1.1. If RAP is to be used in the mixture, it may be specified according to percent dry weight (mass) of the mixture or percent binder replacement. Binder replacement is reclaimed asphalt binder from RAP that replaces virgin binder in asphalt mixtures.

1.1.1. *Percent dry weight (mass) of mixture*)—If the agency elects to use RAP adjustments by percent dry weight (mass) of the mixture, the binder grade selected in Sections 5.1.3 and 5.2 needs to be adjusted according to Table 2 to account for the amount and stiffness of the RAP binder. Procedures for developing a blending chart are included in Appendix X1.

Note 1—Research conducted as part of NCHRP Project 9-12 indicated that the high stiffness RAP (PG 88-4 after recovery) used in the study had a greater effect on the low-temperature properties of the blended asphalt binder than the medium and low stiffness RAP (PG 82-16 and PG 82-22, respectively). This data suggests that the limiting RAP values in Table 2 may be modified depending on the low-temperature stiffness of the recovered RAP binder. Refer to NCHRP Report 452 for more details.

Table 1—Binder Selection Guidelines for Reclaimed Asphalt Pavement (RAP) Mixtures

Recommended Virgin Asphalt Binder Grade	RAP Percentage
No change in binder selection	<15
Select virgin binder one grade softer than normal (e.g., select a PG 58-28 if a PG 64-22 would normally be used)	15 to 25
Follow recommendations from blending charts	>25

1.1.2. *Percent binder replacement*—If the agency elects to use the percent binder replacement method, percent binder replacement is determined by the ratio of reclaimed binder to the total binder in the mixture. Local or regional evaluations need to be completed to determine the maximum RAP amounts allowed or the minimum percentage of virgin binder.

Note 6—If recycled binder properties are not available, effort should be undertaken to characterize typical stockpiled materials. RAP samples should be taken from typical stockpiles in various geographical locations within the state and evaluated to determine the effect of various percentages of RAP binder on typical virgin PG binders. Details on the RAP evaluation process are contained in Appendix X2.

APPENDIX

(Nonmandatory Information)

X1. PROCEDURES FOR DEVELOPING A BLENDING CHART

X1.1. Blending of RAP binders can be accomplished by knowing the desired final grade (critical temperature) of the blended binder, the physical properties (and critical temperatures) of the recovered RAP binder, and either the physical properties (and critical temperatures) of the virgin asphalt binder or the desired percentage of RAP in the mixture.

X1.2. *Determine the physical properties and critical temperatures of the RAP binder*.

X1.2.1. Recover the RAP binder using T 319 (Note X1) with an appropriate solvent. At least 50 g of recovered RAP binder are needed for testing. Perform binder classification testing using the tests in M 320. Rotational viscosity, flash point, and mass loss tests are not required.

Note X1—While T 319 is the preferred method, at the discretion of the agency, R 59 may be used. Research conducted under NCHRP 9-12 indicated that R 59 might affect recovered binder properties.

X1.2.2. Perform original dynamic shear rheometer (DSR) testing on the recovered RAP binder to determine the critical high temperature, $T_c(High)$, based on original DSR values where G*/sin δ = 1.00 kPa. Calculate the critical high temperature as follows:

X1.2.2.1. Determine the slope of the Stiffness-Temperature curve as follows:

$$a = \Delta \log(G^*/\sin\delta)/\Delta T \qquad (X1.1)$$

X1.2.2.2. Determine T_c (*High*) to the nearest 0.1°C using the following equation:

$$T_c\,(High) = \left(\frac{Log(1.00) - Log(G_1)}{a}\right) + T_1 \qquad (X1.2)$$

where:

G_1 = the G*/sin δ value at a specific temperature T_1, and

a = the slope as described in Equation X1.1.

Note X2—Although any temperature (T_1) and the corresponding stiffness (G_1) can be selected, it is advisable to use the G*/sin δ value closest to the criterion (1.00 kPa) to minimize extrapolation errors.

X1.2.3. Perform rolling thin-film oven (RTFO) aging on the remaining binder.

X1.2.4. Perform RTFO DSR testing on the RTFO-aged recovered binder to determine the critical high temperature (based on RTFO DSR). Calculate the critical high temperature (RTFO DSR).

X1.2.4.1. Determine the slope of the Stiffness-Temperature curve as follows:

$$a = \Delta \log(G^*/\sin \delta)/\Delta T \qquad (X1.3)$$

X1.2.4.2. Determine $T_c(High)$ based on RTFO DSR, to the nearest 0.1°C using the following equation:

$$T_c(High) = \left(\frac{Log(2.20) - Log(G_1)}{a} \right) + T_1 \qquad (X1.4)$$

where:

G_1 = the G*/sin δ value at a specific temperature T_1, and

a = the slope as described in Equation X1.3.

Note X3—Although any temperature (T_1) and the corresponding stiffness (G_1) can be selected, it is advisable to use the G*/sin δ value closest to the criterion (2.20 kPa) to minimize extrapolation errors.

X1.2.5. Determine the critical high temperature of the recovered RAP binder as the lowest of the original DSR and RTFO DSR critical temperatures. Determine the high-temperature performance grade (PG) of the recovered RAP binder based on this single critical high temperature.

X1.2.6. Perform intermediate temperature DSR testing on the RTFO-aged recovered RAP binder to determine the critical intermediate temperature T_c (*Int*), as if the RAP binder were pressure aging vessel (PAV) aged.

X1.2.6.1. Determine the slope of the Stiffness-Temperature curve as follows:

$$a = \Delta \log(G^*/\sin \delta)/\Delta T \qquad (X1.5)$$

X1.2.6.2. Determine T_c (*Int*) to the nearest 0.1°C using the following equation:

$$T_c(Int) = \left(\frac{Log(5000) - Log(G_1)}{a} \right) + T_1 \qquad (X1.6)$$

where:

G_1 = the G*/sin δ value at a specific temperature T_1, and

a = the slope as described in Equation X1.5.

Note X4—Although any temperature (T_1) and the corresponding stiffness (G_1) can be selected, it is advisable to use the G*/sin δ value closest to the criterion (5000 kPa) to minimize extrapolation errors.

X1.2.7. Perform BBR testing on the RTFO-aged recovered RAP binder to determine the critical low temperature, T_c (*S*) or T_c (*m*), based on bending beam rheometer (BBR) Stiffness or *m*-value.

X1.2.7.1. Determine the slope of the Stiffness-Temperature curve as follows:

$$a = \Delta \log(S)/\Delta T \qquad (X1.7)$$

X1.2.7.2. Determine $T_c(S)$ to the nearest 0.1°C using the following equation:

$$T_c(S) = \left(\frac{Log(300) - Log(S_1)}{a} \right) + T_1 \qquad (X1.8)$$

where:

S_1 = the S-value at a specific temperature T_1, and

a = the slope as described in Equation X1.7.

Note X5—Although any temperature (T_1) and the corresponding stiffness (S_1) can be selected, it is advisable to use the S-value closest to the criterion (300 MPa) to minimize extrapolation errors.

X1.2.7.3. Determine the slope of the m-value-Temperature curve as follows:

$$a = \Delta m\text{-value}/\Delta T \qquad (X1.9)$$

X1.2.7.4. Determine $T_c(m)$ to the nearest 0.1°C using the following equation:

$$T_c(m) = \left(\frac{0.300 - m_1}{a}\right) + T_1 \qquad (X1.10)$$

where:

m_1 = the m-value at a specific temperature T_1, and

a = the slope as described in Equation X1.9.

Note X6—Although any temperature (T_1) and the corresponding m-value (m_1) can be selected, it is advisable to use the m-value closest to the criterion (0.300) to minimize extrapolation errors.

X1.2.7.5. Select the higher of the two low critical temperatures, $T_c(S)$ or $T_c(m)$, to represent the low critical temperature for the recovered asphalt binder, $T_c(Low)$. Determine the low-temperature PG of the recovered RAP binder based on this single critical low temperature.

X1.2.8. Once the physical properties and critical temperatures of the recovered RAP binder are known, proceed with blending at a known RAP percentage or with a known virgin binder grade.

X1.3. *Blending at a known RAP percentage*.

X1.3.1. If the desired final blended binder grade, the desired percentage of RAP, and the recovered RAP binder properties are known, then the required properties of an appropriate virgin binder grade can be determined.

X1.3.1.1. Determine the critical temperatures of the virgin asphalt binder at high, intermediate, and low properties using the following equation:

$$T_{Virgin} = \frac{T_{Blend} - (\%\text{RAP} \times T_{RAP})}{(1 - \%\text{RAP})} \qquad (X1.11)$$

where:

T_{Virgin} = critical temperature of virgin asphalt binder (high, intermediate, or low);

T_{Blend} = critical temperature of blended asphalt binder (final desired) (high, intermediate, or low);

%RAP = percentage of RAP expressed as a decimal; and

T_{RAP} = critical temperature of recovered RAP binder (high, intermediate, or low).

X1.3.1.2. Using Equation X1.11 for the high, intermediate, and low critical temperatures, respectively, the properties of the virgin asphalt binder needed can be determined.

X1.4. *Blending with a known virgin binder*.

X1.4.1. If the final blended binder grade, virgin asphalt binder grade, and recovered RAP properties are known, then the allowable RAP percentage can be determined.

X1.4.1.1. Determine the allowable RAP percentage using the following equation:

$$\%RAP = \frac{T_{\text{Blend}} - T_{\text{Virgin}}}{T_{RAP} - T_{\text{Virgin}}} \tag{X1.12}$$

where:

T_{Virgin} = critical temperature of virgin asphalt binder (high, intermediate, or low);

T_{Blend} = critical temperature of blended asphalt binder (high, intermediate, or low); and

T_{RAP} = critical temperature of recovered RAP binder (high, intermediate, or low).

X1.4.1.2. Using Equation X1.12 for the high, intermediate, and low critical temperatures, respectively, the allowable RAP percentage that will satisfy all temperatures can be determined.

X2. PROCEDURES FOR EVALUATING RAP STOCKPILES

X2.1. The purpose of this appendix is to characterize properties of RAP asphalt binder within a geographical area to determine appropriate percentages of RAP at which virgin asphalt binder properties should be changed for that geographical area.

X2.2. RAP stockpile locations should be selected throughout the geographical area. Geographical areas should be selected with consideration to climatic zones and material sources. The number of stockpile locations may depend upon size of the geographic area and variability of climate within the area and variation of factors within the area.

X2.3. Evaluation of the physical properties of the recovered RAP binder begins with the sampling and testing of the stockpiles within the geographical area. The sample should be large enough to provide sufficient asphalt binder for PG grading.

X2.4. In locations where RAP containing polymer-modified binders is stockpiled separately, evaluation of the asphalt binder should be performed separately from other stockpiles.

X2.5. Solvent extractions should be performed on the RAP samples to acquire recovered binder samples. Reagent-grade solvents should be used to reduce the potential of the extraction process changing the properties of the recovered binder.

X2.6. Determine the physical properties and critical failure temperatures of the RAP binders as outlined in Appendix X1.

X2.7. In some cases the high temperature DSR grade of the recovered binder may be higher than the temperature range of the DSR equipment. For these cases, the binder should be tested at three temperatures: –3, –9, and –15°C from the high temperature limit of the equipment. Plot the log of the test temperature versus the log of the binder property to project the temperature at which the binder will meet the grade requirements. All binder grading should be performed to provide the actual continuous grades of the RAP binder.

X2.8. Determine the distribution of RAP binder grades from stockpiles within the geographical area of study. From the distribution of low temperature grades, calculate the average low temperature grade from the stockpiles. The average low temperature grade plus two standard deviations will provide 96 percent reliability of the low temperature grade of the RAP binders in the geographic area.

X2.9. Collect multiple samples of asphalt binder for each grade supplied into the geographical area. Determine the continuous low temperature grade for each binder. The average low temperature grade plus two standard deviations will provide 96 percent reliability of the low temperature grade of the virgin binders in the geographic area. Use the highest or the 96 percent reliability continuous low temperature grade in the blending analysis.

X2.10. Evaluation Perform blending analysis using X1.4 to determine the maximum allowable percent of RAP binder to be added to a virgin asphalt binder to meet the needed low temperature grade according to LTPPBind 3.1 software.

Note X7 – For example, PG -22 may be specified however a RAP Blend that produces a PG xx-16 may provide 98 percent reliability according to LTPPBind 3.1 software. In most cases, the reliabilities of less than 98 percent are acceptable and will only provide minor temperature differences.

X2.11. Evaluation of asphalt binder in RAP stockpiles in a typical geographic area allows on asphalt binder replacement from RAP based on properties of both RAP and virgin binders. This allows determination of maximum asphalt binder replacement limits without changing the virgin binder grade. It also establishes the maximum amount of asphalt binder replacement that can be used with a virgin binder that is one low temperature grade lower. This information can be used to establish design criteria within a specific geographical area. In areas where the recovered properties vary significantly establishing a general RAP percentage use may not be appropriate. In these cases, the analysis should be on a project by project basis.