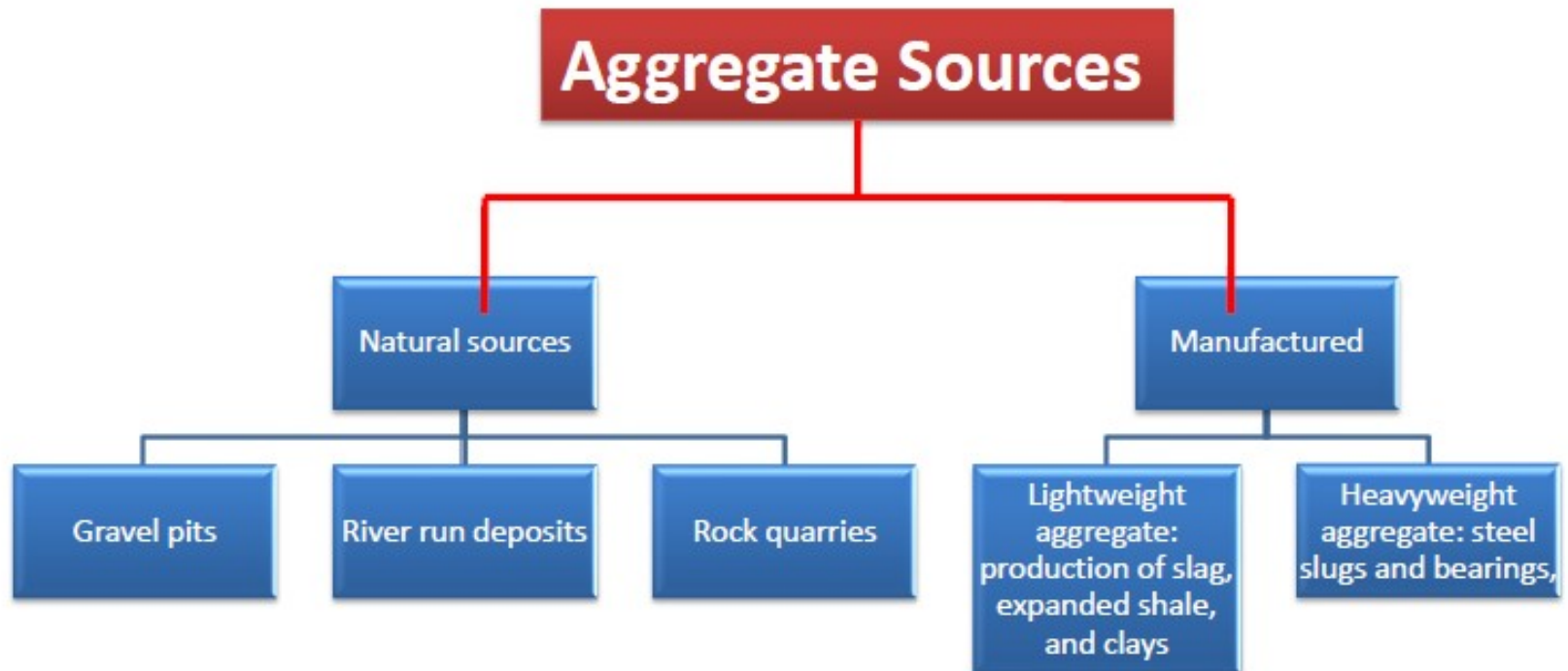




Aggregates

Introduction



Quality of Aggregate by origin

Aggregate	Rock Type	Strength	Durability
Granite	<i>Igneous</i>	Good	Good
Diabase	<i>Igneous</i>	Good	Good
Limestone	<i>Sedimentary</i>	Good	Fair
Sandstone	<i>Sedimentary</i>	Fair	Fair
Shale	<i>Sedimentary</i>	Poor	Poor
Quartzite	<i>Metamorphic</i>	Good	Good

Rating by Rock type

- **Generally, *igneous rocks* that are *fine grained*, well interlocked, and contain low percentages of *feldspars* have the best concrete making properties.**
- **Among the sedimentary rocks, *massive, hard limestones* make usually the best aggregates.**
- **Deep-seated metamorphism can also produce excellent aggregate**

Rating by Rock type

- Any single type of rock may be porous or dense, strong or weak, hard or soft, decayed or unaltered, durable or unsound, fine or coarse grained; *i.e.*, the type of rock by itself does not determine whether or not it can provide an aggregate of adequate quality.

Sand

- ❑ Concrete containing fine sand requires more water for the same consistency, as measured by the slump test, than an equivalent amount of coarse sand.
- ❑ Very coarse sand can have an undesirable effect on finishing quality. Neither very fine nor very coarse sand is desirable but both have been used satisfactorily.

Natural and crushed manufactured sand

- ❑ Rounded river sand gives greater workability than crushed sand composed of sharply angular pieces with rough surfaces.
- ❑ Angular sand particles have an interlocking effect and less freedom of movement in the freshly mixed concrete than smooth rounded particles.
- ❑ Natural sand may give satisfactory results with a coarser grading than would be permitted with crushed manufactured sand.
- ❑ In addition, concrete must contain **2-3% more sand by absolute volume** of total aggregate and 6-9 kg more water/m³ when crushed sand is used.

Manufactured fine aggregate (*MFA*)

- *MFA* processed from crushed stone is gaining wider use as natural sands become depleted in some geographic areas.
- The *MFA* generally contain a greater quantity of fines than natural sands and often mask their good workability with low slump test results.
- The aggregate particle shape and subsequent finishability characteristics are influenced by the type of crusher used in the *MFA* production process.

Gradation

❑ **To Reach Desired Gradation**

- Crushing
- Scalping
- Blending

❑ **Reasons for Blending**

- Obtain desirable gradation
- Single natural or quarried material not enough
- Economical to combine natural and processed materials

❑ **Methods of Proportioning**

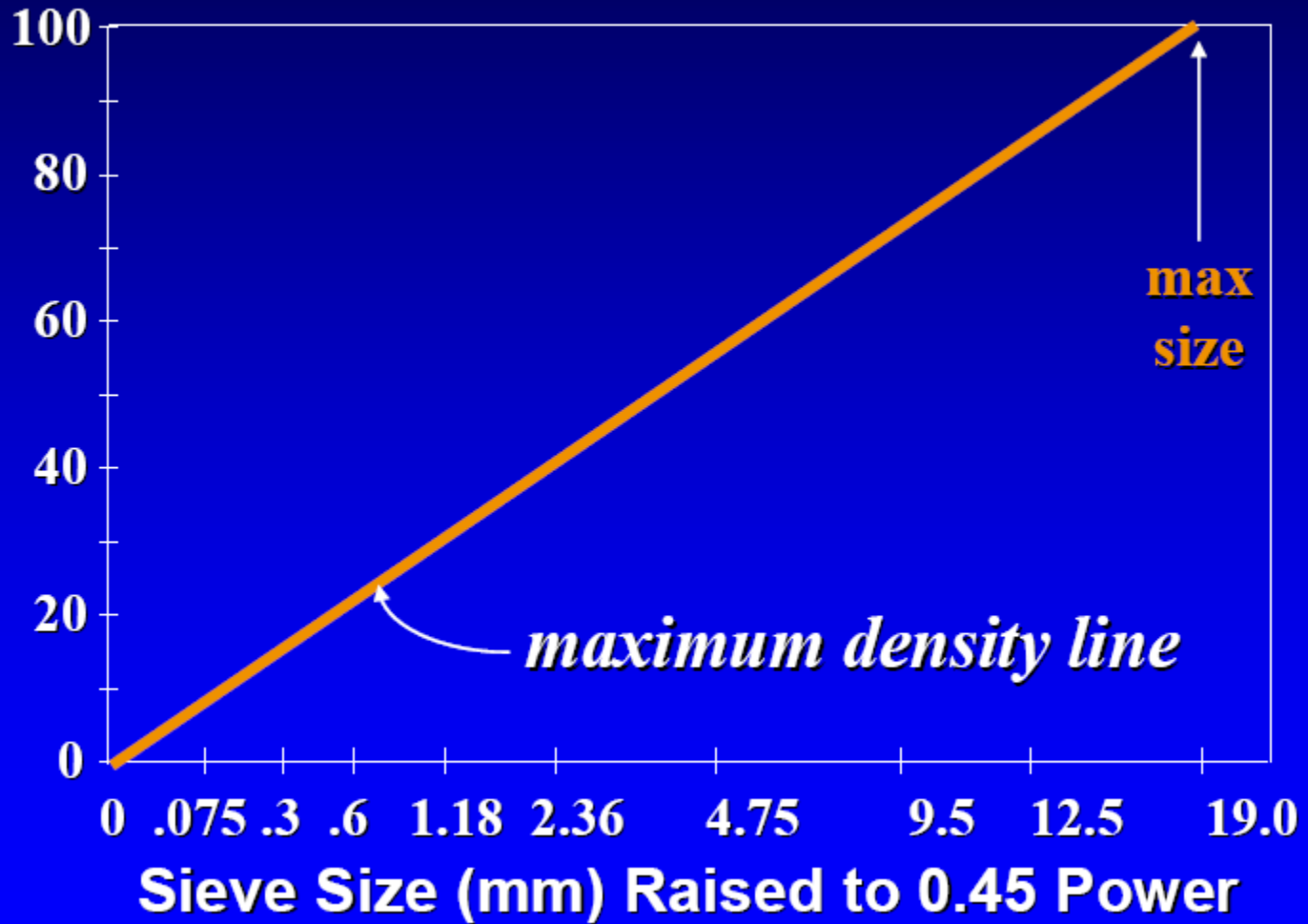
- Graphical Methods
- Analytical Method
- Trail and Error Method

Theoretical Gradation

- **Theoretical gradations generally take the following form:**
- **$P = 100 (d/D)^x$**
- **Where,**
 - *P = percent passing*
 - *d = size of sieve opening*
 - *D = largest size in gradation*
- **The basic idea of the theory is that the amount of material of a given size should be just sufficient to fill the voids between aggregates of larger size.**
- **Fuller suggested a value of 0.5 for x , however, a value of 0.45 for x is being used in Superpave gradations.**

0.45 Power Grading Chart

Percent Passing



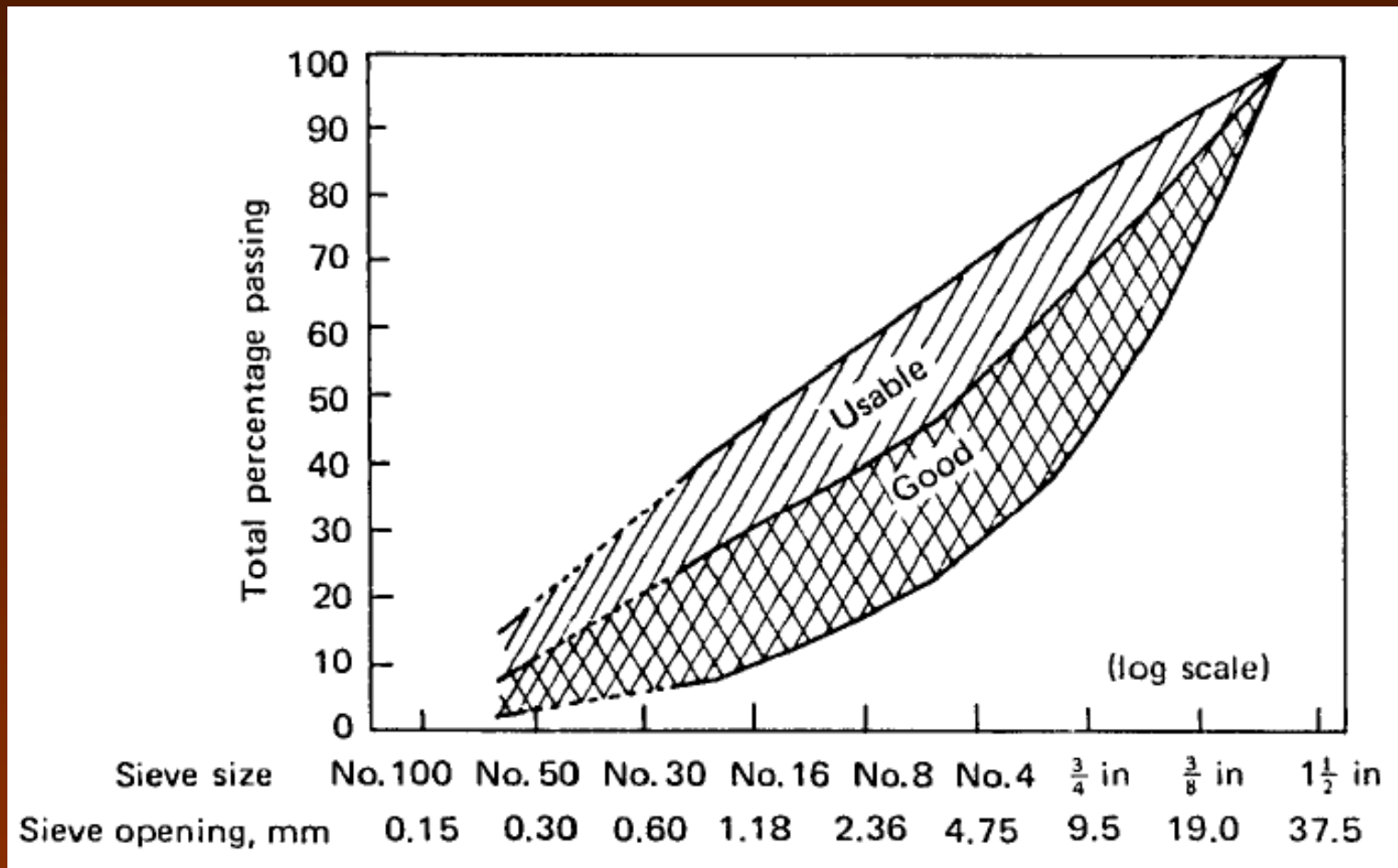
Specified Gradation

- ❑ **Specified gradations are worked out starting from the theoretical gradations.**
- ❑ **Lower and upper limits of gradation for each sieve size are arrived at for allowing window of variation by examining the changes in density and the resulting stability in the final mix.**

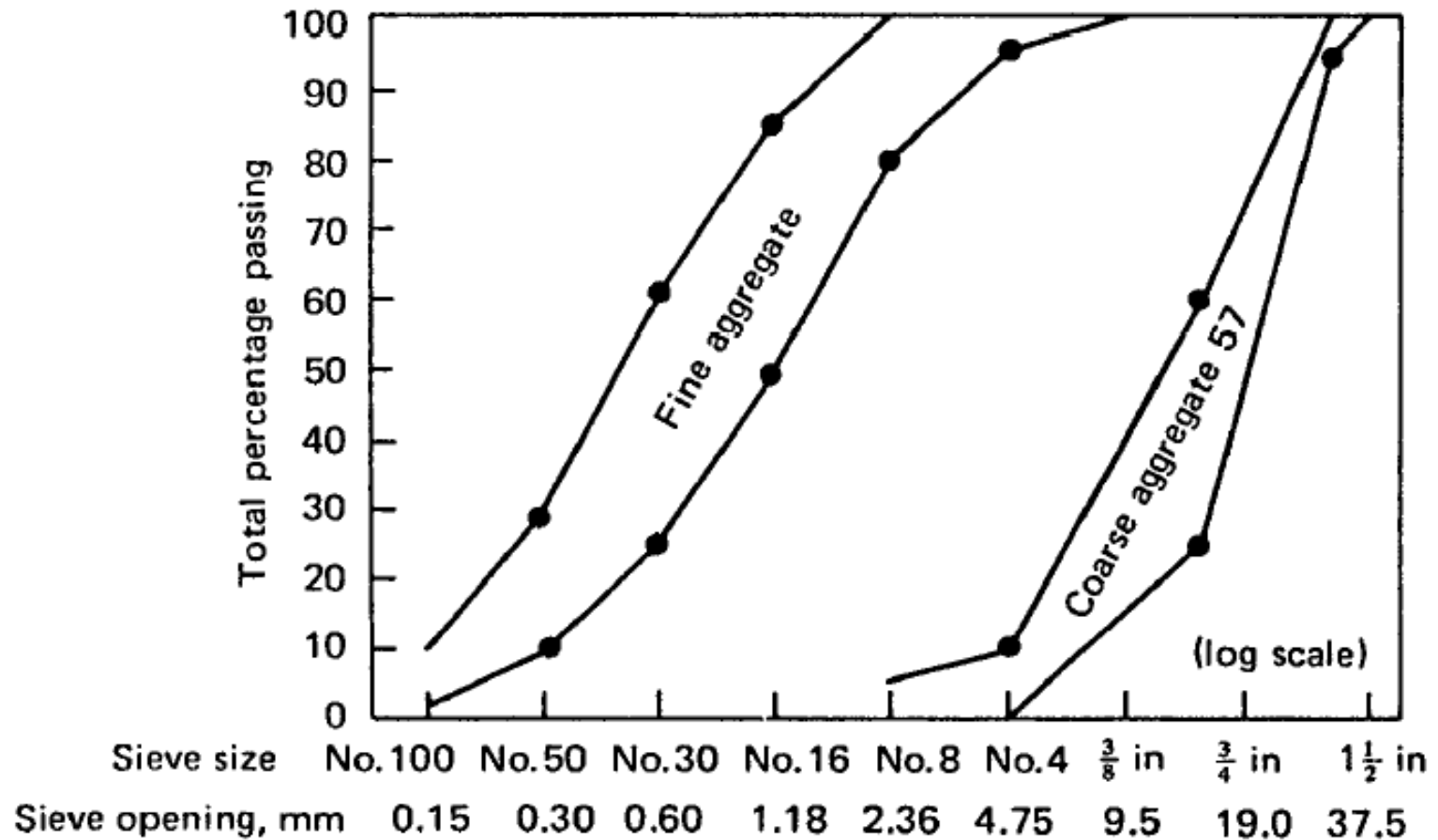
Specified ...

- It is generally considered best when the gradation line is parallel to the maximum density line and a few percentages above or below it.
- The specified gradations are also related to the thickness of construction and the nominal size of aggregate used.

Examples

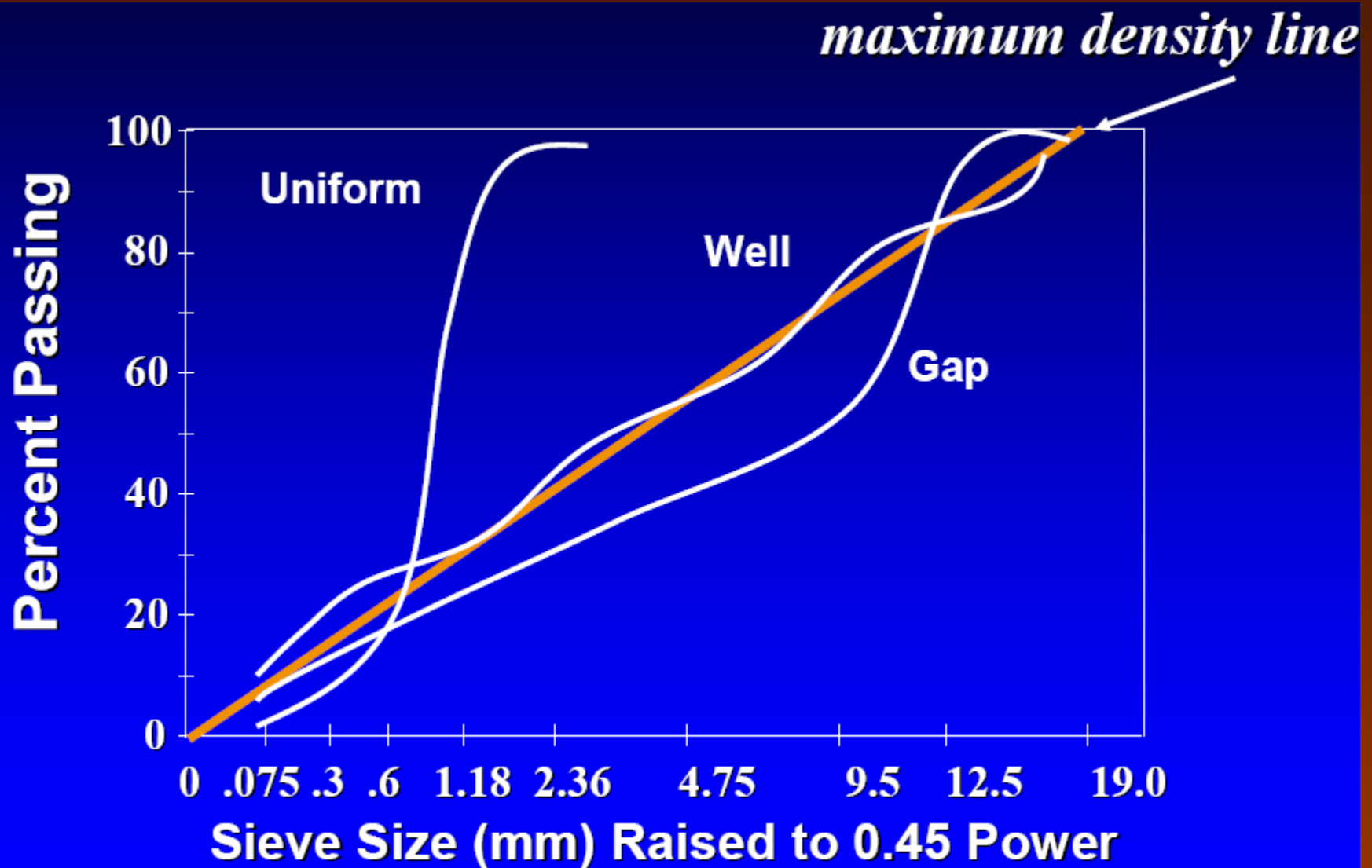


Limit curves for continuous gradings of sand and gravel combinations of D = 30 mm for reinforced concrete (DIN 1045).

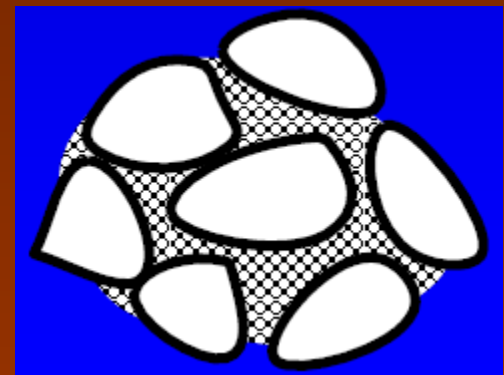
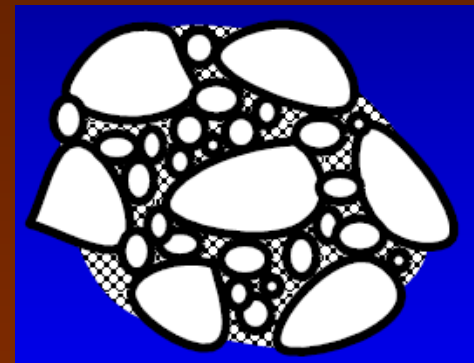
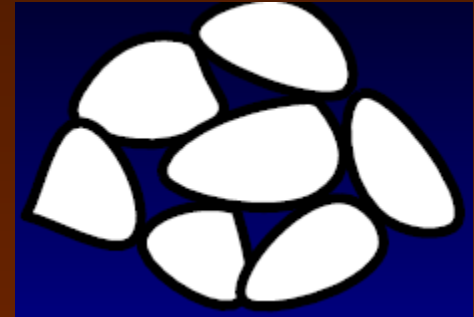


ASTM limit curves for the grading of fine concrete aggregate and that of a coarse aggregate of 1-in (25 mm) nominal maximum particle size.

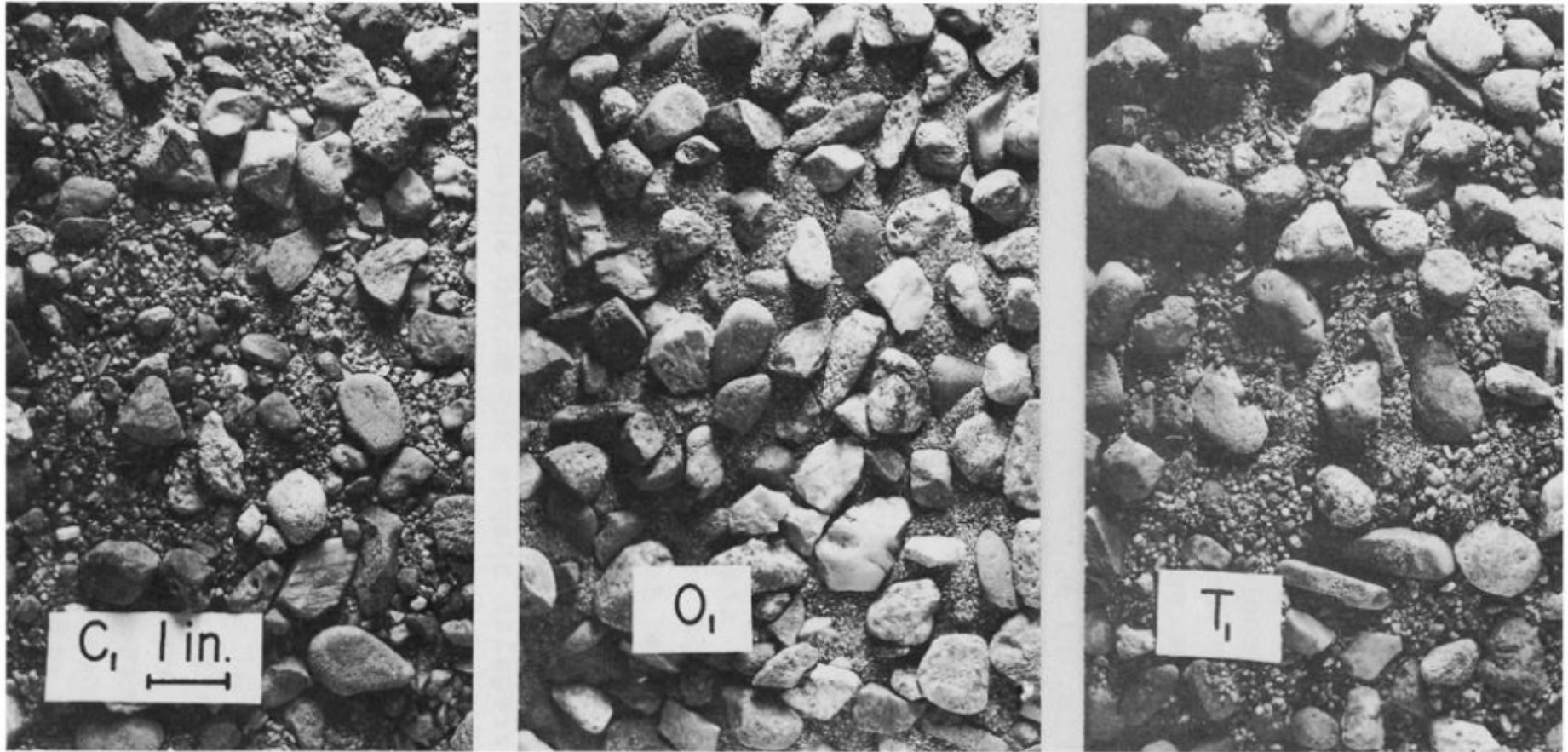
Types of Gradations



- **Uniformly (Open) graded**-Few points of contact-Poor interlock (shape dependent)-High permeability
- **Well (Dense) graded**-Good interlock-Low permeability
- **Gap graded**-Only limited sizes-Good interlock-Moderate permeability



Visual Appearance



Appearance of the continuous (left), one-gap (middle) & two-gap (right) gradings.

Blending Aggregates to Meet Specifications

- ❑ **A single aggregate source is generally unlikely to meet gradation requirements for Portland cement or asphalt concrete mixes.**
- ❑ **Thus, blending of aggregates from two or more sources would be required to satisfy the specifications.**

Blending ...

- **Figure 1 shows a graphical method for selecting the combination of two aggregates to meet a specification.**
- **Table 1 presents the data used in Figure 1.**
- **Determining a satisfactory aggregate blend with the**

FIGURE 1 Graphical method for determining aggregate blend to meet gradation requirements.

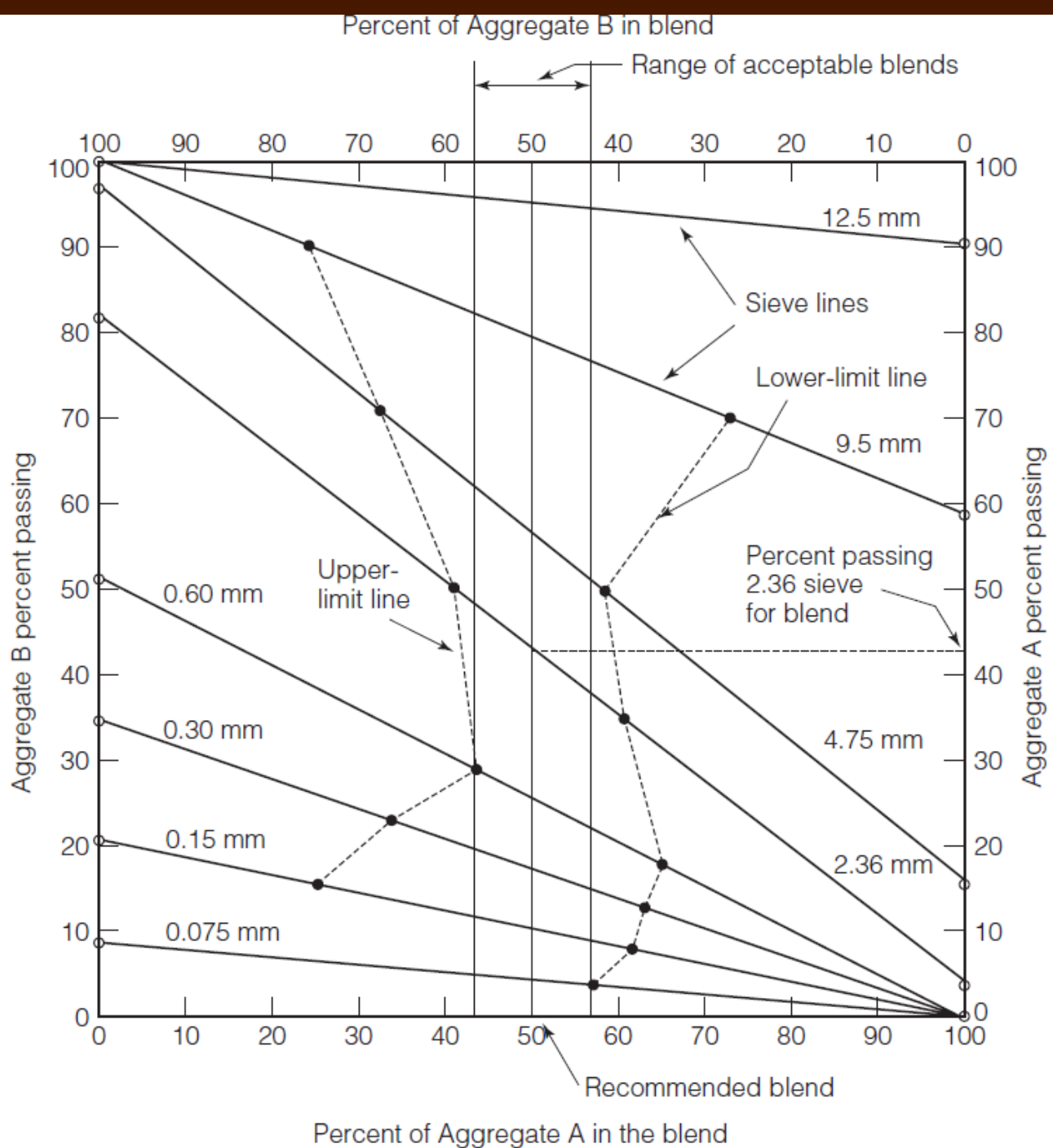


TABLE 1: Example of Aggregate Blending Analysis by Graphical Method

Sieve	19 mm (3/4 in.)	12.5mm (1/2 in.)	9.5mm (3/8 in.)	4.75mm (No. 4)	2.36mm (No. 8)	0.60mm (No. 30)	0.30mm (No. 50)	0.15 mm (No.100)	0.075mm (No. 200)
Speci- fication	100	80–100	70–90	50–70	35–50	18–29	13–23	8–16	4–10
Agg. A	100	90	59	16	3	0	0	0	0
Agg. B	100	100	100	96	82	51	36	21	9
Blend	100	95	80	56	43	26	18	11	4.5

Note: Numbers shown are percent passing each sieve.

Blending ...

1. Plot the percentages passing through each sieve on the right axis for aggregate A and on the left axis for aggregate B, shown as open circles in Figure 1.
2. For each sieve size, connect the left and right axes.

- 3. Plot the specification limits of each sieve on the corresponding sieve lines; *i.e.*, a mark is placed on the 9.5-mm (3/8 in) sieve line corresponding to 70% and 90% on the vertical axis, shown as closed circles in Figure 1.**
- 4. Connect the upper- and lower-limit points on each sieve line.**
- 5. Draw vertical lines through the rightmost point of the upper-limit line and the leftmost point of the lower-limit line. If the upper- and lower-limit lines overlap, no combination of the aggregates will meet specifications.**

6. Any vertical line drawn between these two vertical lines identifies an aggregate blend that will meet the specification.

The intersection with the upper axis defines the percentage of aggregate B required for the blend. The projection to the lower axis defines the percentage of aggregate A required.

7. Projecting intersections of the blend line and the sieve lines horizontally gives an estimate of the gradation of the blended aggregate.

□ Figure 1 shows that a 50-50 blend of aggregates A and B will result in a blend with 43% passing through the 2.36-mm (No. 8) sieve. The gradation of the blend is shown in the last line of Table 1.

Blending More than 2 Aggregate

- When more than two aggregates are required, the graphical procedure can be repeated in an **iterative manner**. However, a trial and error process is generally used to determine the proportions. The basic equation for blending is:

$$P_i = A_i a + B_i b + C_i c + \dots$$

- **Where**
- **P_i = percent blend material passing sieve size i**
- **A_i , B_i , C_i = percent of aggregates A, B, C, passing sieve i**
- **a , b , c = Fractions by weight of aggregates A, B, and C used in the blend, where the total is 1.00**

Rothfuchs method

- ❑ The method described by Rothfuchs has been found most useful as it is reasonably quick and simple and can be applied to blends of any number of components.
- ❑ It consists essentially of the following stages:

1. The cumulative curve of the design aggregate's particle-size distribution is plotted, using the usual linear ordinates for the % passing, but choosing the scale of sieve sizes which allows the particle-size distribution to be plotted as a straight line. This is readily done by drawing an inclined straight line and marking on it the sizes corresponding to the various % passing.
2. The particle-size distribution curves of the fractions to be mixed are plotted on this scale. It will generally be found that they are not straight lines.

3. With the aid of a transparent straight-edge, the **straight lines** which most nearly approximate the **particle-size distribution** curves of each component are drawn. This is done by selecting for each curve a straight line such that the areas enclosed between it and the curve are minimal and are *balanced about the straight line*.
4. The opposite ends of these straight lines are joined together and the proportions for mixing can be read from the points where these *joining lines cross the diagonal straight line* which represents the *design grading (DG)*.

□ **The procedure will be apparent from the following example:**

- The particle-size distributions of 3 fractions of stone and filler available to produce the required *DG* are given in Table A1.
- The design or specification grading is also given in the Right-hand column of the table.

Table A1 Particle-size distribution of components on the basis of wet analysis

Sieve size (mm)	Sample				Design of Spec. Grading
	A	B	C	D	
19.0	100	-	-	-	100
13.2	85	100	-	-	90
6.7	30	90	-	-	78
4.75	0	70	100	-	61
2.36	0	25	95	-	45
1.18	0	10	70	-	30
0.6	0	0	50	100	22
0.3	0	0	30	95	16
0.15	0	0	10	80	12
0.075	0	0	0	50	6

- In Figure A1 the required grading of the blend is represented by the diagonal straight line 0-0'. The vertical ordinates of the grading sheet are graduated from 0 to 100% on a linear scale.
- The horizontal scale for sieve aperture size is graduated by drawing for each sieve size a vertical line which cuts the diagonal at a point where the ordinate equals the percentage passing that sieve, i.e. 100% for 19.0 mm, 90% for 13.2 mm, 78% for 6.7 mm and so on.

- ❑ The size distributions of the fractions to be mixed (A, B, C and D in Table A1) are plotted on this scale of sieve size giving lines EFO' (fraction A), GHI (fraction B), JKL (fraction C) and OPQ (fraction D) in Figure A1.
- ❑ The nearest straight lines to these size distributions are drawn with the aid of a transparent straight-edge, by the 'minimum balanced areas' method. They are the broken lines RO', TS, VU and OW.
- ❑ The opposite ends of these lines are joined giving the chain lines RS, TU and VW. The points where these lines cross the required distribution line (diagonal OO') are marked by the circles 1, 2 and 3.
- ❑ The proportions in which the four fractions should be mixed are obtained from the difference between the ordinates of these points and are shown on the right-hand side of Figure A1 (sections A, B, C and D).
- ❑ The theoretical particle-size distribution which will result from mixing the fractions in these proportions is given in Table A2. Although it is not plotted on the graph, it is the

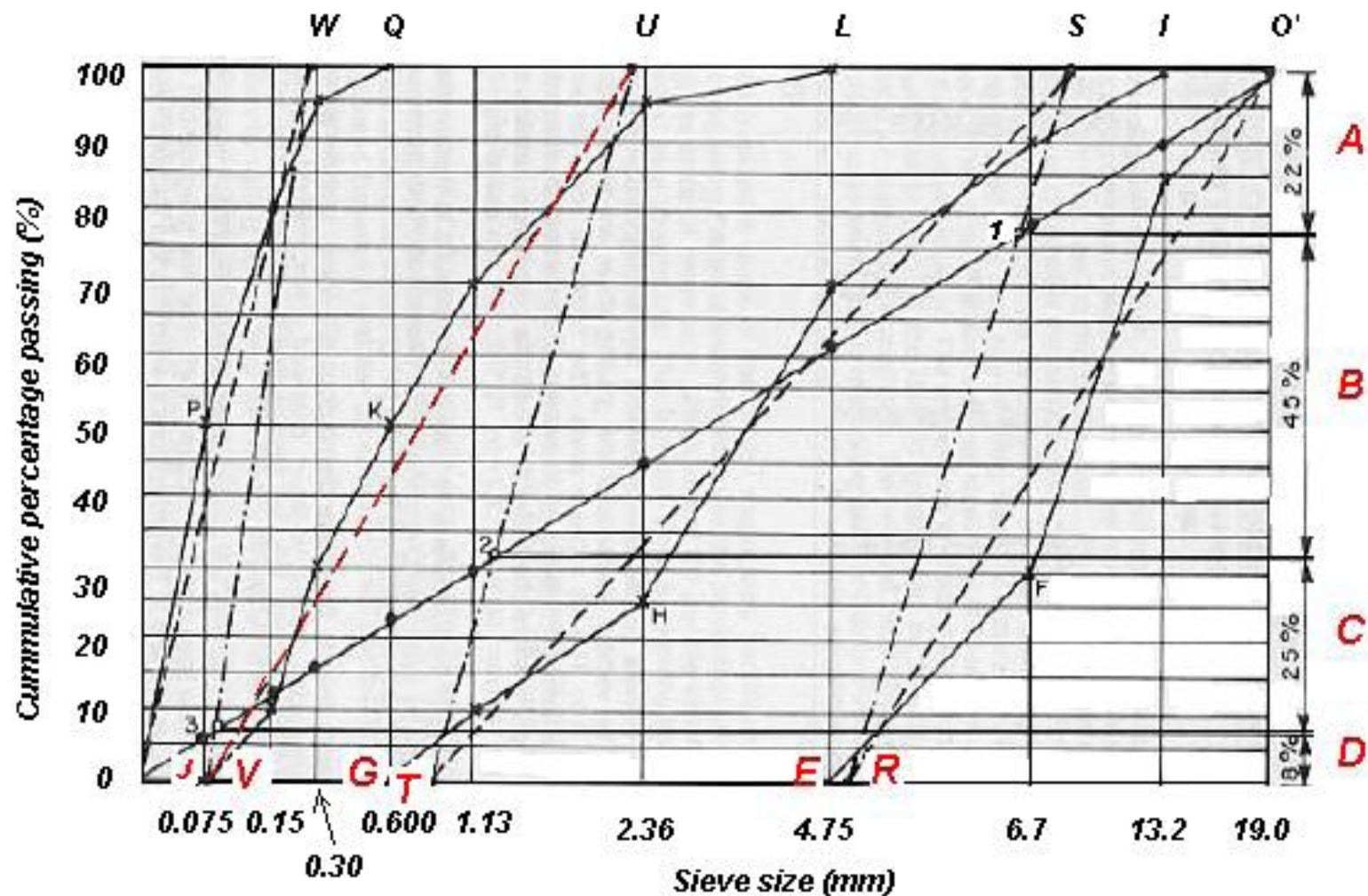


Fig A1. Aggregate blending chart - Rothfuchs's method

Table A2 Theoretical blend resulting from Rothfuchs's method

Percentage of each fraction		22% of A	45% of B	25% of C	8% of D	Total	cumulative grading
passing (mm)	Retained (mm)						
19.0	13.2	3.3				3.3	100
13.2	6.7	12.1	4.5			16.6	96.7
6.7	4.75	6.6	9			15.6	80.1
4.75	2.36		20.25	1.25		21.5	64.5
2.36	1.18		6.75	6.25		13	43
1.18	0.6		4.5	5		9.5	30
0.6	0.3			5	0.4	5.4	20.5
0.3	0.15			5	1.2	6.2	15.1
0.15	0.075			2.5	2.4	4.9	8.9
0.075					4	4	4

Analytical Method Methods

- **For each sieve we write the constraints**
 - $a \times FA + b \times FB + c \times FC + d \times FD \leq UL$
 - $a \times FA + b \times FB + c \times FC + d \times FD \geq LL$
 - Where, a , b , c and d are the proportions of aggregates A , B , C and D respectively
 - FA , FB , FC , and FD are respectively the percent fines of aggregates A , B , C and D passing the sieve

- ❑ **Select critical sieves in blend**
- ❑ **Determine initial proportions which will meet critical sieves**
- ❑ **Check calc. blend against specification**
- ❑ **Adjust if necessary and repeat above steps**

Properties of Blended Aggregates

- When two or more aggregates from different sources are blended, some of the properties of the blend can be calculated from the properties of the individual components.
- With the exception of *specific gravity* and *density*, the properties of the blend are the *simple weighted averages* of the properties of the components.

- Once the percentages of the stockpiles have been established, the combined aggregate specific gravities can also be calculated:

$$G = \frac{1}{\frac{P_1}{100G_1} + \frac{P_2}{100G_2} + \frac{P_3}{100G_3} \dots}$$

Combined Properties of Blend-Angularity, Absorption, Strength, and Modulus

- $X = P_1X_1 + P_2X_2 + P_3X_3 + \dots$
- X = composite property of the blend
- X_1, X_2, X_3 = properties of fractions 1, 2, 3
- P_1, P_2, P_3 = decimal fractions by weight of aggregates 1, 2, 3 used in the blend, where the total is 1.00

Example

- The following laboratory bulk specific gravity and absorption values were obtained for an aggregate sample that consists of 60% coarse aggregate and 40% fine aggregate:
- Coarse aggregate portion: Bulk dry specific gravity = 2.65; absorption = 1.4%
- Fine aggregate portion: Bulk dry specific gravity = 2.81; absorption = 1.9 %
- What is the bulk specific gravity of the blend?
- What is the absorption of the blend?

Solution

	Percentage s	G_{sb}	Absorption, %
Coarse portion	60	2.65	1.4
fine portion	40	2.81	1.9

$$G = \frac{1}{\frac{60}{100 \times 2.65} + \frac{40}{100 \times 2.81}} = 2.71$$

$$Absorption = 0.6 \times 1.4\% + 0.4 \times 1.9\% = 1.6\%$$

Exercise

Blend the given three aggregates in order to satisfy the specification.

Sieve	Spec. limit	Bin A	Bin B	Bin C
1 in	100	100	100	100
3/4 in	95-100	95	100	100
3/8 in	65-80	45	100	100
#4	45-60	12	100	100
#8	30-45	3	85	100
#30	15-25	0	48	100
#200	3 7	0	7	80

Alkali-Aggregate Reactivity



- **Silica** in some agg. reacts with the alkalis (Na_2O , K_2O) in Portland Cement (especially in warm, humid climates)
 - excessive expansion
 - cracking
 - popouts
- **Carbonates** in aggregate can also react to a lesser extent
- **Minimizing reactivity if a reactive aggregate must be used**
 - Type II cement – minimizes alkali content of P.C.
 - Keep concrete as dry as possible Fly Ash (Pozzolans) reduce alkali reactivity (not too much)
 - Sweetening – add crushed limestone to the aggregate

Cleanness and Deleterious Materials

❑ Deleterious Substances

- Organic impurities
- Minus 0.075 mm (No. 200)
- Coal, lignite, or other low density materials
- Clay lumps and friable particles
- Soft particles

❑ Sand Equivalency Test

$$SE = h_{\text{sand}} / h_{\text{clay}} \times 100$$

