of Technology a contract to provide support at M.I.T. for the development, in conjunction with institutions in selected developing countries, of capabilities useful in the adaptation of technologies and problem-solving techniques to the needs of those countries. This particular study describes research conducted in conjunction with Cairo University, Cairo, Egypt.

In the process of making this TAP supported study some insight has been gained into how appropriate technologies can be identified and adapted to the needs of developing countries per se, and it is expected that the recommendations developed will serve as a guide to other developing countries for the solution of similar problems which may be encountered there.

Fred Moavenzadeh

Program Director

FOREWARD

A four-year research program entitled, "Performance of Paraffinic-Waxy Asphalt Cements in Egyptian Road Construction," sponsored jointly by the United States Agency for International Development and a group of Egyptian road construction companies was initiated in June, 1979 by the Massachusetts Institute of Technology, MIT, and Cairo University, CU. The final objective of the project is to improve the performance of pavements constructed with the Egyptian Paraffinic-waxy asphalt.

The first year research (July, 1979 to June, 1980) was mainly aimed at achieving a better understanding of the important factors affecting the use of Egyptian asphalts in road construction. The results of the first year research were published in two previous reports entitled:

1) Performance of Paraffinic-Waxy Asphalt Cements in Egyptian Road Construction: Literature Review and Background of the Problem in Egypt, TAP Report No. 80-4.

2) Performance of Paraffinic-Waxy Asphalt Cements in Egyptian Road Construction: Chemical and Physical Properties of Western Desert Asphalt Cements, TAP Report No. 80-5.

The work during the second year (July, 1980 to June 1981) included the following tasks:

1) Establish the basic chemical, physical and engineering properties of the pavement samples recovered during the first year from selected roadway sections;

2) Investigate methods of improving the performance of pavements constructed with Egyptian waxy asphalt; and

3) Design of a full scale field testing program.

This report presents the results of the first work item listed above. The work was supervised by Professors Abdel-Moneim Osman and Mohsen M. Baligh. The following individuals, listed alphabetically, have participated in the preparation of this report: A. Azzouz (MIT); F. Ezzat (Egyptian Petroleum Research Institute); A. Gadallah (CU); M. Noureldin (CU); L. Radwan (CU); E. Sarhan (Ain Shams University); M. Talaat and S. El Beih (Roads and Bridges Authority). S. Noureldin and O. Zayed provided valuable assistance during the course of the study and the preparation of this report.

ACKNOWLEDGEMENTS

The following individuals and/or organizations provided valuable contributions to this study:

Ministry of Transportation, the General Authority of Roads and Bridges

Eng. Ahmed Shawky
Chairman, The General Authority of Roads and Bridges

National Academy of Science, Egyptian Petroleum Research Institute

Dr. Fathy Ebaid
Chairman, Egyptian Petroleum Research Institute

Dr. Mohamed Rushdy
Director, Research Laboratories

Dr. Gaber El-Fayoumy
Research Staff Member

Matching funds were provided by the following Egyptian road construction companies:

1. The Arab contractors (Osman Ahmed Osman, and Co.):
   Eng. Hussein Osman

2. The Nile Company for Roads and Bridges:
   Eng. Ahmed El-Okaily

3. El-Nasr Contracting Company (Hassan Allam):
   Mr. Mohamed Fahmy Allam
   Mr. Samir Allam

4. The Genral Authority for Roads and Bridges:
   Eng. Ahmed Shawki

5. The Nile Company for Road Construction
   Eng. Ahmed Moussa

6. The Nile Company for Desert Roads
   Eng. Taha El-Keliny

The authors would also like to express their appreciation to the staff of the Highway Authority Central Laboratory and the Highway District.

The views and opinions expressed in this report are those of the authors and do not necessarily reflect those of the sponsors: CU/MIT Technological Planning Program, DRTPC, Cairo University, the Highway and Bridges Authority, or the Road Construction Companies.

TABLE OF CONTENTS

		Page
Title Page		1
PREFACE		2
FOREWORD		3
ACKNOWLEDGEMENTS		5
TABLE OF CONTENTS		7
LIST OF TABLES		9
LIST OF FIGURES		10
CHAPTER 1.	INTRODUCTION	11
CHAPTER 2.	FIELD SAMPLING PLAN AND BACKGROUND DATA	13
2.1	Selection of Roadway Links	13
2.2	Delineation of Test Sections and Sampling Locations	15
2.3	Background and Basic Data	16
CHAPTER 3.	LABORATORY TESTING PROGRAM	27
3.1	Tests on Asphalt Concrete Samples	27
3.2	Tests on Base Course Samples	27
3.3	Tests on Subgrade Soil Samples	28
CHAPTER 4.	ANALYSIS OF TEST DATA	29
4.1	Banha-El Bagour Road	29
4.2	Cairo-Alexandria Desert Road	31
4.3	Malatia-Abu Korkas Road	33
4.4	Components Analysis of Extracted Bitumens	34
CHAPTER 5.	SUMMARY AND CONCLUSIONS	37

		Page
APPENDIX A.	FIELD SAMPLING AND TESTING DATA BANHA-EL BAGOUR ROAD	40
APPENDIX B.	FIELD SAMPLING AND TESTING DATA CAIRO-ALEXANDRIA DESERT ROAD	47
APPENDIX C.	FIELD SAMPLING AND TESTING DATA MALATIA-ABU KORKAS ROAD	55
APPENDIX D.	COMPONENT ANALYSIS OF ASPHALT CEMENT SAMPLES	60

LIST OF TABLES

		Page
2.1	Temperature Records for Representative Egyptian Climatic Zones	18
2.2	General Description of the Selected Roadway Links	19
2.3	Average Daily Traffic for the Selected Links (vpd)	20
4.1	Summary of Component Analysis Test Data	36
5.1	Evaluation of the Study Roadway Test Sections	39

LIST OF FIGURES

		Page
2.1	Location of Field Study Roadway Links (Lower Egypt)	21
2.2	Location of Field Study Roadway Links (Upper Egypt)	22
2.3	Pavement Conditions along the Cairo-Alexandria Desert Road	23
2.4	Pavement Conditions along Banha-El Bagour Road	24
2.5	Sampling Locations along a Segment of the Banha-El Bagour Road	25
2.6	Sampling from the Malatia-Abu Korkas Road	26

CHAPTER 1

INTRODUCTION

Performance data for several Egyptian roadway pavement sections have clearly indicated that both functional and structural failures as well as poor service qualities could be attributed to the use of paraffinic-waxy asphalt cements in either the construction or maintenance of these pavements. A major effort in this research has thus been devoted to establishing the fundamental properties of these asphalt cements and their effects on performance.

This report presents the results of a study aimed at evaluating the factors affecting the performance of roadway pavements constructed and/or maintained by means of Egyptian paraffinic waxy asphalt cements. The study consists of two phases: field investigation, and laboratory testing. The field investigation includes a condition survey and a field performance study of selected roadway sections together with securing pavement and subgrade samples for laboratory testing. The second phase evaluates the chemical, physical and engineering properties of the sampled materials and attempts to correlate these properties to pavement performance.

The first section of this report presents the field sampling plan along with the basic background data related to the selected roadway links. The testing program conducted on the recovered samples from the asphalt concrete surface, the

base materials and the subgrade soils is described in Chapter 3. Test results and an evaluation of the data are provided in Chapter 4. Finally, Chapter 5 presents the main conclusions drawn from this study.

CHAPTER 2

FIELD SAMPLING PLAN AND BACKGROUND DATA

2.1 SELECTION OF ROADWAY LINKS

The selection of representative roadway links in the Egyptian road network represents a difficult task. The following factors affected the choice of the links investigated herein:

(1) Climatic Conditions

Egypt can be divided into four representative climatic zones: the Mediterranean Coast, the Nile Delta, the Red Sea, and the Southern Nile Valley. Table 2.1 shows the summer and winter temperatures (Max., Min., and Mean) in four cities located in each of those four zones.

Generally, the mean temperature increases from the Mediterranean Coast (Zone 1) to the Southern Nile Valley (Zone 4) with significant variations between summer and winter. The highest and lowest temperatures are recorded in Luxor, located on the southern part of the Nile valley, where the average daily maximum temperature is 40.7°C in June/July and the average lowest mean is 5.4°C in January. The Mediterranean and Red Sea Coasts show small differences between average maximum and minimum temperatures.

The highest annual rainfall is recorded along the Mediterranean Coast (Marsa Matrouh receives 144mm, with a maximum of 38mm in December). The annual rainfall decreases slightly

towards the east over the coastal area. The influence of the sea is still evident in Cairo (24mm), but in Luxor, rainfall is almost nil (1mm). No significant precipitation takes place along the Red Sea Coast, e.g., the annual rainfall at Ghardaka is 4mm.

In summary, climatic conditions in Egypt can be considered favorable relative to their effect on pavement performance.

(2) Types of Natural Subgrade Soils

The natural subgrade soils consist mainly of clays and silty clays in the Delta and Nile valley regions. In the desert area, the subgrade consists mainly of sands, with some silt pockets.

Hence, for the purpose of this study, Egypt can be divided into three regions having similar characteristics relative to climate, topography and subgrade soil type. These regions are: 1) Delta and Northern Nile Valley; 2) The Southern Nile Valley or Upper Egypt; and 3) Desert Areas and the Red Sea Coast.

Three roadway links, constructed and/or maintained by means of paraffinic-waxy asphalt cements, were selected from these different regions. The links are illustrated in Figs. 2.1 and 2.2 and include:

1) Banha-El Bagour Road (18km in length);
2) Cairo - Alexandria Desert Road from km 120 to Alexandria (about 85km in length); and

3) Malatia - Abu Korkas Road (100km in length).

In addition, a second section along the Cairo-Alexandria Desert Road (about 140km from Alexandria) was also selected for this study. This section is in a better condition compared to the other one due to the source of asphalt cement used and the surrounding environment.

The pavement conditions at two locations along the Cairo-Alexandria roadway link are illustrated in Fig. 2.3. The figure shows that the pavement suffers from severe rutting (about 10-12cm) with creep towards pavement edges, bleeding and longitudinal as well as map cracking. Similarly, heavy bleeding with longitudinal and transverse corrugations were observed along parts of the Banha-El Bagour link (Fig. 2.4).

2.2 DELINEATION OF TEST SECTIONS AND SAMPLING LOCATIONS

Test sections were delineated along the selected roadway links according to the following criteria:

1) They must be located along straight stretches of the road with flat gradients and uniform conditions;

2) Test sections must exceed 300m in length to permit an adequate performance study, and finally

3) They must not be near villages and town entrances.

A total of 25 sampling locations were selected along the designated sections as follows:

Link	Locations
1. Banha-El Bagour	8
2. Cairo-Alexandria Desert Road	
1st Section (85km from Alexandria)	10
2nd Section (140km from Alexandria)	2
3. Malatia-Abu Korkas	5

For each sampling location, the following data were obtained:

1) cross-section elements;

2) surrounding environment; and

3) subjective description of the surface condition and type of failure (if any).

Samples were secured at about one meter from the pavement edge or from the center line of the road (see Fig. 2.5). Furthermore, samples at locations of "good" and "bad" surface conditions within the same section were secured in order to isolate the effect of pavement layers from other factors (e.g. subgrade, environment, traffic, ... etc.). The asphalt concrete samples were about 35 x 35 x 4cm (see Fig. 2.6) and each weighed about 10kg which allowed a suitable amount of asphalt to be extracted for laboratory testing. Samples of the base, sub-base and subgrade were also secured.

2.3 BACKGROUND AND BASIC DATA

Available data related to the selected roadway links were obtained from the Highways and Bridges Authority prior to the

execution of the field and laboratory evaluation program. The basic data included the following:

1) Historical construction information (Data of last overlay or reconstruction, maintenance activities, initial pavement thickness and materials, ... etc.).

2) Roadway length and cross section elements.

3) Traffic volume estimates, if available.

Tables 2.2 and 2.3 present the general description of the selected roadway links and available traffic volume estimated, respectively. It is important to note that the traffic volume data are obtained from different sources and are not complete, but are however presented to provide qualitative description of the traffic volumes in the study links.

In 1975, the Cairo-Alexandria Desert Road carried about 4736 vehicles per day, vpd, (with the heavy vehicles representing about 50% of the traffic in the first study section). The heavy-vehicles traffic in the second section of this road is noticeably lower than that on the first section. This was followed by the Malatia-Abu Korkas Road (with heavy vehicles representing about 33% of the traffic). Banha-El Bagour Road carries low traffic volume since its upgrading to an asphalt pavement road in 1975.

Table 2.1 Temperature Records for Representative Egyptian Climatic Zones

Climatic Zone	Representative City	Summer (May-Oct.) Daily Max.	Min.	Mean	Winter (Nov. April) Daily Max.	Min.	Mean
1. Mediterranean Sea Coast	Marsa Matrouh	28.0	18.4	21.0	20.5	10.2	15.8
2. Nile Delta	Cairo	32.7	19.7	26.2	22.9	11.2	16.9
3. Red Sea Coast	Ghardaka	30.9	22.8	27.2	23.1	12.6	18.6
4. Southern Nile Valley	Luxor	35.2	21.6	30.6	27.8	9.8	18.4

Source : Climatological Normals for Egypt, A.R.E. up to 1960

Table 2.2 - General Description of the Selected Roadway Links

Roadway Link Name	Study Section Length (km)	Pavement Width (m)	Shoulder Width, type (m)	Initial Pavement Structure Thickness (1) (cm)			Date of Last Overlay or Reconstruction (2)	Overlay Activity	
				AC	B	B/C		AC	B
Banha El-Bagour	18	6	2 Unpaved	5	-	20 (gravel)	74 - 75	New Construction	
Cairo-Alexandria Desert Road	85 (from Alex)	7.5	3 Unpaved	4	-	15 (gravel)	71 - 73	4	4
Malatia-Abu-Korkas	100	7.5	3 Unpaved	5	5	15 (CLS)	69 - 74(3)	5	5

(1) AC = Asphalt Concrete Surface , B = Binder mix, B/C = Base Course, CLS = crushed Limestone

(2) Starting and Completion dates , respectively.

(3) Overlay and Widening with Routine Maintenance (skin patching, sealing, ...) at a later undocumented dates.

Source : Highway and Bridge Authority

Table 2.3 - Average Daily Traffic for the Selected Links (vpd)*

Link Name	1972(2)	1975(2)	1977(3)	1978(4)	Comparative Rating
Banha-El Bagour	NA	NA	709	NA	Low Volume
Cairo-Alex Desert Road (1)	1600	4736	NA	3596	High Volume
Malatia-Abu Korkas					
Malatia-Minya	1600	3360	NA	5633	High Volume
Minya-Abu Korkas	2400	4500	NA	4842	High Volume

NA = Not available

(1) ADT varies along the road. The reported ADT values are for the first study section (85 km from Alex).

(2) Source: Roads and Bridges Authority files

(3) Source:"Road Transport Analysis in Egypt," CU/MIT Technological Planning Program, TAP Report 78-6, Cairo University, 1978.

(4) Estimates from : "Egypt National Transport Study," Phase I, Transport Planning Authority, Ministry of Transport, 1977.

* (vpd) = vehicle per day.

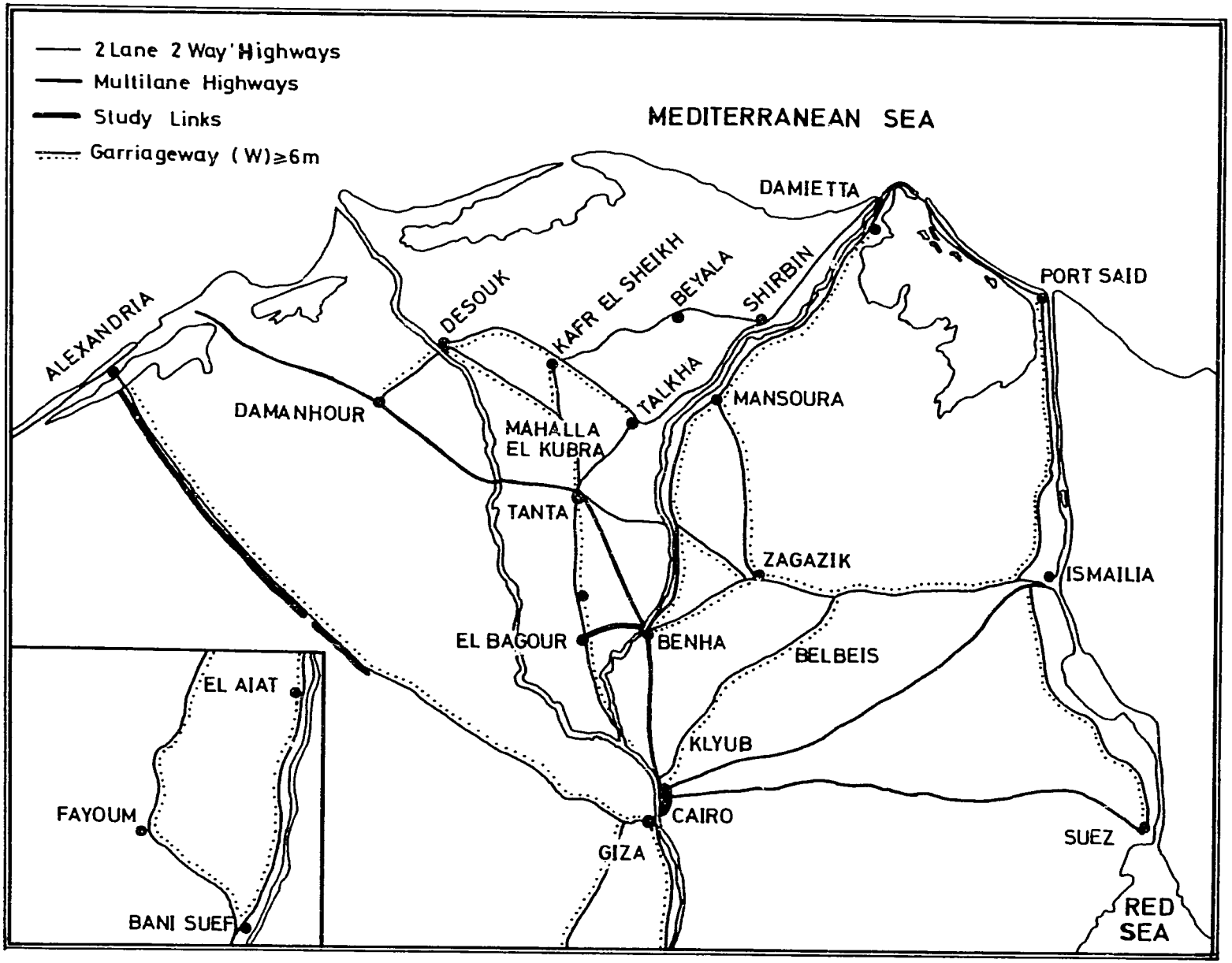


Figure 2.1 Location of Field Study Roadway Links (Lower Egypt)

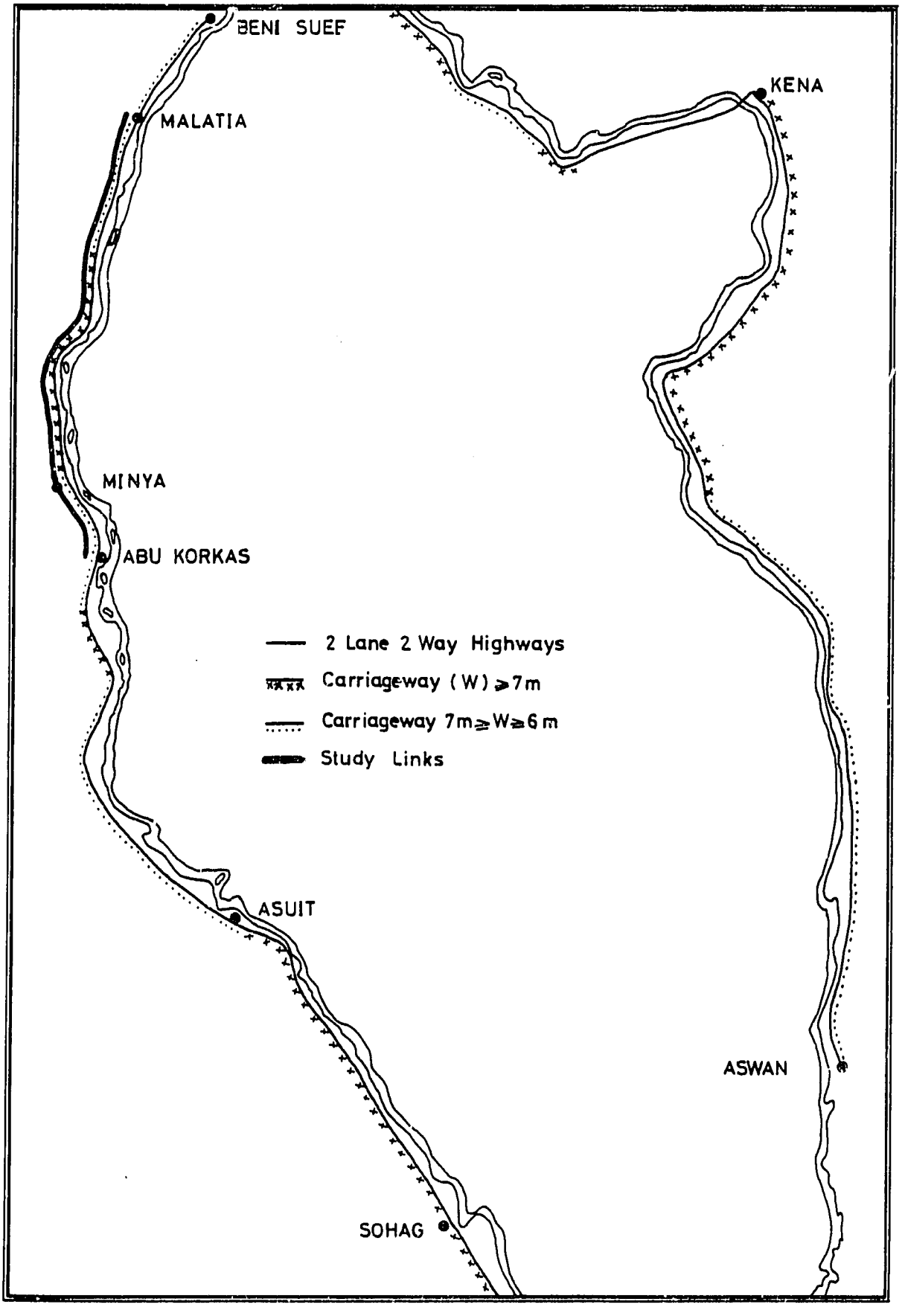
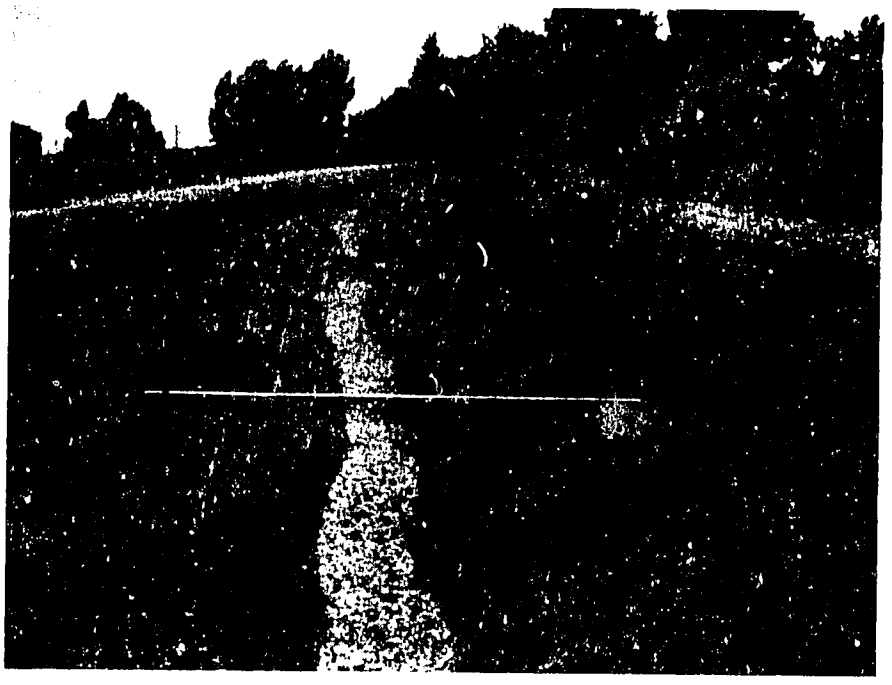


Figure 2.2 Location of Field Study Roadway Links (Upper Egypt)

a) Medium Bleeding with severe rutting on wheel path with longitudinal cracks (picture taken on a rainy day)

b) Bleeding with map cracking, rutting with creep towards pavement edges

Figure 2.3 Pavement Conditions along the Cairo-Alexandria Desert Road



Longitudinal and transverse corrugations

Figure 2.4 Pavement Conditions along Banha-El Bagour Road

Figure 2.5 Sampling Locations along a Segment of the Banha-El Bagour Road

Figure 2.6 Sampling from the Malatia-Abu Korkas Road

CHAPTER 3

LABORATORY TESTING PROGRAM

3.1 TESTS ON ASPHALT CONCRETE SAMPLES

Each asphalt concrete sample was subjected to the following tests:

1) Extraction and recovery by the "Abson" Method.
2) Percent asphalt cement determination.
3) Physical tests on recovered asphalt cements:
   a) Kinematic viscosity (at 135°C)
   b) Penetration test
   c) Ductility test
4) Chemical analysis of recovered asphalt cements:
   a) Wax content
   b) Oil, resins, and asphaltenes components
5) Aggregate type and gradation.

A complete description of the test procedures and the significance of the results can be found in TAP Report No. 80-4.*

3.2 TESTS ON BASE COURSE SAMPLES

Gradation analysis, Los Angeles abrasion test, percent absorption and percent disintegration tests were performed on the secured base course samples.

---

* Performance of Paraffinic-Waxy Asphalt Cements in Egyptian Road Construction," Volume 1, CU/MIT Technological Planning Program, TAP Report 80-4, Cairo University, 1980.

3.3 TESTS ON SUBGRADE SOIL SAMPLES

The subgrade samples were subjected to gradation analyses and plasticity indices tests to determine the subgrade classification

CHAPTER 4

ANALYSIS OF TEST DATA

The field and laboratory test results together with the historical construction data are presented in appendices A, B, and C. The following is a brief discussion of the field and laboratory evaluation for each of the three selected roadway links.

4.1 BANHA-EL BAGOUR ROAD

1) The road has been recently constructed in 1975 with a 20cm of pit-run gravel base followed by 5cm of asphalt concrete surface.

2) Road samples where significant bleeding and surface corrugations were observed have high asphalt contents (samples No. 1, 2, 4, 5 and 7). The asphalt contents of these samples varied between 7.5% and 8.3% which are significantly higher than the design asphalt content (5.8%). On the other hand, samples No. 3, 6, and 8, secured from relatively good road sections, have relatively low asphalt contents: 6.1, 5.98, and 6.4%, respectively.

3) The wax content of the asphalt extracted from samples is about the same (4.2% to 5.3%).

4) The bleeding and corrugation problems observed in some road sections are probably caused by the high asphalt content rather than the high wax content.

5) Results of tests performed on various asphalt cement batches secured during construction indicate inconsistent properties. Penetration values ranged from 57 to 93 and kinematic viscosities between 156 and 400 c.st. In most of the batches, the kinematic viscosity is remarkably high, thus suggesting that stored local or imported asphalt cements were used.

6) Similarly, results of physical tests on extracted (recovered) asphalts show a remarkable variation. This is, however, consistent with the variability of the original asphalt properties. For instance, penetration values varied between 20 and 57 and kinematic viscosity between 483 and 3,686 c.st.

7) Penetration and kinematic viscosity values of extracted asphalt cement are consistent. However, the variation in the physical properties of the 8 samples cannot be attributed to the variation in wax contents (4.22 to 5.3%).

8) The actual thickness of pavement components are within the required values. However, in some samples the plasticity indices of the secured base course material exceed the maximum values specified for such material.

9) The subgrade soil is mainly a plastic clay with high liquid limit and plasticity indices (AASHTO class: A-7-6). However, based on visual inspection of the road surface, no clear indication of base failures (caused by these subgrade soils) could be detected.

4.2 CAIRO-ALEXANDRIA DESERT ROAD

1) The last strengthening and widening was conducted in 1973. The overlay consisted of 4cm of asphalt concrete surface and 4cm of binder course over the old structure (consisting of 4cm of asphalt concrete over a 15cm pit-run gravel base).

2) The secured samples were obtained from two distinct sections. The first section extends for about 85km from Alexandria, while the second section is at km 140 from Alexandria. Further examination of the data indicated that the source of asphalt cement employed in the two sections are different.

3) Samples from sections involving surface corrugation and/or bleeding have high asphalt content and/or high wax content in the asphalt. This might be due to a high asphalt content in the asphalt concrete mixture or due to the migration of the asphalt and/or the wax during pavement service.

4) Results of physical and chemical tests on extracted asphalt cement (AC) samples of the first section show remarkable variations. Penetration values ranged between 33 and 59; and kinematic viscosity varied between 454 and 883 c.st. The wax content ranged form 4.69% to 7.05%.

5) The asphaltene content of the extracted AC samples is relatively high. This could be attributed to the aging and hardening of the asphalt.

6) The base course thickness at the first seven sampled locations are quite variable and generally less than required by the initial structural design. However, the thickness of

the binder course are larger than the design values and that the overall thickness of the pavement layers exceed the design.

7) The subgrade soils in the first section of the road consist of plastic clays (AASHTO class A-6) with high volume change characteristics and moderately plastic silty soils (A-4) with an affinity to water. These (A-4) soils can swell and lose much of their resistance unless properly compacted and drained. On the other hand, the subgrade soil in the second section consists of coarse sand with NP silts (A-1-b & A-2-4) which provide a better subgrade for pavement structure.

8) Plastic deformations in the base and subgrade layers are believed to be due to the drainage conditions. The Cairo-Alexandria road was designed as a desert road. However, agricultural development and land reclamation in the last decade took place along the first section of the road under investigation (within 85km from Alexandria). These changes in the surrounding environment can cause significant changes in the subgrade moisture. The remaining portion of the road towards Cairo (second section) is in much better condition due to the nature of the subgrade soil (sands with some silt pockets), the surrounding environment, and the source of asphalt used.

9) The high traffic volume and the large percentage of heavy vehicles using this section of the road affected the pavement performance.

10) Based on the previous results, the marginal to poor pavement performance can be attributed to one or more of the

following factors: design implementation, material properties, asphalt source, wax content in the asphalt cement, non-homogeneity of asphalts, environmental conditions, and traffic.

4.3 MALATIA-ABU KORKAS ROAD

1) The last major maintenance of the Malatia-Abu Korkas road was completed in 1974. However, the maintenance work duration extended over the period from 1969 to 1974. Routine maintenance (skin patching, sealing,...) was done on subsequent undocumented dates.

2) Results of tests performed on various asphalt cement batches secured during the last major maintenance indicate inconsistent properties. Penetration values ranged from 81 to 120.

3) Road samples where bleeding and surface corrugations were observed have high asphalt contents (6.7% to 7.9%) which are significantly higher than the design asphalt content (5.75%). However, the samples from the good section possessed 5.8% asphalt content.

4) Results of tests performed on extracted asphalts show a remarkable variation. Penetration values ranged between 30 and 39, while kinematic viscosity values ranged between 515 and 1045 c.st.

5) Component analysis of the extracted asphalts show a relatively high wax content (6.3% to 8.3%).

6) The observed significant variations in the physical and chemical properties of the extracted asphalt cement samples could be attributed to the following factors:

a) Aging: difference in asphalt source, environmental conditions and/or duration since last major overlay (1969-1974).

b) Differences in the asphalt cement properties used in the last major maintenance.

7) The actual thickness of pavement components are within the required design thickness and the base course material consist of crushed limestone. In some sections, large limestone blocks are used as a base course, and hence provide an excellent support.

8) The natural subgrade soil is mainly a non-plastic silty sand (A-2-4) which represents a good subgrade for the pavement.

9) Based on the preceding discussion, the problems observed in some sections of the road can be attributed to the non-homogeneity of asphalt cements and the high wax content in these asphalts. Furthermore, the high traffic volume on the road helped in increasing road surface deterioration.

4.4 COMPONENTS ANALYSIS OF EXTRACTED BITUMENS

Table 4.1 presents a summary of the component analysis of the extracted asphalt cement samples together with test

results on asphalt cement samples secured from the Eastern Desert region*, and the western region (refinery and contractor samples)**. Detailed information regarding these data are presented in Appendix D.

Table 4.1 indicates that:

1) The wax content in asphalt cements obtained from Western Desert crudes is relatively high;

2) The wax content in the extracted asphalt cement samples for the three roadway links is different. The lowest wax content is in Banha-El Bagour samples and the highest in Malatia-Abu Korkas samples; and

3) The asphaltene content in the extracted samples is higher than in the original western region asphalt cements. This is due to the aging and hardening that took place in the roadway samples.

The percentage of wax in the oil fraction and the percentage of asphaltene in the resinous fraction appear to provide promising indices to characterize asphalt cement performance. Figures D1 and D2 in Appendix D correlating these two indices to viscosity indicate that asphalt cements derived from Western Desert crudes are very different from Eastern crudes.

---

* "Asphalt Project," Petroleum Research Institute, Academy of Scientific Research, Cairo, Egypt, 1980.

** "Performance of Paraffinic-Waxy Asphalt Cements in Egyptian Road Construction," Vol. 2, CU/MIT Technological Planning Program, TAP Report 80-5, Cairo University, 1980.

Table 4.1 - Summary of Component Analysis Test Data*

	Source of Asphalt Cement Samples	No. of Samples	Range of Test Results					
			Wax,%	Oil,%	Resin,%	Asphaltene, %	Wax in oil fraction,%	Asphaltene in resinous fraction,%
Eastern Desert Crude	Refinery Samples	26	3.9-5.9	22-29	47-54	22-29	15-26	27-38
Western Desert	Refinery Samples	24	5.9-8.0	25-32	46-61	14-20	22-29	18-28
	Contractor Samples (surface)**	9	5.7-7.3	24-28	55-61	12-18	22-28	17-25
	Contractor Sample (middle)**	5	5.2-6.2	24-27	56-62	12-18	20-25	17-26
	Banha-El Bagour Road	8	4.2-5.3	20-26	41-49	27-39	18-22	35-48
	Cairo-Alex. Desert Road (first section)	10	4.7-7.0	23-33	36-48	29-35	18-30	38-49
	(second section)	2	4.7-4.9	28-30	36-39	33	17	46-48
	Malatia-Abu Korkas Road	5	6.3-8.3	23-32	38-44	30-34	25-33	40-45

* See Appendix D

** of storage barrel

CHAPTER 5

SUMMARY AND CONCLUSIONS

This report presents the results of a field and laboratory evaluation of selected roadway test sections constructed and/or overlayed by means of Egyptian paraffinic waxy asphalt cements derived from Western Desert crudes. The following describes the main findings of the study.

1) The asphalt content in most of the samples secured from the three study links exceeds design values. This is probably due to the fact that samples were generally selected in areas where high bleeding took place.

2) The physical and chemical properties of the extracted asphalt cement samples showed significant non-homogeneities and a high wax content.

3) The effects of high wax content on pavement structure performance are obscured by several factors including:

a) Design implementation.

b) Material properties.

c) Asphalt cement properties and its homogeneity.

d) Environmental conditions.

e) Traffic.

All these factors are believed to have contributed to the observed performance of the roadway links. Table 5-1 presents a summary evaluation of the study sections.

4) The most important factors that affected the performance of Banha-El Bagour Road are the design implementation, the non-homogeneity of the asphalt cement, and the relatively high wax content.

5) The first study section of Cairo-Alexandria Desert Road showed functional and structural failures. This can be attributed to the factors listed in Table 5-1, including poor environmental conditions, design implementation, poor subgrade soil, and the high wax content in the asphalt cement. The high traffic volume together with the large percentage of heavy vehicles using this section of the road expedited pavement deterioration.

6) The Malatia-Abu-Korkas road showed only functional failures. Non-homogeneity of asphalt cements, together with the very high wax content (6.3 - 8.3%), are the main factor contributing to the observed surface irregularities. In addition, heavy traffic is believed to have accelerated the surface deterioration of the pavement.

7) Based on the previous results, the study of the effects of using paraffinic-waxy asphalts on pavement performance requires a comprehensive field test to be conducted under controlled conditions where the other factors affecting performance (e.g. pavement components, environment, material properties, ... etc.) are carefully controlled.

Table 5.1 - Evaluation of the Study Roadway Test Sections

Roadway Link	Performance	Traffic Volume Rating	Heavy Vehicles Rating	Surrounding Environment	Wax Content	Pavement Layers Rating		
						Surface	Base	Subgrade
Banha-El-Bagour	F	Low	Medium	Fair	High	In.	adeq.	Poor
Cairo-Alex.Desert Road:.section 1	F + S	High	High	Poor	High	In.	In.	Poor
.section 2	F	High	medium	Fair	High	adeq.	adeq.	Good
Malatia-Abu-Korkas	F	High	Medium	Good	Very High	In.	adeq.	Good

(1) F = Functional Failures ; S = Structural Failures

(2) Relative to the accepted wax content limit of 2%.

(3) Rating is based on thickness and/or quality : adeq. = adequate thickness and quality; In. = Inadequate thickness or quality; Poor = Poor subgrade performance ; Good = Good subgrade performance.

Appendix A

Field Sampling and Testing Data

Banha-El-Bagour Road

Field Sampling and Testing Data

Roadway Name : Banha-El-Bagour

Study Section Length : 18 km.

1. General Road Data

I.1 Construction and/or Last Maintenance Data

Type of work : Construction

Starting Date : 4-9-1974

Completion Date: 11-27-1975.

I.2 Cross Section Data

Pavement Width	Shoulder Width	Shoulder Type
6 m	2 m	Unpaved

II. Materials Used in Design and their Properties

II.1 Material and Percent in Design Mix

Coarse Aggregate : 60% (35% size 1, 25% size 2), hard limestone.

Fine aggregate : 37% sand

Mineral Filter : 3 % limestone dust

Asphalt cement : 5.8% ($\pm$ 0.25%).

II.2.1 Mineral Aggregates

Type	Percent Wear (Los Angeles)		Bulk Sp. gr.	Bulk sp. gr. (SSD)	Apparent sp.gr.	Percent Absorption	Percent Disintegration
	After 100 rev.	After 500 rev.					
C.A.	5	23	2,537	2.587	2.671	2	0.2

II.2.2 Asphalt Cement

II.2.2.2.1 Asphalt Cement Employed in Mix Design

Penetration (100 gm. , 5 sec., 25°c), 0.1 cm = 82
Ductility (5 cm/min., 25°c), cm. = + 100
Softening point (ring-and-ball), °c = 48
Kinematic viscosity (135°c) c.st. = 360

II.2.2.2 Asphalt Cement Batches Received during Construction:

Sample No.& Date	Penetration 0.1 mm.	Ductility cm	Softening Point °c	Kinematic Viscosity (135°c)
1933 8/8/74	93	100+	44	156
1934 "	68	100+	47	306
1935 "	71	100+	48	349
1936 "	71	100+	47	197
1937 "	70	100+	47	209
322 2/19/75	81	100+	45.5	298
323 "	83	100+	45.5	298
324 "	84	100+	46	298
325 "	87	100+	46.5	296
326 "	87	100+	47	299
328 "	61	100+	47	400
329 "	75	100+	46.5	352
330 "	55	100+	48.0	465
331 "	83	100+	45.0	371
487 3/19/75	8k	100+	48.5	284
488 "	83	100+	48.5	284
489 "	82	100+	48	360
490 "	81	100+	48.5	306
491 "	81	100+	48	304
492 "	76	100+	49.5	354
493 "	80	100+	48	283
494 "	60	100+	50.5	395
1420 7/15/75	70	100+	49	-
1421 "	57	100+	46.5	
1577 7/31/75	70	100+	50.5	-
1578 "	70	100+	51	-

III. Design Mix Properties

Stability, Ib	Flow 0.01	Unit Weight	% air voids	% VMA
2500	11	2.332 t/m^3	4%	-

IV. Sampling Locations and Description (starting from El-Bagour)

Sample No.	Sample Location (km) L.	C.L.	R.	Description of Pavement	Actual Thickness of Pavement Components (cm) Surface	Base
1			2.50	Heavy bleeding with corrugations	5.5	25 cm
2		13.00		heavy bleeding	5.5	10 cm
3	13.00			Surface is in a good condition	5.5	32.5
4			14.50	Heavy bleeding	5.0	22.5
5		16.00		Heavy bleeding	5.8	24.7
6	16.00			Surface is in a good condition with slight bleeding	6.0	20
7		17.80		Heavy bleeding with creep towards right shoulder	7.2 9.6	20
8	17.80			A good section with slight bleeding	6.3	22.7

V. Test Results

V.1 Surface Course Materials

V.1.1. Extraction Test Results

Sieve Size	Sample No.	1	2	3	4	5	6	7	8	Sp.lim. (4c)	Design Grad.
1"		100	100	100	100	100	100	100	100	100	100
3/4"		100	100	99	99	98	99	99	100	100	98.3
1/2"		88	34	33	32	32	81	81	84	80/100	-
3/8"		77	73	74	74	72	73	72	76	60/80	60.6
#4		66	58	58	60	57	56	63	66	48/65	43.5
#8		56	43	48	49	47	45	50	56	35/50	41.0
#30		34	29	29	28	29	26	31	37	19/30	33.5
#50		17	14	16	14	15	12	16	20	13/23	23.7
#100		9	8	8	7	8	5	9	11	7/15	9.5
#200		4.6	4.8	5.2	4.2	5.4	3.1	4.8	6.9	3/8	4.8
Asphalt (A.W.B.) Content		7.92	8.26	6.1	7.75	8.27	5.98	7.55	6.4		

V.1.2. Properties of Extracted Asphalt Cements

Sample No.	1	2	3	4	5	6	7	8
1. Physical								
Penetration	57	55	28	38	40	42	37	20
Ductility	150	105	14	50	29	24	19	2
Kinematic Viscosity	483	556	1224	861	864	831	934	3686
2. Chemical								
Wax content,%	4.66	4.91	4.6	4.73	4.44	5.3	5.3	4.22
Asphaltene Content,%	22.57	28.98	21.50	26.42	31.32	31.56	29.76	38.71
Resin Content,%	47.55	45.93	45.19	48.89	45.09	42.36	44.32	41.33
Oil Content, %	24.66	24.35	25.20	25.15	24.57	25.77	25.25	19.92

V.2 Base Course Materials

Sieve Size / Sample No.	1	2	3	4	5	6	7	8	Spc. Lim.
3"	-	100	100	100	100	100	100	100	100
2.5"	-	98	100	100	95	95	98	98	100
2"	-	97	98	99	92	91	96	96	100
1.5"	-	90	93	91	82	81	90	88	70/100
1"	-	83	85	79	73	69	78	79	55/85
3/4"	-	79	74	71	67	61	67	73	50/80
3/8"	-	66	59	60	51	43	45	58	40/70
#4	-	51	54	46	34	30	30	40	30/60
#10	-	42	24	37	27	25	23	30	20/50
#40	-	20	19	18	14	11	12	14	10/30
#200	-	8.8	5.9	7.4	5.4	4.6	5	5.6	5/15
L.L.		-	30	35	35	30	28	30	≯ 34
P.I.		-	11	8	10	8	11	11	≯ 11

V.3 Subgrade Soil

Sieve Size / Sample No.	1	2	3	4	5	6	7	8
#4	-	100	100	100	100	100	100	100
#10	-	99	99	99	99	98	98	100
#40	-	95	96	95	99	93	92	94
#200	-	82	83	83	83	79	75	84
L.L.	-	48	52	62	55	59	54	62
P.I.	-	22	25	33	33	33	29	37
AASHO Classification	-	A-7-6	A-7-6	A-7-6	A-7-6	A-7-6	A-7-6	A-7-6

Appendix B

Field Sampling and Testing Data

Cairo-Alexandria Desert Road

Field Sampling and Testing Data

Roadway Name: Cairo Alexandria Desert Road

Study Section Length: 85 km (starting from Alex)

1. General Road Data

1.1 Construction and/or Last Maintenance Data

Type of Work: Maintenance

Description : Improving, modifying, widening, and enforcing.

Starting Date: 12/4/1971

Completion Date: 7/25/1973

1.2 Cross-Section Data

Pavement Width	Shoulder Width	Shoulder Type
7.5 m	3 m	Unpaved

II. Materials Used in Design and their Properties

II.1 Material and Percent in Design Mix

Coarse aggregate: 70% Hard limestone 40% Size 1 30% Size 2

Fine aggregate: 25% sand

Mineral filler: 5% limestone dust

Asphalt cement: 6.15 - 6.4

II.2 Material Properties

II.2.1 Mineral Aggregates

Type	Percent Wear (Los Angeles)		Bulk sp. gr.	Bulk sp. gr.(SSD)	Apparent sp.gr.	% Absorp-tion	% Disinte-gration
	After 100 rev.	After 500 rev.					
C.A.	2.5	20	2.5 ⁄3	2.587	2.66	1.7	-

II.2.2 Asphalt Cement

II.2.2.1 Asphalt Cement Employed in Mix Design

Not available

II.2.2.2 Asphalt Cement Batches Received during Construction/Maintenance

Not available

III. Design Mix Properties

Stability, lb	Flow 0.01"	Unit weight	Percent air voids	Percent VMA
1820	13.5	-	4.7%	-

IV. Sampling Locations and Description (starting from Alex.)

	Sample No.	Sample Location (Km.) L	C.L.	R	Description of Pavement surface	Actual Thickness of Pavements Components (cm) Surface	Binder	Base
FIRST SECTION	1			52.50	Light bleeding and medium corrugation	4.5cm	9.0cm	20cm
	2	52.490			Heavy bleeding and corrugation	5.5	8.2	12.3
	3			51.700	Light bleeding and corrugation with longitudinal cracks	5	8.7	15
	4			51.680	" "	5	8	15
	5			49.000	Large thickness of asphalt(18cm) due to squeezing and creep towards the edge.	-	-	-
	6			49.010	Heavy bleeding and corrugation	9	6.5	11
	7			49.020	Light bleeding and corrugation with longitudinal cracks	8.2	7	10
	8.	44.[illegible]0			Light bleeding in the tires path.	4.8	5.5	27.7
	9	39.100			Heavy bleeding between tires path with a groove in the tires path.	5.1	4.9	29
	10			39.100	Good section	4.3	3.8	28.9
Second Section	11.	140.00			Good section	4.9	4.8	27.3
	12.			140.00	Good section	5	4	29

V. Test Results

V.1. Surface Course Materials

V.1.1 Extraction Test Results

Sieve Size / Sample No.	1	2	3	4	5	6	7	8	9	10	11	12	Spec. lim.	Design gradation
1"	100	100	100	100	100	100	100	100	100	100	100	100	100	99.7
3/4"	99	98	100	99	100	100	99	98	95	100	100	98	100	99.1
1/2"	89	80	87	86	84	85	86	84	83	92	90	92	80/100	-
3/8"	81	68	75	80	69	74	74	73	77	85	80	83	60/80	73.6
# 4	59	52	57	61	51	56	61	57	59	65	67	67	48/65	48.9
# 8	45	45	45	49	40	44	50	45	46	50	53	55	35/50	41.8
# 30	29	30	29	31	25	28	32	29	30	30	34	34	19/30	30.1
# 50	19	18	20	21	15	19	19	18	19	19	15	15	13/23	22.1
# 100	10	8	12	12	8	11	9	10	11	9	6	7	7/15	13.9
# 200	4.72	3.38	5.78	5.27	3.56	4.32	3.35	4.7	5.4	4.3	3.2	3.7	3/8	7.9
Asphalt (A.W.B.) Content	6.53	6.18	6.96	7.82	7.13	8.36	7.15	7.13	7	6.19	6.64	6.07		

V.1.2. Properties of Extracted Asphalt Cements

Sample No.	1	2	3	4	5	6	7	8	9	10	11	12
1. Physical												
Penetration	33	52	50	59	34	37	49	43	43	37	21	22
Ductility	11.5	73	150+	150+	82	35	72	150+	150+	50	2	4
Kinematic viscosity	662	493	454	496	730	746	482	679	675	883	1620	1211
2. Chemical												
Wax content, %	6.08	6.24	6.0	4.69	5.83	4.79	4.76	6.25	7.05	5.16	4.93	4.79
Asphaltene content,%	33.72	32.44	28.79	32.63	34.34	35.07	33.22	32.07	28.27	31.05	33.74	32.78
Resin content,%	35.47	39.37	38.38	40.73	39.48	41.9	41.85	44.3	47.85	43	36.23	39.08
Oil content,%	30.63	28.12	32.74	26.48	26.10	22.69	24.5	23.61	23.19	25.86	29.73	28.07

V.2 Base Course Materials

Sieve Size / Sample No.	1	2	3	4	5	6	7	8	9	10	11	12	Spec. Lim.
2"	100	100	100	100		99	100	100	100	100	100	100	100
1.5"	98	100	100	100		94	100	97	100	100	95	97	70/100
1"	92	80	96	95		84	93	88	97	97	85	87	55/85
3/4"	83	75	82	82		73	79	73	90	91	77	76	50/80
3/8"	49	43	50	51		46	44	55	69	65	65	65	40/70
# 4	33	36	38	29		35	26	37	44	35	55	57	30/60
#10	24	29	36	25		33	22	34	37	31	46	47	20/50
#40	20	36	33	21		31	21	29	33	27	23	24	10/30
#200	15	21	26	13		23	15	18	23	18	9	9	5/15
Percent wear in Los Angeles Test (500 revs.)	50	-	48	53		77	47	32	32		Gravel Base		≯ 50
L.L.	27	25	34	28		26	26	30	32		----	----	≯ 30
P.I.	10	9	12	6		10	11	6	9		NP	NP	≯ 8

V.3 Subgrade Soil

Sieve Size	Sample No.	1	2	3	4	5	6	7	8	9	10	11	12
#4		100	100	100	100		100	100	95	87	95	90	93
#10		87	81	60	91		96	92	92	82	88	80	86
#40		79	69	51	81		91	87	85	72	77	47	51
#200		63	45	39	69		73	63	65	56	60	13	18
L.L.		30	26	33	35		24	22	29	30	28	---	---
P.I.		14	5	12	17		12	6	11	12	16	NP	NP
AASHO Classification		A-6	A-4	A-6	A-6		A-6	A-4	A-6	A-6	A-6	A-1-b	A-2-4

Appendix C

Field Sampling and Testing Data

Malatia-Abu Korkas Road

Field Sampling and Testing Data

Roadway name : Malatia - Abu Korkas

Study Section Length, 100 Km.

1. General Road Data

1.1 Construction and/or Last Maintenance Data

Type of work : Maintenance and Widening

Starting date: 12/20/1969

Completion date: 3/13/1974

1.2 Cross-Section Data

Pavement width	Shoulder width	Shoulder type
7.5 m.	3.00	unpaved

II. Materials Used in Design and their Properties

II.1. Material and Percent in Design Mix

		Samalot	Bani Mazar
Coarse aggregate: crushed limestone	size 1	55%	25%
	size 2	15%	33%
Fine aggregate: Sand		25%	35%
Mineral filler: Limestone dust		5%	7%

Asphalt cement: 6%

II.2 Material Properties

II.2.1 Mineral Aggregates

Type Station	Percent Wear(Los Angeles) After 100 rev.	after 500 rev.	Bulk sp. gr.	Bulk sp. gr(SSD)	Apparent sp.gr.	% Absorption
C.A. Samalot	10	39.5	2.139	2.408	2.544	3.8
C.A. Bani Mazar	7.3	31	2.452	2.525	2.645	3.0

II. 2.2 Asphalt Cement

II.2.2.1 Asphalt Cement Employed in Mix Design

(No Records)

II.2.2.2. Asphalt Cement Batches Received During Construction/Maintenance

Sample No. & date	Penetration 0.1 mm	Ductility cm	Softening point oC	Kinematic Viscosity c.st.
248) 16/12/72	81	100+	45.5	-
285) "	91	100+	44.5	-
488) 1/4/73	111	100+	44.5	-
490) 1/4/73	116	100+	43.5	-
632) 16/4/73	95	100+	42	-
633) 16/4/73	120	100+	41	-

III. Design Mix Properties

(not available)

IV. Sampling Locations and Description (starting from Malatia)

Sample No.	Sample Location (km)			Description of Pavement surface	Actual Thickness of pavement Components (cm)				
	L.	C.L.	R.		AC	Binder	Old AC	PM	Base
1	21			Heavy bleeding, transverse corrugations	5	5	4	8	20*
2			35	" "	3.5	4.5	3.5	2.5	23*
3	64			" "	45	3	2.5	4	27**
4	64			Pavement surface in good condition	5.5	4.5	7	8	27**
5			88	Heavy bleeding, transverse corrugation	5.5	5.5	4	7	27**

AC = Asphalt Cement surface

PM = Permix Macadam

* Crushed limestone

** Limestone blocks

V. Test Results

V.1 Surface Course Materials

V.1.1 Extraxtion Test Results

Sieve Size / Sample No.	1	2	3	4	5	Spec. lim.	Design Grad.
1"	100	100	100	100	100	100	100
3/4"	100	100	99	99	100	100	97.6
1/2"	94	86	92	89	99	80/100	-
3/8"	88	79	84	82	91	60/80	78.26
# 4	69	64	66	66	75	48/65	50.59
# 8	52	52	51	46	61	35/50	46.26
# 30	29	37	38	42	49	19/30	26.29
# 50	14	16	19	15	34	13/23	14.86
# 100	6	8	10	6	11	7/15	8.36
# 200	3.52	3.99	4.42	3.13	5.11	3/8	5.36
Asphalt (A.W.B.) Content	6.69	7.07	7.61	5.84	7.94		

V.1.2. Properties of Extracted Asphalt Cements

Sample No.	1	2	3	4	5
1. Physical					
Penetration	30	34	44	30	39
Ductility	5	7	27	10.5	93
Kinematic viscosity	768	802	852	1045	515
2. Chemical					
Wax content,%	7.8	8.1	7.3	6.3	8.3
Asphaltene Content,%	30.01	31.30	32.10	30.06	29.90
Resin content,%	38.03	43.00	44.06	42.30	14.10
Oil content,%	31.6	25.6	23.3	23.4	25.5

V.2 Base Course Materials

Sieve Size	Sample No. 1	2	3	4	5	Spec. Lim.
3.0"	94	99	(limestone blocks)	(limestone blocks)	(limestone blocks)	100
2.5"	82	90				100
2.0"	74	95				100
1.5"	63	91				70/100
1"	48	82				55/85
3/4"	41	77				50/80
1/2"	34	69				-
3/8"	29	63				40/70
#4	23	49				30/60
#10	20	45				20/50
#40	16	27				10/30
#200	9.8	14.8				5/15
Percent wear in Los Angeles Test (500 revs.)	54	60	61	60	60	≯ 50
Percent absorption	6.2	8.4	12	9	10	≯ 10
Percent disintegration	2	4.52	2	2.2	2.1	≯ 5

V.3 Subgrade Soil

Sieve Size	Sample No. 1	2	3	4	5
#4	100	100	100		100
#10	85	88	82		90
#40	62	69	65		68
#200	20	24	20		18
L.L.					
P.I.	NP	NP	NP		NP
AASHO Classification	A-2-4	A-2-4	A-2-4		A-2-4

* NP = Non Plastic.

Appendix D

Component Analysis of Asphalt Cement Samples

Table D-1 Component Analysis of Alexandria Refinery Asphalt Cement Samples

Sample	Wax %	Oil %	Resin %	Asphaltene %	% wax in oil fraction	Asphaltene in resinous fraction
1	5.86	24.66	58.27	16.95	23.76	22.53
2	6.73	26.05	54.65	18.98	25.83	25.78
3	6.01	28.28	51.24	19.66	20.80	27.73
4	7.01	28.91	53.71	17.19	24.24	24.25
5	7.27	26.97	54.64	18.19	26.96	24.98
6	6.71	29.74	50.97	18.97	22.56	27.14
7	6.19	34.43	46.03	19.45	17.98	30.23
8	6.08	28.57	53.57	17.71	21.28	24.85
9	7.0	34.54	47.98	17.39	20.27	26.60
10	6.82	28.2	53.64	17.98	24.18	25.10
11	7.17	26.12	65.27	17.41	27.45	21.06
12	7.41	32.0	53.49	13.96	23.16	20.70
13	7.94	32.07	54.41	13.49	24.76	19.87
14	6.37	30.32	51.97	17.53	21.00	25.22
15	7.07	26.73	58.17	15.02	26.45	20.52
16	6.47	22.52	60.66	16.79	28.73	21.68
17	7.51	28.46	56.68	14.74	26.39	20.64
18	7.28	28.73	58.19	15.01	25.34	20.51
19	6.59	28.69	56.41	14.7	22.97	20.67
20	7.7[illegible]	31.81	53.03	15.01	24.21	22.06
21	7.24	28.0	56.78	15.19	25.86	21.11
22	7.13	29.56	55.63	14.79	24.12	21.00
23	6.79	26.79	58.82	14.38	25.35	19.64
24	6.86	28.36	58.17	13.45	24.19	18.78

Source: "Performance of Paraffinic-waxy Asphalt Cements in Egyptian Road Construction," Vol. 2, CU/MIT Technological Planning Program, TAP Report 80-5, Cairo University, 1980.

Table D-2 : Component Analysis of Wester Region Asphalt Cement Samples (secured from contractors)

Position	Sample No.	Wax %	Oil %	Resins %	Asphaltene %	Wax in oil fraction %	Asphaltene in resinous fraction, %
Surface	1-	6.00	23.9	60.84	15.22	25.10	20.01
	2	6.12	25.79	57.90	16.19	23.73	21.85
	3	6.21	27.88	59.74	12.12	22.27	16.87
	4	7.34	26.04	60.44	13.08	28.19	17.79
	5	5.97	26.74	54.70	18.30	22.33	25.07
	6	6.46	27.29	57.97	14.63	23.67	20.13
	7	5.73	25.56	56.31	18.05	22.42	24.27
	8	6.12	27.20	57.21	15.53	22.50	21.35
	9	6.14	23.97	56.52	19.06	25.62	25.22
Middle	1	6.14	26.05	61.35	12.37	23.57	16.78
	2	5.88	25.27	61.12	13.21	23.27	17.77
	3	5.31	26.48	59.90	13.50	20.05	18.39
	4	5.65	23.84	60.42	15.62	23.7	20.54
	5	5.23	25.32	61.55	12.78	20.66	17.19
	6	5.95	24.34	58.92	16.46	24.45	21.84
	7	5.48	23.29	58.39	18.23	23.59	23.79
	8	5.36	26.26	55.83	17.42	20.41	23.78
	9	5.28	26.65	55.65	17.62	19.81	24.05

Source : See Table D-1

Table D-3: Component Analysis of Eastern Region Asphalt Cement Samples

Sample No.	Wax, %	Oil, %	Resin, %	Asphaltene,%	Wax in Oil fraction,%	Asphaltene in resinous fraction
1	4.73	28.64	49.8	21.46	16.52	30.11
2	5.34	25.87	49.44	24.57	20.64	33.2
3	3.91	21.96	49.35	28.49	17.81	36.60
4	3.92	26.16	49.18	24.57	14.98	33.32
5	4.58	26.72	48.18	24.75	17.14	33.94
6	5.31	27.44	50.61	21.93	19.35	30.23
7	5.79	22.25	48.98	28.75	26.02	37.00
8	5.33	24.20	33.13	22.66	22.02	29.90
9	5.91	24.84	51.13	24.02	23.79	31.96
10	3.87	25.99	49.75	24.24	14.89	32.76
11	4.90	26.82	49.81	23.39	18.27	31.91
12	4.99	23.60	55.62	20.75	21.14	27.17
13	5.37	25.22	52.52	22.01	21.29	29.53
14	4.87	26.26	47.36	26.37	18.55	35.77
15	5.11	24.15	53.58	22.18	21.16	29.29
16	5.20	23.77	52.83	23.38	21.88	30.68
17	5.18	24.63	50.84	23.68	21.03	31.78
18	5.24	24.95	49.95	24.98	21.0	33.34
19	4.72	23.43	51.65	24.81	20.15	32.49
20	4.84	21.95	54.42	23.54	22.05	30.19
21	4.54	22.63	53.14	23.46	20.06	30.63
22	4.20	22.36	53.43	24.09	18.78	31.08
23	5.24	22.49	52.24	25.13	23.3	32.48
24	5.37	22.96	53.02	23.96	23.39	31.11
25	4.48	25.70	49.71	24.49	17.43	33.00
26	5.61	28.99	46.66	24.27	19.35	34.22

Source: "Asphalt Project," Petroleum Research Institute, Academy of Science and Technology, 1980.

Table D-4: Component Analysis of the Extracted Asphalt Cement Samples

Roadway link	Sample	Wax, %	Oil, %	Resins, %	Asphaltene,%	Wax in oil fraction	Asphaltene in resinous fraction
Cairo-Alex Desert Road	1	6.08	30.63	35.47	33.72	19.85	48.74
	2	6.24	28.12	39.37	32.44	22.19	45.17
	3	6.0	32.74	38.38	28.79	18.33	42.86
	4	4.69	26.48	40.73	32.63	17.71	44.48
	5	5.83	25.40	39.48	34.34	22.34	46.52
	6	4.79	22.69	41.9	35.07	21.11	45.56
	7	4.76	24.58	41.85	33.22	19.42	44.25
Banha-El Bagour	1	4.66	24.66	47.55	27.57	18.90	36.70
	2	4.91	24.35	45.93	28.98	20.16	38.69
	3	4.60	25.20	45.19	29.50	18.25	39.50
	4	4.73	25.15	48.89	26.44	18.81	35.10
	5	4.44	24.57	45.09	31.32	18.10	41.00
	6	5.30	25.77	42.36	31.56	20.57	42.69
	7	5.30	25.25	44.32	29.76	21.00	40.17
	8	4.22	19.92	41.33	38.71	21.18	48.36
Malatia-Abu Korkas	1	7.8	31.6	38.03	30.01	24.68	44.11
	2	8.1	25.6	43.00	31.30	31.64	42.13
	3	7.3	23.3	44.06	32.10	31.33	42.15
	4	6.3	23.4	42.30	34.06	26.92	44.60
	5	8.3	25.5	44.10	29.90	32.55	40.41

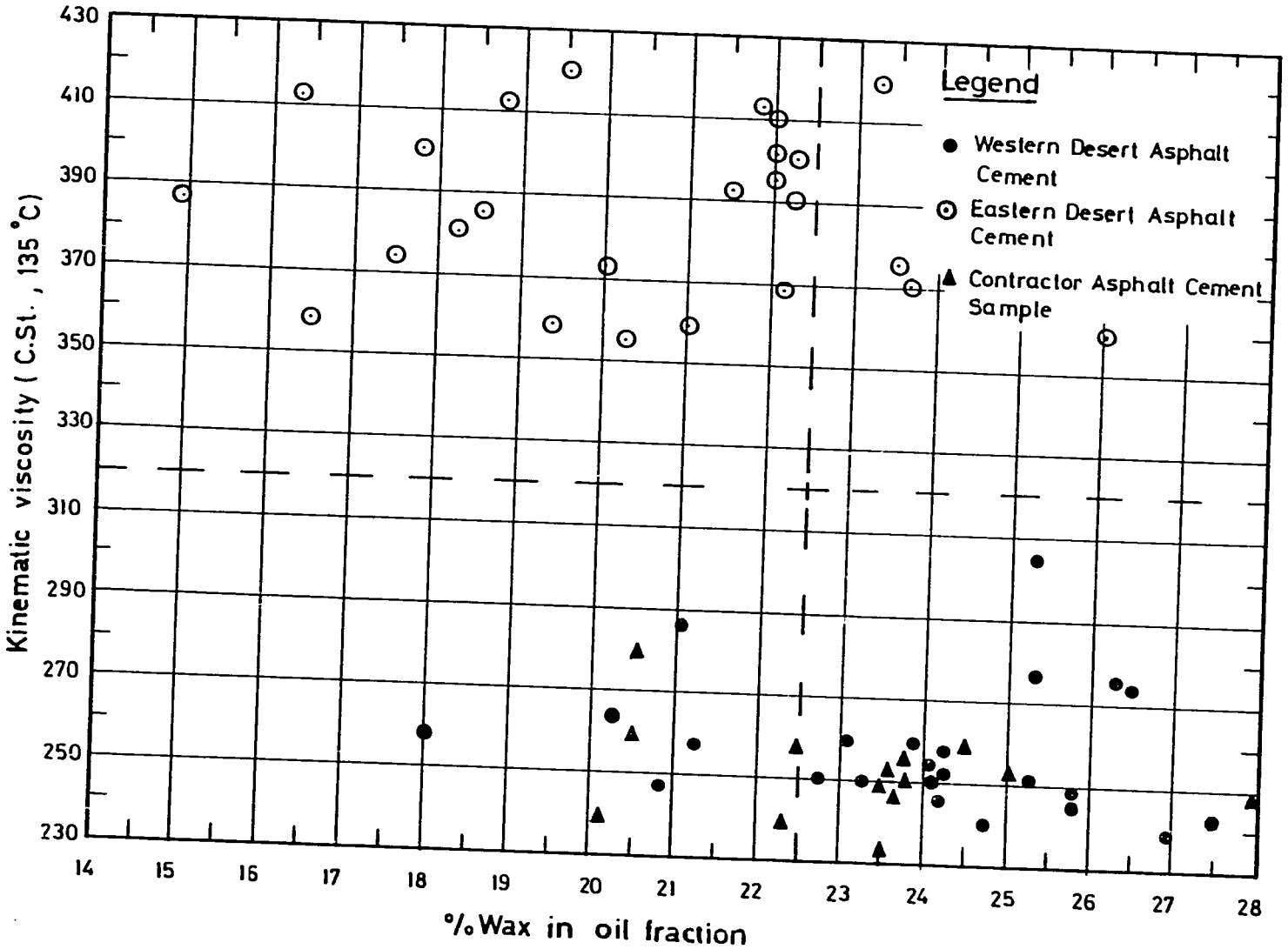


Figure D1, Percent wax in oil fraction VS. Kinematic viscosity for different asphalt cement sources

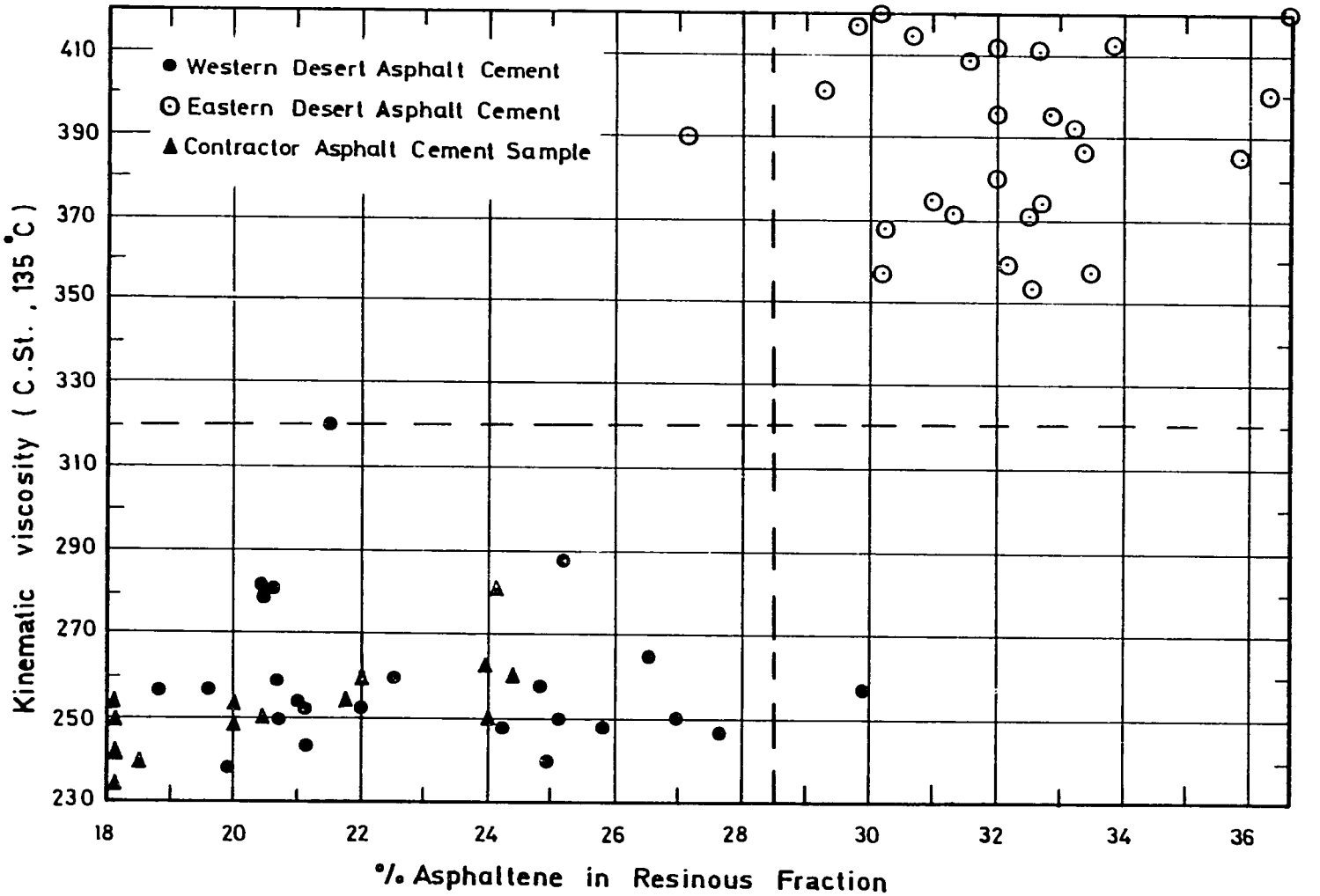


Figure D2, Percent Asphaltene in Resinous Fraction VS. Kinematic viscosity for different asphalt cement sources