

3 Excess Fines Design

- 3.1. Introduction
- 3.2. Summary of Excess Fines Design
- 3.3. Principal Concepts
- 3.4. Stepping Through the Design Process: An Example
- 3.5. Excess Fines Design Using the AKFPD Computer Program

3.1 Introduction

This chapter provides a complete discussion of the excess fines design method. The AKFPD excess fines method is approved only for the design of some new, highway pavements. Chapter 2 provides detailed information concerning appropriate applications for this design method.

3.2 Summary of Excess Fines Design

Research leading to development of the excess fines method started in 1976 with the study of 120 asphalt concrete paved road sections throughout Alaska. Results of this research effort are described in reports published between 1980 and 1983.⁽¹⁰⁻¹¹⁾ An empirically derived design method was generated from this research and officially adopted for use by the DOT&PF in 1982.⁽¹²⁾ The Excess Fines Module of AKFPD provides a simple and rapid implementation of the Excess Fines Design procedures. While the designer can simply fill in the data fields and successfully create an acceptable design, it is important that the designer understand the concepts behind the procedure and the limitations of the procedure. Since the Excess Fines method was empirically derived, it is imperative that the designer stay within the bounds of the data from which the procedure was derived. While the software limits the more obvious inputs, it may not eliminate all potential violations of these bounds.

3.3 Principal Concepts

Alaska's excess fines design method relies on the following two empirically derived concepts:

1. An empirically definable relationship exists between pavement surface deflection at the center of a standard wheel load and the service life of the pavement in terms of the number passes of that wheel load. In the case of highway pavement design, the design load has long been standardized in the form of the 18,000 pounds dual-wheeled axle (110 psi tire pressure). This standard axle load is also known as the Equivalent Single Axle Load (ESAL).

$$\text{Service Life} = f(\text{deflection})$$

2. An empirically definable relationship exists between pavement surface deflection at the center of a standard wheel load and the amount of P_{200} material contained within individual layers of the pavement structure.

$$\text{Deflection} = f(\text{amount of } P_{200} \text{ in aggregate layers})$$

Simple calculations predict deflection at the surface of the pavement structure based on the amount of P_{200} in each granular layer of the structure. Another calculation determines the thickness of asphalt concrete pavement needed to reduce the predicted deflection level to accommodate the design number of ESALs without pavement failure.

3.3.1 Relationship Between P_{200} Content and Pavement Surface Deflection (A Measure of Pavement Structural Strength)

Based on Alaska DOT&PF research cited previously,⁽¹³⁾ increasing the P_{200} increases the potential of springtime thaw weakening which results in higher deflections. Higher deflections translate to fewer loadings to failure. Consequently, the Excess Fines method uses the P_{200} to estimate the deflections during spring thaw.

As wintertime cooling continues, a freezing interface or “freezing front” moves downward through the granular layers of the pavement structure. As the freezing front advances downward, soil moisture continually migrates upward toward the interface between frozen and unfrozen material. The upward transport of moisture during soil freezing satisfies energy balance requirements within the soil mass. After soil moisture reaches the freezing front, it freezes and becomes incorporated as part of the newly frozen soil mass. The process of freezing front progression, upward moisture migration, and freezing continues throughout the winter if appropriate temperature gradients exist in the soil. DOT&PF research correlated the amount of frozen moisture accumulating within a granular layer to the amount of P_{200} contained in that layer, establishing a relationship between P_{200} and frozen moisture content. Figure 3-1 illustrates the condition of the pavement structure during the freezing process.

As common sense suggests, frozen moisture is of little concern. On the other hand, the combination of springtime thawing and high moisture content in pavement structural layers is very much a problem. DOT&PF research derived a useful functional relationship between thaw weakening of the pavement structure and the amount of P_{200} contained in various layers of the pavement structure. The indicator of thaw weakening employed during the research project was measurement of pavement surface deflection in response to a standard test load, thus establishing a relationship between P_{200} and deflection. The standard test load used during research was the one side of a standard ESAL. The dual wheel set weighed 9,000 pounds total with tire pressures set at 80 psi. Figure 3-2 shows the pavement structure weakened by thaw.

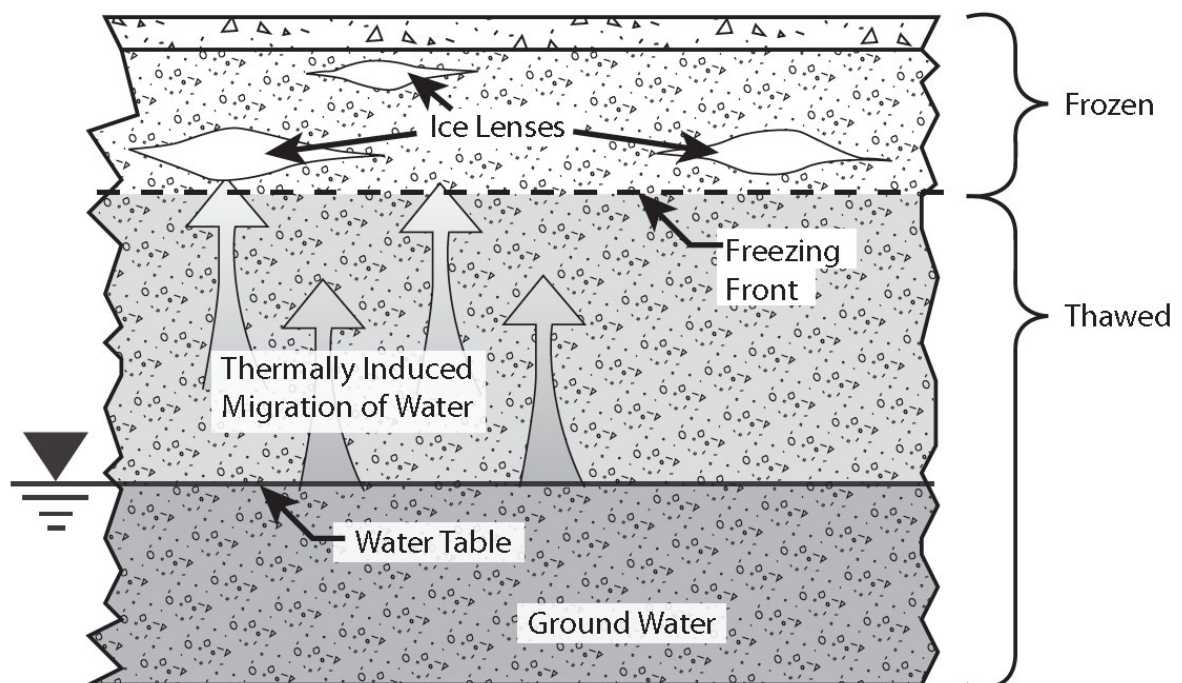


Figure 3-1 Progression of Freezing Front and Ice Formation

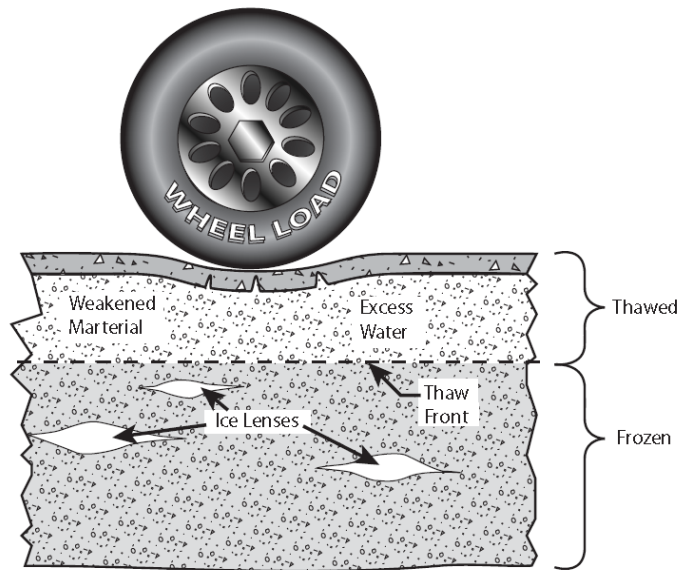


Figure 3-2 Soft Pavement Structure During Thawing

DOT&PF research refined the relationship between P_{200} and deflection by creating a function that attaches increasing importance to high P_{200} contents in upper layers of the pavement structure, which relates to the attenuating distribution of live-load stress with depth. Common sense and research provide the same conclusion: materials deep in the pavement structure “feel” almost none of the vehicle load and are therefore of less concern. Figure 3-3 illustrates the attenuation of strains (also stresses) with depth in the pavement structure.

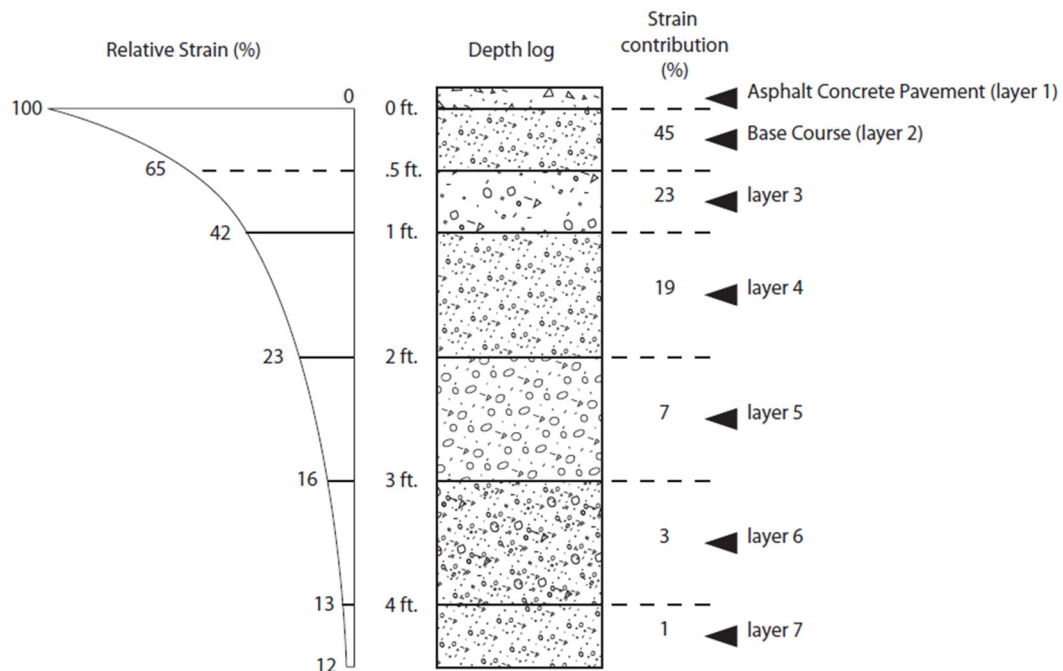


Figure 3-3 Attenuation of Vehicle Load with Depth

3.3.2 Relationship Between Pavement Surface Deflection and Pavement Service Life

As explained above, DOT&PF research derived a functional relationship between aggregate layer P₂₀₀ contents and deflection. However, an additional design step is necessary. The design process requires a relationship between calculated deflection, design ESALs, and required asphalt concrete layer thickness. For this, DOT&PF modified and adopted The Asphalt Institute’s TAI procedure from their 1977 MS-17 publication.⁽¹⁴⁾

3.3.3 Calculations Used in the Excess Fines Method

Separate each material layer into analysis layers based on the P₂₀₀ content, with a maximum of 1-inch layer thickness. Analyze the pavement structure to a depth of 40 inches below the bottom of the asphalt concrete layer. This can include in-place material in the foundation.

Determine the critical fines content (P_{CR}) for each layer, using Figure 3-4. Enter the vertical axis with the depth from the bottom of the asphalt concrete layer to the top of each aggregate layer and move horizontally to intersect the P_{CR} line. Read the value of P_{CR} for that layer on the horizontal axis.

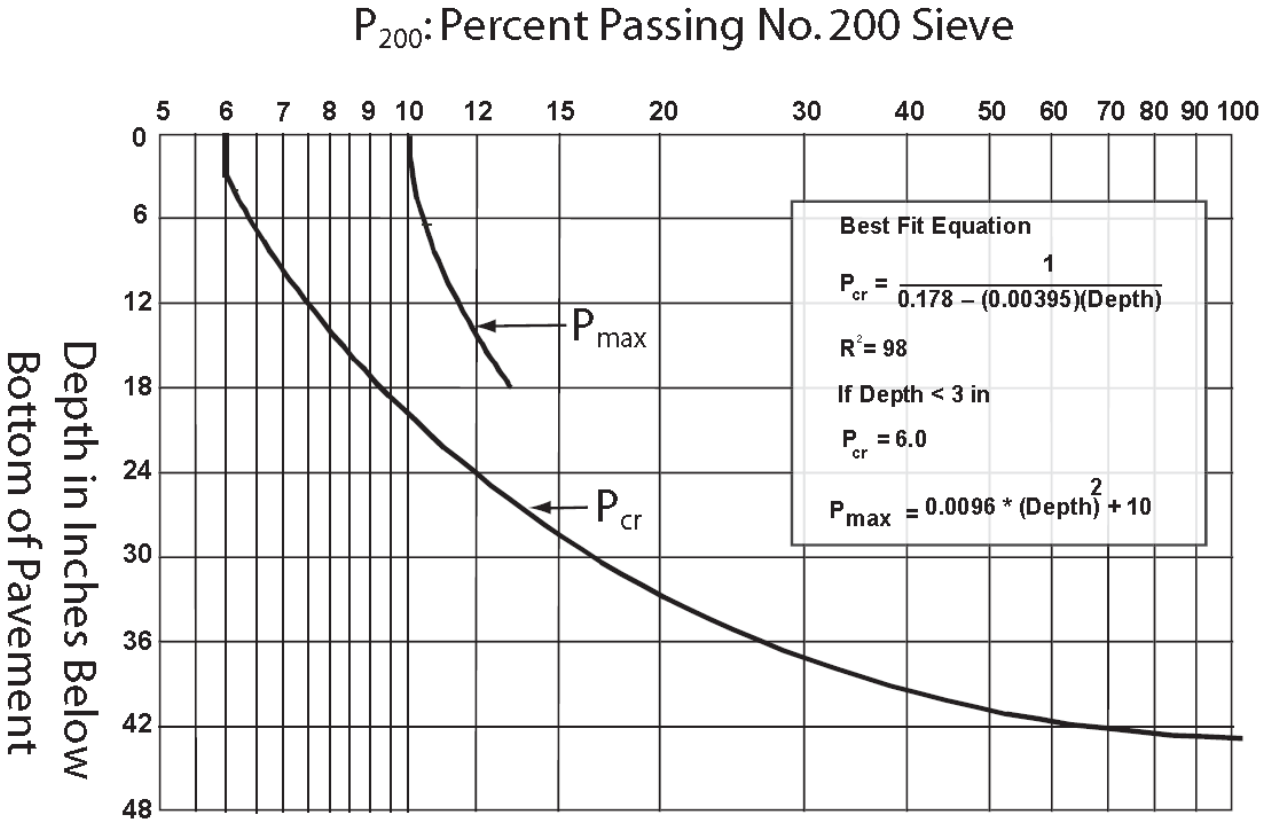


Figure 3-4 Critical and Maximum Fines Versus Depth

In no case shall the P₂₀₀ exceed P_{max} for an analysis layer (i) with its top between 0 inches and 18 inches beneath the asphalt concrete layer (See P_{max} line on Figure 3-4).

Some materials degrade when crushed and handled. It is important that the P₂₀₀ estimated for the base layer is the anticipated P₂₀₀ of the crushed material after it has been placed and compacted. If the degradation value (Alaska

Test Method, ATM 313) of the material is less than 45, check with the regional materials engineer for guidance.

Calculate the excess fines for each layer (i) to the nearest tenth of a percent. If the calculated excess fines are less than or equal to zero, consider them equal to zero.

$$\text{Excess Fines } (i) = (P_{200} - P_{cr})i$$

For each such layer (i) find the change in stress reduction factor (ΔSRF). The ΔSRF is equal to the stress reduction factor (SRF) at the bottom of layer (i) minus the SRF at the top of layer (i). SRF is presented in graphical form in Figure 3-5.

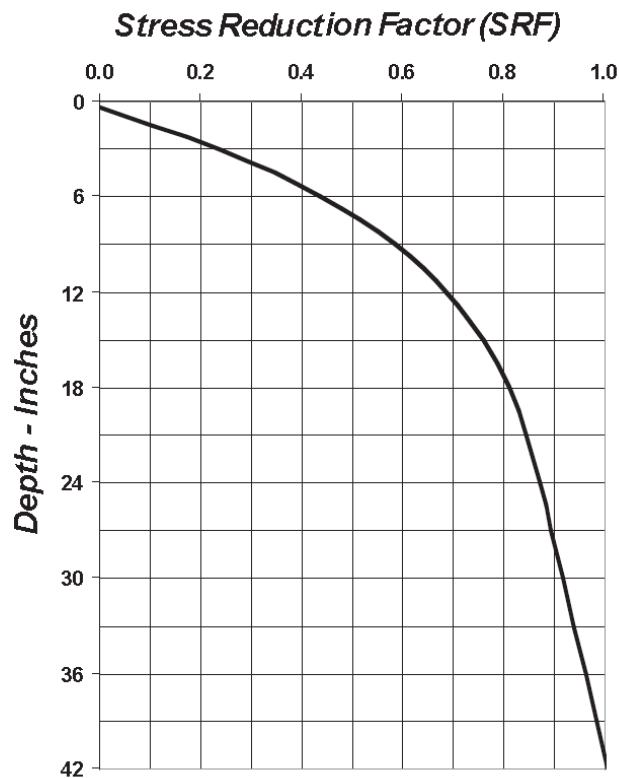


Figure 3-5 Stress Reduction Factor vs Depth Beneath a Thin Asphalt Concrete (assumes homogeneous elastic material and a standard ESAL loading)

$$SRF = -7.6477232 \times 10^{-7} y^4 + 9.7898212 \times 10^{-5} y^3 - 0.0046242158 y^2 + 0.10298199 y - 0.034613$$

where: y = depth in inches

(If SRF is negative, set SRF to zero)

Calculate the excess fines factor (EFF_i) for each layer, i.e.

$$EFF_i = (\Delta SRF_i) [(P_{200} - P_{cr})^{0.8}]$$

Add all the EFF_i values to get total EFF

$$EFF_t = \sum EFF_i$$

Calculate the predicted maximum deflection, D_p , according to the statistical relationship:

If $EFF_t = 0$, then $D_p = 0.034$

If $EFF_t > 0$, then $D_p = 0.056 + 0.0035(EFF_t)$

Determine the required pavement thickness. Enter Figure 3-6, with the predicted maximum deflection, D_p , on the horizontal axis, move vertically to intersect the appropriate equivalent axle loading (ESAL) curve, and read the required asphalt concrete pavement thickness from the vertical axis. The minimum pavement thickness is 2 inches. The thickness should be rounded up to the nearest 0.5 inch.

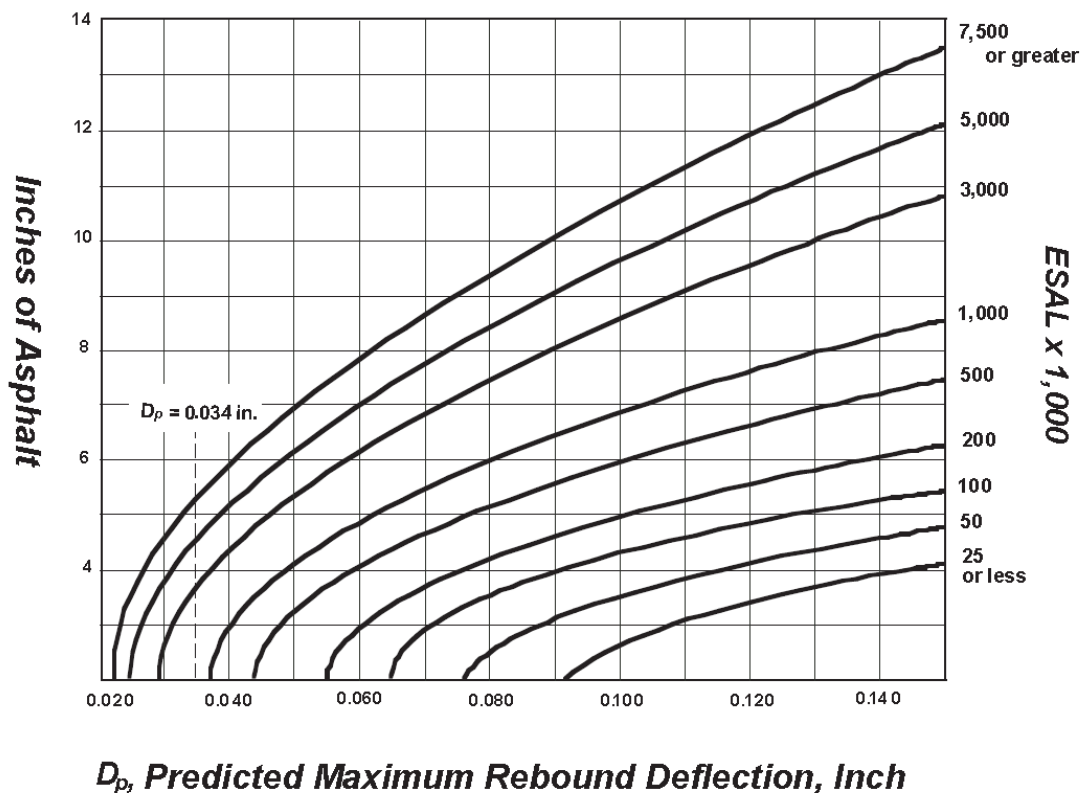


Figure 3-6 Pavement Design Chart

3.4 Stepping Through the Design Process: An Example

This example explains the excess fines design method as a series of simple computational steps. Each computational step in the example is aided by the tabular formatting shown in Table 3-1.

Step 1. Define design ESALs and a system of aggregate layers with P_{200} contents as shown below:

Table 3-1 Example Aggregate Layers

Layer Depth (inch)	P_{200} Content (%)
0 to 6	8
6 to 18	10
18 to 42	20

Design ESALs = 964,200

Step 2. Subdivide actual layering into layering shown in column 1 of Table 3-2.

Step 3. Enter applicable fines content (P_{200}) in column 2 of Table 3-2.

Step 4. Determine critical fines content (P_{cr}) for each layer from Figure 3-4. Place in column 3 of Table 3-2. Ensure that P_{200} in the upper 18 inches does not exceed P_{max} in Figure 3-4.

Step 5. Determine excess fines for each layer to the nearest tenth of a percent. Place in column 4 of Table 3-2.

$$Excess\ Fines = P_{200} - P_{cr}$$

If $P_{200} - P_{cr} < 0$, then excess fines = 0. Do not use negative values. (See layer 34 in Table 3-2.)

Step 6. Determine the change in stress reduction factor (SRF) for each layer from Figure 3-5. To do this, first locate the SRF at the top of the layer and the SRF at the bottom of the layer. Place these numbers in columns 5 and 6, respectively, of Table 3-2. Then subtract the smaller number (SRF at the top of the layer) from the larger number (SRF at the bottom of the layer). This is best done by calculating the SRFs from the equation shown in Figure 3-5. Place the result for each layer in column 7 of Table 3-2.

Step 7. Determine the excess fines factor (EFF) for each layer, and place in column 8 of Table 3-2.

$$EFF = (\Delta SRF) (P_{200} - P_{cr})^{0.8}$$

Step 8. Sum the EFFs for all layers at the bottom of column 8 of Table 3-2.

Step 9. Determine the predicted maximum deflection (D_p) $EFF > 0$, i.e., $EFF = 2.14$

Therefore:
$$D_p = 0.056 + 0.0035(EFF_t)$$

$$D_p = 0.056 + 0.0035(2.14)$$

$D_p = 0.063$ inch (bottom of Table 3.2)

Step 10. Determine the required asphalt concrete pavement thickness from Figure 3-6.

Entering Figure 3-6 with $D_p = 0.064$ and ESALs = 964,200

Figure 3-6 requires pavement thickness = 5.0 inches (rounded up to nearest 0.5 inch)

Table 3-2 Excess Fines Pavement Design Example

Column	1	2	3	4	5	6	7	8
Obtained From	Trial Dimensions	Specifications of Field Data	Figure 3.4	Column 2 minus Column 3	Figure 3.5	Figure 3.5	Column 6 minus Column 5	Column (7)*(4) ^{0.8}
Layer Number	Depth Interval (inches)	Fines Content (P ₂₀₀)	Critical Fines (P _{cr})	Excess Fines	SRF at Top of Layer	SRF at Bottom of Layer	Δ SRF	EFF
1	0 to 1	8	6.00	2.00	0.000	0.064	0.064	0.11
2	1 to 2	8	6.00	2.00	0.064	0.154	0.090	0.16
3	2 to 3	8	6.00	2.00	0.154	0.235	0.081	0.14
4	3 to 4	8	6.00	2.00	0.235	0.309	0.074	0.13
5	4 to 5	8	6.20	1.80	0.309	0.376	0.067	0.11
6	5 to 6	8	6.30	1.70	0.376	0.437	0.061	0.09
7	6 to 7	10	6.50	3.50	0.437	0.491	0.054	0.15
8	7 to 8	10	6.70	3.30	0.491	0.540	0.049	0.13
9	8 to 9	10	6.80	3.20	0.540	0.584	0.044	0.11
10	9 to 10	10	7.00	3.00	0.584	0.623	0.039	0.09
11	10 to 11	10	7.20	2.80	0.623	0.658	0.035	0.08
12	11 to 12	10	7.40	2.60	0.658	0.689	0.031	0.07
13	12 to 13	10	7.70	2.30	0.689	0.716	0.027	0.05
14	13 to 14	10	7.90	2.10	0.716	0.740	0.024	0.04
15	14 to 15	10	8.10	1.90	0.740	0.761	0.021	0.04
16	15 to 16	10	8.40	1.60	0.761	0.780	0.019	0.03
17	16 to 17	10	8.70	1.30	0.780	0.797	0.017	0.02
18	17 to 18	10	9.00	1.00	0.797	0.811	0.014	0.01
19	18 to 19	20	9.40	10.60	0.811	0.825	0.014	0.09
20	19 to 20	20	9.70	10.30	0.825	0.836	0.011	0.07
21	20 to 21	20	10.10	9.90	0.836	0.847	0.011	0.07
22	21 to 22	20	10.50	9.50	0.847	0.856	0.009	0.05
23	22 to 23	20	11.00	9.00	0.856	0.865	0.009	0.05
24	23 to 24	20	11.50	8.50	0.865	0.873	0.008	0.04
25	24 to 25	20	12.00	8.00	0.873	0.881	0.008	0.04
26	25 to 26	20	12.60	7.40	0.881	0.888	0.007	0.03
27	26 to 27	20	13.30	6.70	0.888	0.895	0.007	0.03
28	27 to 28	20	14.00	6.00	0.895	0.902	0.007	0.03
29	28 to 29	20	14.80	5.20	0.902	0.910	0.008	0.03
30	29 to 30	20	15.80	4.20	0.910	0.917	0.007	0.02
31	30 to 31	20	16.80	3.20	0.917	0.924	0.007	0.02
32	31 to 32	20	18.00	2.00	0.924	0.932	0.008	0.01
33	32 to 33	20	19.40	0.60	0.932	0.939	0.007	0.00
34	33 to 34	20	21.00	0.00	0.939	0.947	0.008	0.00
35	34 to 35	20	22.90	0.00	0.947	0.955	0.008	0.00
36	35 to 36	20	25.20	0.00	0.955	0.963	0.008	0.00
37	36 to 37	20	27.90	0.00	0.963	0.971	0.008	0.00
38	37 to 38	20	31.40	0.00	0.971	0.979	0.008	0.00
39	38 to 39	20	35.80	0.00	0.979	0.986	0.007	0.00
40	39 to 40	20	41.80	0.00	0.986	0.994	0.008	0.00
							EFF_t	2.14
<p>Calculations: Predicted Deflection D_p = 0.064 If EFF_t = 0 then D_p = 0.034.. If EFF_t > 0 then D_p = 0.056 + 0.0035(EFF_t) Pavement thickness from Figure 3-6 (Enter with D_p on the horizontal Axis, rise vertically to curve for ESALs, then horizontally to read pavement thickness on vertical axis) = 5.0 inches for 964,200 ESALs.</p>								

3.5 Excess Fines Design Using the AKFPD Computer Program

Perform excess fines designs for projects using the AKFPD program. The previous example “by hand” was meant to acquaint you with the computations used by AKFPD.

3.5.1 Generalized Steps Through the Excess Fines Module

1. After opening the program select *Start a New Project* and insert the project data, designer, etc.
2. Select the Excess Fines Design Method.
3. Input design ESAL data supplied by Regional Traffic/Planning Section (see chapter 6).
4. Input P_{200} content and thickness of each layer of material that will be used to a depth of 40 inches below the asphalt concrete layer into the Excess Fines Design page and run the program.
5. AKFPD subdivides each aggregate layer into 1-inch-thick sublayers.
6. AKFPD assigns each sublayer the appropriate P_{200} content at that depth (using the P_{200} content entered as design input data).
7. AKFPD calculates the amount of pavement deflection that would occur if the pavement structure were to be subjected to the dual tire loading from one side of a standard ESAL axle.* Pavement deflection is a function dependent on (1) the percent P_{200} at each sublayer depth and (2) the amount of load support contributed by each sublayer (derived from Boussinesq stress distribution theory).

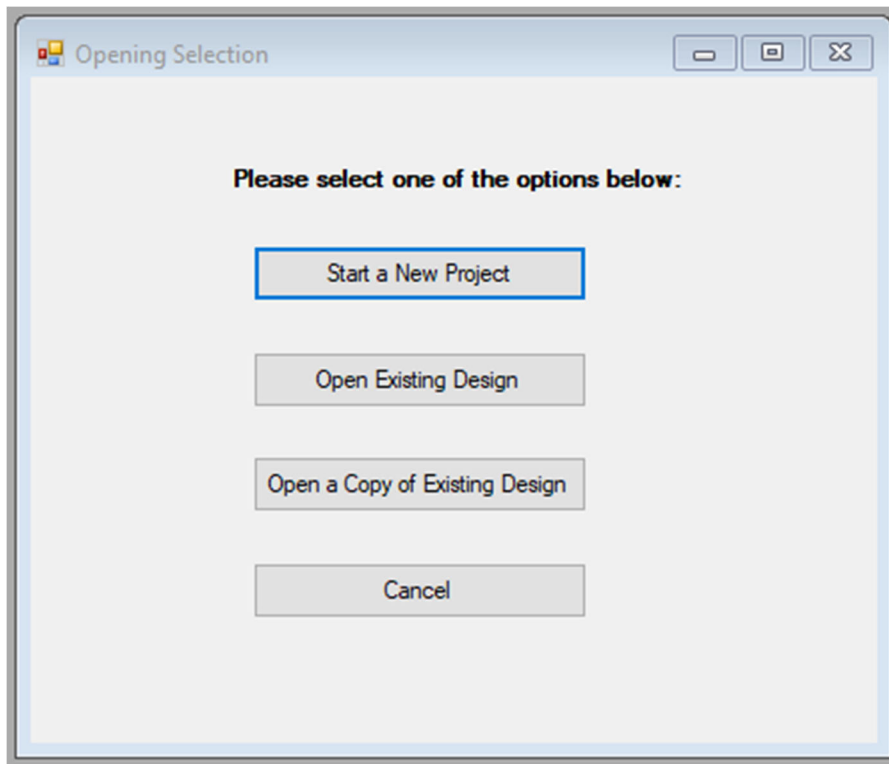
* The standard ESAL wheel load is now defined as two tires, each inflated to 110 psi, each loaded to 4,500 lbs., with a centerline-to-centerline separation of 13.5 inches.
8. AKFPD then calculates the required asphalt concrete thickness. Pavement thickness is a function dependent on (1) pavement deflection and (2) the total number of design ESALs.
9. If the calculated asphalt concrete thickness is not acceptable, the designer adjusts the input data and rerun the Excess Fines Design module.

3.5.2 Example 1—Getting Started and Performing a Simple Design

The following steps lead you through a simple example of AKFPD excess fines pavement design analysis and interpretation of the results. It is assumed that the software is installed on the computer and that the designer is familiar with the computer.

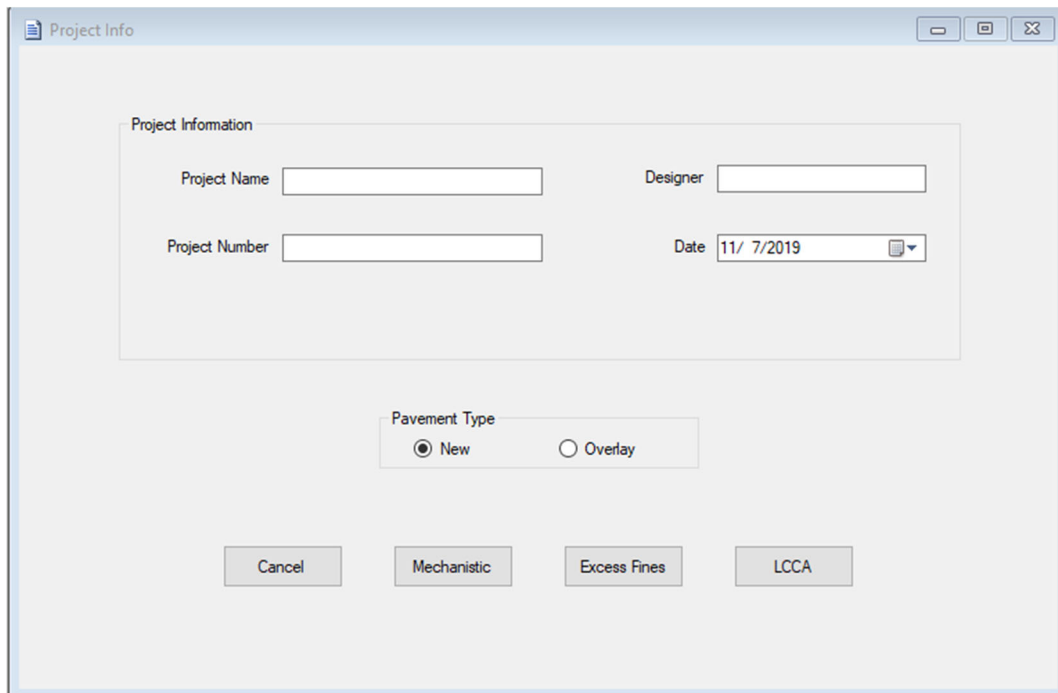
The first design example, which is explained in detail, does not use a previously saved input data file. You will use a previously saved input data file in the next example.

Step 1. Start the AKFPD software using the Start Menu. This varies slightly for each operating system. The AKFPD title screen will briefly appear followed by the landing page. (Screen Clip 3-1): To start a new project, click *Start a New Project*. This will open the project input screen with all fields blank. The *Open Existing Design* button will open an existing project in its current file location. Any changes to the data will be made in the current file and previous data will be lost. The *Open a Copy of Existing Design* button will create a new copy of an existing project so that the original data will be preserved. This is quite useful when exploring multiple options of a project design.



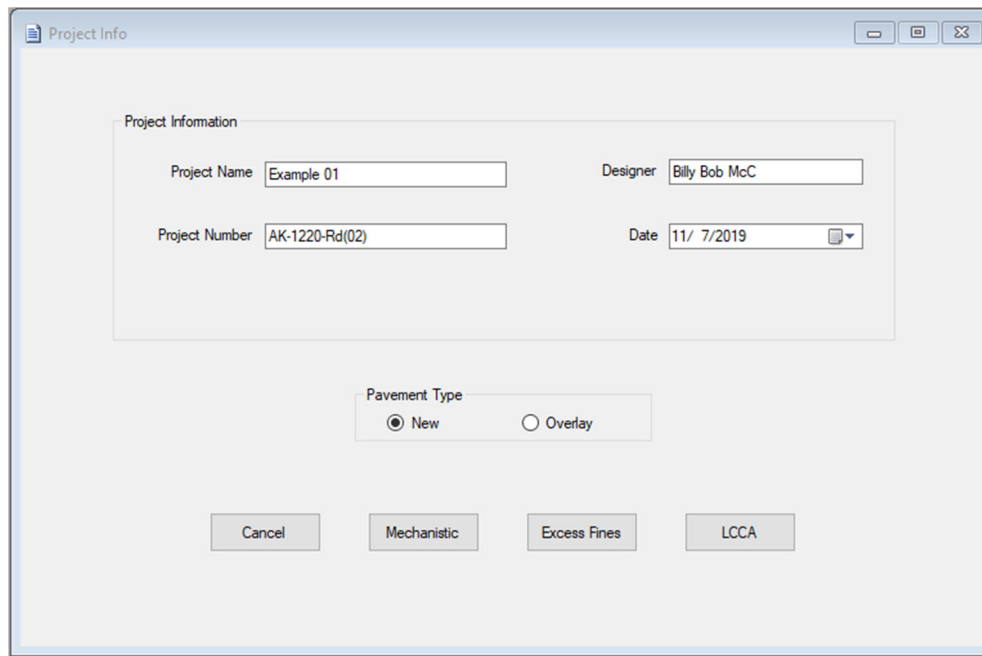
Screen Clip 3-1

Step 2. Start a new project for this example click on *Start a New Project*. The Project Info page will appear. (Screen Clip 3-2)



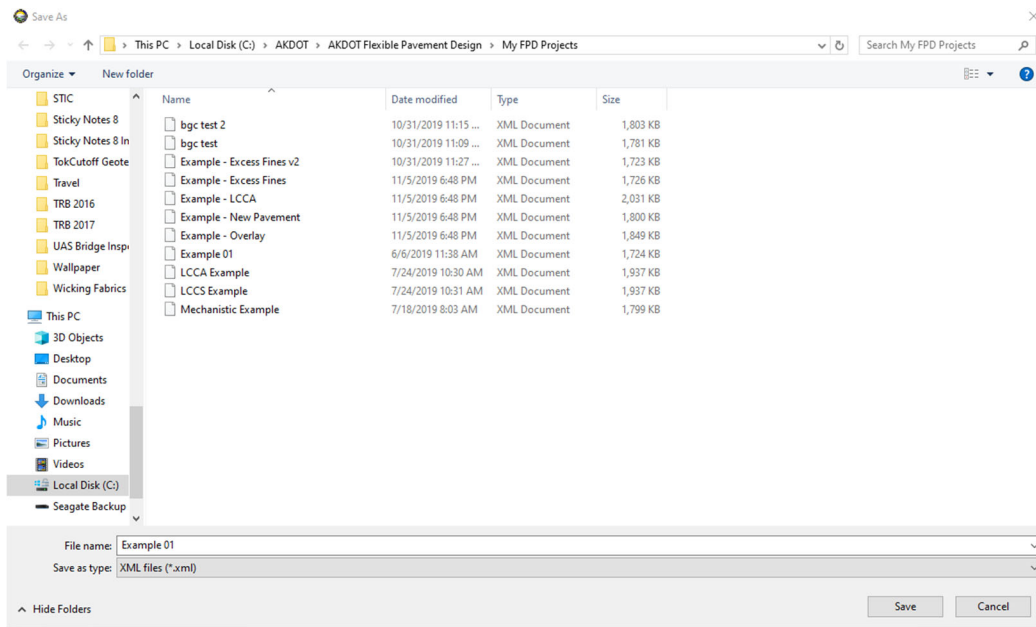
Screen Clip 3-2

Step 3. Fill in the appropriate data and click *New* then *Excess Fines*. (Screen Clip 3-3)



Screen Clip 3-3

Step 4. Enter a filename tied to the project. In this case “Example01.” Click *Save*. (Screen Clip 3-4)



Screen Clip 3-4

Step 5. There are two choices based on the information supplied by the Regional Traffic Section:

- a. Manually enter ESALs as provided by the Traffic Section. The design period, design construction year, base year, and base year total AADT must still be entered. After entering required data click **Manual ESALS**. (Screen Clip 3-5)

Or,

- b. Enter requested data and compute ESALs by clicking “Calculate.” If the Computed Design ESALs appears reasonable, click **Next**. Otherwise correct incorrect values and recalculate. (Screen Clip 3-6)

Screen Clip 3-5

Screen Clip 3-6

Step 6. This brings up the Excess Fines input screen (Screen Clip 3-7). This screen contains all input data for the analysis. All data items required for doing the complete excess fines analysis are typed as input onto the input screen (Screen Clip 3-8); click **Analyze**. Your completed screen should look like the one shown in Screen Clip 3-8. Note, the Total ESALs on the traffic page (Step 5 will be brought forward. The user is not allowed to enter values in the gray blocks. Consequently, if the ESALS require change, return to the traffic page.

Screen Clip 3-7

Layer No.	Depth Interval (in)	Thickness (in)	P200(%)
1	0 - 6	6	8
2	6 - 18	12	10
3	18 - 42	24	20

	Thickness (in)		
	Design Alternative	Asphalt Concrete	Stabilized Base
1	1.5	6	
2	2	5.5	
3	2.5	4.5	
4	3	3.5	
5	3.5	2.5	
6	4	2	
7	4.5	1	
8	5	0	

Screen Clip 3-8

The solution is shown in the Solution box (right-hand side of Screen Clip 3-8). The estimated deflection is 0.062 inches. Refer to Figure 3-6 with a traffic level of 964,200 ESALs. The required thickness of asphalt concrete is 5 inches which agrees with the AC thickness computed by the Excess Fines Design example. This example considers a case where the excess fines design method will require a pavement thickness of more than 3 inches. When the design process requires more than 3 inches of asphalt concrete, the software provides an alternative Stabilized Base Design. (Screen Clip 3-9) The alternative design assumes an asphalt stabilized base of with a Marshall Stability of 800 pounds. Note this value can be changed by the user based on values obtained from the laboratory. Contact the regional materials laboratory to obtain values for the material that will be used on the project. Any combination of Asphalt Concrete and Stabilized Base thickness is acceptable. It is the responsibility of the designer to select the most cost-effective combination.

Alternative Stabilized Base Design

Marshall Stability (lbs):

Design Alternative	Thickness (in)	
	Asphalt Concrete	Stabilized Base
1	<input type="text" value="1.5"/>	<input type="text" value="6"/>
2	<input type="text" value="2"/>	<input type="text" value="5.5"/>
3	<input type="text" value="2.5"/>	<input type="text" value="4.5"/>
4	<input type="text" value="3"/>	<input type="text" value="3.5"/>
5	<input type="text" value="3.5"/>	<input type="text" value="2.5"/>
6	<input type="text" value="4"/>	<input type="text" value="2"/>
7	<input type="text" value="4.5"/>	<input type="text" value="1"/>
8	<input type="text" value="5"/>	<input type="text" value="0"/>

Screen Clip 3-9

Step 7. If the design is not acceptable go back and modify the layer thicknesses and fines content and recalculate until an acceptable design is reached. Then click **Generate Report**. This report documents the design and contains the project information, the name of the designer, traffic information, design input, the solution, and the date of the analysis (Screen Clip 3-10). The report cannot be altered by the user. Any modifications must be made by returning to the Excess Fines Module.

Alaska DOT&PF Flexible Pavement Design Software, Version 2.0 - Project: Excess Fines Example (Filename: Example - Excess Fines.xml) - [Workbook: Excess Fines]

	A	B	C	D	E	F
1	Project Name: Excess Fines Example			Designer: AKDOT&PF		
2	Project Number: EX03			Date: 1/27/2020		
3	Pavement Type: New Design			Unit: US Customary		
4						
5						
6	INPUT DATA			SOLUTION		
7						
8	TRAFFIC DATA			Predicted Deflection: 0.063 in		
9	ESALs: 964,200			AC Thickness: 5 in		
10	AADT: 5,000					
11				ALTERNATIVE STABILIZED BASE DESIGN		
12	UNBOUND LAYERS DATA			Marshall Stability (lbs): 800		
13						
14				Thickness (in)		
15				Asphalt Concrete Stabilized Base		
16	Layer	Thickness (in)	P200 (%)	1.5	6	
17	1	6	8	2	5.5	
18	2	12	10	2.5	4.5	
19	3	24	20	3	3.5	
20				3.5	2.5	
21				4	2	
22				4.5	1	
23				5	0	
24						
25						
26						

Screen Clip 3-10

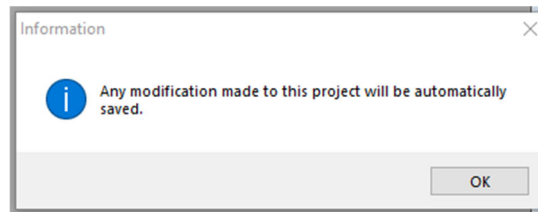
Step 8. Print the report selecting **File** then **Print** using the Ribbon at the top of the primary window.

Step 9. If you wish to perform another analysis, it is suggested that you select **File** then **Copy To** and give the file a new name such as “Example 01a.” The software will create another file that can be modified without altering the file you just completed. Make any desired changes and analyze as before.

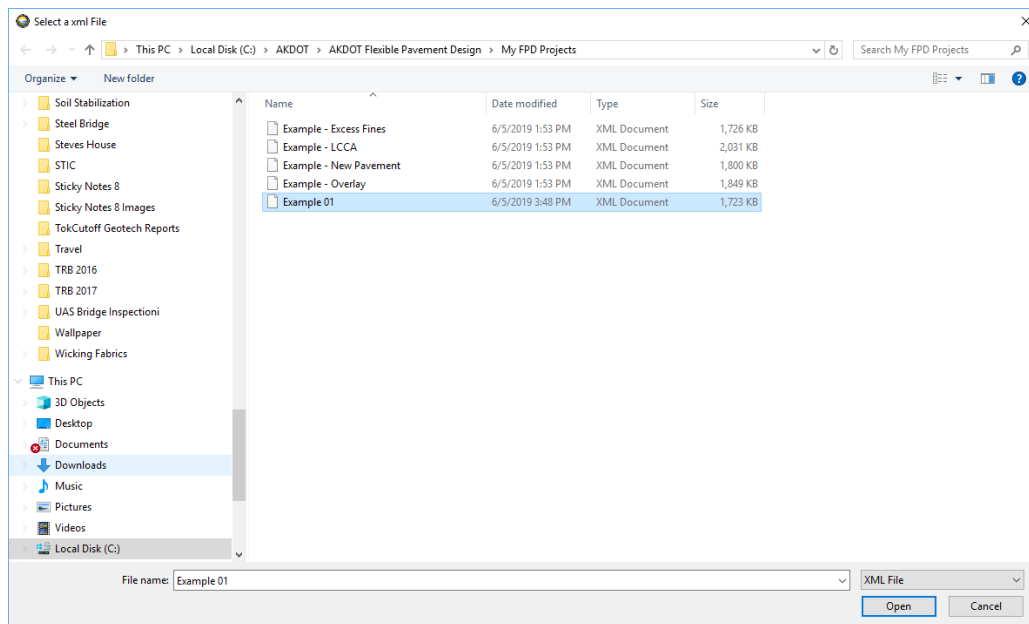
If you are finished, you may exit the program by clicking **File** then **Exit** in the left corner of ribbon across the top of the Excess Fines windows. The data has been saved for future reference.

3.5.3 Recalling Files and Modifying Files

There are two ways of recalling an existing file. By clicking the **Open Existing Design** button on the landing page shown in Screen Clip 3-1, Screen Clip 3-11 will appear warning the user that modifications will be saved. Saved data will overwrite the existing data. The warning screen will be replaced with a list of available files (Screen Clip 3-12).

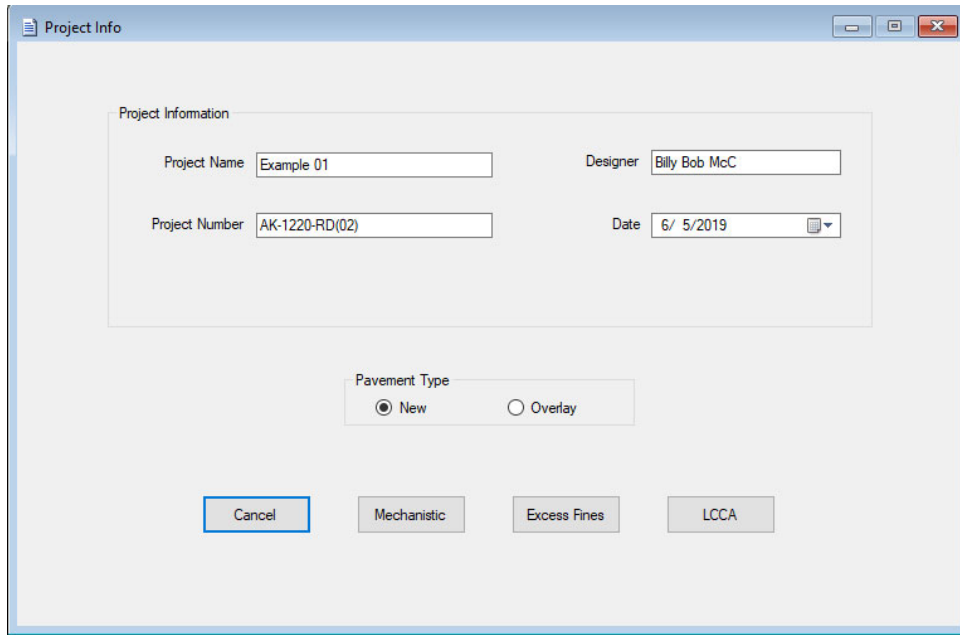


Screen Clip 3-11



Screen Clip 3-12

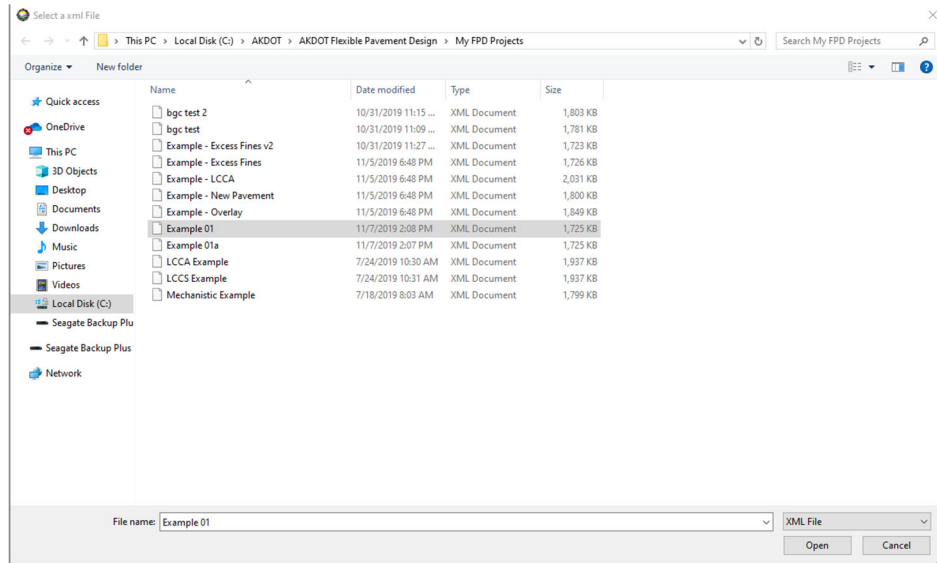
Type in or select “Example01” and then click **Open**. The Project Info page will open. (Screen Clip 3-13)



Screen Clip 3-13

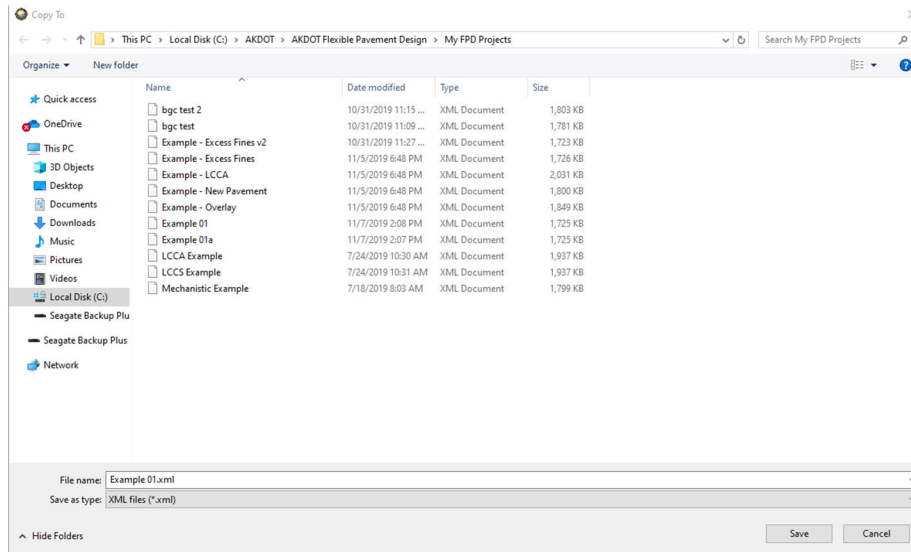
At this point, any changes to the data will overwrite the data in that file causing the loss of previously stored data.

If the user wishes to save the existing data, select ***Open a Copy of Existing Design*** from the opening screen (Clip 3-1). Available files will be displayed (Screen Clip 3-14).



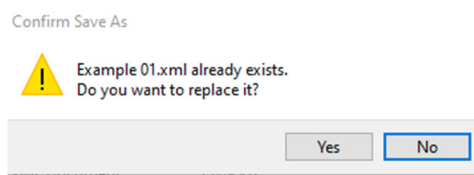
Screen Clip 3-14

Select the desired file and click ***Open***. In this case Example 01. The screen shown in Screen Clip 3-15 will appear.



Screen Clip 3-15

Note that this screen looks much like the previous screen except the button in the lower right has been changed from “Open” to “Save”. Give the filename a unique name such as “Example 01a” indicating this is a variation of Example 01. If a unique name is not selected or the user forgets to change the name a message will appear as shown in Screen Clip 3-16.



Screen Clip 3-16

Select **No** to go back to the file list to revise the name. Select **Yes** to accept the name and the data in that file will be replaced with the new data. From this point forward, any changes to the file will overwrite existing data. If the user does not wish to make changes to the file either click **File**, then **Exit** and restart the program or click **File** then **Close All**.

