

FULL DEPTH RECLAMATION USING FOAMED ASPHALT

13.1 OVERVIEW

This guide has been prepared to provide guidance on project selection, materials, pavement structure design, and development of full depth reclamation with foamed asphalt (FDR-FA) projects in California. FDR-FA was previously referred to as cold foam in-place recycling (CFIPR). This chapter provides specific information to supplement the Highway Design Manual (HDM), specifications, and other available guidance.

FDR-FA is an in-place flexible pavement rehabilitation strategy that transforms existing asphalt concrete (AC) into stabilized base for a new pavement surface layer. This guide is presented as for an FDR-FA project designed as a flexible pavement structure. If project parameters dictate a concrete surface is an effective strategy, design the rigid structure using the tables in Index 623.1 for the appropriate climate region and subgrade instead of using Sections 13.3.2, 13.7, and Appendix A. Use the thickness indicated for Class 2 aggregate base.

FDR-FA is considered a roadway rehabilitation strategy but may be suitable for limited locations within a highway maintenance (HM) or capital preventive maintenance (CAPM) project with the concurrence of the headquarters pavement reviewer if the amount of FDR-FA meets the program or cost limitations for digouts. Refer to Chapter 9 of the Project Development Procedures Manual (PDPM), the HDM, and Design Information Bulletins (DIB) 79 and 81-01 for additional information.

13.1.1 Full Depth Reclamation Using Foamed Asphalt

The FDR-FA process pulverizes existing AC and a portion of the underlying material to a maximum depth of 12 inches, while simultaneously mixing with foamed asphalt, cement, and water. After recycling, the mixture is graded, compacted, and overlaid. FDR-FA is constructed with a recycling train that consists of an asphalt binder tanker truck, the recycling machine, and a water tanker truck.



Figure 13.1: FDR-FA recycling train

FDR-FA offers benefits including:

- Cost effective, in-place pavement structure rehabilitation and base reconstruction
- Increased structural capacity
- Reflection cracking mitigation (obliteration of existing cracking pattern)
- Facilitates cost effective corrections to profile, cross slope, and roughness
- Expedited construction and simplified staging

FDR-FA effectiveness is governed by the quality of the design, materials being reclaimed, underlying layer support, variability in materials and subgrade conditions along the project, drainage, and construction practice.

13.1.2 Appropriate Applications

FDR-FA can treat a variety of project conditions, but is most cost effective on cracked surfaces requiring digouts of 20% or more by paving area. Appropriate applications include:

- Structurally inadequate pavement sections, which would otherwise require a thick overlay, as indicated by:
 - Advanced pavement distress such as severe cracking (wider than ¼ inch, continuous deep reflective cracking, or Alligator ‘C’—see Figure 13.2.3) or plastic deformation (shoving or rutting greater than ¾ inch).
 - Significant cracking and a deflection study with 80th percentile deflections greater than 0.015 inch (see California Test 356).
- Rough surfaces that require smoothing of bumps and dips to improve ride quality.
- Needed longitudinal or transverse corrections to grade, cross-slope, or superelevation.
- Base deterioration due to fatigue, moisture intrusion, pumping, or other causes.
- Minimum existing AC and underlying material (aggregate base or good subgrade) ≥ 8 inches

For pavement sections with rutting or cracking distress caused by localized subgrade or base failures and drainage problems, subsurface repairs should be performed prior to FDR-FA and must be completed before overlaying (see HDM Index 625.1 or 635.1(8)).

13.1.3 General Limitations

The following conditions are generally not suitable for FDR-FA:

- Areas with drainage problems such as:
 - saturated subgrade or base layers
 - inadequate drainage systems to divert water away from the pavement structure
- Pavement structures with concrete, treated base, or a geosynthetic pavement interlayer (or fabric stress absorbing membrane). Older lean concrete base (LCB) or cement treated base (CTB) layers are only suitable for FDR-FA if penetrated by a dynamic cone penetrometer (DCP, see Section 13.3.2).
- Subgrade material plasticity index > 12
- Traffic volume, sufficient to produce construction delays exceeding 30 minutes under one-way traffic control (typically > 20,000 ADT). Higher volumes can be accommodated if detours are available.
- Truck traffic > 1000 ADTT
- Roadways with numerous shallow utilities or drainage facilities within 6 inches of the proposed FDR-FA depth.
- Roadways with adequate structural capacity and good quality base, grades, and cross slopes despite a moderately cracked pavement surface with less than ½ inch crack widths.
- Urban areas where noise created by the recycling machine may be problematic.

If any of these conditions or various combinations exist, careful consideration should be made before selecting a pavement strategy. Mitigation may be feasible but will increase costs and could reduce the effectiveness of FDR-FA or other rehabilitation strategies such as overlay, mill and fill, or remove and replace. Consult with the district materials engineer or Division of Maintenance Pavement Program for available pavement strategy alternatives.

FDR-FA is a moisture sensitive material. If a project location has widespread problems with subgrade or surface drainage, consider alternative FDR treatment with cement, lime, or emulsion as well as other HMA rehabilitation strategies.

13.2 PROJECT EVALUATION

A comprehensive project evaluation is important for understanding the existing pavement conditions, materials, and project surroundings. The findings are used to determine a rehabilitation strategy and, if selected, as input to the FDR-FA mix design, pavement structure design, and project specifications.

The three stages in a project evaluation include:

- Desktop study
- Preliminary field review and recommendations
- Detailed site investigation, testing, analysis, and recommendations

13.2.1 Desktop Study

The desktop study is the first stage in the project evaluation, which involves collecting all relevant reference information pertaining to the road including, but not limited to:

- **Consult** the headquarters pavement advisor, district materials engineer, and district maintenance for input prior to any detailed analysis. Consider the funding program, expected design life, construction year, and traffic index. A flowchart to guide this decision is shown in Figure 13.2.1.
- **As-built plans** are available on the Caltrans intranet (<http://drs.dot.ca.gov/falcon/websuite.shtml>) to provide historical information about existing roadway features, including pavement structure design (layer thicknesses, types, materials, design life, traffic), drainage structures, etc.
- **Photo surveys** can be used to obtain an initial indication of the condition of the pavement, problem areas and localized failures, and project surroundings. Google maps (www.googlemaps.com) provides viewable photos of many state highways and other roadways. For Caltrans employees, the photolog is also available on the intranet.
- **Pavement Condition Report/ Pavement Management System** contains current and historical information on the pavement condition. Copies can be obtained from the district maintenance engineer, or the Pavement Program intranet site. Distress rating definitions are contained in the Pavement Condition Survey Pavement Evaluation Manual, also at the Pavement Program intranet site.
- **Traffic data** are used to determine the pavement structure design requirements and predict traffic growth or decline. Project data should be obtained from the district travel forecasting office but traffic counts are available from the Division of Traffic Operations at <http://www.dot.ca.gov/hq/traffops/saferesr/trafdata/>.
- **Climate data** relevant to pavement design in California can be obtained from the Caltrans Office of Concrete Pavement and Foundations or http://www.dot.ca.gov/hq/maint/Pavement/Offices/Pavement_Engineering/Climate.html.
- **Maintenance records** from the area Maintenance Superintendent can identify problem areas along the project that may require additional investigation and pretreatment repair.

- **Maps**, Google Earth, Map Quest, and, for Caltrans employees, the interactive application CT Earth, are available.

When the reference information is gathered, it should be analyzed using the criteria in Section 13.1. If FDR-FA is a viable strategy, a preliminary field review should be conducted.

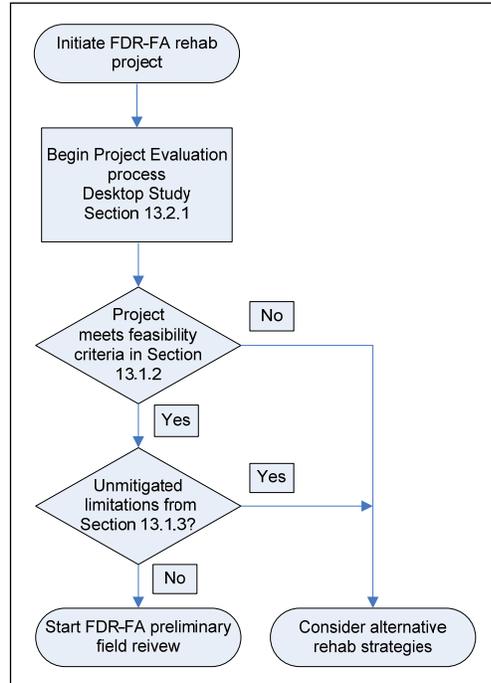


Figure 13.2.1: Project Evaluation Flowchart (8).

13.2.2 Preliminary Field Review

A preliminary field review is needed to supplement data from the desktop study and assess whether FDR-FA is suitable for a project. This preliminary review should be carried out as early as possible during project scoping, preferably during the rainy season when subgrade moisture and drainage issues can be assessed, to identify costs and maximize analysis time for FDR-FA and alternative pavement strategies. Review and assessment of the project surroundings, pavement conditions, structural capacity, material properties, geometrics, traffic issues, constructability, and cost effectiveness should be conducted as part of the project evaluation process. Recommendations for proceeding with a more detailed study or investigating an alternative rehabilitation strategy should be included in the project initiation document (PSSR, PSR, etc.).

Visual Assessment

The visual assessment should identify the existing pavement failure modes and any specific reasons why FDR-FA may not be a suitable rehabilitation option. The Maintenance Supervisor should have knowledge of problem areas and the frequency and extent of maintenance work. The assessment should include a determination of whether distress is confined to the surface (i.e., environmental or traffic) or whether the distress was caused by structural inadequacy or a related cause, such as poor drainage. This can be achieved by studying the pavement and adjacent area for:

- Type, severity, and extent of alligator cracking or pumping (extensive fatigue cracking and pumping of fines through the cracks usually indicates subgrade problems)

- Extent of maintenance (especially digouts) and the condition relative to the service life of maintained areas (i.e., are the digouts failing within one year?)
- Road height above natural ground level and presence of an existing granular base layer (roads at or below natural ground level, without drainage systems, will usually have drainage problems)
- Drainage design efficiency (i.e., road shape, side drains, culverts, etc.)
- Land use immediately adjacent to the road (irrigated agricultural lands and the use of side drains for irrigation purposes may lead to moisture related pavement structure problems)
- Locations of natural water sources and adjacent roadway impacts

The primary cause of pavement failure (e.g., age, increased traffic loading, overloading, inadequate structural design or layer thicknesses, lack of existing base material, poor drainage, weak subgrade, etc.) should be noted. Observations should be recorded on an appropriate worksheet (example in Appendix F, Form 2).

Preliminary Recommendations

Recommendations summarizing the initial project evaluation from the desktop study and preliminary field review should be prepared and attached to the project initiation document. Include a brief description of the project, a summary of the observations, and a recommendation on whether to proceed with a detailed site investigation for FDR-FA or to consider an alternative method of rehabilitation. A template for preliminary recommendations is provided in Appendix F, Form 3. The recommendations should contain:

- General project description, project identification, road description, program, and funding source.
- Existing pavement structure, including layer thicknesses and materials
- General description of existing pavement condition
- Current traffic data
- Climate region
- Potential problem areas and mitigation
- Life cycle cost analysis of alternative pavement strategies
- Analysis recommendations. Include features that make FDR-FA a viable strategy, may limit effectiveness, or fatal flaws that exclude FDR-FA as a rehabilitation option (e.g., drainage problems, weak subgrade, underlying concrete pavement, shallow utilities, etc.).

13.2.3 Detailed Site Investigation

The detailed site investigation is carried out by district materials staff during project design to gather additional pavement and materials information and verify FDR-FA is a suitable strategy for the project location. Investigations can be done any time of year, but during the wet season is preferable since construction activities are minimal and drainage problems are readily identified.

The detailed site investigation should include:

- Pavement Evaluation
 - Distress assessment
 - Digouts and failure cause
 - Drainage systems
- Existing Pavement Structure Assessment (Section 13.3)

- Coring or ground penetrating radar (GPR) survey (Section 13.3.1—Surface Layer Thickness)
- Deflection (falling weight deflectometer: FWD) and DCP testing (Section 13.3.2—Subgrade Analysis)
- Test pit recommendation for contractor mix design and material properties assessment (Section 13.3.4)
- Material sampling
- Laboratory Testing (Section 13.3.4)
- Analysis summary and recommendation (Section 13.5)

Inadequate site investigations can lead to misapplication of FDR-FA and premature failures associated with unidentified areas of weak subgrade materials, inadequate drainage, and material variability.

Pavement Evaluation

The pavement evaluation should supplement the visual assessment during the preliminary field review (Section 13.2.2) and identify the existing modes of failure and any specific reasons why FDR-FA may not be the optimum rehabilitation strategy. Information should be captured on a form (Appendix F, Form 4) and summary sheet (Appendix F, Form 5).

Procedure

The following tasks need to be completed during the pavement evaluation. Problem areas and potential solutions should be identified on the summary sheet:

1. Assess the distress type, severity, extent (percentage of project length), and failure modes. Emphasize cracking, rutting, and pumping. Large areas of loose AC in areas of severe alligator cracking may influence the consistency of the reclaimed material (oversized chunks). Pumping often indicates weak support conditions. Deep, wide ruts are often an indication of weak subgrade and insufficient pavement structure. These areas may require additional investigation, such as test pits, coring, DCP, or FWD; and repair prior to FDR-FA.
2. Assess the extent and condition of existing digouts, with special attention given to areas where digouts are failing again at regular intervals. The causes of failure in these areas should be identified and documented (e.g., drainage problems, change in subgrade materials, etc.).
3. Assess the condition of drainage systems (i.e., side drains, and culverts) and problem areas associated with inadequate drainage, including but not limited to areas where:
 - Side ditches and culverts are:
 - Blocked by erosion or agricultural activity
 - Used for agricultural irrigation water flows
 - Plough furrows run perpendicular or towards the road
 - Water flows into the pavement structure from access roads and driveways



Blocked ditch and culvert.



Side ditch used for irrigation water.



Plough furrows perpendicular to road.



Irrigation water sprays on the road.



Access road drainage problems (note digout).



Severe alligator cracking.

Figure 13.2.3: Example Pavement Evaluation Features

13.3 EXISTING PAVEMENT STRUCTURE ASSESSMENT

13.3.1 Surface Layer Thickness

Coring can be used to obtain an indication of surface layer thicknesses and variability within the project limits. While coring data is limited to an intermittent sampling interval, project trends can often be identified from the resulting pavement profile and information from local maintenance personnel.

Ground penetrating radar (GPR) can provide a continuous evaluation of pavement layer thickness and also identify the location of underground utilities. Network level GPR surveys are available through the pavement management system under the Division of Maintenance Pavement Program and project specific GPR surveys can be arranged through the Office of Roadway Materials Testing in Materials Engineering and Testing Services (METS). If a GPR survey is undertaken, limited coring will still be required to verify the data and conduct DCP testing described in Section 13.3.2.

Coring Procedure

The following procedure should be used for coring:

1. Core once every 1,500 ft in the center of the lane (minimum 4 inch diameter) and alternate between lanes.
2. Core in additional problem areas identified during the pavement evaluation and where differences in pavement design or construction are apparent, such as digouts.
3. Conduct a DCP test after removing the core to analyze variability in subgrade strength and validate FWD measurements (see Section 13.3.2). DCP measurements should be taken in each core hole to check variability in subgrade strength and to validate FWD measurements.
4. Measure each core and record the AC thickness and any special characteristics (e.g., layers with rubberized asphalt, stripping, the presence of interlayers, thin areas, digouts, adhesion to the base, etc.). An example core log is provided in Appendix F (Form 6).
5. Photograph the core against a tape measure (Figure 13.3)
6. After measurement, cores can be used to backfill the hole or discarded unless required for other purposes.



Figure 13.3: Core (4" diameter)

Core thicknesses should be entered into a spreadsheet to calculate the average and standard deviation. A high standard deviation indicates that thickness varies along the section. Thicknesses should be plotted to identify areas above and below the average thickness. If the average AC thickness is greater than 0.90 foot, consideration should be given to cold planing to establish an acceptable FDR-FA depth. A thick AC layer may also indicate areas with weak subgrade, inadequate base, or ongoing maintenance problems that may not be suitable for FDR-FA.

13.3.2 Subgrade Analysis

The primary purpose of analyzing the subgrade using an FWD and DCP is to evaluate the stiffness of materials below the anticipated FDR-FA depth (typically the base or subbase and subgrade), locate weak areas that require special treatment before recycling, and identify suitable locations for test pit excavation (Section 13.3.4).

Falling Weight Deflectometer (FWD)

California Test 356 is used to determine overlay requirements from pavement deflection measurements. To obtain deflection measurements for subgrade analysis during FDR-FA site investigation, follow CT 356, Method A with the following modifications:

- Testing should ideally be carried out at the end of the rainy season, when subgrade moisture is likely to be highest.
- The lane with the worst existing condition should be tested unless each lane is designed separately, in which case both lanes should be tested.
- Use core thicknesses to determine the pavement structure profile and conduct DCP analysis (see below).
- Use a calibrated FWD unit capable of applying impact loads of 9,000 lb on a standard 12 inch diameter plate and measuring pavement deflection at a distance of 24 ± 1.0 inch from the plate center.
- Conduct tests between the wheelpaths to minimize the effects of severe wheelpath cracking on the seating of the FWD load and sensors.
- Use a test interval of 200 ft to obtain 26 deflection measurements per lane-mi. Testing productivity will be approximately 2.0 lane-mi/hr. Longer test intervals can be adopted if there are constraints such as traffic or limited closure schedules; however, this increases the risk of missing weaker sections. Areas of interest identified during the pavement evaluation should be tested in addition to measurements at the regular interval.
- Analyze FWD test results according to the procedures in Appendix B. Assess all areas with FWD determined subgrade stiffness less than 6500 psi or R-value < 20. Likely reasons for low strength should be identified (e.g., drainage problems, subgrade materials, etc.).

Dynamic Cone Penetrometer (DCP)

Use a standard DCP with 60° cone and a 1500 ft test interval for DCP measurements. DCP testing should coincide with the removal of cores, discussed in Section 13.3.1. In areas of suspected high variability in underlying materials, such as cut and fill transitions, changes in moisture condition, soil or vegetation type, or failed or repaired areas, more frequent measurements (every 300 to 500 ft) should be taken to better understand the pavement structure and layer thicknesses. DCP measurements can be taken inside the core hole, although care must be taken when interpreting the results as water used to cool the core bit will soften the upper layer of material under the surfacing, giving an unrealistically low shear strength for the upper layer. Measure the penetration after every five blows up to a depth of 800 mm (31.5 in.) An example is provided in Appendix F Form 7. Analyze DCP results according to the procedures in Appendix C.

If historical R-value information based on actual test data is not available, subgrade material samples should be collected from the edge of the road to determine plasticity and R-value (see Section 13.3.3). Sampling intervals should take into account potential variability based on experience and geologic, geographic, topographic, and hydrologic changes throughout the project limits. Samples should be collected from alternate sides of the road as close to the edge of the road

as possible, without including base, subbase, or other imported material. Sampling depth should be from 1 to 2 feet and a minimum of 65 lb should be collected.

13.3.3 Laboratory Testing

Standard materials tests (Table 13.3) are required to characterize the existing pavement structure and subgrade to determine the viability of FDR-FA as a project strategy. Additional indicator tests are carried out by the contractor during the mix design (Section 13.6). If the AC layer is thicker than 0.90 foot, the sample should be scalped to obtain the correct proportion of AC and underlying material based on the preliminary pavement structure design. If any of the following minimums are not met, add sufficient material to the design to improve the engineering properties (see Section 13.5.2) or select a strategy other than FDR-FA:

Table 13.3: Material Test Minimum Targets

Material/Layer	Sample Size (lbs)	Grading (CT 202)	Plasticity (CT 204)	R-value ³ (CT 301)
Exist AC + underlying material ¹	65	5% ≤ passing #200 ≤ 15%	-	-
Base ²	10	-	PI < 12	See Figure 13.7.1
Subgrade	65	-	PI < 12	20

¹Maximum 1 foot depth of material. Sample and blend proportionally according to the preliminary design FDR-FA depth. Minimum 2" underlying material.

²Layer may not be present.

³If mechanistic-empirical analysis is used for pavement structure design, R-value testing is not required for base or subgrade characterization.

The minimum targets in Table 13.3 should be interpreted carefully. Subgrade material with an R-value < 20 may still be adequate for FDR-FA or other pavement strategies, but could also require special design considerations. If the existing pavement structure has a base layer, subgrade plasticity is less critical than for non-engineered sections where native material is underlying the existing AC surface layer and will be blended into FDR-FA material.

13.3.4 Test Pit Recommendation

The contractor is responsible for excavating test pits and sampling material for the FDR-FA mix design, according to the criteria in Section 13.6 and CT 305, after a project is awarded. As part of the Materials Information Handout included in the bid package, the District Materials Engineer is responsible for presenting the results of the project evaluation and recommending the minimum number of test pits required for the contractor to adequately characterize material variability throughout the project length. Potential locations can be noted for the project records but should not be provided as recommendations to the contractor due to liability issues.

Each FDR-FA project should have at least two test pits, but more may be indicated by variability in surface layer thickness or materials, subgrade analysis results (FWD or DCP), or changes in geologic, geographic, topographic, and hydrologic features throughout the project limits.

13.4 ANALYSIS SUMMARY

The detailed site investigation should be summarized, documented, and included in the Materials Information Handout to support a final recommendation on the use of FDR-FA or an alternative rehabilitation strategy. An example form is shown in Appendix F, Form 8 and the flow chart in Figure 13.4 can be used to guide the decision process.

Improvement of weak subgrade must be considered in the pavement structure recommendation, whether or not FDR-FA is determined to be a viable strategy. FDR-FA design features that can mitigate weak subgrade include:

FULL DEPTH RECLAMATION USING FOAMED ASPHALT

- Add Class 2 AB prior to FDR-FA
- Remove and replace poor material
- Increase overlay thickness
- Enhance drainage features
- Stabilize subgrade with lime, cement, or subgrade enhancement geotextile (SEG)

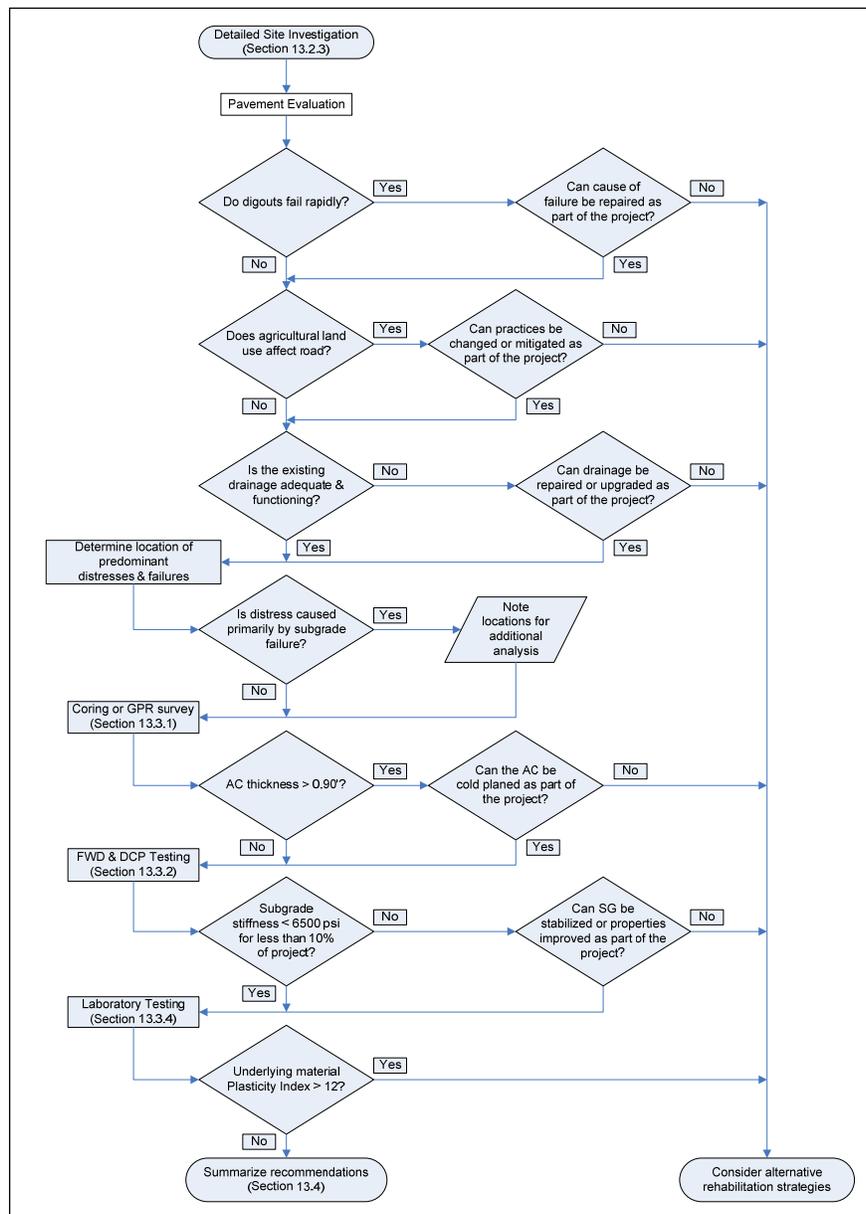


Figure 13.4: Detailed site investigation decision process.

13.5 MATERIALS

13.5.1 Asphalt Binder for Foamed Asphalt

The Performance Graded (PG) system is used to grade asphalt binder according to climate region, which is not applicable for foamed asphalt applications. A soft, neat binder characterized by half-life and expansion ratio is most suitable for foaming. If a neat binder is unavailable, PG 64-10 can be used although the foaming characteristics may vary since different crude oil sources are used

and antifoaming additives may be added for transportation. A binder half-life of at least 12 seconds and expansion ratio of 10 is desirable for adequate dispersion and foaming consistency.

13.5.2 Additives

Cement is added to the roadway surface immediately prior to mixing at a rate of 1.5% by dry weight of FDR-FA material. Laboratory research has indicated this relatively small amount of additive will improve engineering properties, including early strength gain to support initial traffic loads as the FDR-FA material cures. Using higher amounts of additive can cause brittleness and shrinkage cracking. Mixing must occur within 30 minutes of application and all grading and compaction must be completed within 4 hours. At least 2 hours of curing time without equipment or traffic loading should be provided.

If the material characterization indicates a poorly graded or plastic material (Table 13.3), a granular material such as Class 2 AB or a fine material such as crusher dust may be added to improve the FDR-FA material characteristics and thicken the base layer, or the FDR-FA depth can be increased. More commonly, Class 2 AB may be needed to provide additional material for shoulder widening, profile, or cross slope corrections. The percent passing the #200 sieve should be between 5 and 15 for FDR-FA material.

13.6 MIX DESIGN

Mix design is a key component of the FDR-FA process carried out by the contractor to assess the properties and variability of the sampled materials, optimize the foamed asphalt application rates, and gain an understanding of expected pavement performance. The cost and effort involved in optimizing the mix design are inconsequential in terms of the overall project costs, minimizing the risk of premature failure, and maximizing the benefits from extending the useful life of the road.

FDR-FA mix designs use a combination of 1.5% cement and approximately 3.0% foamed asphalt. Foamed asphalt and cement serve different purposes in the stabilization process. The stabilized layer is not simply an asphalt or cement stabilized layer, but a hybrid with unique properties (see Figure 13.6).

The FDR-FA mix design process includes:

- Excavation of test pits for material sampling and pavement layer analysis (Section 13.6.1)
- Optimization and documentation of FDR-FA mix designs according to California Test 305 "*Determining the Asphalt Binder Content For Full Depth Reclamation With Foamed Asphalt*" (Section 13.6.2)

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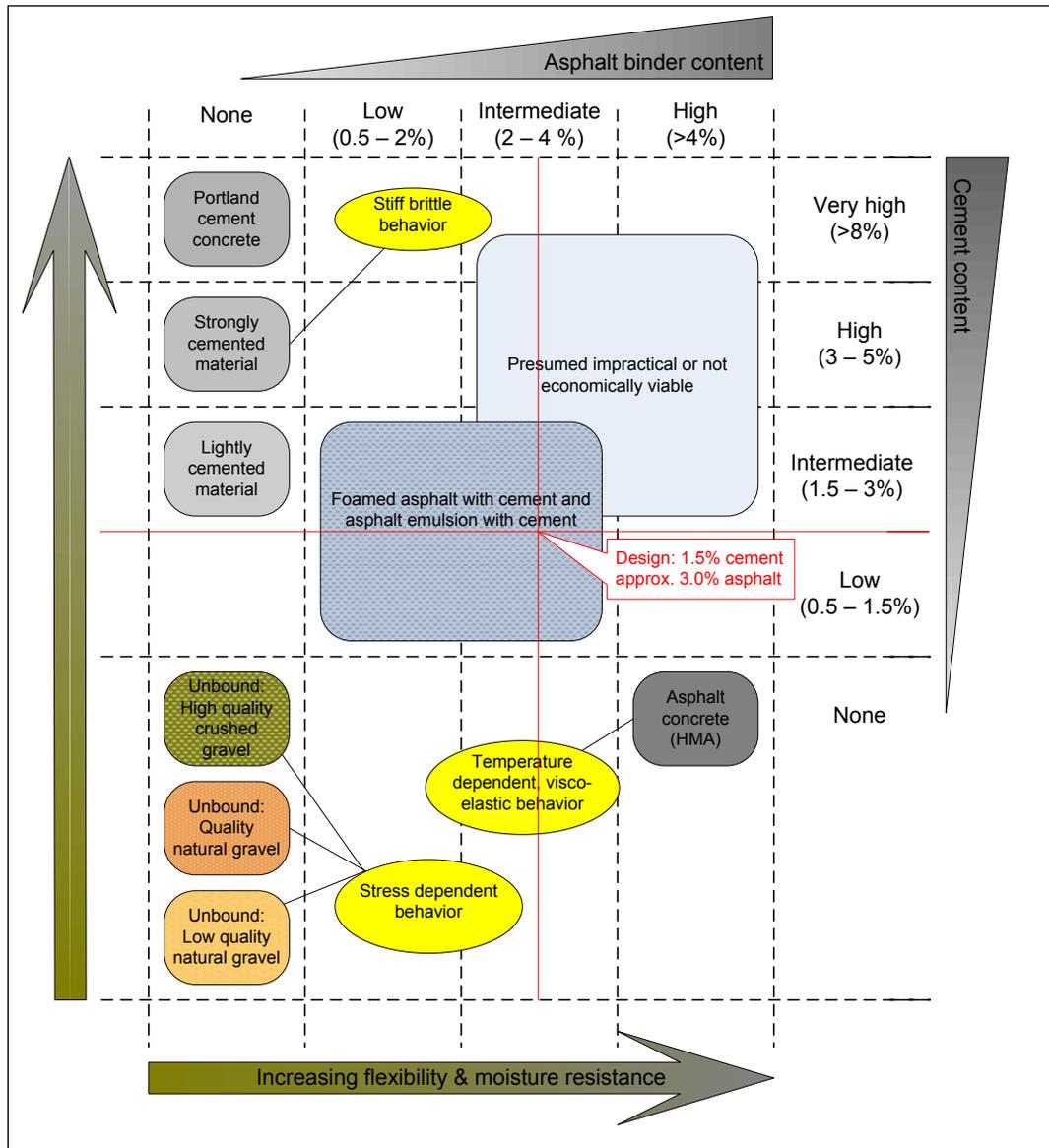


Figure 13.6: FDR-FA Material Characteristics (4).

13.6.1 Test Pits

Pavement layers can be assessed by excavating test pits to provide a cross section of the pavement layers and subgrade, an indication of subgrade moisture conditions, and a source of material for laboratory testing. The project specifications will indicate the minimum number of test pits recommended by the district materials engineer. For longer projects with variable terrain and pavement structures, additional test pits should be excavated in problem areas or where weak subgrade is indicated.

Test pits are excavated between the wheelpaths in the center of a lane approximately 3.5 ft x 3.5 ft x 3.5 ft to provide sufficient material for laboratory testing purposes (Figure 13.7.1). A cold milling machine can be used to excavate the AC and at least the top 2.0 inches of base material to ensure that representative samples are collected, or a portable crusher with a movable jaw can be used to process samples and simulate FDR-FA grading for laboratory testing.

Representative material samples are required for the laboratory mix design determination and should be collected during the excavation of the test pits. Sample bags must be clearly labeled, including the test pit location and layer descriptions. Approximately 500 lbs of existing AC and

underlying material is required for mix design testing, but actual amounts will vary based on the extent of testing. Enough material must be collected from each layer to blend samples proportionally according to the FDR-FA depth and pavement structure design (see Section 13.7). Uniform material samples from different test pits can be combined to reduce sample sizes and testing demand.



Figure 13.6.1 Test pit excavation

Analysis Procedure

When the test pit has been excavated and samples collected, clean the test pit face and delineate the individual layers with string. Carefully inspect the test pit face to assess and document the following features according to CT 305:

1. **Layer moisture contents.** Remove a sample of material from each of the underlying layers and place in a sealed container immediately after excavation for moisture content determination. This will be used to refine the DCP analyses and to establish a mixing moisture content range for recycling operations.
2. **Layer thickness.** Measure the thickness of each layer across the test pit face and calculate averages. This data will be used to determine the FDR-FA depth, verify as-built information, correlate with the DCP determined layer thicknesses, and to determine whether additional Class 2 AB is required.
3. **AC assessment.** Inspect each layer of AC to identify the presence of fabrics, or other materials that may influence the FDR-FA operation.
4. **Base layer assessment.** Inspect the base to assess material type, gradation, presence of large aggregate, and signs of contamination from the subgrade (pumping) or severe moisture fluctuations (mottling). Moisture problems will typically be associated with high subgrade deflection modulus values and DCP penetration rates.
5. **Subgrade assessment.** Inspect the subgrade to identify moisture condition, plasticity, signs of fluctuating moisture conditions (mottling), shearing (slickensides), inadequate support for the overlying layer (punching of aggregate), and any other problems that could influence FDR-FA effectiveness.

13.6.2 Mix Design Testing

- Material evaluation is primarily focused on the strength of water-soaked specimens.
- Additional sampling and testing to refine mix designs is encouraged.
- According to California Test 305 "*Determining the Asphalt Binder Content For Full Depth Reclamation With Foamed Asphalt:*"
 1. Determine the grading of the reclaimed material
 2. Determine the compaction curve of the reclaimed material

3. Select the asphalt binder and determine the foaming parameters
4. Determine the mixing moisture content (MMC)
5. Determine the asphalt binder content. Optimize the foamed asphalt application rate using wet indirect tensile strength (ITS) test results.
6. Determine the final ITS and tensile strength ratio of the combined mixture.

13.7 FDR-FA PAVEMENT STRUCTURE DESIGN FOR FLEXIBLE PAVEMENTS

The design of the flexible pavement structure follows the project evaluation, detailed site investigation, and laboratory testing. Although FDR-FA is a process for rehabilitation of an existing road, the design process is similar to that for a new pavement since the pavement structure is being reconstructed from the base up, with the FDR-FA forming a new base for the new pavement layer. For design purposes, material below the FDR-FA depth can be considered subgrade, aggregate subbase, or aggregate base depending on test R-values (see Figure 13.7.1). HDM Topic 633 describes the engineering procedures for new design of flexible pavement structures based on gravel equivalent (GE) and gravel factor (G_f). For FDR-FA layers, $G_f = 1.4$. Pavement structures with FDR-FA layers should be treated as full depth designs with a fixed safety factor of 0.10 ft. An example FDR-FA pavement structure design is given in Appendix A.

Mechanistic-empirical analysis procedures can also be used for FDR-FA pavement structure design. For more information, contact the Office of Asphalt Pavement in the Division of Maintenance Pavement Program.

13.7.1 Design Life and Traffic Index (TI)

If subgrade support is adequate, the expected design life of the pavement structure is related to the FDR-FA depth and the type and thickness of the new flexible surface layer. FDR-FA projects should be designed with a minimum pavement design life of 20 years, unless a life cycle cost analysis indicates a 40-year pavement design life is more cost effective (HDM Topic 612). The FDR-FA layer must be designed thick enough to provide the required GE and form a stable base for the new pavement layer. If the underlying granular material is of sufficient quality, it may be more cost effective to increase the FDR-FA thickness to decrease the required surface layer thickness. If analysis of the subgrade during the detailed site investigation indicated extensive areas of weak material, special pavement design considerations or alternative strategies should be considered.

Pavement design requires knowledge of anticipated traffic volumes and loading, which help determine the pavement structure requirements. Contact the district traffic forecasting office and refer to HDM Topic 613 for procedures to determine the traffic index for the required design life.

13.7.2 FDR-FA Depth

Depth and material consistency can be achieved when FDR-FA production takes place in a continuous manner. The FDR-FA depth should be at least 0.10 foot more than the existing flexible surface layer thickness. The pulverizing teeth must extend into the existing base to prevent excessive wear and lost productivity. FDR-FA depth may be increased to provide additional GE from the base layer, reducing the required flexible pavement layer thickness and material costs.

The FDR-FA equipment should be able to process depths up to 1 foot. If the FDR-FA depth exceeds 1 foot, the FDR-FA material should be collected, placed on the side of the roadway in a windrow, and spread and compacted in two lifts due to the difficulty of compacting deep layers. Alternative compaction methods may be available to increase the allowable single pass thickness. Either of these modifications will require approval of a nonstandard special provision. Depending on the project parameters, it may be necessary to cold plane the pavement surface prior to FDR-FA to attain the maximum FDR-FA depth. If cold planing is needed on a widespread basis, the specified depths should maximize the percentage of RAP in FDR-FA material.

13.7.3 Gravel Equivalent (GE)

Gravel equivalence is determined by multiplying the actual layer thickness by the gravel factor:

$$GE = (\text{Actual Layer Thickness}) \times G_f$$

Table 13.7 provides the range of GE's for FDR-FA based on various design depths with $G_f = 1.4$:

Table 13.7: Gravel Equivalents of FDR-FA Layer

Base Portion (ft)	0.10		0.15		0.20		0.25		0.30		0.35		0.40	
	Min. Design FDR-FA Depth (ft)	GE _{FDR-FA} (ft)	Design FDR-FA Depth (ft)	GE _{FDR-FA} (ft)	Design FDR-FA Depth (ft)	GE _{FDR-FA} (ft)	Design FDR-FA Depth (ft)	GE _{FDR-FA} (ft)	Design FDR-FA Depth (ft)	GE _{FDR-FA} (ft)	Design FDR-FA Depth (ft)	GE _{FDR-FA} (ft)	Design FDR-FA Depth (ft)	GE _{FDR-FA} (ft)
0.30	0.40	0.56	0.45	0.63	0.50	0.70	0.55	0.77	0.60	0.84	0.65	0.91	0.70	0.98
0.35	0.45	0.63	0.50	0.70	0.55	0.77	0.60	0.84	0.65	0.91	0.70	0.98	0.75	1.05
0.40	0.50	0.70	0.55	0.77	0.60	0.84	0.65	0.91	0.70	0.98	0.75	1.05	0.80	1.12
0.45	0.55	0.77	0.60	0.84	0.65	0.91	0.70	0.98	0.75	1.05	0.80	1.12	0.85	1.19
0.50	0.60	0.84	0.65	0.91	0.70	0.98	0.75	1.05	0.80	1.12	0.85	1.19	0.90	1.26
0.55	0.65	0.91	0.70	0.98	0.75	1.05	0.80	1.12	0.85	1.19	0.90	1.26	0.95	1.33
0.60	0.70	0.98	0.75	1.05	0.80	1.12	0.85	1.19	0.90	1.26	0.95	1.33	1.00	1.40
0.65	0.75	1.05	0.80	1.12	0.85	1.19	0.90	1.26	0.95	1.33	1.00	1.40	----	----
0.70	0.80	1.12	0.85	1.19	0.90	1.26	0.95	1.33	1.00	1.40	----	----	----	----
0.75	0.85	1.19	0.90	1.26	0.95	1.33	1.00	1.40	----	----	----	----	----	----
0.80	0.90	1.26	0.95	1.33	1.00	1.40	----	----	----	----	----	----	----	----
0.85	0.95	1.33	1.00	1.40	----	----	----	----	----	----	----	----	----	----
0.90	1.00	1.40	----	----	----	----	----	----	----	----	----	----	----	----

Note: $G_{f \text{ FDR-FA}} = 1.4$

13.8 SPECIAL CONSIDERATIONS

13.8.1 Volumetric Change

The FDR-FA process alters gradation and lowers the density of existing roadway materials as it is transformed into compacted base material. Even without adding new material, compacted FDR-FA material typically swells from 5 to 10% relative to the original material. Excess material must be accounted for in the project design and may be used as embankment fill or to increase the

actual FDR-FA layer thickness (use design depth for pavement structure calculations), correct profile and cross slope, or widen sections. If more material is required for the design, supplemental Class 2 AB can be added to the roadway surface immediately prior to FDR-FA.

13.8.2 FDR-FA Area

The width and crown of the roadway to be reclaimed dictates the number of passes to cover the full width. Drums are typically 8 feet wide but can vary in width from 6 to 12 feet. Several passes will normally be required to pulverize the roadway. If the roadway is crowned, the FDR-FA equipment should not pass over the crown to ensure uniform treatment depth and consistency in the FDR-FA material.

FDR-FA should proceed from the outside of the roadway towards the centerline to maintain a reference to the profile elevation. The first pass uses the full width of the drum. In subsequent passes, the treatment width will be reduced by a minimum overlap of 4 inches. If the FDR-FA depth is more than 12 inches or the FDR-FA material is coarse, the overlap width should be increased. Overlapped FDR-FA material should not be treated with foam or cement on subsequent passes.

Other factors to consider are obstructions adjoining the edge of pavement such as curb and gutter, dike, guard rail, concrete barrier, or retaining walls. For dikes or curb and gutter, the recycling train should be able to treat the roadway up to the dike face or gutter edge. For taller obstructions, the adjacent roadway will have to be removed using another method. The treatment area should include the entire cross section of the pavement structure from edge of pavement to edge of pavement.

13.8.3 Underlying Unsuitable Material

The potential for unsuitable material below the FDR-FA depth should be considered during the detailed site investigation. Areas exhibiting drainage problems, pumping, rutting, severe cracking, or moisture intrusion may indicate deteriorated base or subgrade that is unsuitable for pavement construction. Analysis of abnormally high deflections or DCP penetration rates generally indicate weak underlying layers (see Appendices B and C). Localized areas of unsuitable material should be removed, disposed, and replaced with excess FDR-FA material or new Class 2 AB. Often, unsuitable material cannot be identified until commencement of construction operations when removal of the pavement surface and repeated loading from heavy equipment and compaction induces pumping action, causing rutting and cracking in the FDR-FA layer.

If weak material is widespread throughout the project limits, the pavement structure design should be strengthened and any moisture or drainage issues addressed. Alternatives include increasing the FDR-FA depth, importing Class 2 AB, and subgrade stabilization. FDR-FA material is moisture sensitive and requires support from underlying layers to achieve compaction and design strength. If mitigation cannot be attained, alternative rehabilitation or reconstruction strategies should be considered.

13.8.4 Constructability

FDR-FA pavement structure designs should account for significant variations in controlling parameters such as subgrade R-values or existing pavement structure layers and thicknesses in a consistent manner. For ease of construction, design parameters such as material additives, FDR-FA depth, FDR-FA area, and overlay thickness should not vary more frequently than 1-mile long segments. Transverse variations in the design cross section should take into account equipment width (see Section 13.8.2) and other considerations.

As with all in-place recycling operations, control over material uniformity is largely dependent on site conditions. Field adjustments to parameters such as production and application rates will be

necessary during construction as indicated by changes to in-situ conditions or QC/QA test results. Large clumps of RAP greater than 3 inches in diameter are detrimental to FDR-FA material and should be removed prior to final grading and compaction. If the existing pavement surface has extensive fatigue cracking, the FDR-FA machine's forward speed should be slowed to ensure adequate gradation. The particle distribution should be 100% smaller than 3 inches with 85 to 100% passing the 1½ inch sieve.

Conflicting utilities, including valves and access points, must be referenced and lowered at least 6 inches below the FDR-FA depth. If utility depths have not been confirmed by field inspection, potholing, or GPR, the design FDR-FA depth should be at least 12 inches above the approximate utility depth.

13.8.5 Traffic Handling

FDR-FA is best suited for moderate to low volume roadways (see Section 13.1.3). Since FDR-FA surfaces are exposed to traffic during construction, high traffic volumes prior to paving can cause raveling. Accordingly, FDR-FA operations require reduced work zone speeds as determined by the district traffic operations office. For two-lane conventional highways, a pilot car should be used to escort vehicles through the work zone during FDR-FA operations.

No public traffic or heavy contractor equipment should be allowed on the finished FDR-FA surface until all construction activities in the work zone are complete and the layer has been allowed to cure for at least 2 hours after final compaction. On routes with high truck traffic volumes > 1000 ADTT, a curing period of 4 hours from completion of mixing should be provided.

Temporary striping must use bid Item 120159 Temporary Traffic Stripe (Paint) since floppy markers and tape will not adhere to the finished FDR-FA surface.

13.9 PLANS, SPECIFICATIONS, AND ESTIMATING

13.9.1 Plans

The plans for a FDR-FA project are analogous to a project using common roadway rehabilitation strategies. The layout plans should show the existing roadway and the limits of FDR-FA (width and length). The typical cross sections should clearly show the cross slope, width, and depth of the existing pavement layers, new FDR-FA base layer, and new flexible pavement layers. If survey data is not available and superelevation diagrams are not provided, indicate "match existing" cross slope and the contractor will reference the existing profile along the roadway centerline.

If existing roadway grades are consistent, they can be maintained and surveyed slope stake information may not be necessary. More commonly, existing flexible pavement structures exhibit undulations and uneven settlement. The FDR-FA operation offers a rare opportunity to correct these defects and properly construct and finish the roadway surface. It is much more cost effective to adjust the grade of FDR-FA material with extra grading or imported AB than to grade the finished surface using additional HMA. Any design changes to profile, cross slope, and superelevation should be indicated in the plans so the contractor can account for additional grading or material handling. If the finished surface is leveled with HMA, include Item 390135 HMA (leveling), which is paved separately from the HMA surface to improve final compaction and smoothness and does not include geometric changes.

The construction details should include conforming transverse tapers where the FDR-FA pavement structure ties into existing or new roadway. Quantity sheets should include the stationing and corresponding FDR-FA areas and additive amounts in the roadway items table. Appendix D contains example plan sheets for an FDR-FA project.

13.9.2 Specifications

Standard special provision (SSP) 30-2 is used for FDR-FA. The specification addresses a number of material and equipment requirements, construction methods, inspection, quality control and quality assurance (QC/QA), acceptance requirements, measurement, and payment. The SSP requires the contractor to perform FDR-FA mix designs based on adequate characterization of the existing materials and make any adjustments due to material variability in the field based on results of QC testing for 1,000 square yard lots. The Department performs periodic QA testing to ensure accuracy and compliance.

13.9.3 Estimating

The estimation process for FDR-FA cost must take into account several project specific features such as location, length, schedule, geometrics, traffic handling, as well as FDR-FA depth and area. There are multiple items associated with FDR-FA which need to be estimated:

Table 13.9A: Estimating Unit Costs

Item Code	Item Description	Unit	Estimate Basis	Historical Item
300100	Full Depth Reclamation-Foamed Asphalt	sqyd	reclaimed pavement area	<i>Cold Foam In-Place Recycling (CFIPR)</i>
300600	Mix Design (Full Depth Reclamation-Foamed Asphalt)	LS	\$15-20K	<i>N-A</i>
300300	Asphalt Binder (Full Depth Reclamation-Foamed Asphalt)	ton	3.0% by FDR-FA dry wt	<ul style="list-style-type: none"> • <i>Paving Asphalt (foaming)</i> • <i>Bitumen (CFIPR)</i> • <i>397200 Stabilizing Agent (Foamed Asphalt)</i>
300400	Cement (Full Depth Reclamation-Foamed Asphalt)	ton	1.5% by FDR-FA dry wt	<i>397205 Stabilizing Agent (Cementitious Material)</i>
300200	Asphaltic Emulsion (Full Depth Reclamation-Foamed Asphalt)	ton	0.08 gal/sq yd residual rate	<i>N-A</i>
260201	Class 2 AB	ton	If necessary, determined by DME	<i>No change</i>
120159	Temporary Traffic Stripe (Paint)	LF	Total length of each stripe for each stage	<i>No change</i>
390135	HMA (leveling)	ton	Percentage of total HMA	<i>390107 AC (leveling)</i>
066670	Payment Adjustment for Price Index Fluctuation	LS	Change in binder cost from asphalt price index	<i>No change</i>

Typical project mobilization costs for FDR-FA equipment run under \$10,000, keeping the process cost effective for smaller projects and areas. Historical cost data for a limited number of FDR-FA projects is available on the intranet from the Unit Cost Database (see Appendix E) for some items. Among other considerations, analysis of historical costs must consider that past FDR-FA projects were located primarily in the North Region and used an nSSP with different item codes, design, materials, and QC/ QA requirements:

- Contractor performed FDR-FA mix designs are a new requirement so historical cost data is not yet available. The FDR-FA mix design item is based on a lump sum that includes work for material sampling, lab testing, and 1.5 days traffic control.
- Material quantities for FDR-FA are based on assumed values of 1.5% cement and 3.0% asphalt binder, by dry unit weight of FDR-FA, and the processed volume of FDR-FA material.

FULL DEPTH RECLAMATION USING FOAMED ASPHALT

- Class 2 aggregate base is only required if recommended by the DME or if necessary for widening, profile, or cross slope requirements. Historical data can be used for estimating but note that payment should be based on tonnage since spreading and grading is included in the FDR-FA item.

Measurement and Payment

Item 300100 “Full Depth Reclamation-Foamed Asphalt” is measured and paid for by the square yard based on the theoretical FDR-FA area and includes all labor, materials, tools, equipment, and testing related to the FDR-FA operation and preparation of the existing roadway. The roadbed dimensions to be reclaimed should be shown on the typical sections, layout plans, and quantity sheets to clearly indicate the work limits (See Appendix D).

Additional stabilizing agents and additives such as asphalt binder, cement, and Class 2 AB are measured and paid for by ton. The item includes all labor, materials, tools, equipment, and incidentals for placing and mixing the additive with FDR-FA. No cost adjustment is made for increases or decreases in additive quantities during construction operations unless the FDR-FA dimensions are changed. Section 9-1.06B, “Increases of More Than 25 Percent” and Section 9-1.06C, “Decreases of More than 25 Percent” of the Standard Specifications do not apply.

Supplemental Work

Due to the difficulty in identifying underlying unsuitable material (see Section 13.8.3), a supplemental work item for roadway excavation to remove and dispose of the material should be included in the estimate if unsuitable material has been identified, is difficult to accurately quantify, or is otherwise likely to be present on a project. Any unsuitable material that has already been identified and located should be quantified and estimated as a roadway item and not included in supplemental work.

Section 9-1.07 of the Standard Specifications requires payment adjustment for asphalt materials when the statewide crude oil price index fluctuates by more than 5 percent between the time of the bid and the month the material is placed. Include supplemental work Item 066670 “Payment Adjustment for Price Index Fluctuation” to fund this cost.

Working Days

Due to the wide array of equipment available and varying roadway distress addressed using FDR-FA, it is difficult to suggest a single expected production rate. Daily production rates may vary on average from 4,750 yd² to 9,500 yd² based on the interaction of variables such as existing pavement structure, distress, FDR-FA depth, area, gradation, and grading. The experience level of the general and subcontractors with the FDR-FA process is also a factor. If the subcontractor uses multiple recycling trains, production will be increased, but grading and compacting typically constrain construction productivity and are usually the general contractor’s responsibility. Based on experience with rural, 2-lane conventional highways in District 2, a single recycling train can typically cover 1 mile in three passes during an 8-hour shift, but grading and compacting takes an additional half a shift. Daily paving operations typically consist of two lifts over half a mile. Table 13.9B provides a general guide for estimating FDR-FA production rates:

Table 13.9B: Daily FDR-FA Production

	Existing AC Thickness (in.)	FDR-FA Depth ¹ (in.)	Alligator Cracking (extent)	Profile/Cross Slope Corrections	Daily Production Rate (yd ²)
Range	Thick (7-9 inches)	Deep (8-10 inches)	Continuous (85-100%)	Numerous	4700

	Medium (5-7 inches)	Medium (6-8 inches)	Nearly continuous (50-85%)	Some	7100
	Thin (3-5 inches)	Shallow (4-6 inches)	None to intermittent (0-50%)	Minor	9500

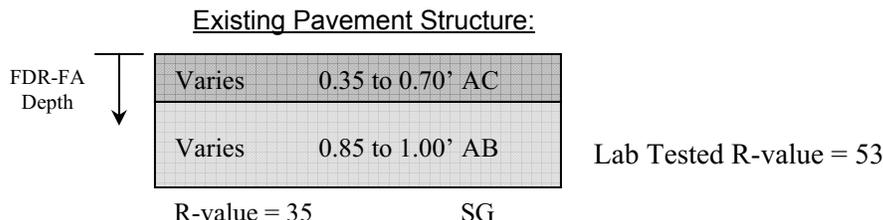
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APPENDIX A: FDR-FA FLEXIBLE PAVEMENT STRUCTURE DESIGN EXAMPLE

GIVEN PROJECT:

Description	2-lane, rural conventional highway
Traffic Index	$TI_{20} = 10.5$
Length	4.3 miles
Width (EP to EP)	28 ft



DETERMINE:

FDR-FA Pavement Structure Design:

- Minimum design FDR-FA depth
- Estimated excess FDR-FA material quantity
- FDR-FA layer thickness
- HMA overlay thickness

SOLUTION:

①

Calculate the minimum FDR-FA depth

For a single depth pavement structure design throughout the project, the **maximum existing AC thickness governs the minimum design FDR-FA depth:**

From Table 13.7: *With max existing AC thickness = 0.70 ft →*

Min. design FDR-FA depth = 0.80 ft

②

Estimate the excess FDR-FA material

From Section 13.8.1: *Compacted FDR-FA material swells by 5-10%*

Assume swell factor = 7%

$$\begin{aligned} \text{FDR-FA material volume} &= (4.3 \text{ miles})(5280\text{ft/mi})(28\text{ft})(0.80\text{ft}) \\ &= 508,570 \text{ ft}^3 \end{aligned}$$

$$\text{Excess FDR-FA material} = 7\%(508,570 \text{ ft}^3)$$

Est. excess FDR-FA material = $35,600 \text{ ft}^3 = 1,319 \text{ yd}^3$

Optional: This quantity can be considered roadway excavation or used to increase the actual thickness of the FDR-FA layer, correct profile or cross slope, level existing surface undulations, or widen the roadway. FDR-FA material can also be used as embankment. **Do not** include estimates of excess material in pavement structure design calculations.

APPENDIX A: FDR-FA FLEXIBLE PAVEMENT STRUCTURE DESIGN EXAMPLE

$$\begin{aligned} \text{FDR-FA thickness increase} &= (\text{swell factor})(\text{min design FDR-FA depth}) \\ &= 7\%(0.80 \text{ ft}) + 0.80 \text{ ft} \end{aligned}$$

$$\text{Actual FDR-FA layer thickness} = 0.85 \text{ ft}$$

3

Calculate the total required gravel equivalent

$$GE_{\text{Total}} = GE_{\text{HMA}} + GE_{\text{FDR-FA}} + GE_{\text{AB}}$$

From HDM Index 633.1, for a 20-year design:

$$GE_{\text{Total}} = 0.0032(TI_{20})(100 - R_{SG})$$

$$GE_{\text{Total}} = 0.0032(10.5)(100 - 35)$$

$$GE_{\text{Total}} = 2.18 \text{ ft}$$

Apply safety factor (treat as full depth design):

$$\rightarrow SF = 0.10 \text{ ft}$$

$$G_{\text{req'd}} = GE_{\text{Total}} + SF$$

$$= 2.18 + 0.10$$

$$G_{\text{req'd}} = 2.28 \text{ ft}$$

4

Calculate GE of each pavement structure layer

$$\text{Thickness} = \frac{GE}{G_f}$$

Using the minimum FDR-FA design depth:

$$GE_{\text{FDR-FA}} = (\text{design thickness})(G_f) = (0.80)(1.4)$$

$$\rightarrow GE_{\text{FDR-FA}} = 1.12$$

To determine the GE of the remaining AB, average the existing thicknesses from the pavement structure profile:

$$\text{Average Existing AC Thickness} = \frac{0.35 + 0.70}{2} = 0.525 \text{ ft}$$

$$\text{Average Existing AB Thickness} = \frac{0.85 + 1.00}{2} = 0.925 \text{ ft}$$

$$\text{FDR-FA Depth} = 0.80 \text{ ft}$$

$$\begin{aligned} \text{Average Remaining AB Thickness} &= 0.525 + 0.925 - 0.80 \\ &= 0.65 \text{ ft} \end{aligned}$$

APPENDIX A: FDR-FA FLEXIBLE PAVEMENT STRUCTURE DESIGN EXAMPLE

From Figure 13.7.1: With existing pavement structure & $R\text{-value}_{AB} = 53$, $G_f = 1.0$

$$GE_{AB} = 0.65 \times 1.0$$

$$\rightarrow GE_{AB} = 0.65$$

The GE required for the HMA layer is:

$$GE_{HMA} = GE_{Total} - GE_{FDR-FA} - GE_{AB}$$

$$GE_{HMA} = 2.28 - 1.12 - 0.65$$

$$\rightarrow GE_{HMA} = 0.51$$

5

Determine the HMA overlay thickness

From HDM Table 633.1:

$$\text{With } TI_{20} = 10.5 \rightarrow G_{f(HMA)} = 1.71$$

$$\text{Thickness} = \frac{GE}{G_f} = \frac{0.51}{1.71}$$

$$= 0.298 \text{ ft}$$

From HDM Index 633.1(1)(d):

Round up to the nearest 0.05 ft increment

Actual HMA Thickness = 0.30 ft

APPENDIX B: FWD ANALYSIS

The following analysis procedures are intended for use with deflection measurements obtained using a falling weight deflectometer (FWD) under CT 356 modified by Section 13.3.2 to evaluate the stiffness of underlying layers and identify areas of weak subgrade.

Site evaluation often involves testing pavements with severe alligator cracking, which violates the continuity assumption for modulus backcalculation based on FWD data. Pavement layer modulus backcalculation is not appropriate in these instances but valuable information about the subgrade properties can be obtained by approximating the modulus from the measured deflection using the following Boussinesq's equation (Equation B.1):

$$E_r = \frac{(1 - \nu^2) \times P}{\pi \times r \times d} \quad \text{(B.1)}$$

- where:
- E_r = deflection modulus at distance r (psi)
 - P = the applied load (lbs)
 - ν = Poisson's ratio, generally using 0.35
 - r = the distance from the load center to the measured deflection (inches)
 - d = measured deflection at distance r (inches)

For a layered pavement structure the calculated deflection modulus (E_r) is a function of the distance from the load center (r) at which the deflection is measured. Typically, the deflection modulus at $r = 24 \pm 1.0$ in. (distance to the fifth FWD sensor) is approximately equivalent to the subgrade modulus ($E_{24} \approx E_{SG}$). Consider:

- To calculate E_r , use the measured distance between the sensor and the load center.
- No temperature correction is necessary since the calculated deflection modulus E_{24} is not significantly affected by the surface layer condition,

Results of the analysis should be plotted against postmile or station on a graph (Figure B.1). The graph can be used to identify problem subgrade or drainage areas. The following criteria (Table B.1) should be used to interpret the deflection data from the 24 in. sensor with the load normalized to 9,000 lb:

Table B.1: Deflection Criteria for Assessing Subgrade

$d_{(24)}^*$	E_r^*	Subgrade Zone (Figure B.1) ¹	Conclusion	Potential Corrective Actions
< 15 mils	>6,500 psi	A	SG sufficient	None
15 – 49 mils	3,600 – 6,500 psi	B	May need to improve SG prior to FDR-FA	None, soil stabilization, geosynthetic reinforcement, remove and replace, raise profile, address drainage, thicker pavement structure
> 49 mils	< 3,600 psi	C	Improve SG prior to FDR-FA or other strategy	Conduct more detailed survey and consider corrective actions or other rehab/reconstruction strategies
*Values are only an approximate guide				

APPENDIX B: FWD ANALYSIS

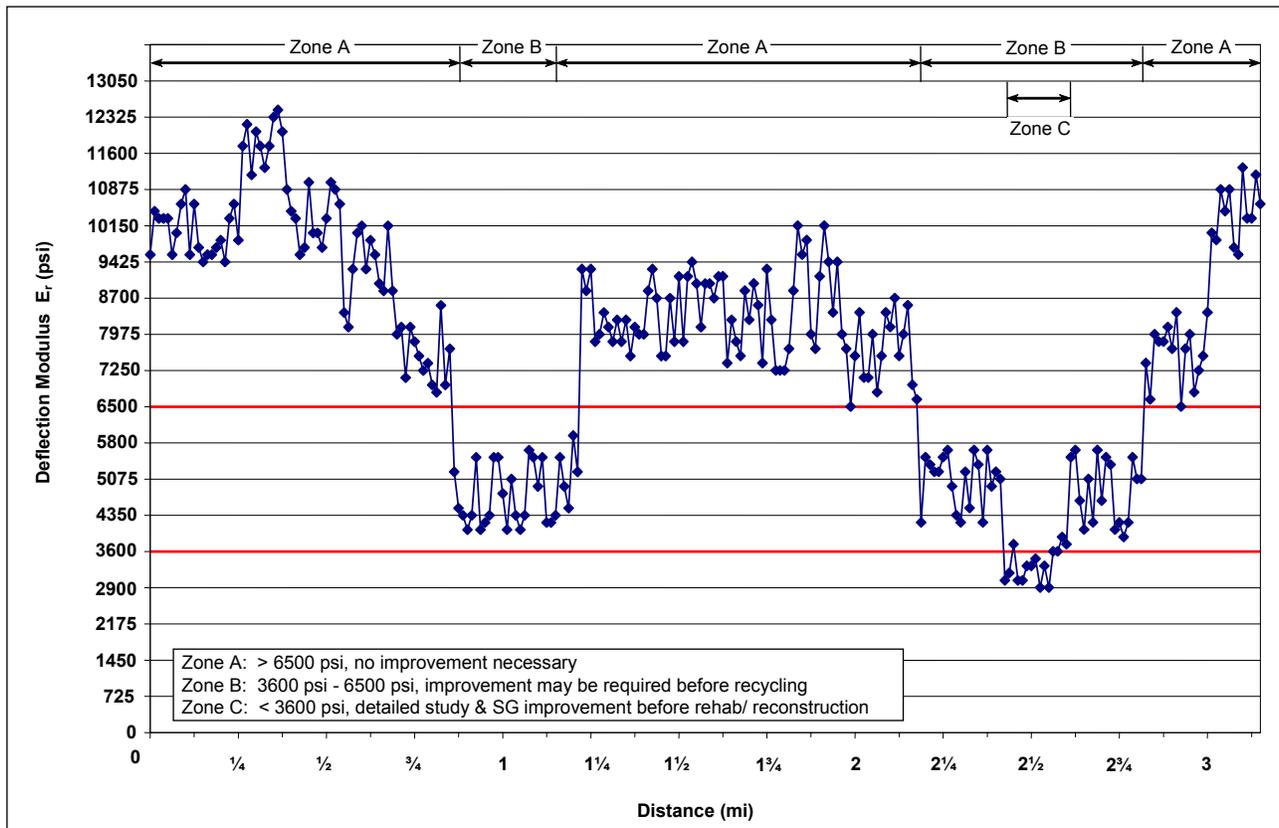


Figure B.1: Example FWD analysis.

Ideally, Zone B + Zone C $<$ 10% total project length.

If Zone B + Zone C $>$ 10% total project length, FDR-FA can still be considered as a rehabilitation strategy. As with other alternatives, the service life may be reduced and additional design features should be included to mitigate poor subgrade material (see Section 13.3).

APPENDIX C: DCP ANALYSIS

Dynamic cone penetrometer (DCP) results are typically analyzed in terms of the DCP Number (DN) to provide a relative indication of layer shear strength and thickness. AC layers are excluded from the evaluation. The DCP layer Structure Number (DSN) and the DCP Pavement Structure Number (DSN₈₀₀) can also be used to assess pavement structures but are not covered in this guidance.

1. Calculate the DCP Number (DN) as the DCP rate of penetration in millimeters (mm) per hammer blow (mm/blow). This provides an indication of the relative shear strength of the material at the depth where it was calculated. Shear strength will typically reduce with increasing depth. If the DN is plotted against depth, distinct jumps are often apparent. The points of each jump can be used to indicate changes in material type, properties, or moisture conditions and to estimate underlying layer thicknesses.

No comprehensive studies have been documented to relate DN to R-value, but empirical relationships have been developed to relate the penetration rate to the effective layer stiffness and California Bearing Ratio (CBR) (9). These relationships provide useful indicators that can be combined with FWD measurements and visual assessments to identify and evaluate potential problem areas, but resulting stiffness and CBR values should be considered **approximate estimates** only.

2. Calculate the effective elastic modulus. An example relationship between stiffness and penetration rate developed in South Africa is given below (Equation C.1) and a summary of DN ranges, corresponding stiffnesses, and subgrade zone is provided in Table C.1.

$$E_{eff} = 145.04 \times 10^{3.05-1.066(\text{Log}(\text{DN}))} \quad (\text{C.1})$$

where: E_{eff} is the effective elastic modulus (psi)

Table C.1: Approximate Relationship between DN, CBR & E_{eff}

DN Range (mm/blow)	CBR Range ¹ (%)	E_{eff} ¹ (psi)	R-value ^{1,2}	Subgrade Zone (Figure C.1) ¹	Subgrade Description
< 4	>70	>37400	>80	A	Relatively strong
4 – 5	50 – 70	29600 – 37400	75 – 80		
5 – 8	30 – 50	18000 – 29600	65 – 75		
8 – 14	30 – 15	9900 – 18000	50 – 65		
14 – 19	10 – 15	6500 – 9900	42 – 50		
19 – 25	7 – 10	5400 – 6500	35 – 42	B	Marginal strength
25 – 30	3 – 7	4350 – 5400	18 – 35		
30 – 35	1 – 3	3600 – 4350	1 – 18		
> 35	< 1	< 3600	< 1	C	Weak, potentially wet

¹Values are only an approximate guide. Use with caution as there is no published correlation between DN and R-value.

²From Huang 1993 based on CBR comparison to R-value through laboratory testing. Not developed from DCP and R-value analysis. Not verified for use in California. R-value < 50 appears to be too high for rate of DCP penetration.

3. Plot DN over the project length and calculate the average and standard deviation to help identify uniform sections and potential problem areas (Figure C.1):

APPENDIX C: DCP ANALYSIS

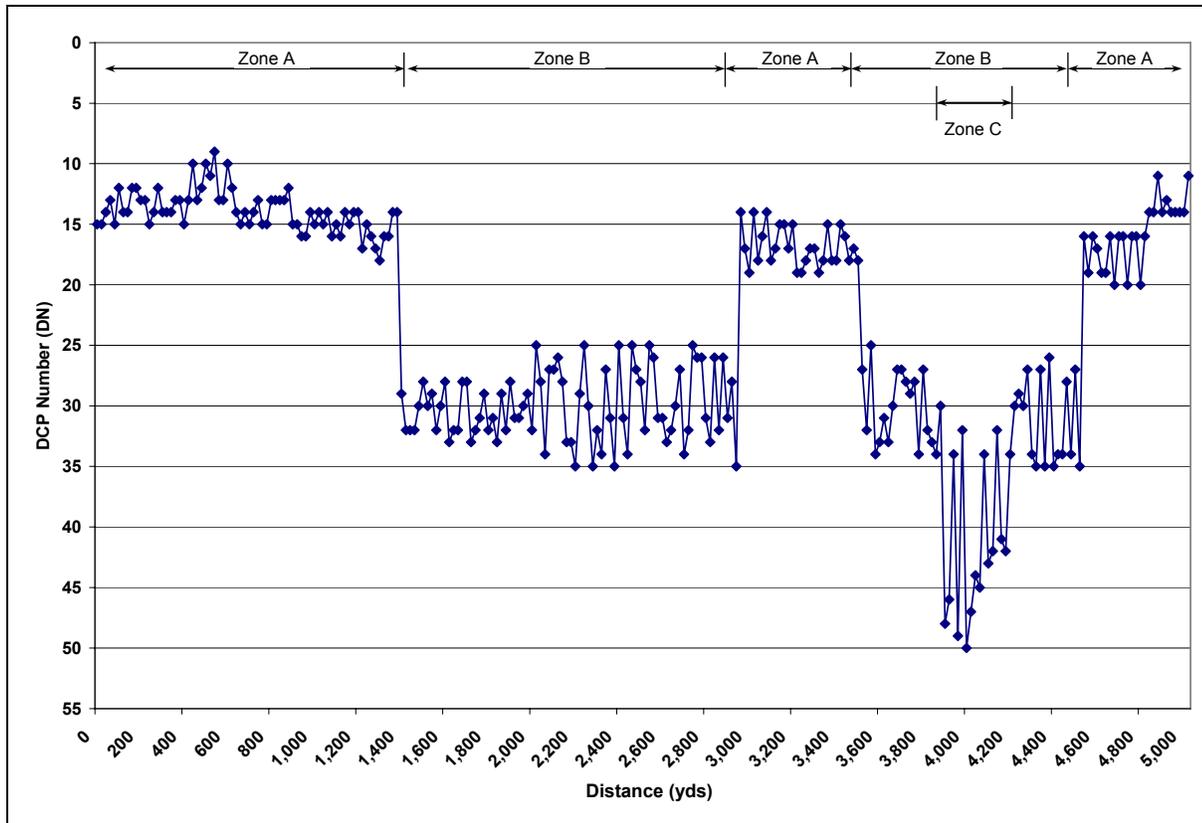


Figure C.1: Example DCP Number analysis.

4. Categorize the data relative to a subgrade zone. For the example in Figure C.1, eight uniform sections can be identified and divided into three different zones: A, B, and C.

Zone A can be considered reasonably strong for subgrade material. Zone B has marginal strength, and Zone C is very weak, indicating potentially wet, clay soils

As with FWD analysis, ideally Zone B + Zone C < 10% total project length.

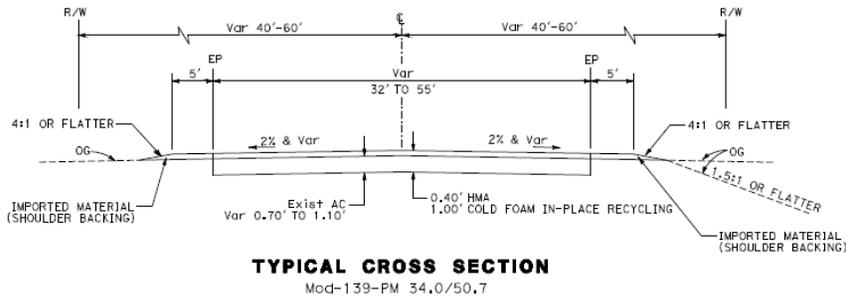
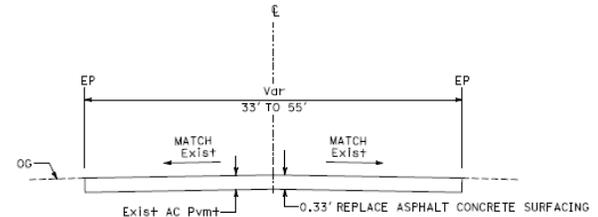
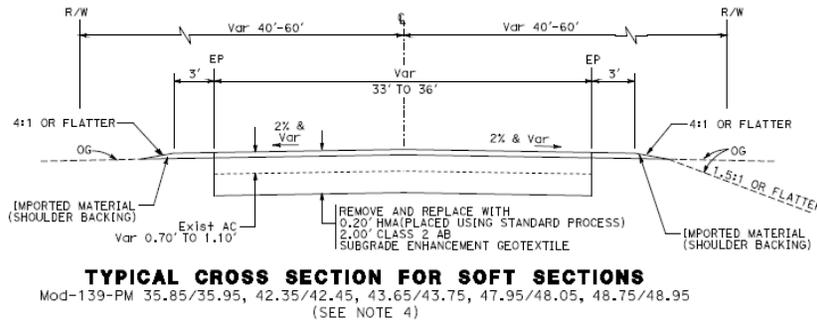
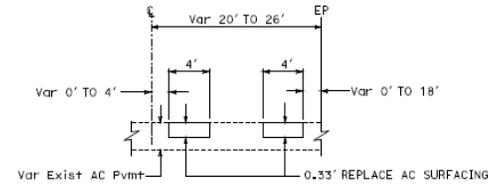
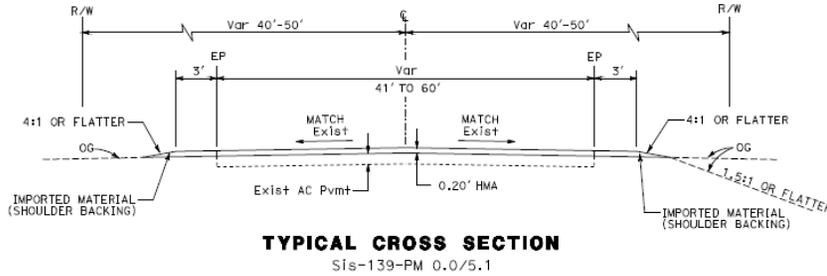
If Zone B + Zone C > 10% total project length, FDR-FA can still be considered as a rehabilitation strategy. As with other alternatives, the service life may be reduced and additional design features should be included to mitigate poor subgrade material (see Section 13.3)

APPENDIX D: EXAMPLE FDR-FA PLANS

NOTES:

1. DIMENSIONS OF THE PAVEMENT SECTION (STRUCTURAL SECTIONS) ARE SUBJECT TO TOLERANCES SPECIFIED IN THE STANDARD SPECIFICATIONS.
2. SUPERELEVATIONS AS SHOWN OR AS DIRECTED BY THE ENGINEER.
3. REMOVE AND REPLACE SOFT SECTIONS PRIOR TO RECYCLING.

DIST	COUNTY	ROUTE	POST MILES TOTAL PROJECT	SHEET No.	TOTAL SHEETS



- REPLACE AC SURFACING**
Mod-139-PM 40.02*
- PM 40.17*
 - PM 41.05*
 - PM 44.14*
 - PM 44.30-44.31
 - PM 44.31-44.32
 - PM 47.75-47.74
 - PM 47.74-47.75
 - PM 48.78*
- *SEE ADDITIONAL DETAILS ON C-2

TYPICAL CROSS SECTIONS

NO SCALE

X-1

STATE OF CALIFORNIA - DEPARTMENT OF TRANSPORTATION
Caltrans

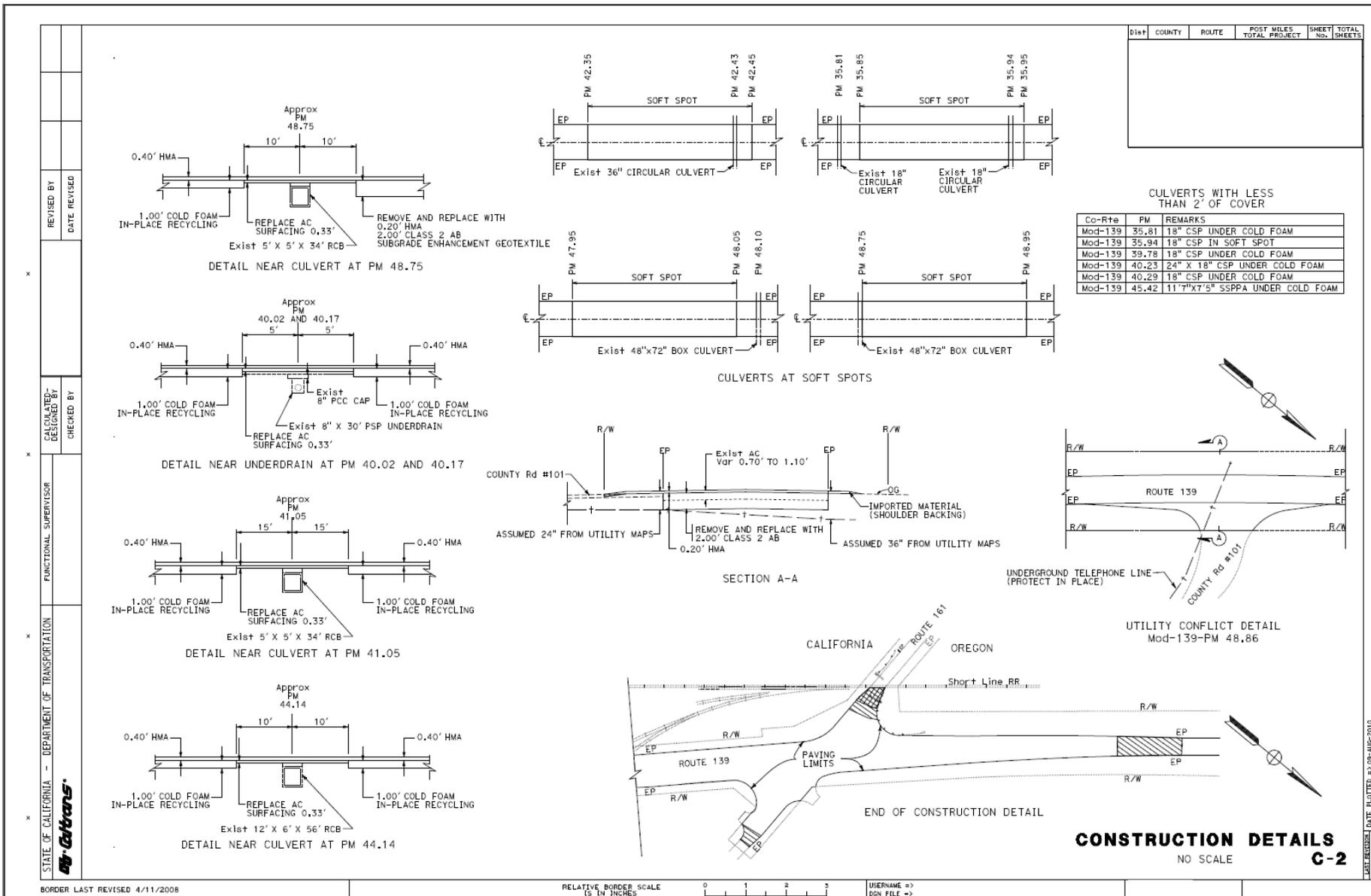
BORDER LAST REVISED 4/11/2008



USERNAME =>
DGN FILE =>

LAST REVISION DATE PLOTTED => 09-AUG-2010
06-24-10 TIME PLOTTED => 10:17

APPENDIX D: EXAMPLE FDR-FA PLANS



APPENDIX D: EXAMPLE FDR-FA PLANS

NOTE:
1. (N) - NOT A SEPARATE PAY ITEM, FOR INFORMATION ONLY.

ROADWAY QUANTITIES SUMMARY

Co-Rte	POST MILE LIMITS	WIDTH (N)	LENGTH (N)	COLD FOAM IN-PLACE RECYCLING	STABILIZING AGENT (FOAMED ASPHALT)	HMA	STABILIZING AGENT (CEMENTITIOUS MATERIAL)	ASPHALTIC EMULSION	IMPORTED MATERIAL (SHOULDER BACKING)	TACK COAT	ROADWAY EXCAVATION	CLASS 2 AB	SUBGRADE ENHANCEMENT GEOTEXTILE			
														SOYD	TON	TON
Mod-139	34.00-35.00	40-32	5280.0													
	35.00-35.08	32-33	422.4													
	35.08-40.50	33	28,617.6													
	40.50-40.57	33-45	369.6													
	40.57-40.65	45-36	422.4													
	40.65-40.80	36-33	792.0													
	40.80-41.85	33	5544.0													
	41.85-42.45	33-36	3168.0													
	42.45-42.54	36-44	475.2													
	42.54-42.70	44-33	844.8													
	42.70-42.77	33-38	369.6													
	42.77-42.85	38-42	422.4													
	42.85-43.00	42-33	792.0													
	43.00-44.00	33-32	5280.0													
	44.00-44.17	32-38	897.6		340,745	6900	92,001	4140	270	9582	100					
	44.17-44.46	38-46	1531.2													
	44.46-44.82	46	1900.8													
	44.82-45.00	46-33	950.4													
	45.00-45.16	33-45	844.8													
	45.16-45.34	45-32	950.4													
	45.34-46.00	32-33	3484.8													
	46.00-46.54	33-46	2851.2													
	46.54-46.65	46-33	580.8													
	46.65-47.62	33	5121.6													
	47.62-47.70	33-54	422.4													
	47.70-47.82	54-55	633.6													
	47.82-47.90	55-33	422.4													
	47.90-50.15	33	11,880.0													
50.15-50.50	33-44	1848.0														
50.50-50.68	44	950.4														
Sis-139	0.00-0.87	42	4593.6													
	0.87-1.08	42-53	1108.8													
	1.08-1.45	53-60	1953.6													
	1.45-1.70	60-42	1320.0													
	1.70-2.36	42-56	3484.8													
	2.36-2.58	56-41	1161.6			19,051			2982	42						
	2.58-3.14	41	2956.8													
	3.14-4.00	41-43	4540.8													
	4.00-4.80	43-48	4224.0													
	4.80-4.89	48-60	475.2													
	4.89-5.04	60-64	792.0													
5.04-END	64-38	800.0														
TRUCK SCALE (MODOC PM 39.36-39.75)*						553			144	2						
SOFT SPOT LOCATIONS*						1592			345	4	7862	7862	11,792			
50 ROAD CONNECTIONS						18015				25						
92 DRIVEWAYS						2480				4						
TOTAL						340,745		6900	133,692	4140	270	13,053	177	7862	7862	11,792

*PLACED USING STANDARD PROCESS

DIST	COUNTY	ROUTE	POST MILES TOTAL PROJECT	SHEET TOTAL NO. SHEETS
------	--------	-------	--------------------------	------------------------

REMOVE SURVEY MONUMENT

Co-Rte	POSTMILE	SIDE	QUANTITY	
			Lt/Rt	EA
Mod-139	39.09	Lt	1	
	39.65	Lt	1	
	40.23	Lt	1	
	40.41	Lt	1	
	40.99	Lt	1	
	41.18	Lt	1	
	41.34	Lt	1	
	41.55	Lt	1	
	41.74	Lt	1	
	41.93	Lt	1	
	42.12	Lt	1	
	42.31	Lt	1	
	42.69	Lt	1	
	42.88	Lt	1	
	43.07	Lt	1	
	43.26	Lt	1	
	43.45	Lt	1	
	43.63	Lt	1	
	43.81	Lt	1	
	44.02	Lt	1	
	44.20	Lt	1	
	44.58	Lt	1	
	44.76	Lt	1	
	44.95	Lt	1	
	45.52	Lt	1	
	45.72	Lt	1	
	45.91	Lt	1	
	46.10	Lt	1	
	46.29	Lt	1	
	46.48	Lt	1	
	46.66	Lt	1	
	46.84	Lt	1	
	47.06	Lt	1	
	47.24	Lt	1	
	47.44	Lt	1	
	47.62	Lt	1	
	48.00	Lt	1	
	48.18	Lt	1	
	48.37	Lt	1	
	48.56	Lt	1	
	48.76	Lt	1	
	48.94	Lt	1	
	49.11	Lt	1	
	49.32	Lt	1	
	49.50	Lt	1	
	49.68	Lt	1	
	49.87	Lt	1	
	50.23	Lt	1	
	50.41	Lt	1	
TOTAL			49	

SUMMARY OF QUANTITIES

Q-1

BORDER LAST REVISED 4/11/2008

RELATIVE BORDER SCALE
IN INCHES

USERNAME =>
IGN FILE =>

DATE PLOTTED: 06-24-10
 TIME PLOTTED: 08:54
 USER: JEFFREY

APPENDIX E: ONLINE RESOURCES

Information	Internet Address
<u>Highway Design Manual (HDM)</u>	<u>http://www.dot.ca.gov/hq/oppd/hdm/hdmtoc.htm</u>
<u>Design Information Bulletins (DIB)</u>	<u>http://www.dot.ca.gov/hq/oppd/dib/dibprg.htm</u>
<u>Project Development Procedures Manual</u>	<u>http://www.dot.ca.gov/hq/oppd/pdpm/pdpmn.htm</u>
<u>Traffic Data</u>	<u>http://www.dot.ca.gov/hq/traffops/saferesr/trafdata/</u>
<u>Life Cycle Cost Analysis</u>	<u>http://www.dot.ca.gov/hq/maint/Pavement/Offices/Pavement_Engineering/LCCA_index.html</u>
<u>Office of Roadway Materials Testing (ORMT-METS)</u>	<u>http://www.dot.ca.gov/hq/esc/Translab/ofpm/index.htm</u>
<u>Pavement Management Program</u>	<u>http://www.dot.ca.gov/hq/maint/Pavement/Pavement_Program/index.html</u>
<u>FDR-FA</u>	<u>http://www.dot.ca.gov/hq/maint/Pavement/Offices/Pavement_Engineering/CFIPR.html</u>
<u>Standard Specifications (2010)</u>	<u>http://www/hq/esc/oe/specifications/std_specs/2010_StdSpecs/</u>

APPENDIX F: EXAMPLE FORMS

The following example forms are provided in this appendix:

1. FDR-FA Project Evaluation: Desktop Study
2. FDR-FA Preliminary Field Review
3. FDR-FA Project Evaluation: Preliminary Recommendations
4. FDR-FA Detailed Site Investigation: Visual Assessment
5. FDR-FA Detailed Site Investigation: Visual Assessment Summary
6. FDR-FA Detailed Site Investigation: Core Log
7. FDR-FA Detailed Site Investigation: DCP Assessment
8. FDR-FA Project Evaluation: Detailed Site Investigation Analysis Summary

1	FDR-FA Project Evaluation: Desktop Study			
Project Name or Description:				
Dist-Co-Rte:		Beg PM:		Date:
EA/ Project ID:		End PM:		Prepared By:
Record of HQ Decision Approving Investigation:				
Program:		Funding Source:		
Traffic:				
Climate:				
Existing Pavement Structure				
Layer	Description	Thickness	Material	
1				
2				
3				
4				
5				
6				
General condition:				
Potential problems:	1			
	2			
	3			
	4			
	5			
	6			
	7			
	8			
	9			
	10			
Fatal flaws:				
Continue with preliminary investigation?		Yes		No

2		FDR-FA Project Evaluation: Preliminary Field Review							
Project Name or Description:									
Dist-Co-Rte:		Beg PM:		Date:		EA/ Project ID:		Reviewer:	
		End PM:							
Observation								Comments	
1. Crack type and extent	Alligator		Thermal		Longitudinal		Extent	%	
2. Pumping	From cracks		From other				Extent	%	
3. Rut depth and extent	Depth		Surface		Structural		Extent	%	
4. Maintenance	Digouts		Digout failure				Extent	%	
5. Cause of failures	Age		Traffic		Structural		Drainage		
6. Granular base	Yes		No						
7. Height above natural ground									
8. Drainage	Adequate		Irrigation						
9.									
10.									
11.									
12.									
13.									
14.									
15.									
Samples taken?	Yes		No		Purpose				
Fatal flaws?	Yes		No		Reason				

4	FDR-FA Detailed Site Investigation: Pavement Evaluation	
----------	--	---

Project Name or Description:			
Dist-Co-Rte:		Beg PM:	
EA/ Project ID:		End PM:	
		Date:	
		Prepared By:	

Surface Assessment												
--------------------	--	--	--	--	--	--	--	--	--	--	--	--

Surface type															
	Degree						Extent					Length	Width	Number	Location
	Slight			Severe			<5		>80						
Bleeding/flushing	0	1	2	3	4	5	1	2	3	4	5				
Raveling	0	1	2	3	4	5	1	2	3	4	5				

Structural Assessment												
-----------------------	--	--	--	--	--	--	--	--	--	--	--	--

	Degree						Extent					Narrow (% area)	Wide (% area)	Position	Location
	Slight			Severe			<5		>80						
Cracks - block	0	1	2	3	4	5	1	2	3	4	5				
Cracks - longitudinal	0	1	2	3	4	5	1	2	3	4	5				
Cracks - transverse	0	1	2	3	4	5	1	2	3	4	5				
Cracks - alligator	0	1	2	3	4	5	1	2	3	4	5				
Pumping	0	1	2	3	4	5	1	2	3	4	5				
Rutting	0	1	2	3	4	5	1	2	3	4	5				
Undulation/settlement	0	1	2	3	4	5	1	2	3	4	5				
Edge cracking	0	1	2	3	4	5	1	2	3	4	5				
												Small	Medium	Large	Location/Number
Patching/digouts	0	1	2	3	4	5	1	2	3	4	5				
Potholes	0	1	2	3	4	5	1	2	3	4	5				
Delamination	0	1	2	3	4	5	1	2	3	4	5				

Functional Assessment												
-----------------------	--	--	--	--	--	--	--	--	--	--	--	--

	Degree					Influencing Factors							
	Good			Poor		Potholes	Patching	Undulation	Corrugation	Fatigue			
Riding quality	1	2	3	4	5								
Surface drainage	1	2	3	4	5								
Side drainage	✓	✗											

Notes	Photographs
	1
	2
	3
	4
	5
	6
	7
	8

5	FDR-FA Detailed Site Investigation: Pavement Evaluation Summary					
	Project Name or Description:					
Dist-Co-Rte:		Beg PM:		Date:		
EA/ Project ID:		End PM:		Prepared By:		
Distress/problem	% Area	Yes	No	Influence FDR-FA decision?		
Patching/digouts						
Alligator Cracking						
Pumping						
Rutting						
Undulation/settlement						
Adjacent irrigation						
Other						
Cause of failure requiring digout						
Cause of low strength areas in FWD survey						
Drainage systems	Side drains	OK		Bad		
	Culverts	OK		Bad		
Notes				Photographs		
				1		
				2		
				3		
				4		
				5		
				6		
				7		
				8		
				9		
				10		
				11		
				12		

7 FDR-FA Detailed Site Investigation: DCP Assessment



Project Name or Description:								
Dist-Co-Rte:			Beg PM:			Date:		
EA/ Project ID:			End PM:			Prepared By:		
Core No./ PM			Core # or PM			Core # or PM		
0			0			0		
5	205	405	5	205	405	5	205	405
10	210	410	10	210	410	10	210	410
15	215	415	15	215	415	15	215	415
20	220	420	20	220	420	20	220	420
25	225	425	25	225	425	25	225	425
30	230	430	30	230	430	30	230	430
35	235	435	35	235	435	35	235	435
40	240	440	40	240	440	40	240	440
45	245	445	45	245	445	45	245	445
50	250	450	50	250	450	50	250	450
55	255	455	55	255	455	55	255	455
60	260	460	60	260	460	60	260	460
65	265	465	65	265	465	65	265	465
70	270	470	70	270	470	70	270	470
75	275	475	75	275	475	75	275	475
80	280	480	80	280	480	80	280	480
85	285	485	85	285	485	85	285	485
90	290	490	90	290	490	90	290	490
95	295	495	95	295	495	95	295	495
100	300	500	100	300	500	100	300	500
105	305	505	105	305	505	105	305	505
110	310	510	110	310	510	110	310	510
115	315	515	115	315	515	115	315	515
120	320	520	120	320	520	120	320	520
125	325	525	125	325	525	125	325	525
130	330	530	130	330	530	130	330	530
135	335	535	135	335	535	135	335	535
140	340	540	140	340	540	140	340	540
145	345	545	145	345	545	145	345	545
150	350	550	150	350	550	150	350	550
155	355	555	155	355	555	155	355	555
160	360	560	160	360	560	160	360	560
165	365	565	165	365	565	165	365	565
170	370	570	170	370	570	170	370	570
175	375	575	175	375	575	175	375	575
180	380	580	180	380	580	180	380	580
185	385	585	185	385	585	185	385	585
190	390	590	190	390	590	190	390	590
195	395	595	195	395	595	195	395	595
200	400	600	200	400	600	200	400	600

