A STUDY OF OREGON'S SURFACING DESIGN PROCEDURES

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ABSTRACT

This study of the Oregon State Highway Division's surfacing design procedures was undertaken to determine if the expected service is being obtained from current design practices, and to provide an economic comparison of different design alternatives to permit an optimum strategy to be selected. The economic analysis included full depth and staged construction alternatives for both 20 year and 10 year designs.

An analysis of deflection measurements taken for this study indicate that the predicted pavement performance is being achieved; however, none of the projects are old enough to confirm the performance through the entire design life. There was some spread in the results, indicating some pavement performed better and some not as well as anticipated. The projects studied also showed that cracking and patching start to occur at the age the second stage overlay was expected to be needed.

The economic analysis of surfacing design alternatives indicated that a 20 year design life with the entire depth placed initially has the lowest total cost of the alternatives studied. The total cost over a 20 year period for a full depth 20 year design is about 20 percent lower than the cost for a 10 year full depth design, and about 4 percent lower than the cost of a 20 year design with 2 inches delayed and placed when required. The analysis included an example of the affects of the alternatives on the backlog of poor pavements which indicated that for a 20 year period, the 20 year stage constructed design life would result in the lowest backlog.

INTRODUCTION

During the past several months several questions have arisen concerning Oregon's surfacing design procedures, and also about the state's pavement management system.

Most of the questions were raised by the Federal Highway Administration in their report Review of Oregon's Pavement Management System. This review was conducted by FHWA personnel during June of 1978, with the report being issued on October 6, 1978. Some of the questions raised by FHWA have also been asked in two study reports by the Oregon Department of Transportation's Policy and Program Development Branch.

The Research Unit, in cooperation with the Surfacing Design Group and Policy and Program Development, made a study in an attempt to answer these questions. This study, as reported in this paper, was intended to:

1) Analyze ODOT's current surfacing design procedures to determine if the department is getting the full design life from its projects.
2) Make an economic analysis of various surfacing design life alternatives.
3) Analyze the effects of various surfacing design life alternatives on Oregon's highway system.

HISTORY

Design Procedure

Oregon has been using a modification of the California Division of Highways' surfacing design procedures for it's projects since 1951. The modifications were made to fit Oregon's climatic, traffic, and soil conditions.

This method is based on empirical relationships developed from test roads and observed pavement performance of various sections of highway under traffic. The basis of the design procedure is the existing surface strength and traffic volume. The existing surface for new construction is the subgrade and for overlays is the existing road surface. Traffic is represented by the number of equivalent 5,000 lb wheel loads expected to be applied during the design life of the pavement.

The end of the design life or design period used in Oregon's design procedure is the time at which the accumulated traffic loadings have caused the surfacing to deteriorate to a minimum acceptable service level. The consensus of opinion applied in this study was that the minimum level of service incorporated into Oregon's design system equates, for average traffic, to a 4 inch overlay to provide a second 20 year service period and to a 2.5 inch overlay to provide a second 10 year service period. The end of the design life or the time at which the pavement reaches the minimum service level is also identified by an accelerating level of surface maintenance. The interpretation is that the condition of a highway at the end of its design life, if designed according to current practice, will usually be better than existed at the time of the original rehabilitation; thus, less thickness is required for successive overlays.

Since ODOT implemented the California surfacing design procedure various design periods have been used. On most Interstate Freeway projects the department has designed for a 20 year period with the full depth of surfacing called for in the design being placed initially. On Primary and Secondary Highways the 20 year design placed full depth was used until the early 1960's. From that time until 1975, ODOT used a 20 year design with two inches of A.C.

being withheld for future application. From 1975 to the present, Oregon has used a 10 year design with part of the C.B.E. requirement withheld for future application. In many of the 10 year designs, the first stage has been a 1.5 inch lift of open graded A.C. with the remainder of the C.B.E. requirement shown as a future application.

There have been approximately 200 projects constructed with a staged surfacing design on Oregon highways since 1964. In designs such as this, the final stage must be applied before the pavement shows significant distress. If this is not done a thicker overlay than originally called for will be required to carry the pavement through to the end of its intended life. However, it should be noted that the current Six Year Plan does not allow for the final application on any of the stage constructed pavements.

Contract Projects

The present condition of Oregon highway pavements is largely due to efforts at constructing, re-constructing, or overlaying these pavements. Below is a table of mileages of pavement projects completed during the fiscal years of 1975, 1976, and 1977. These projects were completed under formal contracts with the data shown being taken from ODOT's Annual Report for each of these years.

Table 1. PAVEMENT PROJECTS COMPLETED

	INTERSTATE (miles)		PRIMARY & SECONDARY (miles)		
Fiscal Year	New Construction or Re-Construction	Overlay	New Construction or Re-Construction	Overlay	Total Miles
1975	34	23	47	52	156
1976	0	76	31	136	243
1977	18	136	27	49	230

During these three fiscal years, 33 miles of Portland Cement Concrete pavement were completed on the Interstate System, and 11 miles of oil mat surfacing were accomplished on Primary and Secondary Highways.

Information provided by the Construction Section of the Highway Division shows the tonnages of asphalt concrete placed under contracts over the last eight calendar years have ranged from a low of 1.01 million tons in 1969 to a high of 3.20 million tons in 1975. The average yearly tonnage placed during that period was 2.04 million tons. In 1977, 1.35 million tons were placed. The number of projects during those years ranged from a low of 60 projects in 1969, to a high of 134 projects in 1975.

Maintenance

In looking at Oregon's Highways and the factors influencing their present condition, maintenance efforts must also be considered. Following is a chart showing the tons of asphalt concrete placed by state forces and the amount placed under contracts financed with maintenance funds.

Table 2. MAINTENANCE ASPHALT CONCRETE TONNAGES

Calendar Year	A.C. Placed By State Maintenance Crews (tons)	A.C. Placed Under General Services Contracts (tons)
1977	283,151	70,539
1976	292,793	1,330
1975	405,627	108,034
1974	275,399	1,925
1973	482,110	112,250
1972	429,372	23,044
1971	468,211	65,817
1970	554,449	72,550
1969	520,625	45,675
1968	317,031	---

State forces place the asphalt concrete under their patching program. Most of this mix is placed with graders and generally is one to two inches thick.

Most of the asphalt concrete under General Services contracts has been placed at the end of a biennium when there has been a projected surplus in the maintenance fund. This tonnage is generally machine placed in a two inch thick overlay.

A general downward trend in the amount of A.C. placed with maintenance funds is indicated by the previous data. This is attributed to the assumption that funds available, and not highway condition, dictates the amount of asphalt concrete to be placed.

DATA COLLECTION

Selection

As indicated before, there have been approximately 200 projects constructed in Oregon with a stage construction surfacing design. These projects were identified through an extensive effort made earlier this year by the Surfacing Design Group. A sampling of these 200 projects were chosen for use in this study. An effort was made to include projects from the entire period. Both new construction and overlay projects were used, and a geographical spread in the projects was attempted. Because the principal means of analyzing the existing condition of the sample projects was by deflection tests, an effort was made to group projects in areas where several projects could be tested without an undue amount of travel between projects. A sampling of 76 projects was used.

Benkleman Beam deflection measurements were obtained by the Surfacing Design Group on 69 projects during Summer, 1978. These deflection values were used not only for this study but also for work being done by the Operation Planning Section. In addition to the 69 projects deflected this summer, another 26 measurements taken previously were used in the study. These projects had post-construction deflections taken during the last two or three years. A few of the projects had two or three post-construction deflection measurements.

Collection

After the projects comprising the sample were selected, the Research Unit reviewed the surfacing design file for each project and tabulated the length, width, surfacing design used, year completed, and the basic design data for each project. The basic surfacing design data consisted of the subgrade "R" values for new construction and deflections for overlays, plus estimates of the equivalent 5,000 lb wheel load applications expected to be applied during the design period for the pavement.

Updated traffic estimates were provided by the Traffic Unit for 38 of the projects to obtain an indication of the accuracy of earlier forecasts. The new estimates were provided by projecting physical counts of trucks taken during 1976.

ANALYSIS

Design Procedure

The method used to analyze the design procedure was to work through a stage constructed design to find the theoretical life of the first stage, and then to verify the actual performance three ways; through initial deflections, historical deflection data, and by finding the point at which the pavement performance would begin to deteriorate rapidly if a surface treatment was not applied.

To determine the theoretical life of the first stage of a stage constructed project, a typical full depth design was developed. The "R" value and traffic coefficient for this design were found by averaging those used in a large number of projects. After the full depth design was developed, the typical second stage of two inches of A.C. were removed, and the design procedure was reversed to determine the maximum traffic coefficient this design would accept. These calculations, presented on page 2 of the Appendix, indicate that the theoretical life for the first stage of a 20 year design is about 6½ years.

The first method of verifying the design procedure was to determine, using historical deflection data, the initial deflections immediately following the overlay. As can be seen from the plots (Figures 1 and 2) of deflection vs. time for both new construction and overlays, the least squares regression line indicates the initial deflection is within the range of the design tolerable deflection.

The second method of verification was to determine the time at which a two inch overlay is required to be placed on the first stage. Again, this was done using historical deflections (Figures 1 and 2). Although the regression lines on the overlay and new construction plots are not identical, the deflections in the 5 to 8 year period are virtually the same. This is the period used in this analysis. Since these plots represent a variety of job types, the line can be considered as the deflection curve for various jobs. By performing calculations (shown in the Appendix) to determine when two inches are needed for various traffic loadings, it is shown that this overlay is needed at 6½ years for the average traffic situation.

The third method of confirming the design procedure involved determining the point at which pavement performance would begin to deteriorate rapidly

FIG. 1

DEFLECTION
VS
YEARS OF SERVICE

20 YEAR DESIGN
NEW CONSTRUCTION

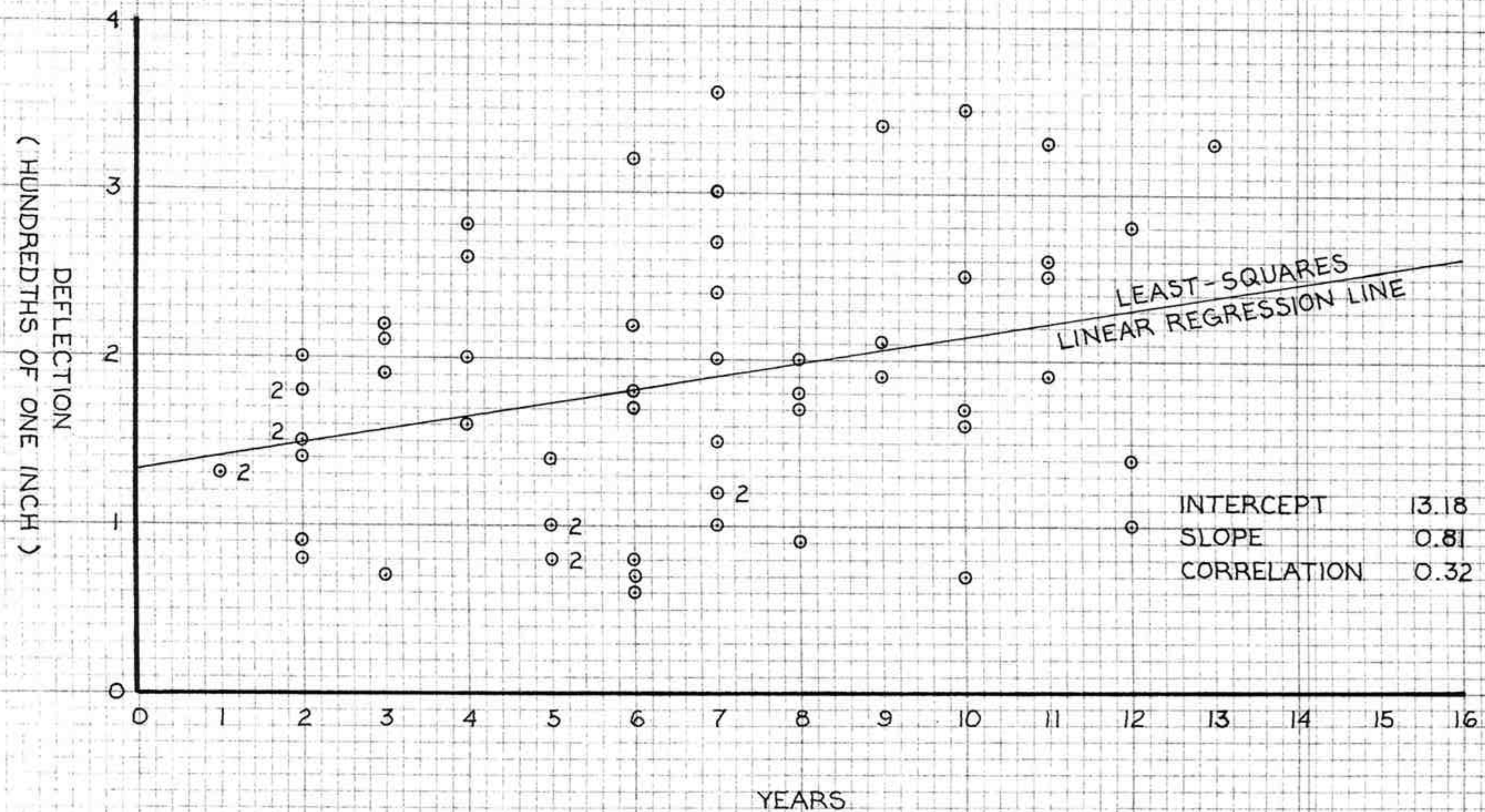
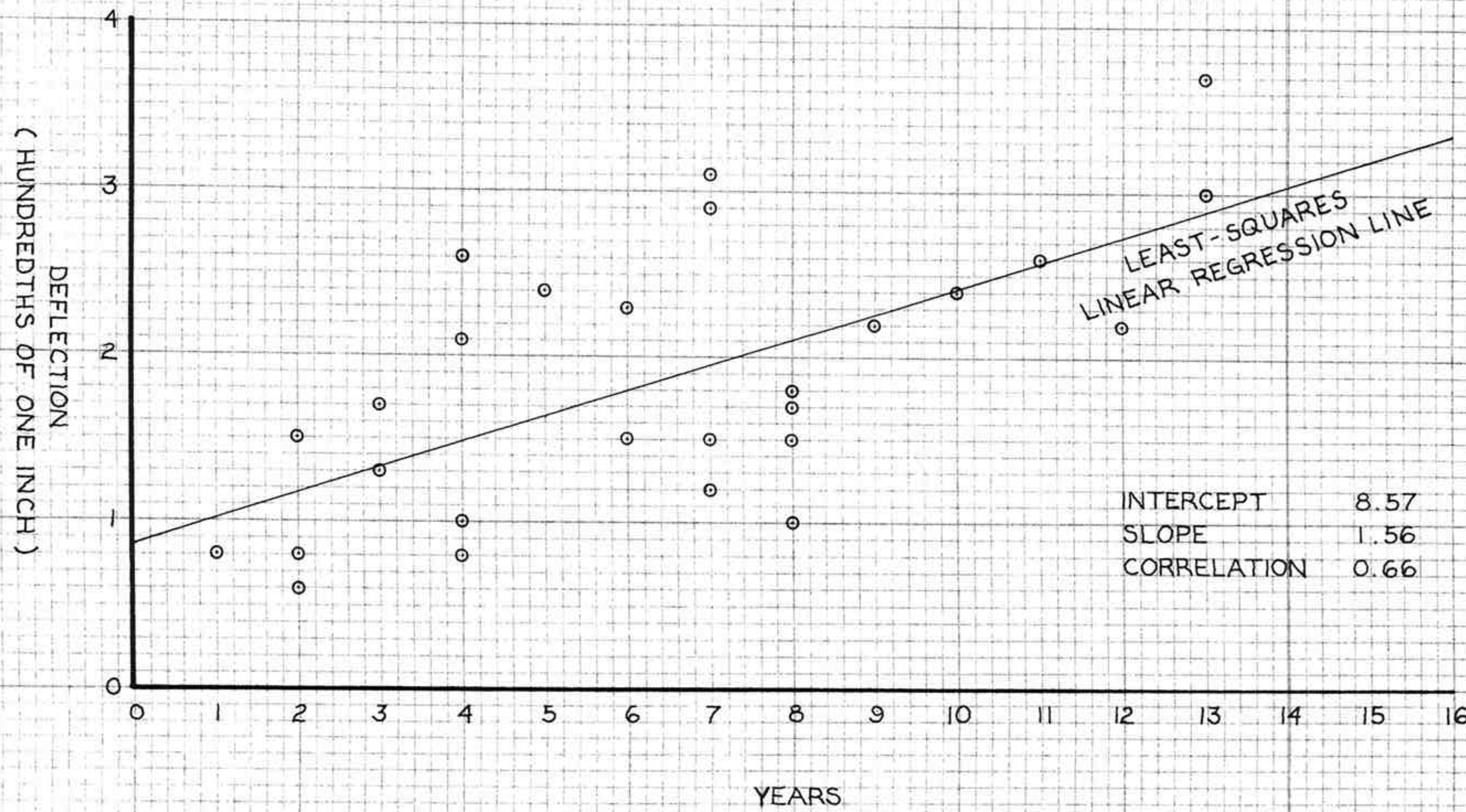


FIG. 2

DEFLECTION
VS
YEARS OF SERVICE

20 YEAR DESIGN
OVERLAY CONSTRUCTION



if some type of surface is not applied. This point occurs at the same time extensive maintenance begins. As can be seen from the plot (Figure 3) of cumulative percent patching, determined from the surface condition rating, vs. time, significant patching begins between 6 and 7 years after construction.

A theoretical life for the thin, flexible first stage of a 10 year stage constructed project could not be determined. Literature on this type of design is scarce, and it has been in use in Oregon only during the last 3 years so there is not enough historic data to develop any useful performance information. It is speculated that the thin flexible overlays used as the first stage will provide about four years of service life. Since a thin flexible overlay doesn't provide the stiffness to yield a significant reduction in deflection, but rather only a wearing surface and a seal, it is logical to assume that the deflections will increase fairly rapidly over a four year period. This rapid increase in deflection will dictate the need for a deeper overlay than originally required for the second stage. Since there was no data to determine what this increased depth would be, this analysis was based on the assumption that the 1½ inch first stage will require only the remainder of the initial full depth design as the second stage, and it will be placed at four years.

An analysis of traffic projections was made to assure that the factors used in the design procedure are accurate. To perform this analysis, data was plotted (Figure 4) showing the years since the pavement was placed vs. the accumulated wheel loads (expressed in years by: Accumulated Wheel Loads/Originally Projected Average Annual Wheel Loads) applied to the pavement since placement. From the plot it can be seen that the traffic projections are underestimated by only about one year in eight. This degree of accuracy

FIG. 3

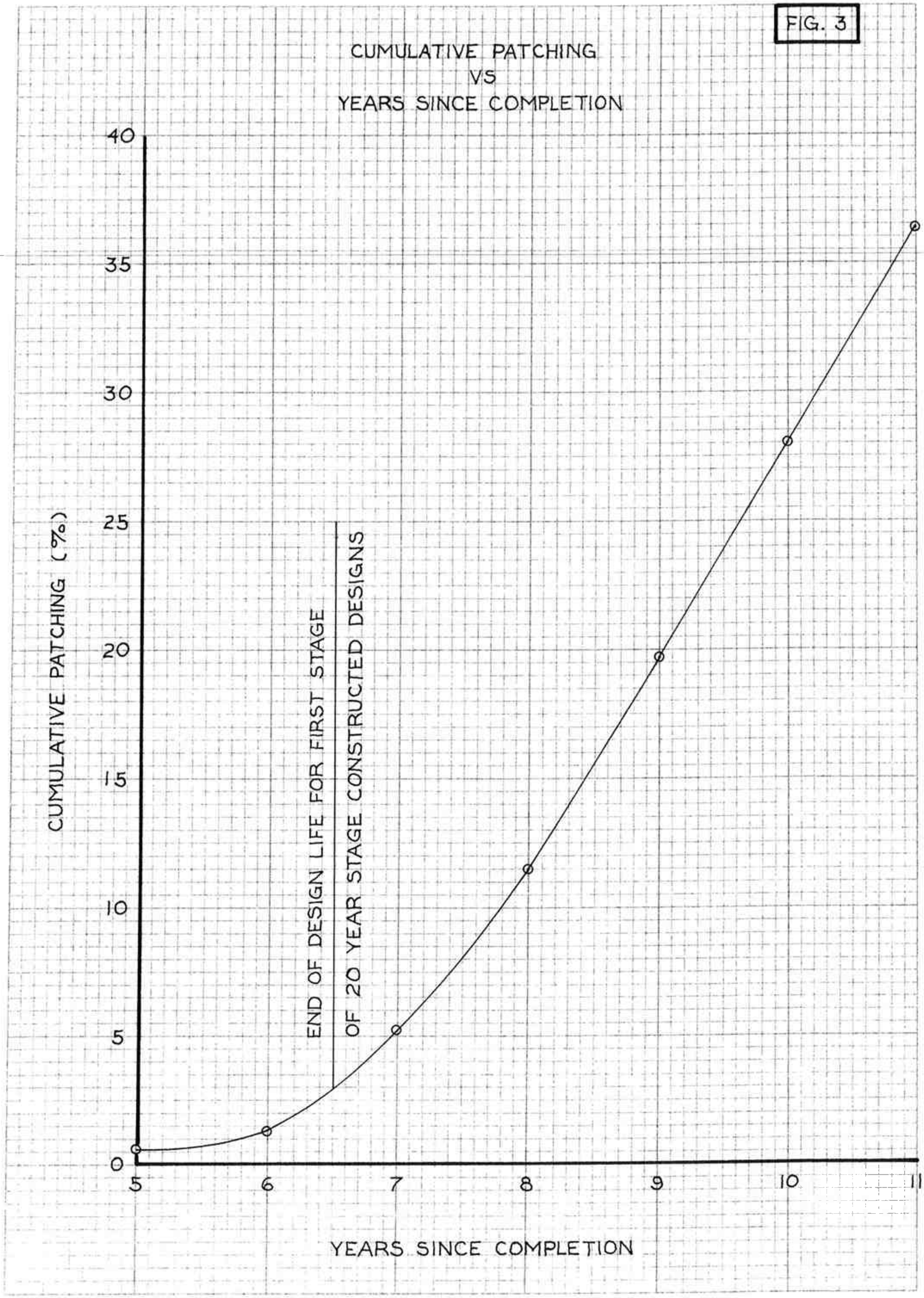
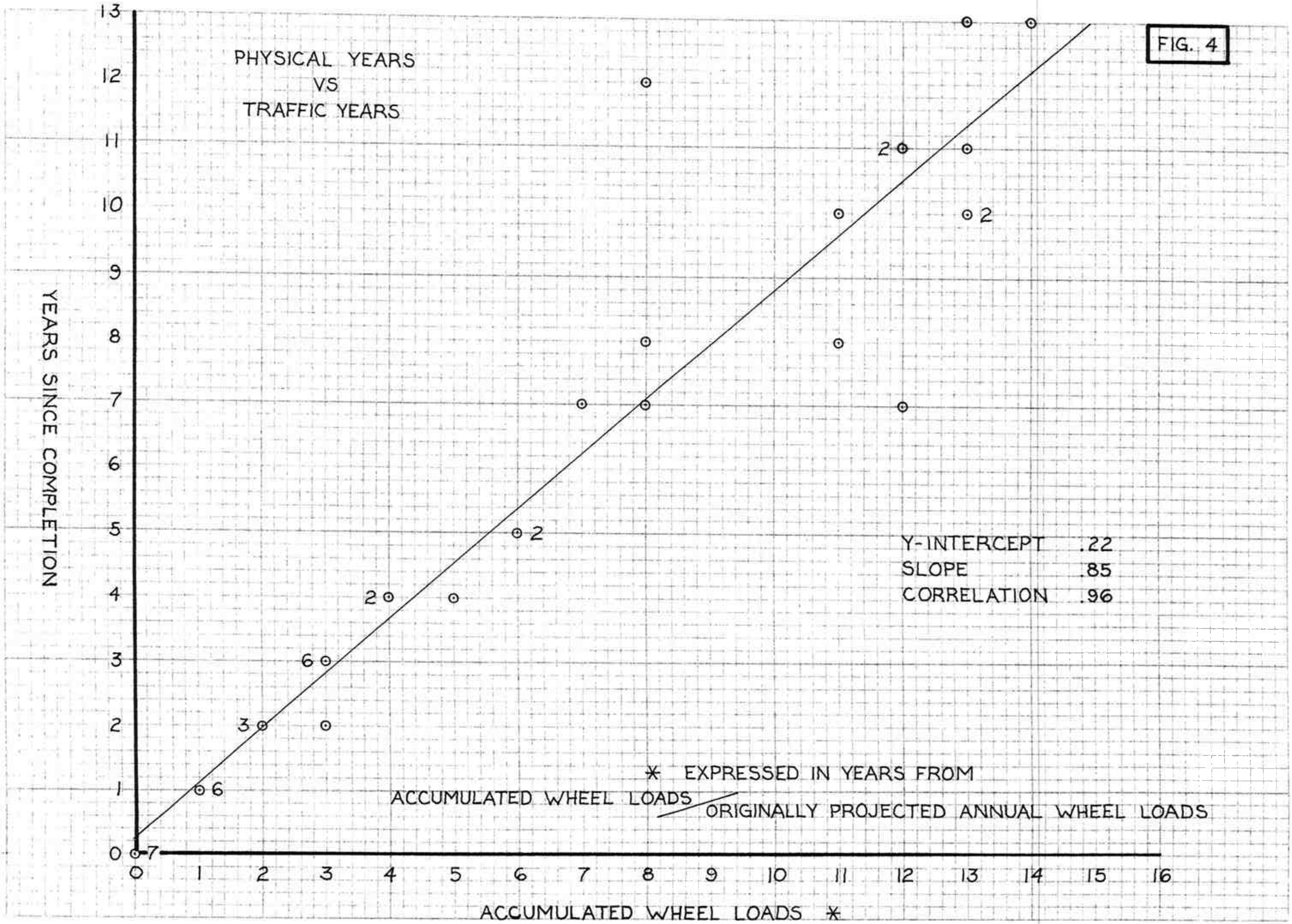

CUMULATIVE PATCHING
VS
YEARS SINCE COMPLETION
CUMULATIVE PATCHING (%)
0
5
10
15
20
25
30
35
40
END OF DESIGN LIFE FOR FIRST STAGE
OF 20 YEAR STAGE CONSTRUCTED DESIGNS
5
6
7
8
9
10
11
YEARS SINCE COMPLETION

FIG. 4


PHYSICAL YEARS
VS
TRAFFIC YEARS
YEARS SINCE COMPLETION
ACCUMULATED WHEEL LOADS *
Y-INTERCEPT .22
SLOPE .85
CORRELATION .96
* EXPRESSED IN YEARS FROM
ACCUMULATED WHEEL LOADS / ORIGINALLY PROJECTED ANNUAL WHEEL LOADS

should provide data accurate enough for design.

From the analysis of the traffic projections, which are fairly accurate, and the three methods of verification of the design procedure, all of which show that the design procedure generally produces what is expected of it, it can be said that the design procedure and assumptions based on it are valid, at least within the initial stage of the surfacing.

Traffic Volume Effect

In reviewing the design procedure analysis it was noted that traffic volume would be expected to have an effect on the required total depth of an overlay, and also on the time at which the final stage should be placed since two inches are reserved for the final stage regardless of the required total depth. Calculations pertaining to this thought follow the theoretical design life dalculations in the Appendix.

To find the required total overlay depth all stage constructed jobs in this study that were overlays were reviewed to find the average deflection at the time just prior to the overlay. Then the tolerable initial deflection, which is based on traffic volumes, was found. Knowing these items it was possible to use the overlay design procedure to determine the required depth of an overlay for the 10 and 20 year design periods. The difference between the 10 and 20 year designs was found to be only about one inch of asphalt concrete.

The method used to determine the time at which the second stage of two inches should be placed was the same method used in the second verification of the design procedure. An assumption in this analysis was that the second stage would bond to the first stage making the design thickness equivalent to the total of the first stage and second stage thicknesses.

It was shown that the time since construction at which the two inch second stage should be applied ranges from 5.5 years for high traffic to 7.5 years for low traffic.

Delayed Second Stage

An inspection was made of the effect on the required second stage depth by delaying its application for two and four years past the time when two inches were required. The Cumulative Percent Patching vs. Time plot shows maintenance begins to occur at about the time two inches is required, so maintenance was considered in analyzing the effect of delaying the second stage. The analysis indicated that the longer the second stage is delayed the greater the required depth for the second stage becomes. Calculations pertaining to this inspection may be found in the Appendix.

Chip Seals

An attempt was made to analyze thin seals, such as chip seals. The main benefits of these treatments is the sealing of the cracks and the rejuvination of the existing pavement. A survey of District Engineers in Regions 4 and 5 revealed that approximately 140 miles of highway received a thin chip seal this past summer. They were mostly one shot seals placed by state forces.

The consensus of opinion among the District Engineers was that these seals would last two to four years before cracking would return to the level existing just prior to the treatment. For good performance, most of the District Engineers agreed that it is necessary to apply the seal as soon as cracking first appears, and that the seals should generally be used only on highways with low traffic volumes. From the survey, the life for a one-shot 0-33 chip seal was estimated to be two years, with the life for a two-shot 0-32 chip seal being set at four years. It was not possible to obtain any historical data to either confirm or refute this estimate. The present cost of an 0-33 chip seal 30 ft wide is about $3,100 per mile, with an equivalent width 0-32 chip seal costing $5,200 per mile.

Cost Analysis Procedures

To analyze the economics of each design strategy, a typical section 32 ft wide and one mile long was used. The previously determined average before-construction deflection of 0.045 inch was used for design criteria. The costs of construction of the initial and second stage were provided by the Policy and Program Development Branch.

To determine the cost of rut repair, an average one inch thick surface course was applied to a width of 24 ft. The cost of rut repair materials and labor was estimated at $25 per ton.

In determining the cost of maintenance the percent of area patched, based on a 24 ft wide section, was used. From the Percent Patching vs. Years Since Completion plot (Figure 3), the percent patching was set at six percent per year for the first four years, ten percent per year for the following four years, and fifteen percent per year for any time past eight years. It was assumed that maintenance prior to an extensive surface treatment would not extend the performance of the road. The cost of maintenance materials and labor was estimated at $24 per ton for six percent patching and $20 per ton for ten and fifteen percent patching.

In all analyses the costs were equated to a present worth using inflation and discount rates. The Financial Planning and Economics Branch recommended seven percent be used for each rate.

Several options were considered for 20 year designs, including a full depth design and variations of a stage constructed design. These variations included placing the second stage when required and delaying this second stage for two or four years past the time at which the two inch overlay was needed. The postponement was accomodated by performing additional maintenance. Another option delayed the second stage with the use of a chip seal; however, this was considered valid only for low traffic conditions. Another design completely deletes the second stage and replaces it with yearly maintenance applications. This last procedure would leave the roads in worse condition at the end of 20 years than the other 20 year designs; therefore, a negative salvage value was assumed.

In all of these designs, it was assumed that surface maintenance will be required during each of the last four years of the 20 year design period due to the magnitude of the deflections after about 16 years service. Repair to eliminate excessive rutting was assumed to be needed only on the 20 year full depth design. Rut depth problems would be resolved in the stage constructed projects with the application of the leveling course placed prior to the second stage, or included in maintenance when the second stage has been deleted.

Only two options were considered in the 10 year designs. These were 10 year full depth and stage constructed. A full depth design does not require a second treatment as deep as the original design due to the minimum level of performance built into the design procedure. Although termed a "10 year design", the pavement condition at the end of the ten years service is expected to be better than at the time of the original design, thus reducing the thickness requirement and cost for a subsequent 10 year design.

A 1.5 inch, thin flexible overlay was used as the first stage in the stage construction analysis. The remainder of the thickness required for a full depth design was placed four years later.

EFFECTS OF VARIOUS DESIGN ALTERNATIVES ON THE HIGHWAY SYSTEM

Analysis

A discussion of an analysis of the effects of various surfacing design alternatives on the backlog of highways in need of rehabilitation or heavy maintenance took place with the Policy and Program Development Branch. It was determined that all information needed for a detailed analysis was not available at the time. The rates of deterioration of the existing highways had not been well enough established to determine the number of miles reaching the poor category each year.

However, an economic analysis was made to determine the present costs of rehabilitating a one mile section of highway with a 32 ft pavement width and maintaining that section over a 20 year period under various design alternatives. The study indicated that a 20 year design life with the entire thickness placed initially is the most economical surfacing design. The economic analysis also indicated that for medium traffic it would cost 4.2 percent more for a 20 year stage constructed design rather than a 20 year full depth design. A 20 year stage constructed design with the second stage application delayed two years would cost 21.3 percent more, while a four year delay in the application would cost 30.6 percent more. A 24.0 percent greater cost would be required to construct a 10 year full depth design with a subsequent overlay to provide a second 10 year period.

A 10 year stage constructed project would cost 35.6 percent more than a 20 year full depth design for a 20 year period of time.

User costs were not considered in this analysis since there appears to be no consensus as to the amount or effect of these costs. It is assumed a reasonable level of maintenance is provided to keep the highways ina safe and serviceable condition. In addition, there is no way for the State to recover the savings in user costs that might accrue by accepting one alternative over another.

Backlog

As an illustrative example, an analysis of an assumed 1,000 mile backlog was made for the following design alternatives: 1) Twenty year full depth, 2) twenty year stage constructed, and 3) ten year full depth. The 10 year stage constructed design was not considered because of the uncertainty of the behavior of the initial stage. Assumptions made in the analysis were an initial backlog of 1,000 miles, a fixed new construction expenditure of $8 million per year, and a fixed maintenance fund of $4.6 million per year. The $4.6 million assumed for maintenance resulted from an estimated annual cost of $4,600 per mile to maintain a two-lane highway that is in poor condition, as would be the condition of the 1,000 mile backlog. As progress was made in overlaying the backlog, the money saved through maintenance not required was applied to the new construction fund. Recognizing that all of the mileage must be maintained in a safe and serviceable condition, this illustration provides a realistic comparison of the different design alternatives.

The analysis indicated that the 20 year stage constructed option will leave the least backlog at the end of a 20 year period. This largely occurs because the lower cost of the initial stage allows the backlog to drop rapidly for the first few years, and by the time the second stage is to be applied much of the maintenance money may be used for new construction. Table 3 shows the number of miles and the cost in thousands of dollars for new construction, second stage application, and maintenance. Similar data is shown for 20 year and 10 year full depth designs in Tables 4 and 5, respectively. A comparison of the backlog for all three of these designs is illustrated in Figure 5.

This analysis was performed as an illustrative example only, and does not reflect the actual miles of backlog in need of overlay nor the funding available to provide rehabilitation and maintenance for that mileage.

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

Ninety-five deflection tests taken from 76 various construction projects were studied to determine if Oregon has been achieving the desired results through use of its surfacing design procedures. The project sites provided both 10 and 20 year stage constructed designs for new construction and overlay projects. Deflections on the sampling of projects were taken during the first part of this study with the majority having been performed this past summer.

An analysis of the deflection data confirmed that the surfacing design procedures currently in use in Oregon are valid. The Maintenance Patching graph (Figure 3) helps to confirm this validity by illustrating that Oregon has been receiving the predicted life from the initial stage

Table 3. BACKLOG - 20 YEAR STAGE CONSTRUCTED DESIGN

Illustrative Example Only*

		NEW CONSTRUCTION		2nd STAGE		MAINTENANCE	
Year	Backlog	Miles	Cost (Thousands)	Miles	Cost (Thousands)	Miles	Cost (Thousands)
0	1000	0	0	0	0	1000	4600
1	951	49	8261	0	0	951	4375
2	901	50	8430	0	0	901	4145
3	850	52	8767	0	0	850	3910
4	797	53	8935	0	0	797	3666
5	742	54	9104	0	0	742	3413
6	686	56	9441	0	0	686	3156
7	653	33	5563	49	4018	653	3004
8	619	34	5732	50	4100	619	2847
9	586	33	5563	52	4264	586	2696
10	552	34	5732	53	4346	552	2539
11	518	34	5732	54	4428	518	2383
12	483	34	5732	56	4592	483	2222
13	437	47	7924	33	2706	437	2010
14	389	48	8092	34	2788	389	1789
15	340	49	8261	33	2706	340	1564
16	289	50	8430	34	2788	289	1329
17	238	52	8767	34	2788	238/49	1095/54
18	185	53	8935	34	2788	185/99	851/109
19	137	48	8092	47	3854	137/151	630/166
20	88	49	8261	48	3936	88/204	405/224

* Assume $8 million available for new construction; $4.6 million available for maintenance; unused maintenance funds applied to new construction.

Table 4. BACKLOG - 20 YEAR FULL DEPTH DESIGN

Illustrative Example Only*

		NEW CONSTRUCTION		RUT DEPTH REPAIR		MAINTENANCE	
Year	Backlog	Miles	Cost (Thousands)	Miles	Cost (Thousands)	Miles	Cost (Thousands)
0	1000	0	0	0	0	1000	4600
1	963	37	8191	0	0	963	4430
2	925	38	8413	0	0	925	4255
3	887	38	8413	0	0	887	4080
4	848	39	8634	0	0	848	3901
5	807	40	8856	0	0	807	3712
6	767	41	9077	0	0	767	3528
7	725	42	9298	0	0	725	3335
8	682	43	9520	0	0	682	3137
9	641	40	8856	37	703	641	2949
10	600	41	9077	38	722	600	2760
11	558	42	9298	38	722	558	2567
12	515	43	9520	39	741	515	2369
13	472	44	9741	40	760	472	2171
14	427	45	9963	41	779	427	1964
15	382	45	9963	42	798	382	1757
16	336	46	10184	43	817	336	1546
17	288	47	10405	40	760	288/37	1325/41
18	240	48	10627	41	779	240/75	1104/83
19	191	49	10848	42	798	191/113	879/124
20	142	50	11070	43	817	142/152	653/167

* Assume $8 million available for new construction; $4.6 million available for maintenance; unused maintenance funds applied to new construction.

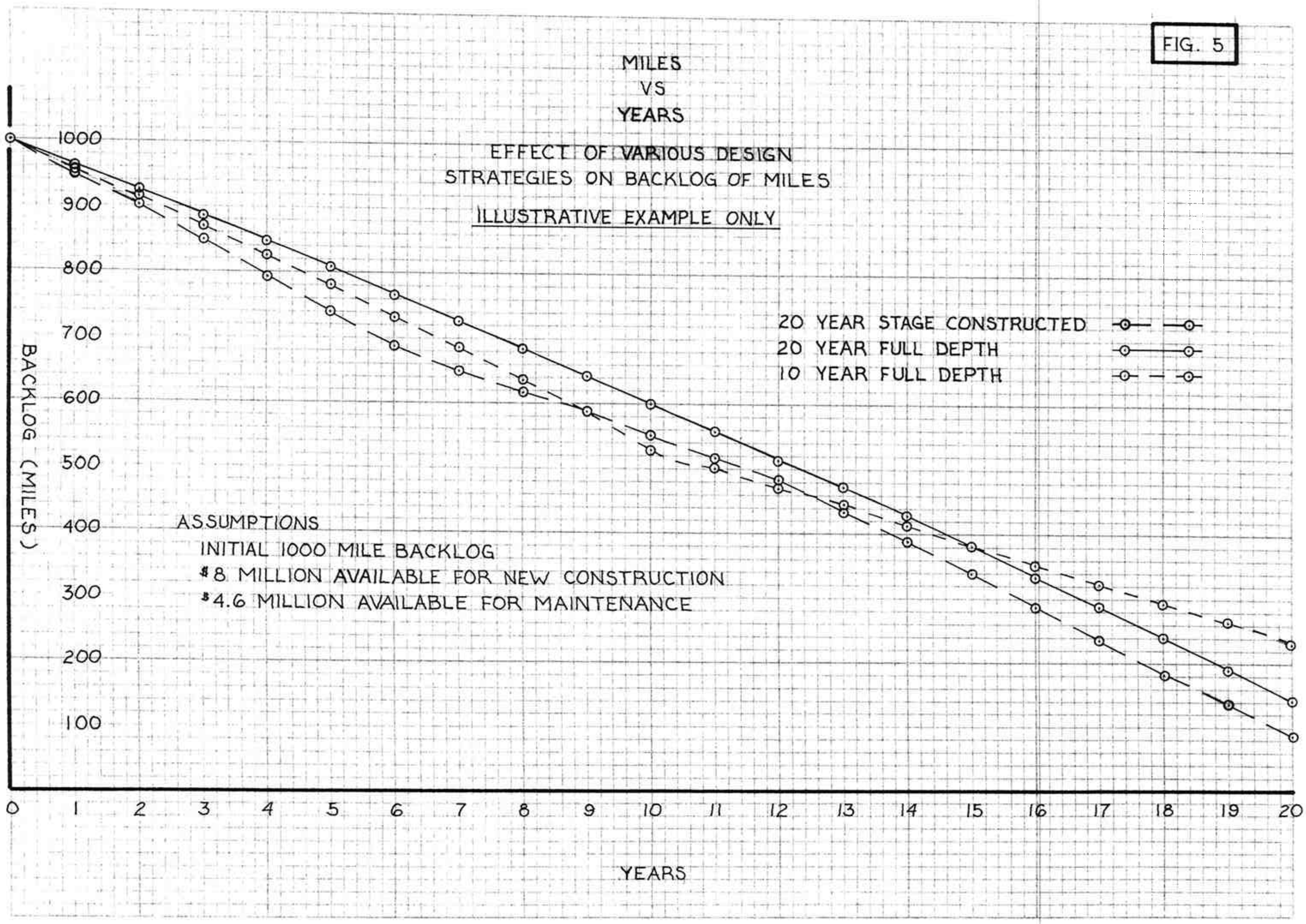
Table 5. BACKLOG - 10 YEAR FULL DEPTH DESIGN

Illustrative Example Only*

		NEW CONSTRUCTION		2nd 10 yr. TREATMENT		MAINTENANCE	
Year	Backlog	Miles	Cost (Thousands)	Miles	Cost (Thousands)	Miles	Cost (Thousands)
0	1000	0	0	0	0	1000	4600
1	958	42	8190	0	0	958	4407
2	915	43	8385	0	0	915	4209
3	871	44	8580	0	0	871	4007
4	826	45	8775	0	0	826	3800
5	780	46	8970	0	0	780	3588
6	732	47	9165	0	0	732	3367
7	684	48	9360	0	0	684	3146
8	634	50	9750	0	0	634	2916
9	583	51	9944	0	0	583	2682
10	531	52	10139	0	0	531	2443
11	502	29	5655	42	4553	502	2309
12	472	30	5850	43	4661	472	2171
13	442	30	5850	44	4770	442	2033
14	412	30	5850	45	4878	412	1895
15	382	30	5850	46	4986	382	1757
16	352	30	5850	47	5095	352	1619
17	322	30	5850	48	5203	322	1481
18	292	30	5850	50	5420	292	1343
19	262	30	5850	51	5528	262	1205
20	232	30	5850	52	5637	232	1067

* Assume $8 million available for new construction; $4.6 million available for maintenance; unused maintenance funds applied to new construction.

FIG. 5



MILES
VS
YEARS
EFFECT OF VARIOUS DESIGN
STRATEGIES ON BACKLOG OF MILES
ILLUSTRATIVE EXAMPLE ONLY
20 YEAR STAGE CONSTRUCTED
20 YEAR FULL DEPTH
10 YEAR FULL DEPTH
ASSUMPTIONS
INITIAL 1000 MILE BACKLOG
$8 MILLION AVAILABLE FOR NEW CONSTRUCTION
$4.6 MILLION AVAILABLE FOR MAINTENANCE
BACKLOG (MILES)
1000
900
800
700
600
500
400
300
200
100
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
YEARS

of its projects.

By joint analysis of the deflection data and the level of maintenance patching, as determined from the Surface Condition Ratings, it was observed that patching has a positive effect on the pavement condition. Maintenance patching prevents the rapid acceleration of deflection values towards the end of the initial stage design life.

An economic comparison was made of various design lives. It was concluded that design lives longer than 20 years are not practical for asphalt pavements. A 20 year design life with the full C.B.E. requirement being placed initially was found to be the most economical design. The total cost of this design over a 20 year period is about 20 percent lower than that of a 10 year design life. Due to the lower overall cost of this 20 year design life as compared to a 10 year design used over a 20 year period, the backlog of miles of poor pavement under a 20 year design would be less.

Recommendations for Continued Study

Data covering a sufficiently long period of time was not available to verify the effectiveness of thin flexible overlays and thin chip seals. Due to the relatively low initial cost of these treatments, it is recommended further study be made in these areas as indicated below:

1) Deflection tests should continue to be conducted on a sampling of the projects which have been overlayed with a thin open-graded flexible pavement during the last three years.
2) Deflection tests should be made on sections of highway receiving 0-33 or 0-32 thin chip seals. This should include measurements prior to the placement of the seals and continue for two to three years after the seals have been placed.

APPENDIX

Form 81-734-3106

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OREGON STATE HIGHWAY DIVISION

Calculations for STAGE CONSTRUCTION ANALYSIS

Made by D.T. 10-6, 1978. Checked by ...., 19..... Backchecked by ...., 19.....

1) EXISTING DEFLECTION AT TIME OF OVERLAY

ANALYSIS OF OVERLAY PROJECTS TO DETERMINE THE AVERAGE DEFLECTION AT THE TIME OF OVERLAY YIELDS:

AVERAGE DEFLECTION = 45.3 (DEFLECTION IN .001 INCHES)

STANDARD DEVIATION = 14.0

2) TRAFFIC LOAD ON 20 YR DESIGN

ANALYSIS OF ALL 20 YR DESIGN PROJECTS TO DETERMINE AVERAGE ANNUAL EQUIVALENT WHEEL LOADS AND THE AVERAGE 20 YR EXPANSION FACTOR YIELDS:

AVERAGE ANNUAL EQUIVALENT WHEEL LOADS = 887260 E.W.L.

STANDARD DEVIATION = 523890 E.W.L.

AVERAGE 20 YR EXPANSION FACTOR = 1.8

STANDARD DEVIATION = 0.18

HIGH TRAFFIC = AVERAGE TRAFFIC + (1) STD. DEVIATION
= 887,260 + 523890 = 1411150 EWL
20 YR TRAFFIC COEFFICIENT = 10.0

MED. TRAFFIC = AVERAGE TRAFFIC
= 887 260 EWL
20 YR TRAFFIC COEFFICIENT = 9.5

LOW TRAFFIC = AVERAGE TRAFFIC − (1) STD. DEVIATION
= 881260 − 523890 = 363 370 EWL
20 YR TRAFFIC COEFFICIENT = 8.5

Form 81-734-3106

Job No. ....

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OREGON STATE HIGHWAY DIVISION

Calculations for STAGE CONSTRUCTION ANALYSIS

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THEORETICAL DESIGN LIFE FOR 1ST STAGE OF STAGE CONSTRUCTION
20 YR DESIGN

TYPICAL TRAFFIC CONDITION – AVERAGE ANNUAL E.W.L. = 887260
TRAFFIC COEFF = 9.5

FROM SAMPLE OF DESIGN CALCULATIONS
"R" VALUE IS 20

TOTAL C.B.E. REQUIRED:

C.B.E = (.03546)(T.C.)(100-R) = (.03546)(9.5)(80) = 26.9"

ACTUAL C.B.E. PLACED = 26.9" - 4" = 22.9" (FIRST STAGE)

T.C. (FIRST STAGE) = 22.9"/(.03546)(80) = 8.07

E.W.L. @ T.C. = 8.07 IS 4 605 522

1ST YEAR E.W.L. = AVERAGE E.W.L/1.4 = 887260/1.4 = 633 757

YR	TRAFFIC	CUMULATIVE TRAFFIC
1	633757	633757
2	659 107	1292 864
3	685471	1978 335
4	712 890	2691 225
5	741 406	3432 631
6	771 062	4 203 693
7	801 904	5005 597

> 6.5 4604645

THE THEORETICAL DESIGN LIFE OF THE FIRST STAGE OF A 20 YR DESIGN IS ~6.5 YEARS

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OREGON STATE HIGHWAY DIVISION

Calculations for STAGE CONSTRUCTION ANALYSIS

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REQ'D OVERLAY DEPTH FOR
LOW TRAFFIC

ANNUAL E.W.L = AVERAGE ANNUAL E.W.L. − STD. DEVIATION = 363 370 EWL

20 YR TOTAL E.W.L = 363 370 (20) = 7 267 400

TOLERABLE DEFLECTION @ 7 267 400 E.W.L = 12.8

% REDUCTION IN DEFLECTION = 45.3 − 12.8 / 45.3 = 71.7%

C.B.E. INCREASE @ 71.7% DEFLECTION REDUCTION = 12.0 INCHES (6" A.C.)

2) TIME AT WHICH 2" IS REQ'D TO BE PLACED PROVIDED ONLY THE FIRST STAGE (FULL DEPTH MINUS 2") IS PLACED

AT 7.75 YRS:

1ST YEAR TRAFFIC = 363 370 / 1.4 = 259 550

20 YR TRAFFIC = 259 550 (1.8) = 467 190

7.75 YR TRAFFIC = 259 550 (1 + (7.75 (.8/20))) = 340 010

TRAFFIC FOR YEARS 7.75 TO 20 = (340 010 + 467 190 / 2) (12.25) = 4 944 103

TOLERABLE DEFLECTION AT 4 944 103 E.W.L = 13.4

FROM CURVE TAKEN FROM DEFLECTION VS. TIME PLOT, DEFLECTION AT 7.75 YEARS IS

$\delta = 8.57 + 1.555 (7.75) = 20.62$

% REDUCTION IN DEFLECTION = 20.62 − 13.4 / 20.62 = 35

REQ'D INCREASE IN C.B.E. @ 35% = 3.5" ∴ 2" OF A.C. @ 7.75 YRS

FOR USE IN THIS ANALYSIS 2" REQ'D @ ≈ 7.5 YRS

OREGON STATE HIGHWAY DIVISION

Calculations for STAGE CONSTRUCTION ANALYSIS

Made by SKB 10-06, 19 78 Checked by ...., 19...... Backchecked by ...., 19......

REQ'D OVERLAY DEPTH FOR AVERAGE TRAFFIC

1) DATA KNOWN

AVERAGE ANNUAL 5 KIP EWL = 887,260 (FOR 20 YR. PERIOD)
AVERAGE DEFLECTION AT WHICH OVERLAY IS NEEDED IS 45.3 THOUSANDTHS OF AN INCH FOR 20 YEARS (FROM GRAPH)
AVERAGE DEFLECTION AT WHICH OVERLAY IS NEEDED FOR OTHER THAN 20 YEARS IS FOUND BY THE FORMULA $\delta = 8.57 + (1.555)(\text{YEARS})$ (FROM THE GRAPH OF DEFLECTION VS. TIME)
EXPANSION FACTOR TO CONVERT INITIAL TRAFFIC TO 20 YEAR TRAFFIC $\bar{x} = 1.8$

2) CBE REQUIREMENT FOR 20 YEARS

$(887,260)(20) = 17,745,200$ TOTAL 5 KIP EWL FOR 20 YEARS

FROM DESIGN CHART TOLERABLE DEFLECTION IS 11 THOU OF AN INCH

$\left(\frac{45.3 - 11}{45.3}\right)(100) = 75.72$ % REDUCTION IN DEFLECTION

FROM DESIGN CHART THE CRUSHED BASE EQUIVALENT IS 12.9 INCHES

$12.9/2 = 6.45$ INCHES OF A.C. REQUIRED

3) TOTAL TRAFFIC IN YEARS 7 TO 20

$887,260/1.4 = 633,757$ INITIAL TRAFFIC

$(633,757)(1.8) = 1,140,763$ 20 YEAR TRAFFIC

OREGON STATE HIGHWAY DIVISION

Calculations for STAGE CONSTRUCTION ANALYSIS

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$(633{,}757)(1+7(0.8/20)) = 811{,}209$ 7 YEAR TRAFFIC

$(811{,}209 + 1{,}140{,}763/2)(13) = 12{,}687{,}818$ TOTAL TRAFFIC IN YEARS 7 TO 20

4) CBE REQUIREMENT AT 7 YEARS

$8.57 + (1.555)(7) = 19.455 = 19.46$ THOU OF AN INCH AVERAGE DEFLECTION

FROM DESIGN CHART TOLERABLE DEFLECTION IS 11.8 THOU OF AN INCH FOR 12,687,818 TOTAL EWL

$(19.46 - 11.8/19.46)(100) = 39\frac{36}{}\%$ REDUCTION IN DEFLECTION

FROM DESIGN CHART THE CRUSHED BASE EQUIVALENT IS 4.4 INCHES

$4.4/2 =$ <u>2.2 INCHES</u> OF AC REQUIRED AT 7 YEARS FOR AVERAGE TRAFFIC

OREGON STATE HIGHWAY DIVISION

Calculations for STAGE CONSTRUCTION ANALYSIS

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5) TOTAL TRAFFIC IN YEARS 6.3 TO 20

$(633{,}757)(1+6.3(0.8/20)) = 793{,}464$ TRAFFIC @ 6.3 YEARS

$(793{,}464 + 1{,}140{,}763/2)(13.7) = 13{,}249{,}455$ TOTAL TRAFFIC FOR YEARS 6.3 TO 20

6) CBE REQUIREMENT AT 6.3 YEARS

$8.57+(1.555)(6.3) = 18.37$ THOU OF AN INCH AVE. δ

FROM THE DESIGN CHART TOLERABLE δ IS 11.5 THOU OF AN INCH FOR 13,249,455 TOTAL TRAFFIC

$(18.37 - 11.5/18.37)(100) = 37.40$ % REDUCTION IN DEFLECTION

FROM THE DESIGN CHART THE CRUSHED BASE EQUIVALENT IS 4.0 INCHES

$4.0/2 =$ 2.0 INCHES OF A.C. REQUIRED AT 6.3 YEARS FOR AVERAGE TRAFFIC

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OREGON STATE HIGHWAY DIVISION

Calculations for STAGE CONSTRUCTION ANALYSIS

Made by D.T. 10-6, 1978 Checked by ...., 19...... Backchecked by ...., 19......

REQ'D OVERLAY DEPTH FOR
HIGH TRAFFIC

ANNUAL E.W.L. = AVERAGE ANNUAL E.W.L. + STD DEVIATION

ANNUAL E.W.L. = 887260 + 523890 = 1411150

20 YR TOTAL EWL = 1411150 (20) = 28 223 000

TOLERABLE DEFLECTION @ 28 223 000 = 10.1

% REDUCTION IN DEFLECTION = 45.3 − 10.1/45.3 = 77.7%

C.B.E. INCREASE AT 77.7% DEFLECTION REDUCTION = 13.5" (6.75" A.C.)

TIME AT WHICH 2" IS REQUIRED TO BE PLACED

AT 6 YEARS:

1ST YEAR TRAFFIC = 1411150/1.4 = 1007964

20 YEAR TRAFFIC = (1007964)(1.8) = 1814336

6 YEAR TRAFFIC = 1249876

TRAFFIC FOR YEARS 6 TO 20: (1249876 + 1814336/2)(14) = 21449484

TOLERABLE DEFLECTION AT 21 449 484 E.W.L. = 10.8

FROM CURVE TAKEN FROM DEFLECTION VS TIME, DEFLECTION AT 6 YEARS IS

$\delta = 8.57 + (1.555)(6) = 17.9$

% REDUCTION IN DEFLECTION = 17.9 − 10.8/17.9 = 39.1%

C.B.E INCREASE @ 39% REDUCTION IN DEFLECTION = 4.3" (2.25" OF A.C.)

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OREGON STATE HIGHWAY DIVISION

Calculations for STAGE CONSTRUCTION ANALYSIS

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AT 5.5 YEARS:

5.5 YEAR TRAFFIC = (1007964)(1 + 5.5(.8/20)) = 1007964

TRAFFIC FOR YEARS 5.5 TO 20: (1007964 + 1814336/2)(14.5) = 22069377

TOLERABLE DEFLECTION AT 22069377 EWL = 10.6

$\delta = 8.57 + (1.555)(5.5) = 17.1$

% REDUCTION IN DEFLECTION = 17.1 − 10.8/17.1 = 38.0%

C.B.E. INCREASE @ 38% REDUCTION IN DEFLECTION = 4.1" (2" OF A.C.)

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OREGON STATE HIGHWAY DIVISION

Calculations for STAGE CONSTRUCTION ANALYSIS

Made by D.T. 10-6, 1978 Checked by ...., 19...... Backchecked by ...., 19......

OVERLAY REQ'D AT 2 & 4 YRS PAST 2" REQUIREMENT TIME

LOW TRAFFIC - 10.5 YEARS; 12.5 YEARS

10.5 YR TRAFFIC = 259550(1 + 10.5(.8/20)) = 368561

TRAFFIC FOR YEARS 10.5 TO 20: (368561 + 467190/2)(9.5) = 3969817

TOLERABLE DEFLECTION AT 3969815 EWL = 14

FROM CURVE TAKEN FROM DEFLECTION VS. TIME, DEFLECTION AT 10.5 YEARS IS

$\delta = 8.57 + 1.555(10.5) = 24.9$

% REDUCTION IN DEFLECTION = 24.9 - 14/24.9 = 43.7%

INCREASE IN C.B.E. @ 43.7% REDUCTION IN DEFLECTION = 5.5"

2.75" OF A.C. IS REQUIRED AT 10.5 YEARS

12.5 YR TRAFFIC = 259550(1 + 12.5(.8/20)) = 389325

TRAFFIC FOR YEARS 12.5 TO 20: (389325 + 467190/2)(7.5) = 3211931

TOLERABLE DEFLECTION AT 3211931 EWL = 14.6

$\delta = 8.57 + 1.555(12.5) = 28.0$

% REDUCTION IN DEFLECTION = 28 - 14.6/28 = 47.9%

INCREASE IN C.B.E. @ 47.9% REDUCTION IN DEFLECTION = 6.5"

3.25" OF A.C. IS REQUIRED AT 12.5 YEARS

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OREGON STATE HIGHWAY DIVISION

Calculations for STAGE CONSTRUCTION ANALYSIS

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OVERLAY REQ'D AT 2 & 4 YRS. PAST 2" REQUIREMENT TIME

AVERAGE TRAFFIC: 8.5 YEARS ; 10.5 YEARS

8.5 YR. TRAFFIC = $633,757(1 + 8.5(0.8/20)) = 849,234$

TRAFFIC FOR YRS. 8.5 TO 20: $(849,234 + 1,140,763/2)(11.5) = 11,442,483$

TOLERABLE DEFLECTION AT 11,442,483 EWL = 11.5

FROM CURVE TAKEN FROM DEFLECTION VS. TIME, DEFLECTION AT

8.5 YEARS IS $\delta = 8.57 + 1.555(8.5) = 21.8$

% REDUCTION IN DEFLECTION = $21.8 - 11.5/21.8 = 47.2\%$

INCREASE IN CBE @ 47.2% REDUCTION IN DEFLECTION = 6.25"

3.125" OF A.C. IS REQUIRED AT 8.5 YEARS

10.5 YR. TRAFFIC = $633,757(1 + 10.5(0.8/20)) = 899,935$

TRAFFIC FOR YRS. 10.5 TO 20: $(899,935 + 1,140,763/2)(9.5) = 9,693,316$

TOLERABLE DEFLECTION AT 9,693,316 EWL = 12.0

$\delta = 8.57 + 1.555(10.5) = 24.9$

% REDUCTION IN DEFLECTION = $24.9 - 12.0/24.9 = 51.8\%$

INCREASE IN CBE @ 51.8% REDUCTION IN DEFLECTION = 7.3"

3.65" OF A.C. IS REQUIRED AT 10.5 YEARS

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OREGON STATE HIGHWAY DIVISION

Calculations for STAGE CONSTRUCTION ANALYSIS

Made by SKB 10-06, 1978 Checked by ...., 19...... Backchecked by ...., 19......

OVERLAY REQ'D AT 2 & 4 YRS. PAST 2" REQUIREMENT TIME

HIGH TRAFFIC: 7.5 YEARS ; 9.5 YEARS

7.5 YR. TRAFFIC = $1,007,964 (1 + 7.5 (0.8/20)) = 1,310,353$

TRAFFIC FOR YRS. 7.5 TO 20: $\left(\frac{1,310,353 + 1,814,336}{2}\right)(12.5) = 19,529,306$

TOLERABLE DEFLECTION AT 19,529,306 EWL = 10.8

FROM CURVE TAKEN FROM DEFLECTION VS. TIME, DEFLECTION AT

7.5 YRS. IS $\delta = 8.57 + 1.555 (7.5) = 20.2$

% REDUCTION IN DEFLECTION = $\frac{20.2 - 10.8}{20.2} = 46.5\%$

INCREASE IN CBE @ 46.5 % REDUCTION IN DEFLECTION = 6.1"

3.05" OF A.C. IS REQUIRED AT 7.5 YEARS

9.5 YR. TRAFFIC = $1,007,964 (1 + 9.5 (0.8/20)) = 1,390,990$

TRAFFIC FOR YRS. 9.5 TO 20: $\left(\frac{1,390,990 + 1,814,336}{2}\right)(10.5) = 16,827,962$

TOLERABLE DEFLECTION AT 16,827,962 EWL = 11.0

$\delta = 8.57 + 1.555 (9.5) = 23.3$

% REDUCTION IN DEFLECTION = $\frac{23.3 - 11.0}{23.3} = 52.8\%$

INCREASE IN CBE @ 52.8 % REDUCTION IN DEFLECTION = 7.4"

3.70" OF A.C. IS REQUIRED AT 9.5 YEARS.

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OREGON STATE HIGHWAY DIVISION

Calculations for STAGE CONSTRUCTION ANALYSIS

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REQUIRED DEPTH OF OVERLAY FOR 10 YR DESIGN

1) LOW TRAFFIC ANNUAL E.W.L. = 311 460

10 YR TOTAL E.W.L. = (311 460)(10) = 3 114 600

TOLERABLE DEFLECTION @ 3114 600 EWL (ASSUME 5" O-LAY)
δ = 17.1

% REDUCTION IN DEFLECTION = 45.3 - 17.1 / 45.3 = 62.3%

C.B.E INCREASE AT 62.3% REDUCTION = 9.8" (5.0" OF A.C.)

2) MEDIUM TRAFFIC ANNUAL E.W.L. = 760 508

10 YR TOTAL E.W.L. = (760 508)(10) = 7 605 080

TOLERABLE DEFLECTION @ 7 605 080 EWL (ASSUME 5.5" O-LAY)
δ = 14.0

% REDUCTION IN DEFLECTION = 45.3 - 14.0 / 45.3 = 69%

INCREASE IN C.B.E AT 69.0% REDUCTION = 11.2" (5.5" OF A.C)

3) HIGH TRAFFIC ANNUAL E.W.L = 1209 557

10 YR TOTAL E.W.L. = (1 209 557)(10) = 12 095 570

TOLERABLE DEFLECTION @ 12 095 570 (ASSUME 6" O-LAY)
δ = 11.9

% REDUCTION IN DEFLECTION = 45.3 - 11.9 / 45.3 = 73.7%

INCREASE IN C.B.E. @ 73.7% = 12.3" (6.0" OF A.C.)

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Job No. ....

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OREGON STATE HIGHWAY DIVISION

Calculations for DESIGN ECONOMICS

Made by D.T. 11-22, 1978 Checked by ...., 19..... Backchecked by ...., 19.....

20 YR. FULL DEPTH

MAINTENANCE

INITIAL - FULL DEPTH

RUT DEPTH REPAIR
@ 9 YEARS

HIGH TRAFFIC 7.0" INITIAL
MED. TRAFFIC 6.5" INITIAL
LOW TRAFFIC 6.0" INITIAL

HIGH TRAFFIC : (7.0+1.0)(32)(825)+23390 = 234 590
1 RUT REPAIR @ $19000/EACH = 19 000
4 MAINTENANCE @ $1100/YR = 4 400
$ 257 990 /MILE

MEDIUM TRAFFIC : (6.5+1.0)(32)(825)+23390 = 221 390
1 RUT REPAIR @ $19000/EACH = 19 000
4 MAINTENANCE @ $1100/YR = 4 400
$ 244 790 /MILE

LOW TRAFFIC : (6.0+1.0)(32)(825)+23390 = 208 190
1 RUT REPAIR @ $19000/EACH = 19 000
4 MAINTENANCE @ $1100/YR = 4 400
$ 231 590 /MILE

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OREGON STATE HIGHWAY DIVISION

Calculations for DESIGN ECONOMICS

Made by D.T. 11-22, 1978 Checked by ...., 19...... Backchecked by ...., 19......

20 YR. - STAGE CONSTRUCTED

INITIAL FULL DEPTH - 2"

2ND STAGE IS A 2" OVERLAY

MAINTENANCE

HIGH TRAFFIC 5.0" INITIAL; 2ND STAGE @ 5.5 YEARS
MED. TRAFFIC 4.5" INITIAL; 2ND STAGE @ 6.5 YEARS
LOW TRAFFIC 4.0" INITIAL; 2ND STAGE @ 7.5 YEARS

HIGH TRAFFIC: (5.0+1.0)(32)(825) + 23390 = 181 790
(2.0+0.5)(32)(825) + 16000 = 82 000
4 MAINTENANCE @ $1100 / YR = 4 400
\$268 190 / MILE

MED. TRAFFIC: (4.5+1.0)(32)(825) + 23390 = 168 590
(2.0+0.5)(32)(825) + 16000 = 82 000
4 MAINTENANCE @ $1100 / YR = 4 400
\$254 990 / MILE

LOW TRAFFIC: (4.0+1.0)(32)(825) + 23390 = 155 390
(2.0+0.5)(32)(825) + 16000 = 82 000
4 MAINTENANCE @ $1100 / YR = 4 400
\$241 790 / MILE

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OREGON STATE HIGHWAY DIVISION

Calculations for DESIGN ECONOMICS

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20 YR - STAGE CONSTRUCTION - 2ND STAGE DELAYED FOR 2 YEARS

MAINT. 2ND STAGE MAINTENANCE

INITIAL FULL DEPTH - 2"

HIGH TRAFFIC 5.0" INITIAL; 2ND STAGE @ 7.5 YEARS
MED. TRAFFIC 4.5" INITIAL; 2ND STAGE @ 8.5 YEARS
LOW TRAFFIC 4.0" INITIAL; 2ND STAGE @ 9.5 YEARS

2ND STAGE 3.0"

2ND STAGE IS DELAYED FOR 2 YEARS BY MAINTENANCE

HIGH TRAFFIC: (5.0 + 1.0)(32)(825) + 23390 = 181 790
(3.0 + 1.0)(32)(825) + 16000 = 121 600
6 MAINTENANCE @ $1100/YR = 6 600
$309 990/MILE

MED. TRAFFIC: (4.5 + 1.0)(32)(825) + 23390 = 168 590
(3.0 + 1.0)(32)(825) + 16000 = 121 600
6 MAINTENANCE @ $1100/YR = 6 600
$296 790/MILE

LOW TRAFFIC: (4.0 + 1.0)(32)(825) + 23390 = 155 390
(3.0 + 1.0)(32)(825) + 16000 = 121 600
6 MAINTENANCE @ $1100/YR. = 6 600
$283 590/MILE

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OREGON STATE HIGHWAY DIVISION

Calculations for DESIGN ECONOMICS

Made by D.T. 11-22, 1978. Checked by ...., 19...... Backchecked by ...., 19......

20 YR - STAGE CONSTRUCTION - 2ND STAGE DELAYED FOR 4 YEARS

INITIAL - FULL DEPTH - 2"

2ND STAGE IS 3.5"

2ND STAGE IS DELAYED 4 YEARS BY MAINTENANCE

HIGH TRAFFIC 5.0" INITIAL; 2ND STAGE @ 9.5 YEARS

MED. TRAFFIC 4.5" INITIAL; 2ND STAGE @ 10.5 YEARS

LOW TRAFFIC 4.0" INITIAL; 2ND STAGE @ 11.5 YEARS

HIGH TRAFFIC : (5.0+1.0)(32)(825) + 23390 = 181790

(3.5+1.0)(32)(825) + 23390 = 142190

8 MAINTENANCE @ $1100/YR = 8800

$332 780 /MILE

MED. TRAFFIC : (4.5+1.0)(32)(825) + 23390 = 168 590

(3.5+1.0)(32)(825) + 23390 = 142 190

8 MAINTENANCE @ $1100/YR = 8 800

$319 580 /MILE

LOW TRAFFIC : (4.0+1.0)(32)(825) + 23390 = 155 390

(3.5+1.0)(32)(825) + 23390 = 142 190

8 MAINTENANCE @ $1100/YR = 8 800

$306 380 /MILE

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OREGON STATE HIGHWAY DIVISION

Calculations for DESIGN ECONOMICS

Made by D.T. 11-24, 1978 Checked by ...., 19...... Backchecked by ...., 19......

20 YR - STAGE CONSTRUCTED - 2ND STAGE DELAYED BY SEAL COAT

INITIAL - FULL DEPTH - 2"

2ND STAGE IS DELAYED 2 YEARS BY O-33 SEAL COAT ($3,100)

LOW TRAFFIC 4.0" INITIAL
O-33 SEAL COAT; 2ND STAGE IS 3.0"
N/A TO MEDIUM AND HIGH TRAFFIC

LOW TRAFFIC: $(4.0+1.0)(32)(825)+23390 = 155\,390$

$(3.0+1.0)(32)(825)+16000 = 121\,600$

SEAL COAT $= 3\,100$

4 MAINTENANCE @ $1100/YR $= 4\,400$

$284 490/MILE

20 YR - STAGE CONSTRUCTED - 2ND STAGE DELAYED BY SEAL COAT

INITIAL - FULL DEPTH - 2"

2ND STAGE IS DELAYED 4 YEARS BY O-32 SEAL COAT ($5,200)

LOW TRAFFIC 4.0" INITIAL
O-32 SEAL COAT; 2ND STAGE IS 3.5"
N/A TO MEDIUM AND HIGH TRAFFIC

LOW TRAFFIC: $(4.0+1.0)(32)(825)+23390 = 155\,390$

$(3.5+1.0)(32)(825)+16000 = 134\,800$

SEAL COAT $= 5200$

4 MAINTENANCE @ $1100/YR $= 4400$

$299 790/MILE

Form 81-734-3106

Job No. ....

OREGON STATE HIGHWAY DIVISION

Calculations for DESIGN ECONOMICS

Made by D.T. 11-24, 1978 Checked by ...., 19...... Backchecked by ...., 19......

10 YR – FULL DEPTH

INITIAL – FULL DEPTH	HIGH TRAFFIC 6.0"	
	MED. TRAFFIC 5.5"	
	LOW TRAFFIC 5.0"	
2ND TREATMENT REQUIRED AT 10 YEARS		HIGH TRAFFIC 3.0"
		MED. TRAFFIC 2.5"
		LOW TRAFFIC 2.0"

HIGH TRAFFIC : $(6.0+1.0)(32)(825) + 23390 = 208\ 190$
$(3.0+1.0)(32)(825) + 16000 = \underline{121\ 600}$
\$ 329 790 /MILE

MED. TRAFFIC : $(5.5+1.0)(32)(825) + 23390 = 194\ 990$
$(2.5+1.0)(32)(825) + 16000 = \underline{108\ 400}$
\$ 303 390 /MILE

LOW TRAFFIC : $(5.0+1.0)(32)(825) + 23390 = 181\ 790$
$(2.0+1.0)(32)(825) + 16000 = \underline{95\ 200}$
\$ 276 990 /MILE

Form 81-734-3106

Job No. ....
Sheet 7 of 8 Sheets

OREGON STATE HIGHWAY DIVISION

Calculations for DESIGN ECONOMICS

Made by D.T. 11-27, 1978. Checked by ...., 19..... Backchecked by ...., 19.....

10 YR - STAGE CONSTRUCTED (1½" INITIALLY PLACED)

INITIAL 1½" E-MIX

2ND STAGE @ 4 YEAR
3"-2½"-2" @ 10 YRS (FOR 2ND 10 YR DESIGN)

HIGH TRAFFIC	1.5" INITIAL	4.5" @ 4 YEARS
MED. TRAFFIC	1.5" INITIAL	4.0" @ 4 YEARS
LOW TRAFFIC	1.5" INITIAL	3.5" @ 4 YEARS

HIGH TRAFFIC: (1.5 + 1.0)(32)(944) + 5700 = 81 220
(4.5+0.5)(32)(825) + 23390 = 155 390
(3.0+1.0)(32)(825) + 16000 = 121 600
$ 358 210 /MILE

MED. TRAFFIC: (1.5+1.0)(32)(944) + 5700 = 81 220
(4.0+0.5)(32)(825) + 23390 = 142 190
(2.5+1.0)(32)(825) + 16000 = 108 400
$ 331 810 /MILE

LOW TRAFFIC: (1.5+1.0)(32)(944) + 5700 = 81 220
(3.5+0.5)(32)(825) + 23390 = 128 990
(2.0+1.0)(32)(825) + 16000 = 95 200
$ 305 410 /MILE

Form 81-731-3106

Job No. ....

OREGON STATE HIGHWAY DIVISION

Calculations for DESIGN ECONOMICS

Made by D.T. 10-9 1978 Checked by ...., 19...... Backchecked by ...., 19......

MAINTENANCE: 6% - 4 YEARS \$24/TON
10% - 4 YEARS \$20/TON
15% - PAST 8 YRS \$20/TON

20 YR - STAGE 2ND STAGE NOT APPLIED

INITIAL FULL DEPTH MINUS 2"

HIGH TRAFFIC 5.0" INITIAL; MAINTENANCE STARTS @ 5.5 YRS
MED. TRAFFIC 4.5" INITIAL; MAINTENANCE STARTS @ 6.5 YRS
LOW TRAFFIC 4.0" INITIAL; MAINTENANCE STARTS @ 7.5 YRS

HIGH TRAFFIC: $158400 + 23390 + \underbrace{4(1100) + 4(3000) + 8(4600)}_{\text{MAINTENANCE}} + \underbrace{82000}_{\text{NEGATIVE SALVAGE VALUE}} = \$316990/\text{MI}$

MED. TRAFFIC: $145200 + 23390 + \underbrace{4(1100) + 4(3000) + 7(4600)}_{\text{MAINTENANCE}} + 82000 = \$299190/\text{MI}$

LOW TRAFFIC: $132000 + 23390 + \underbrace{4(1100) + 4(3000) + 6(4600)}_{\text{MAINTENANCE}} + 82000 = \$281390/\text{MI}$

100% OF MAINTENANCE COSTS ARE PAID BY STATE FUNDS; NO FEDERAL AID
LAST FIGURE IN THE EQUATIONS IS THE COST TO BRING THE ROAD BACK TO THE LEVEL IT WAS IN PRIOR TO INITIAL OVERLAY

SENSITIVITY ANALYSIS OF % MAINTENANCE PER YEAR (SHEET 5A) SHOW DIFFERENCES IN PER MILE COST (LESS THE NEGATIVE SALVAGE VALUE) FOR A 1% PER YEAR DIFFERENCE THROUGH OUT THE MAINTENANCE, AND A 5% DIFFERENCE IN THE MAINTENANCE DONE PAST THE FIRST 8 YEARS OF MAINTENANCE

Form 81-734-3106

Job No. ....

Sheet 1 of 1 Sheets

OREGON STATE HIGHWAY DIVISION

Calculations for MAINTENANCE COSTS

Made by D.T. 11-27-1978 Checked by ...., 19...... Backchecked by ...., 19......

MAINTENANCE THICKNESSES:

% OF AREA PATCHED	THICKNESS
$\leq 6\%$	1"
$> 6\%$	2"

COST OF PATCHING MATERIALS + LABOR = \$24/TON FOR $\leq 6\%$
\$20/TON FOR $> 6\%$

COST/MILE FOR MAINTENANCE:

6%: (1 IN)(5280 FT)(24 FT)(6%)(.006 TONS/FT^2·IN)(24 \$/TON) = \$1100/MILE

10%: (2 IN)(5280 FT)(24 FT)(10%)(.006)(20 \$/TON) = \$3000/MILE

15%: (2 IN)(5280 FT)(24 FT)(15%)(.006)(20 \$/TON) = \$4600/MILE

OVERLAY COST COMPUTATIONS FOR BOTH BENKELMAN BEAM DESIGNS & DISTRICT ENGINEER ESTIMATES

$Cost_{Overlay} = L$

For Curbed Section When $T > 2''$: $4'' W_p \overset{K_5}{K_{AC}} + W_p \overset{K_6}{K_B} + \overset{K_7}{K_{UF}}$

Non Curbed Section Or Curbed Section When $T \leq 2''$: $(T + 1''\ \text{Leveling Course})\ W_p \overset{K_5}{K_{AC}} + T W_g \overset{K_8}{K_g} +$

When $T > 3''$:
- For Interstate & Principal Arterial → K_{F1} (K_7)
- Minor Arterial → K_{F2} (K_{10})
- Collector & Local → K_{F3} (K_{11})

When $T \leq 3''$:
- For Interstate & Principal Arterial → K_{F4} (K_{12})
- Minor Arterial → K_{F5} (K_{13})
- Collector & Local → K_{F6} (K_{14})

L = Length of highway section

T = Thickness of asphaltic concrete overlay

W_p = Width of pavement

$K_5 = K_{AC}$ = Cost of asphaltic concrete per inch of thickness, foot of width, & mile length

$K_6 = K_B$ = Cost of 10" thick Bituminous Base per foot of width & mile length

$K_7 = K_{UF}$ = Cost of utilities adjustment, flagging, & other per mile costs

W_g = Width of graveled shoulders if any

$K_8 = K_g$ = Cost of aggregate for gravel shoulders per foot of width & mile length

K_{F1}, K_{F2}, K_{F3} = Cost for flagging, guardrail, & other per mile varied by Functional Classification

K_{F4}, K_{F5}, K_{F6} = Cost for flagging & other per mile varied by Functional Classification