DRAFT - NOT FOR PUBLICATION

LABORATORY DESIGN OF CONVENTIONAL MONOLAYER SLURRY SEAL AND MULTILAYER, DENSE GRADED COLD MIXES.

by

C. ROBERT BENEDICT,
CONSULTANT

C/O POLYMAC CORPORATION
ALPHA LABORATORY
P.O. BOX 74
ALPHA, OHIO 45301
(513) 298-6647

and

DIRECTOR OF RESEARCH
INTERNATIONAL SLURRY SEAL ASSOCIATION
1101 CONNECTICUT AVE., N.W.
WASHINGTON, D.C. 20036
(202) 857-1160

FOR PRESENTATION
AT THE
TRANSPORTATION RESEARCH BOARD MEETING
WASHINGTON, D.C.
JANUARY 11-14, 1988

TABLE OF CONTENTS

ABSTRACT

Slurry Seals have developed over the years from the original very thin mass crack treatments to the present day coarse mixes applied as thick as 10 cm in the case of rutfilling. Non-conventional polymer modified emulsion-aggregate quick traffic systems are currently applied with highly productive sophisticated machinery.

The differences in design problems of thermoplastic hot mixes and water fluidized cold mixes are discussed. A design method for conventional monolayer slurry seal is reviewed. Many of the monolayer test procedures are not adequate for the design of the new multilayer "performance" systems.

New testing procedures are briefly reviewed. Initial research is reported on simulated rolling traffic compaction of layer thicknesses, one, two and three stones deep. Five cases of compaction characteristics are described. Inverted, Marshall-like curves were discovered in the initial experiments.

To explain the varieties of rolling compaction behavior, a number of variables were investigated: filler content, mix additives, polymer type and quantity, emulsifier type and bitumen type. Compaction behavior was found to range to a factor 5 depending upon the variables.

Further research is planned to attempt correlation with the Marshall Stability, Marshall quotient and British Wheel Tracking Test.

INTRODUCTION

The introduction of emulsified bitumens in the early 20th century made possible the use of thin layered, cold applied emulsified bitumen - aggregate mixes in the treatment of pavement surfaces. The German Schlamme, the original slurry seal developed in the 20's and 30's, was applied in very thin layers as a mass crack sealer and surface dressing. Since that time there has been a long and steady trend toward the use of thicker and coarser mixes ranging from the early 1.5 - 3 kg/m (3-6 lbs/yd) through the more normal 8 kg/m (15 lbs/yd) up to 100 kg/m (220 lbs/yd), but now more commonly in the 8-16 kg/m (15-30 lbs/yd) range.

Equipment to produce and lay these heavier slurries and cold mixes has evolved to the present day, highly sophisticated, continuously self-loading machines. Production rates of 500 to 700 tons per day are common with these machines. As many as 15 lane - miles per day have been achieved.

Productivity restraints caused by the use of conventional "slow-set" and "quick'set" emulsion-aggregate systems has stimulated the development of "quick-traffic" systems. The demand for improved bitumen properties and for improved aggregate quality brought about by heavier, multilayered applications has, in turn, stimulated the rise of "performance" material systems produced in contractor-controlled emulsion and aggregate plants.

These factors, in turn, have required a reappraisal of slurry seal and cold overlay tests and design methods. Here, we wish to:

1. Review the current ISSA and ASTM mono-layer testing and design procedures.
2. Relate some current research on testing and design methods.
3. Report the results of initial research on a method to design for variable layer thickness by measuring compaction characteristics produced by traffic simulated rolling compaction.

DISCUSSION

Thin layered surface mixes magnify the problems of both cold and hot mixed thick layered mixes. Any defect in thin layers becomes apparent in less time than in thicker layers. The design problems of conventional mono-layered slurry seals are very different from those of multi-layered systems, as in rutfilling, and each must be approached differently.

Hot mixed asphaltic concrete systems (HMAC) are relatively simple systems to design and apply since they are usually only a 2-component system (bitumen and aggregate). Their thermoplastic binders are fluidized for application by heat and "set" to traffic simply by cooling to the ambient temperature.

Cold mixed asphaltic concrete (CMAC) or dense graded emulsion mixes are fluidized for application by water. The "set" to traffic (wet adhesion, wet cohesion, particle coalescence) are chemical rather than mechanical phenomena. CMAC must consider and overcome the effects of the presence of mix water.

CMAC's have the advantages of using the effects of the residual emulsifying agents and additives to improve adhesion, cohesion, high and low temperature properties. Additionally, no heat or hot air is used so there is no premature hardening of the binder as is the case with HMAC's.

Vast differences are found in the laboratory performance characteristics of various systems. These differences are not mechanical; rather, they are due to the interrelationships of the combined chemistry of the bitumen, emulsifiers, aggregate and admixtures. When any single ingredient is changed there will be a substantial change in testing results.

CONVENTIONAL MONO-LAYER SLURRY SEAL TESTING AND DESIGN

The history of slurry seal testing and design has been the history of the search for objective, performance related numbers. Kari and Coyne (1), in their 1964 AAPT paper, introduced the Wet Track Abrasion Test and correlated the test to field performance. Since then, many researchers (2-19) have contributed to the body of slurry seal testing and design technology; essentially dealing only with conventional, mono-layer design.

DESIGN OBJECTIVES

Slurry seals and cold overlays are used in the treatment or renewal of the surface element. This renewal of the surface element may include the design objectives of:

1. Prevention or control of weathering
2. Repair of weather and wear damage
3. Improvement of wet friction characteristics
4. Improvement of surface drainage problems caused by rutting or cross-slope deficiencies.

METHOD

Because of the huge numbers of variables, a theoretical method of slurry design has not been developed. The empirical or direct experimental method is used to design slurry seals and cold overlays; i.e., construct a representative range of laboratory specimens and subject them to field-related tests. The designer must proceed by answering the questions:

1. Will "it" mix?
2. Will "it" set?
3. Will "it" last?
4. Will "it" be safe?
5. Will "it" meet the objectives?

To help answer these questions, some 33 technical bulletins have been published in ISSA's "Design Technical Bulletins" (20) Additionally, ASTM D3910-80a (21) and the AEMA 1983 "Performance Guidelines" (22) have been published.

PROCEDURE

ISSA Technical Bulletin #111, "Outline Guide Design Procedure for Slurry Seal", presents a step-by-step check list of all tests from which the specifying agency may select those tests relevant to the particular job at hand.

A typical design procedure selection follows:

1. MATERIALS TESTING: AGGREGATE AND EMULSION. Testing of the materials submitted usually is a simple quality check of the aggregate gradation and sand equivalent and the emulsion sieve, stability and residue content.

2. TRIAL MIX: Trial mixes are then made using a range of emulsion, water and filler contents to determine mixing properties and the desirability of filler or other admixtures as well as setting characteristics.

3. COMPATIBILITY. After curing overnight, the "cured" trial mixes are examined for aggregate and bitumen segregation, adhesion and appearance and judged for system compatibility.

4. CONSISTENCY. Three emulsion contents are selected such as 12, 15, & 18% and consistency tests run at each of these emulsion levels to determine the water content required to give a uniform 2-3 cm outflow consistency or mixture viscosity with each emulsion content (figure 1).

5. WET TRACK ABRASION TEST (WTAT). Triplicate Wet Track Abrasion Test specimens are prepared at 2-3 cm consistency for each level of emulsion content. The specimens are then dried to constant weight, immersed in water for one hour and abraded for 5 minutes with a weighted hose using a standard WTAT machine (Hobart C-100 planetary mixer). The loss results are determined by dry weight difference. The loss results are plotted to determine the percent emulsion required to yield a maximum loss of 800g/m^2 (75 grams/ft^2) (figure 2).

The Wet Track Abrasion Test determines the MINIMUM bitumen content.

6. LOADED WHEEL TEST (LWT). Triplicate Loaded Wheel Test specimens are prepared as in the WTAT procedure. The cured specimens are subjected to 1000 reciprocating cycles of a 2-cm wide rubber wheel loaded to 57 kg. The number of cycles to tackiness, if any, is noted as well as the macro-texture. After compaction, hot, standard sand is compacted onto the specimen surface and the amount of adhered

sand is determined. Less than 50 g/ft^2 of adhered sand is deemed safe for very heavy traffic while 70-75 $grams/ft^2$ is considered adequate for low density traffic (figure 3).

The Loaded Wheel Test determines the MAXIMUM bitumen content.

7. GRAPHICAL SELECTION OF OPTIMUM BITUMEN CONTENT. Finally, the results of the WTAT and LWT are plotted together (figure 4). The maximum bitumen content without flushing is desirable. However, the field application tolerances must be considered so that the maximum or minimum bitumen content limits are not exceeded.

8. REPORT. The results of these tests are reported and translated into field quantities.

NEW TESTING METHODS

In recent years, remarkably effective new materials have become available which far outperform conventional systems. With these new materials, conventional slurry design methods and tests give unusual if not Utopian results. New testing and design methods are needed. Among the tests in use or under developement are:

1. Aggregate Quality -	Methyl Blue Filler Saturation
2. System Compatibility	Schulze-Breuer Tumbling Pill Abrasion and Adhesion
3. System Compatibility and Classification	6-Day Immersion Wet Track Abrasion Test (figure 5)
4. System Classification by Set and Cure Measurement	Modified Cohesion Test (figure 6)
5. Bitumen Residue Quality	60C Cured Cohesion Tests (figure 7)
6. High Temperature Strength and Stretch	Motorized Cohesion Test Rotational Shear (figure 8)

7. Mixing Characteristics	Strip chart recording of phase energy requirements (figure 9)
8. Low Temperature Flexibility	4C Flexural Tension Test
9. Optimum Bitumen Content	Modified Marshall Test
10. Compaction Resistance	Loaded Wheel Test and Wheel Tracking Test Traffic Simulators

MULTILAYER DESIGN RESEARCH: EFFECTS OF ROLLING COMPACTION

When dense graded emulsion mixes are applied in variable thicknesses (single and multiple stone depths) as is required in rutfilling or levelling, some special design problems arise. Conventional mono-layer slurry seal design is not generally applicable to multilayers because the bitumen contents required are too high or too rich. As water is removed from the mix, additional voids are created. The prediction of the degree of traffic compaction, if any, becomes important if the rutfilling or levelling operation is to succeed.

The Marshall test method uses high temperature impact compaction and does not simulate the ambient temperature, rolling traffic compaction typical in unrolled, thin layered cold mixes. In this initial study of traffic compaction prediction, we have used the Loaded Wheel Tester described in ISSA Technical Bulletin #109. LWT specimens were prepared using 5 different emulsions at 8, 12, and 16% emulsion contents mixed with an ISSA type 2 (0/5 mm) aggregate gradation cast into 6, 9, and 12 mm molds (one, two and three stones deep). The emulsion was prepared from a high quality AC-20 using a "performance" emulsifier.

After curing, the specimens were subjected to, 1000, 57 kg Loaded Wheel Cycles. The compacted specimens were measured for rut depth or vertical displacement using the uncompacted edge as reference. The percent vertical displacement was calculated and plotted.

5 cases of compaction behavior related to layer thickness and bitumen content were observed:

CASE I	Track depth proportional to layer thickness.
(fig. 10)	Percent compaction converges at high bitumen content.
CASE II	Track depth reduced at thicker layers.
(fig. 11)	Percent compaction converges at low bitumen content.
CASE III	Track depth proportional to layer thickness.
(fig. 12)	Percent compaction converges at both high and low bitumen contents. Least compaction is at "optimum".
CASE IV	Track depth proportionally reduced at thicker layers.
(fig. 13)	Percent compaction varies inversely with layer thickness at "optimum".
CASE V	Track depth proportional to layer thickness. Percent
(fig. 14)	compaction same for all thicknesses at "optimum".

In all cases it is noted that something happens to cause a break in the compaction curves at about 12% emulsion content (7.5% AC). In some cases, the curves, though inverse, are similar to Marshall curves. In contrast to the Marshall Test results however, voids are highest at the lowest compaction (vertical displacement or maximum rutting resistance) values.

The Case V curve, where the percent compaction at the optimum bitumen content is independent of layer thickness, may be the best case with which to predict rutting resistance.

Under the severe, 57 kg loading of the LWT, it appears that minimum vertical displacement values may be in the 10% range; perhaps as low as 5%. Under more realistic loadings of 28-29 psi (200 kPa), there may be no vertical displacement which would, of course, be the ideal system; there would be no compaction by traffic.

VARIABLES AFFECTING COMPACTION CHARACTERISTICS

The study was continued to investigate some of the variables that may have caused the variety of compaction characteristics observed in the initial experiments. These variables included:

1. MEASUREMENT METHOD. The measurement method was refined to include width, thickness and uncompacted edge measurements before and after compaction (figure 15). Figure 16 shows the results using these measurements on 13 mm specimens prepared with 1.5% and 3% Polymer "A" contents. These results are typical of results found throughout this testing program.
2. EFFECT OF AGGREGATE FILLER CONTENT. The effect of filler content was examined by using 5 and 15% -200 mesh filler with and without cement. As expected, lower filler contents were less resistant to compaction. Cement addition reduced vertical displacement at "optimum" in the system tested (figure 17).
3. EFFECT OF MIX ADDITIVES. Figure 18 compares the effect on percent compaction of 3 additives, KX, KY and KZ and a nonadditive control all using Polymer "A" at 3% concentration. Both KX and KY achieved a very low compaction at the 12% "optimum" emulsion content. The KX additive produced an excellent, nearly flat compaction curve over a wide range of bitumen content.

4. EFFECT OF POLYMER TYPE AND CONTENT, BITUMEN QUALITY AND EMULSIFIER TYPE. Six different polymers at 1.5% and 3% concentration's were co-emulsified with a high quality bitumen using emulsifier "P". For comparison, the same high quality performance grade bitumen and a commodity grade bitumen were each emulsified using emulsifiers "P", "M" and "TE" plain with no polymers. Figure 19 summarizes the percent compaction of 13 mm specimens at the 12% "optimum" emulsion content.

Compaction behavior varies by a factor of 5 over the complete range of variables. There is little difference between the 3% polymer modified systems and a selected unmodified performance system under the test conditions. While bitumen quality effects the test performance, the greatest effects are seen in emulsifier type and additive type.

FUTURE RESEARCH

In the UK, Choyce Lammiman and Taylor (23) have correlated the British Wheel Tracking Test (45C) with the Marshall Test (60C). Here, our investigation is continuing to attempt a correlation with their data and "cold rolled" simulated traffic compaction of multi-layered uncompacted cold mixes. Both the Loaded Wheel Test and the British Wheel Tracking Test are being used for comparison.

SUMMARY

1. Conventional Mono-layer slurry seal testing and design methods have been reviewed as well as several new methods of testing new "performance" materials systems.

2. An approach to the design of variably thick, multilayerd cold mix has been examined. Peak resistance to compaction has been bitumen content and "cold rolled" Marshall-

The variables of bitumen quality, emulsifier type, filler quantity polymer type and quantity and mix control additives were found to substantially affect the rates of rolling compaction.

3. In future research it is hoped that correlations of the British Wheel Tracking rates with Marshall Stability and Marshall Quotients may be applied to multilayered slurry seals and cold mixes.

REFERENCES

1. Kari, W.J., and Coyne, L.D., "Emulsified Asphalt Slurry Seal Coats", Proc. AAPT, 1964.

2. Harper, W.J., Jimenez, R.A., and Gallaway, B.M., "Effects of Mineral Fillers in Slurry Seal Mixtures", Highway Research Board Record No. 104, 1965.

3. Goodrich, J.L., Ferm, R.L., Rogers, E.D., and Schmitz, C.G., "Practical-Quick-Set Slurry Seal Coats", Proc. ISSA Conv., Miami, 1969.

4. Fiock, E.F., "Laboratory Experiences with Asphalt Slurries and their Constituents" Proc. ISSA Conv., Miami, 1969.

5. Skog, J., "Wet Track Abrasion Testing", Proc. ISSA Conv., San Diego, 1970.

6. Fiock, E.F. and McAtee, L., "A Shaker method for Evaluating the Quality of Cured Slurries", Proc. ISSA Conv., New Orleans, 1972.

7. Benedict, C.R., "An Introduction to the Potential Uses of a Loaded Wheel Tester (LWT) for the Traffic Count Design of Slurry Seal", Proc. ISSA Conv., Las Vegas, 1975.

8. Godwin, L.N., "Instruction Report S-75-1, Slurry Seal Surface Treatments" U.S. Army, W.E.S., Vicksburg, Miss., 1975.

9. Benedict, C.R., "Design and Control of Slurry Seal Mixes", Proc. AEMA, Phoenix, 1977.

10. Gordillo, J., Tomas, R., "The Contribution of the Use of Bituminous Emulsions with Elastomers in the Slurry Seal Technique", Proc. ISSA World Congress, Madrid, 1977.

11. Ajour, A.M., "Aspects Chemiques de la Formulation des Emulsion de Bitume", Proc. ISSA World Congress, Madrid, 1977.

12. Harkness, L.M., "Surface Area and Zeta Potential and Their Relation to Slurry Mixes", Proc. ISSA Symposium on Quick-Set, Quick-Cure Slurry Seal Systems, Atlanta, 1978.

13. Lee, D.Y., "Laboratory Study of Slurry Seal Coats" Final Report, 781-88, Engineering Research Institute, Iowa State University, Ames, Iowa, 1978.

14. Ordemir, O., "The Effects of Aggregate Gradation on Slurry Seal Texture", Masters Thesis, Civil Engineering Dept., Iowa State University, 1982.

15. Reinke, G.H., and Brooker, A.C., "Latex Stabilized Soft Asphalt Emulsion", Proc. ISSA Conv., Guadalajara, 1982.

16. Benedict, C.R., "Classification of Asphalt Emulsion-Aggregate Mixture Systems by Cohesion Tester Measurement of Set and Cure Characteristics", Proc. ISSA Conv., Phoenix, 1983.

17. Benedict, C.R., "Uses of the Modified Cohesion Test for Emulsion Formulation and Mix Design of Performance Cold Mix Systems", Proc. AEMA Conv., New Orleans, 1985.

18. Benedict, C.R., "Experiments with Cured Cohesion Testing of Slurry Seals and Thin Layered Cold Mixes", Proc. ISSA Conv., San Francisco, 1986.

19. Benedict, C.R., "Introduction to a Loaded Wheel Test Method for the Measurement of Compaction Stability and Rutting Resistance of Multilayered, Dense Graded, Fine Aggregate Cold Mixes", Proc. ISSA World Congress, Geneva, 1987.

20. "Design Technical Bulletins-1984" ISSA pub. International Slurry Seal Association, 1101 Connecticut Ave., N.W., Washington, D.C. 20036.

21. "Standard Practices for Design, Testing and Construction of Slurry Seal", ASTM designation D3910-80a, Annual Book of ASTM Standards, 1981-part 15, ASTM, 1916 Race St., Phila. PA. 19103

22. "Recommended Performance Guidelines-Slurry Seal", rel. 1983 Asphalt Emulsion Manufactures Association, 1133 Fifteenth St., N.W., Washington, D.C. 20005

23. Choyce, P.W., Lammiman, P.A., and Taylor, I.F., "Resistance to Deformation of Hot Rolled Asphalt", Highway and Transportation Volume 31, No. 1, Jan. 1984 (J. of Inst. of Hgwy Group and Tptn and HTTA). (U.K.).

LIST OF FIGURES

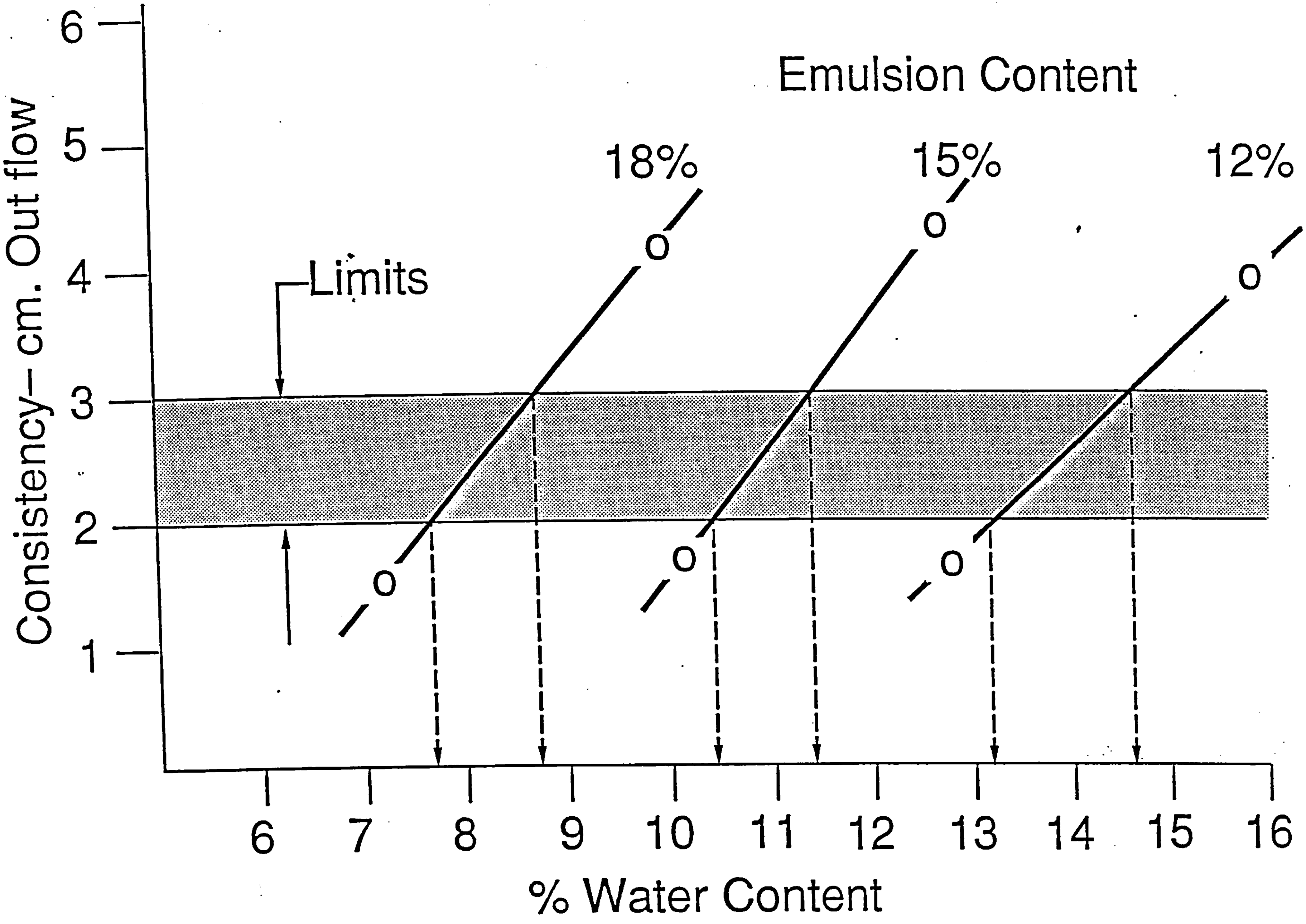

Figure 1 **Slurry Consistency vs. Water Content**

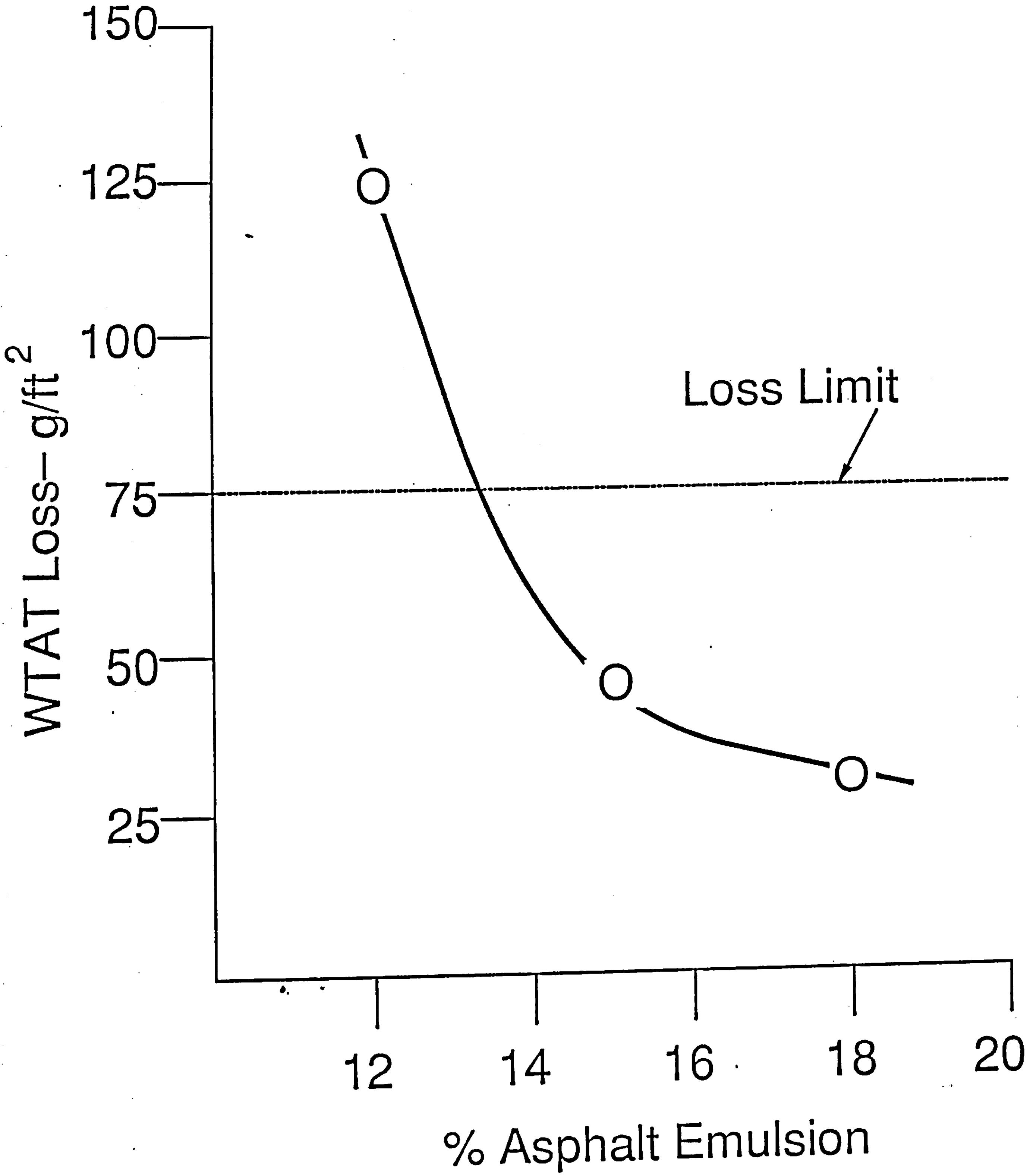

Figure 2 Wet Track Abrasion Loss vs. Emulsion Content

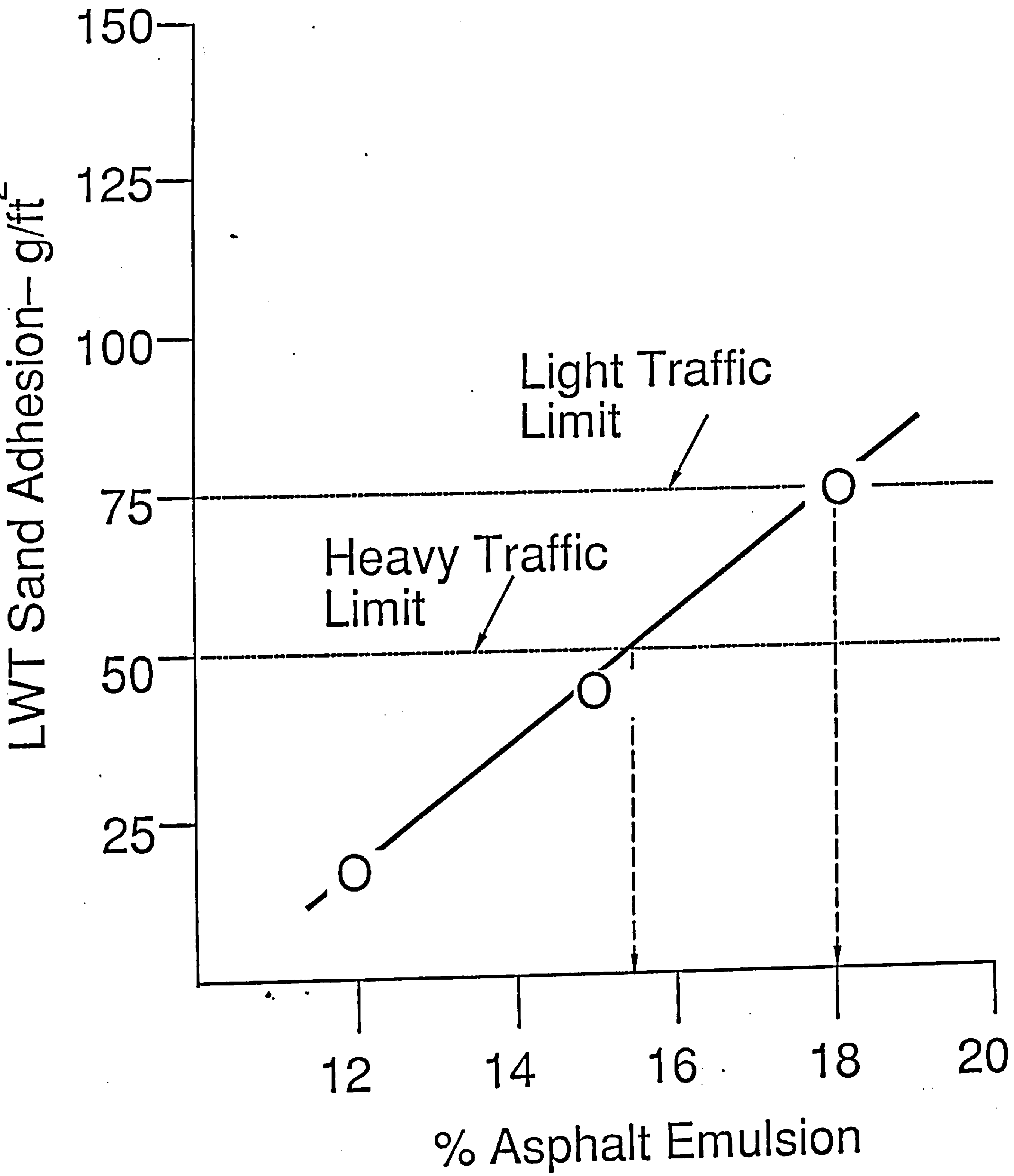

Figure 3 LWT Sand Adhesion vs. Emulsion Content

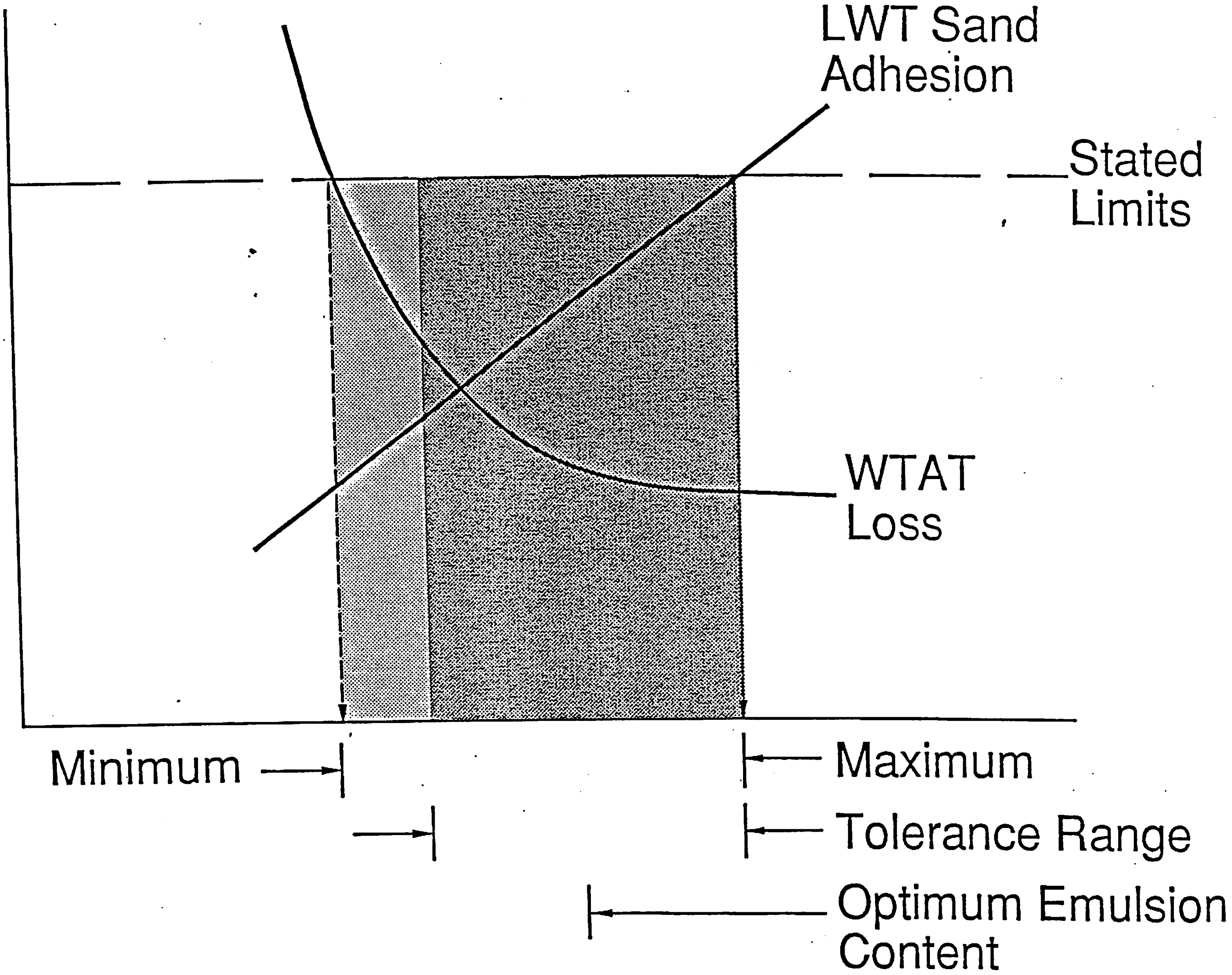

Figure 4 **Optimum Emulsion Content**

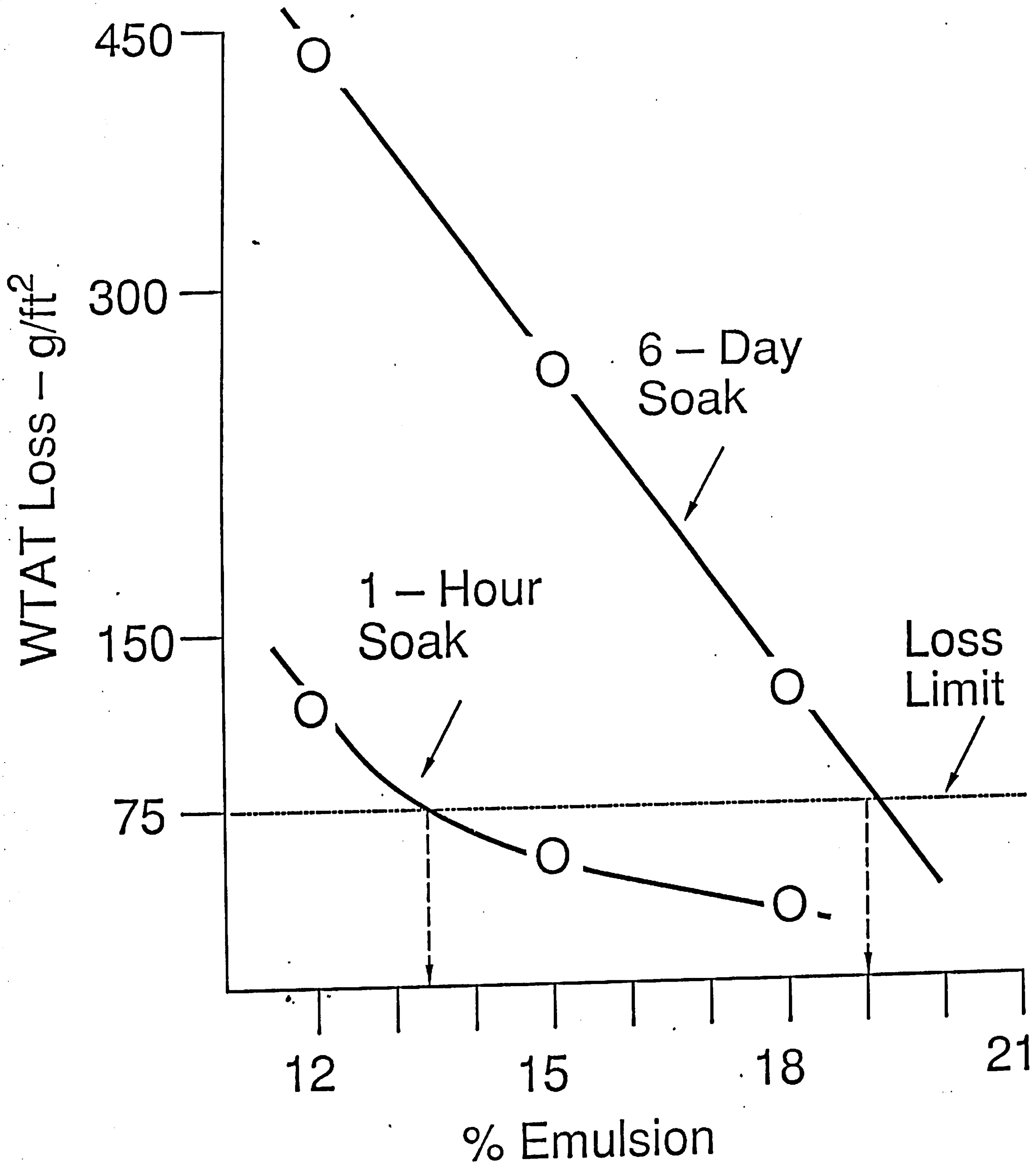

Figure 5 6– Day Soak WTAT Loss

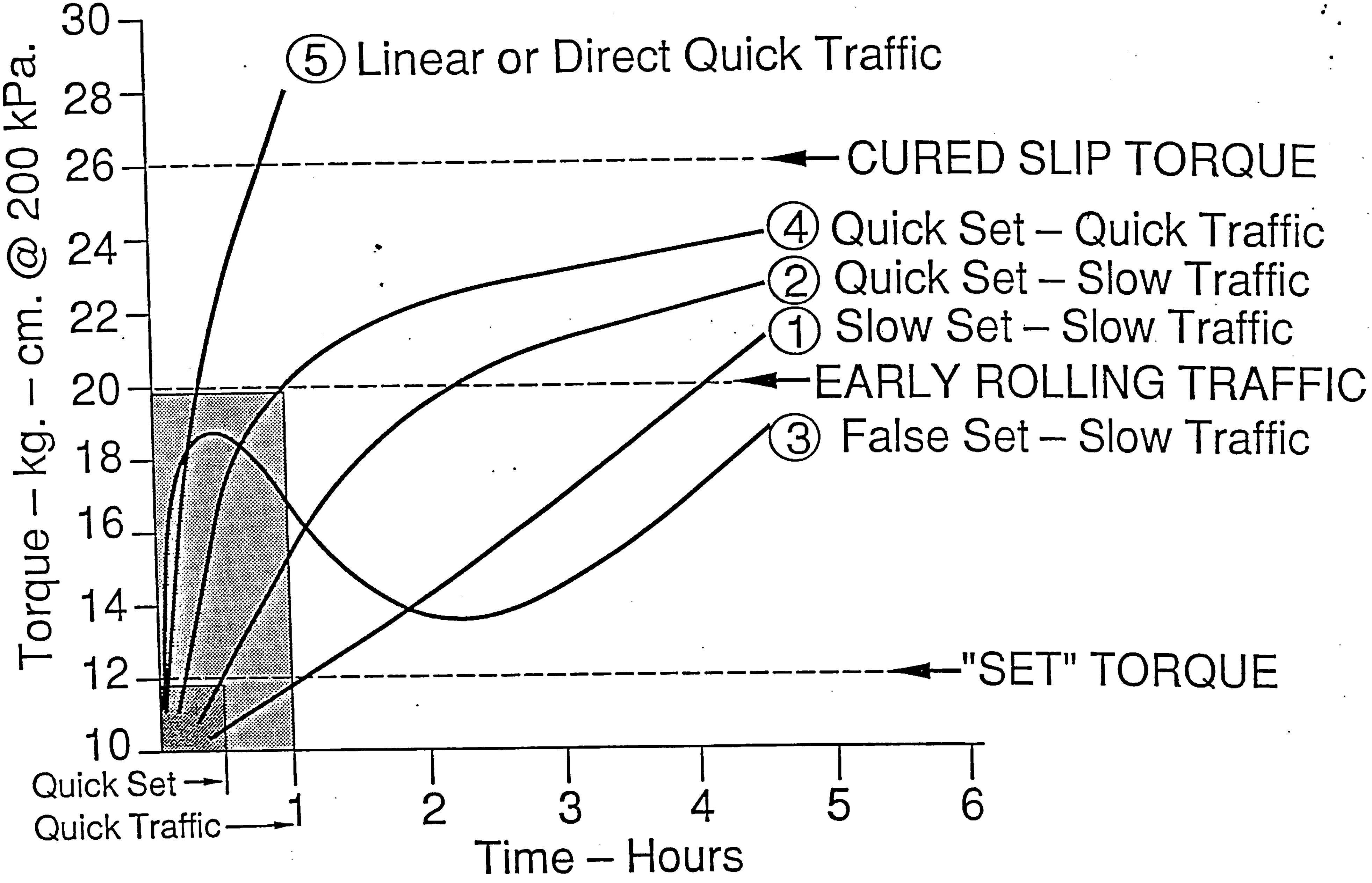

Figure 6 Classification of Mix Systems by Modified Cohesion Test Curves

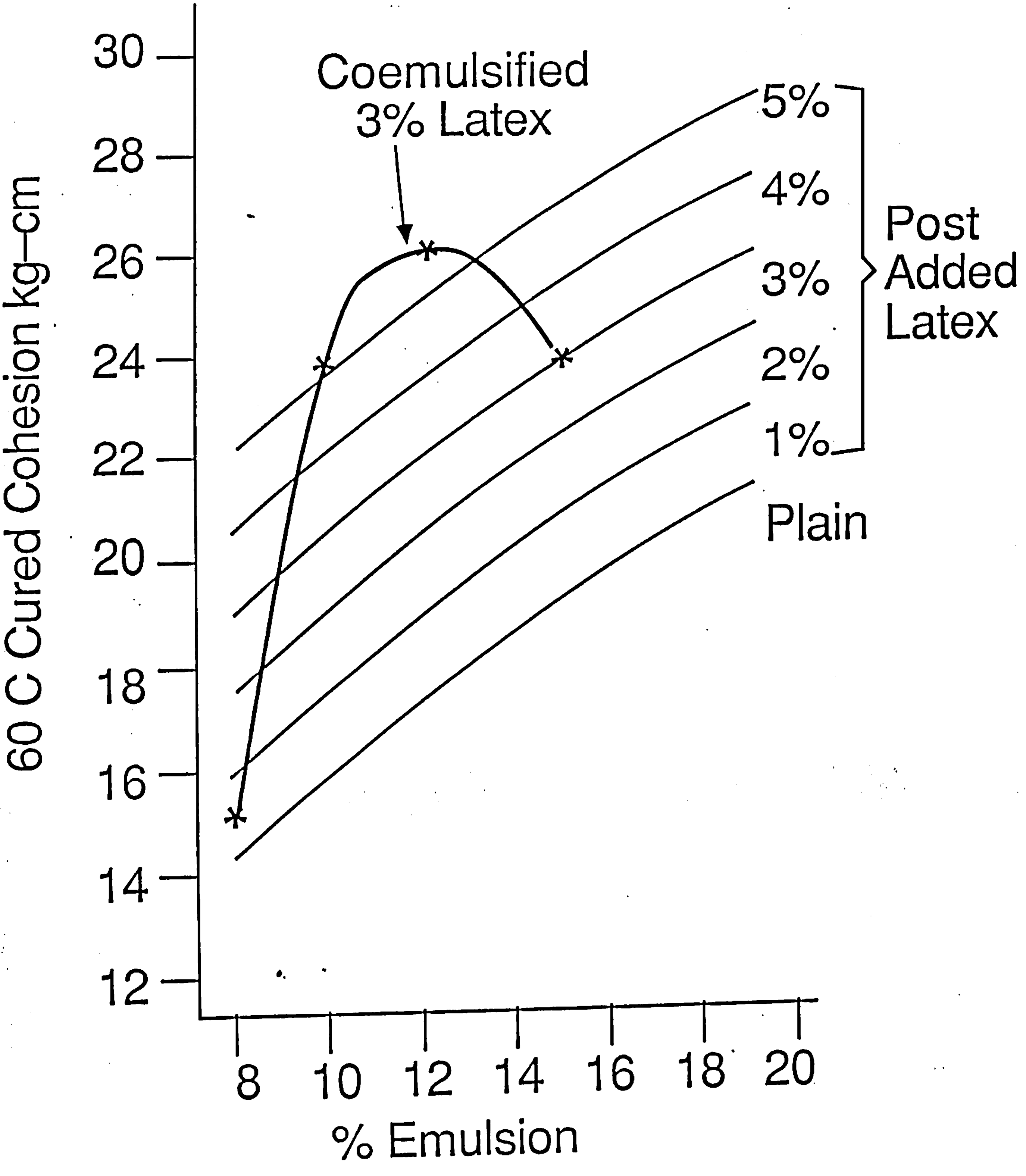

Figure 7 Cured Cohesion

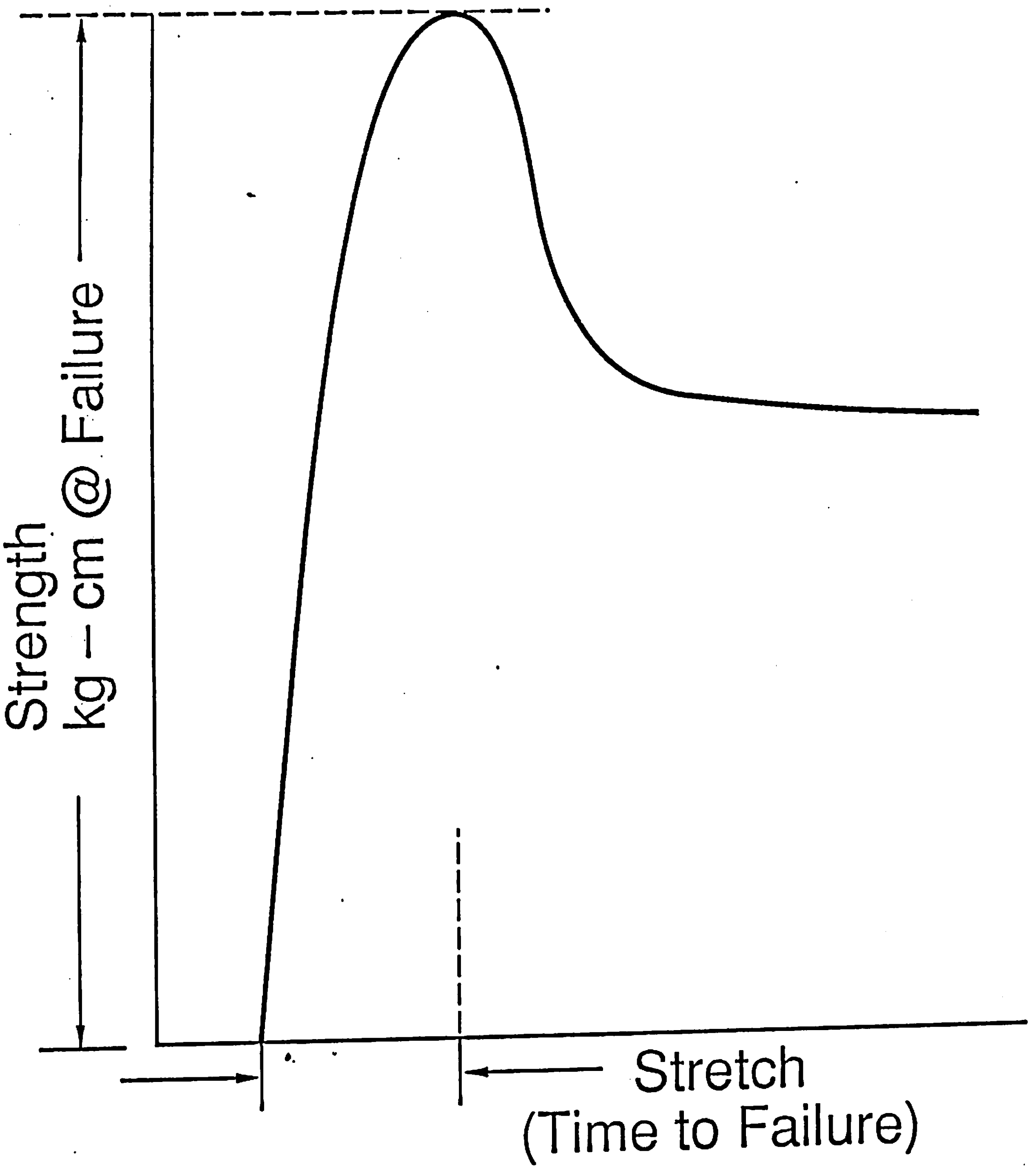

Figure 8 Rotational Shear

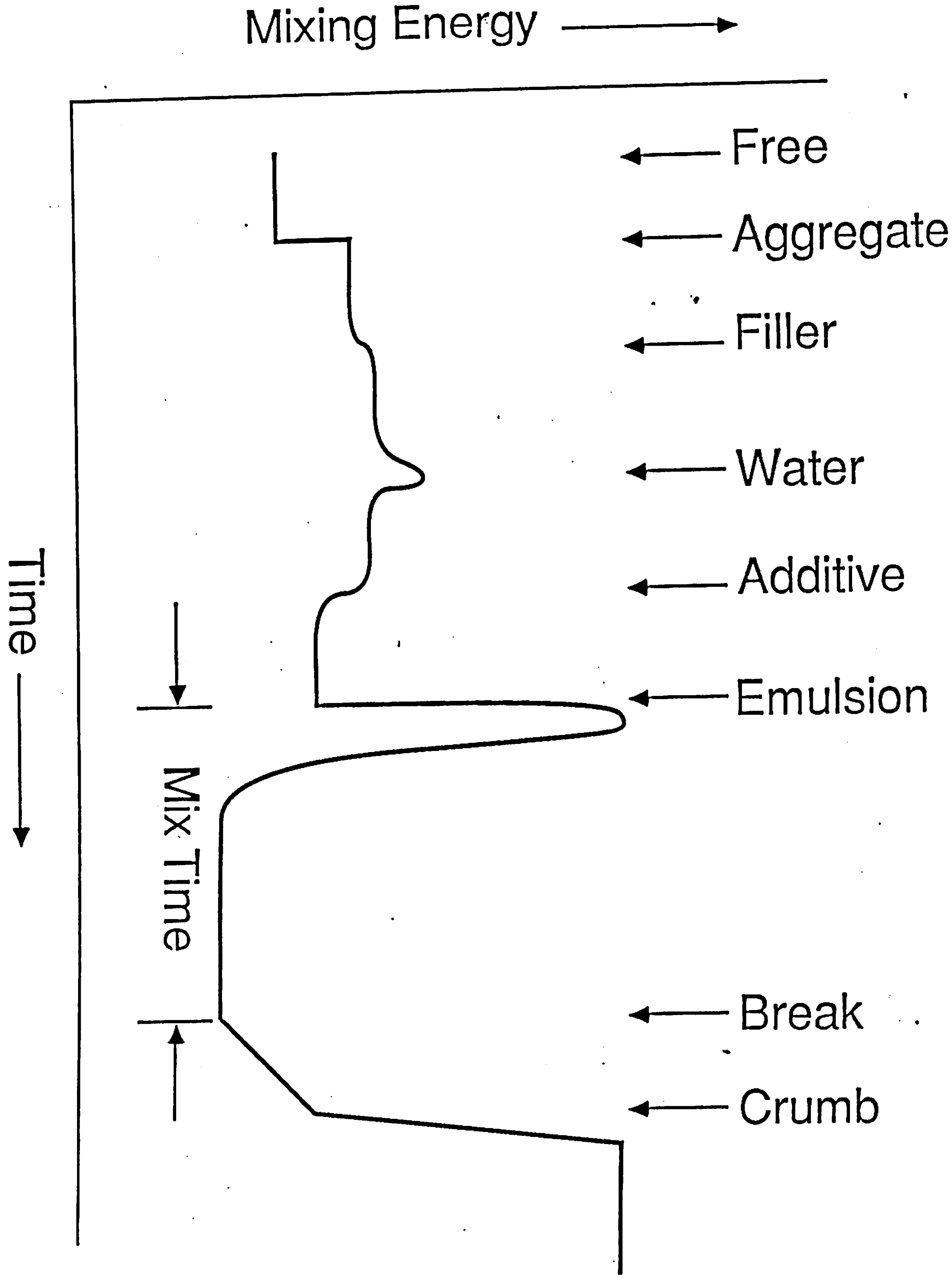

Figure 9 Mixing Characteristics

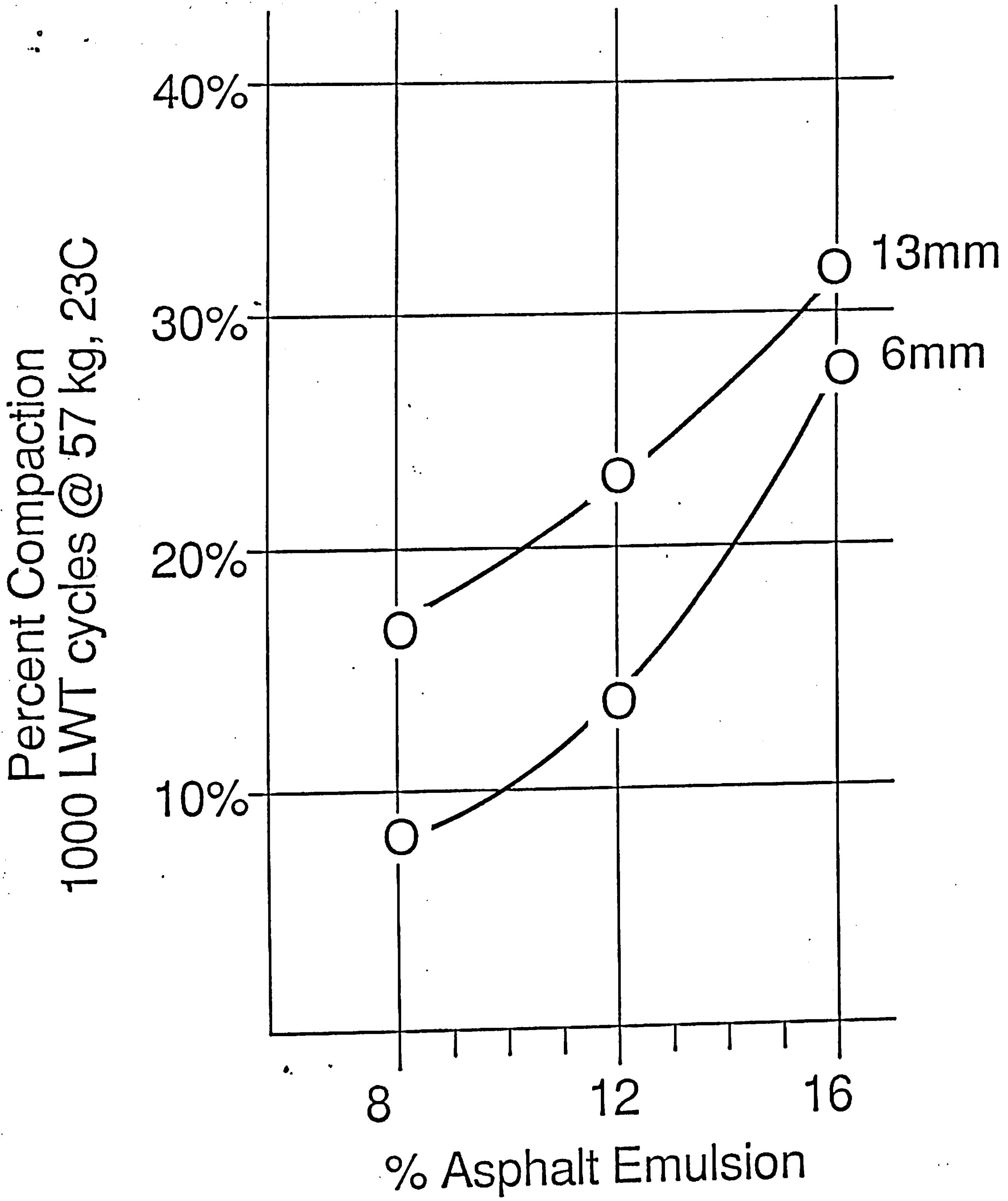

Figure 10 Case I
Percent Compaction
Converges at High
Bitumen Content

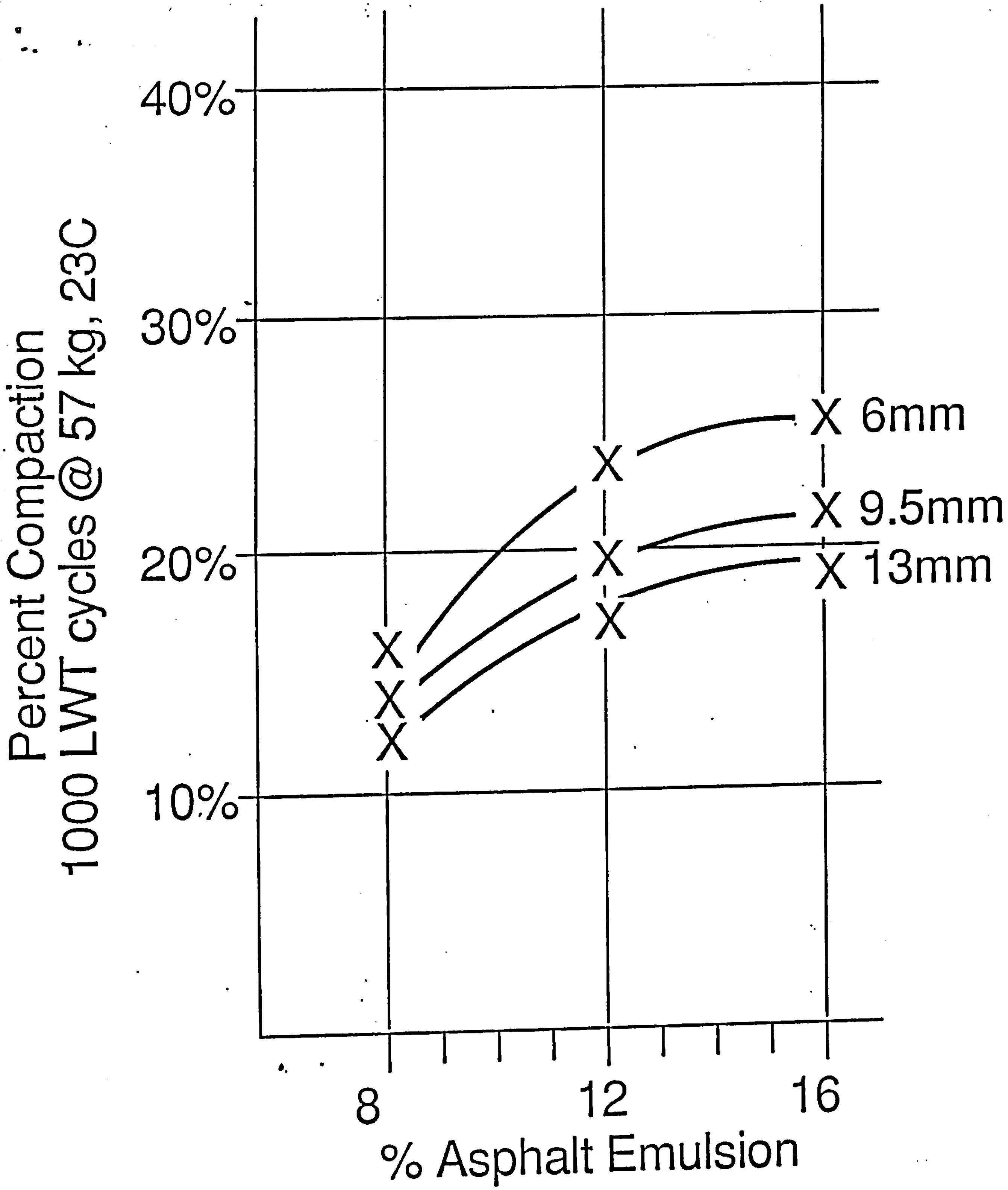

Figure 11 Case II
Percent Compaction
Converges at Low
Bitumen Content

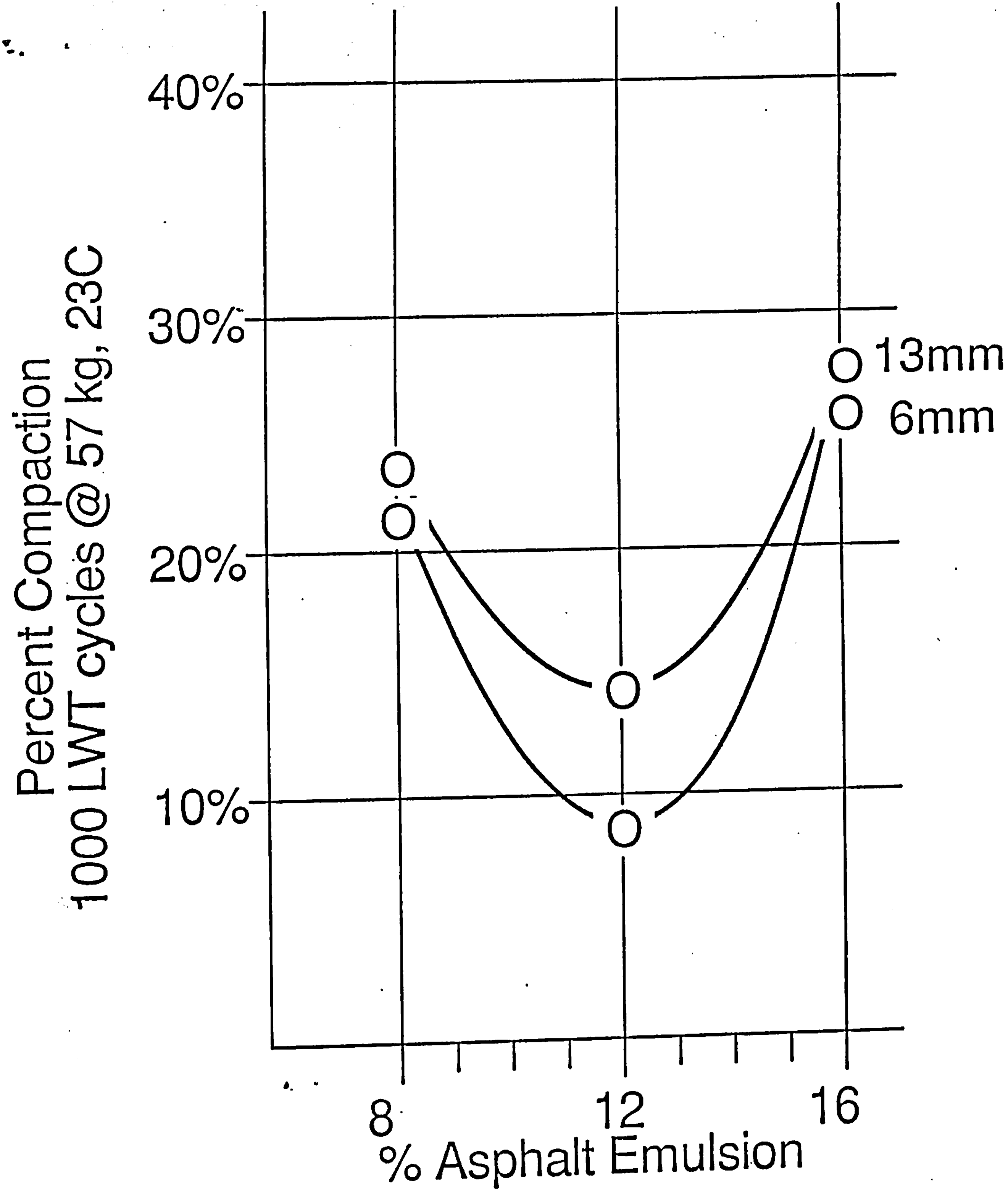

Figure 12 Case III
Percent Compaction
Converges at Extremes.
Compaction at Optimum,
Proportional to Thickness

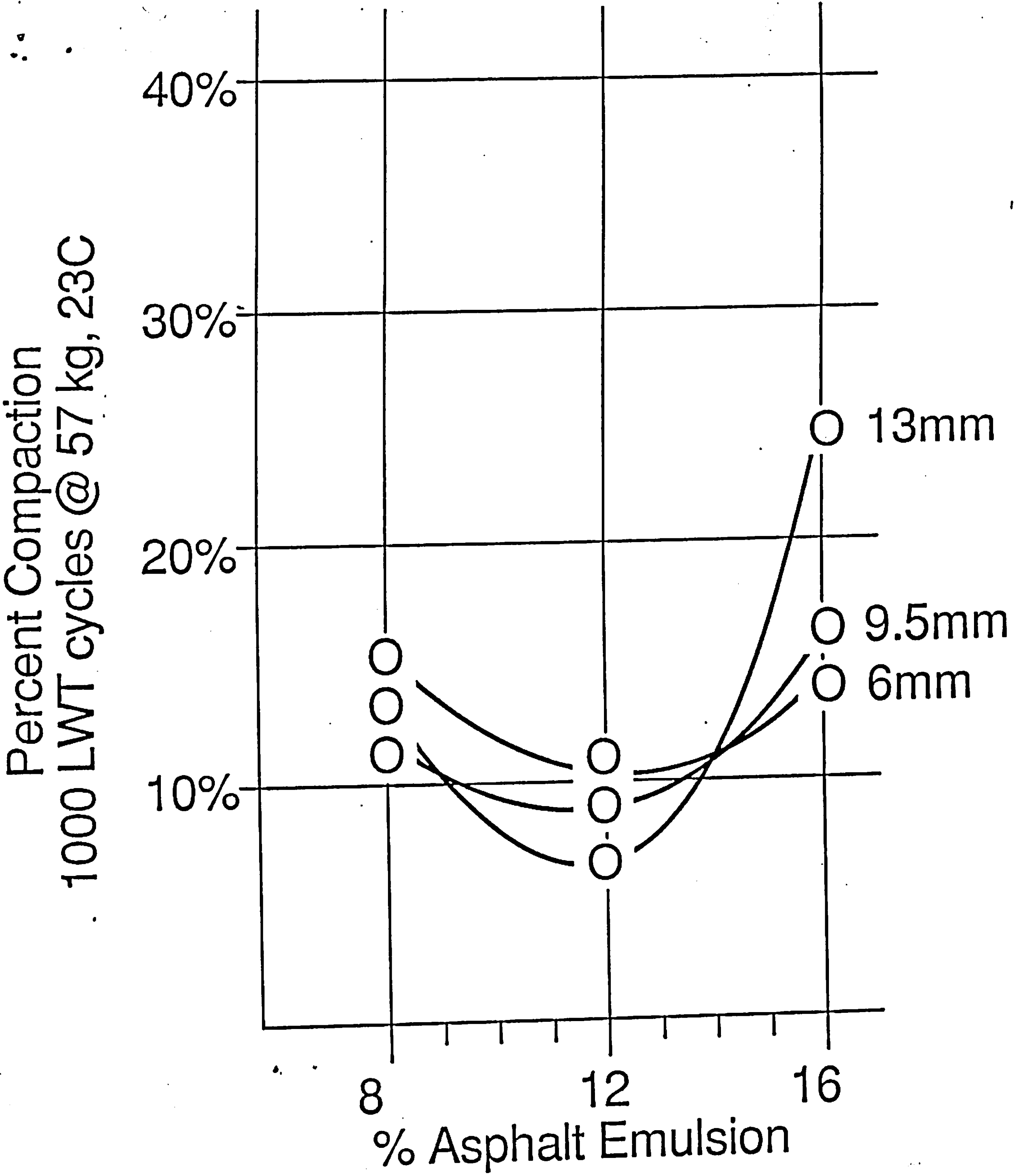

Figure 13 Case IV
Percent Compaction
Varies Inversely with
Layer Thickness
at Optimum

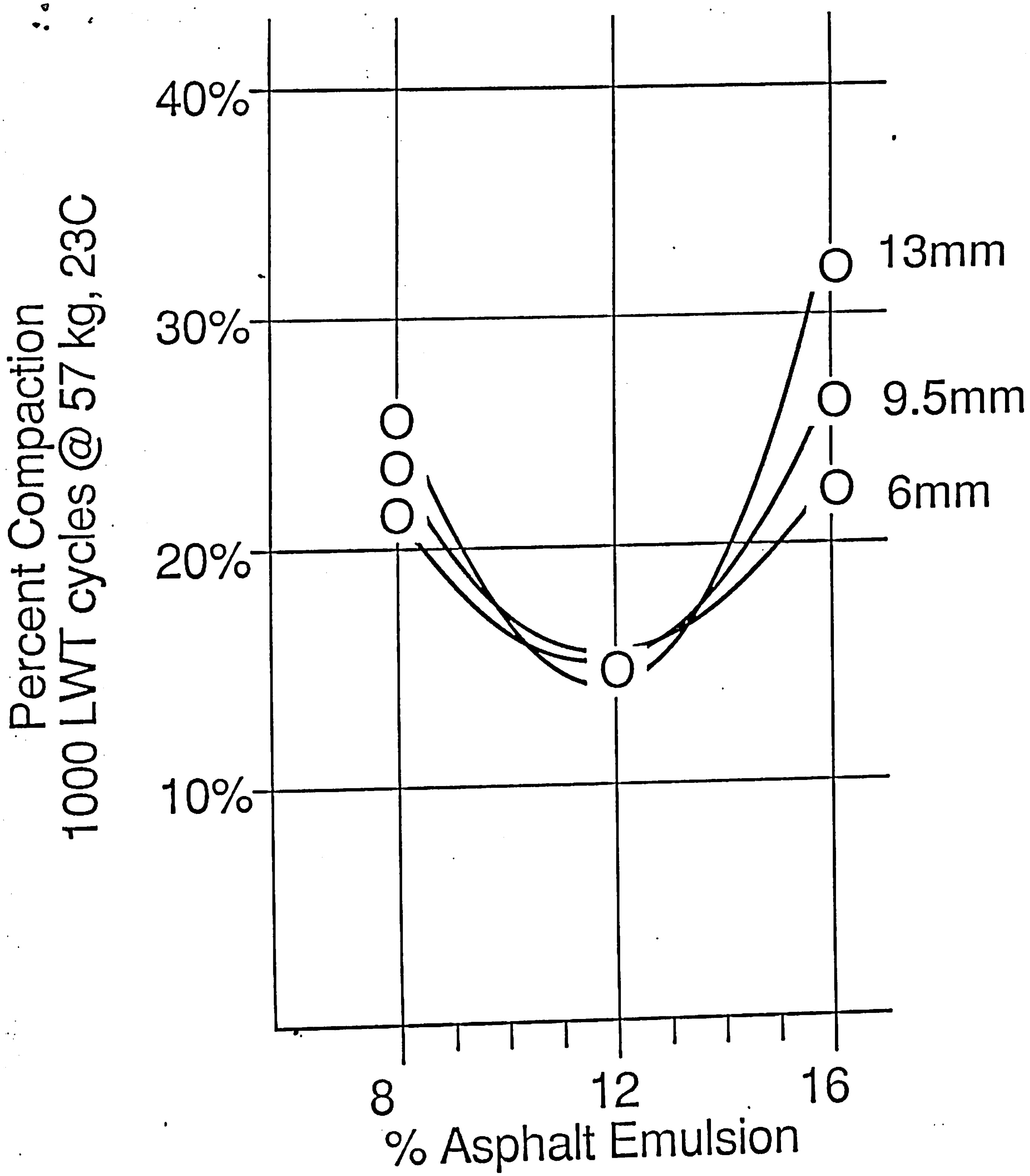

Figure 14 Case V
Percent Compaction
Converges at Optimum

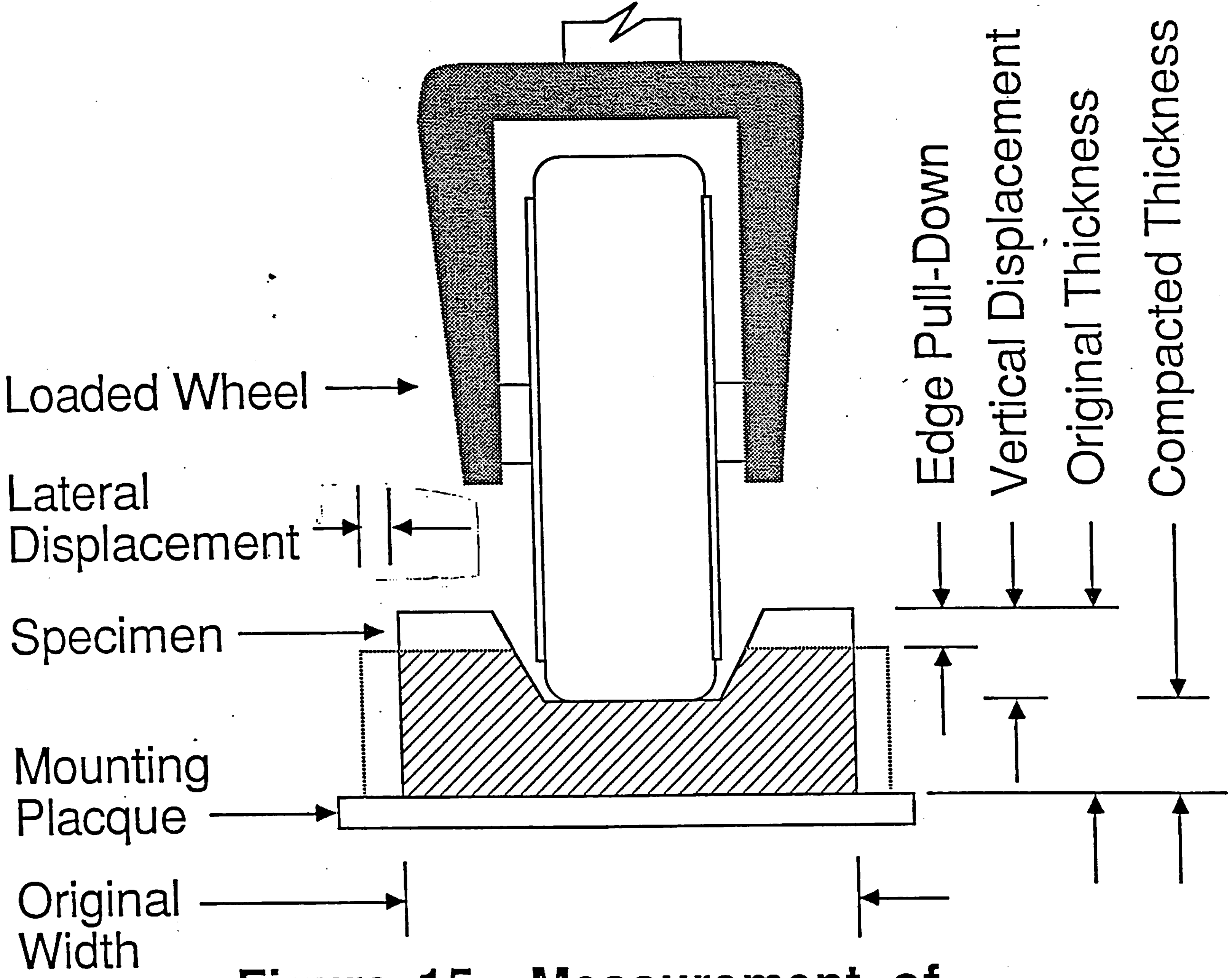

Figure 15 Measurement of Loaded Wheel Specimens

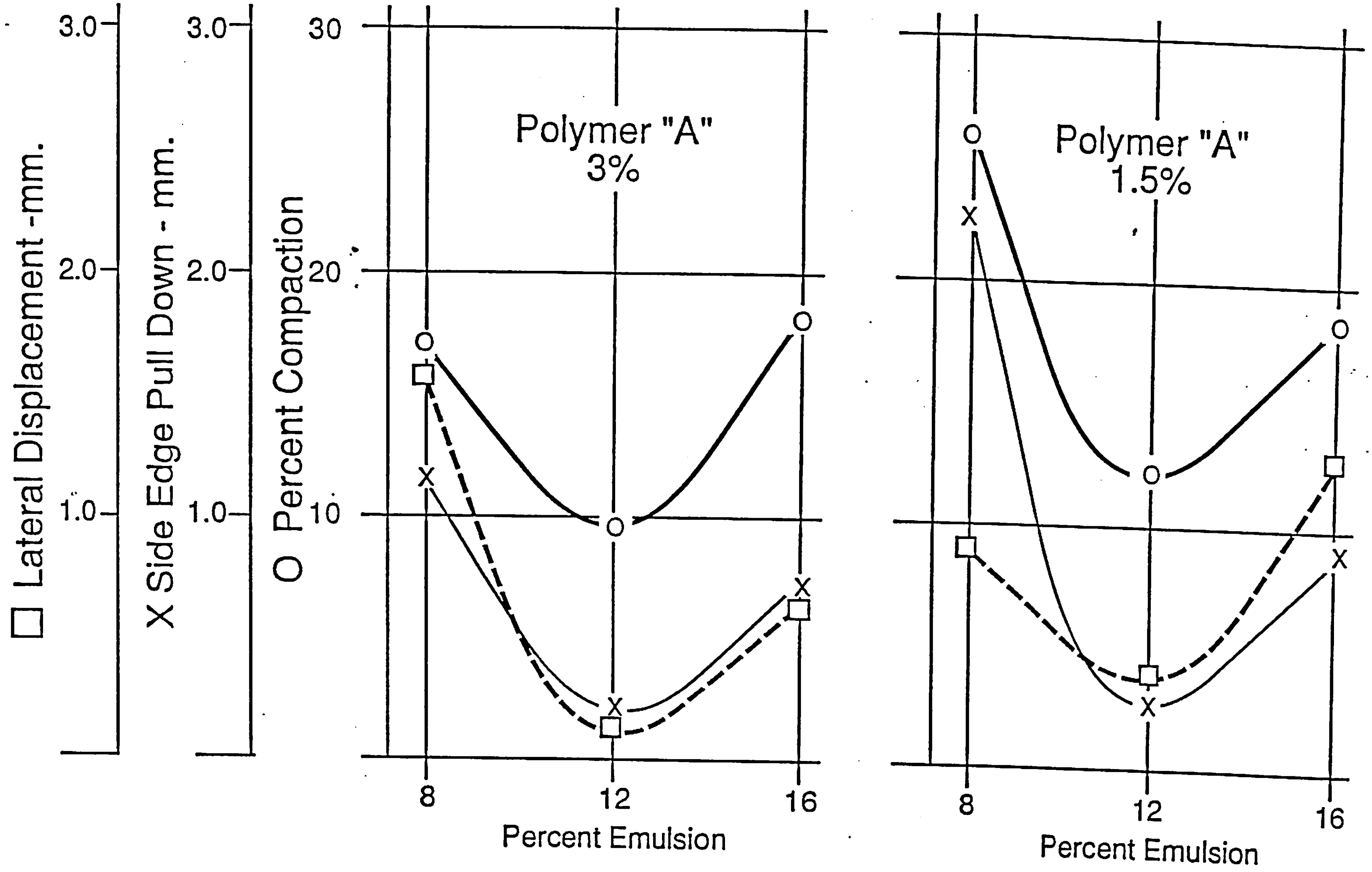

Figure 16 Dimensional Changes after 1000 cycles Loaded Wheel Test at 57kg & 22 C

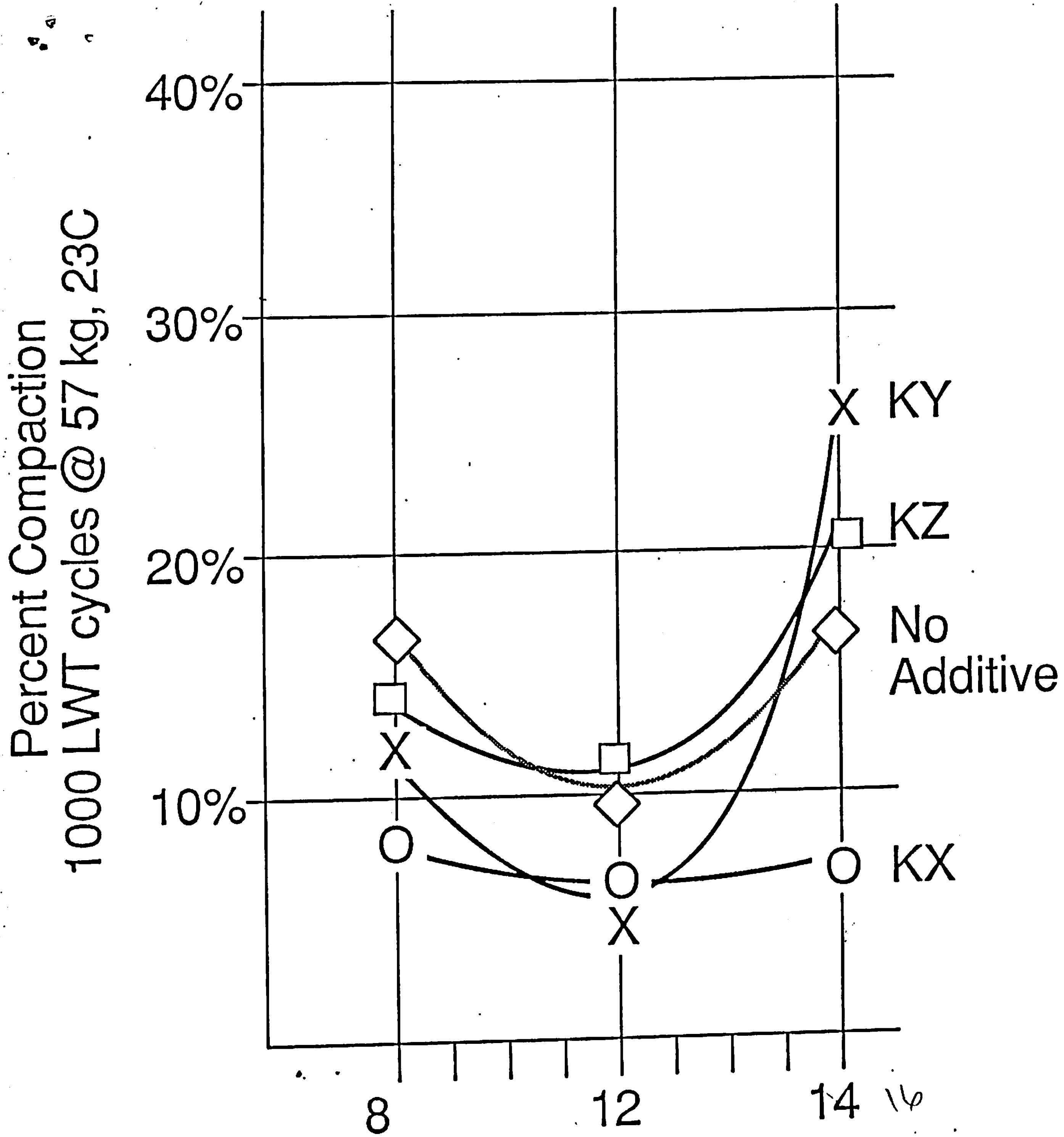

Figure 18 **Effect of Mix Additives**
3% polymer "A"

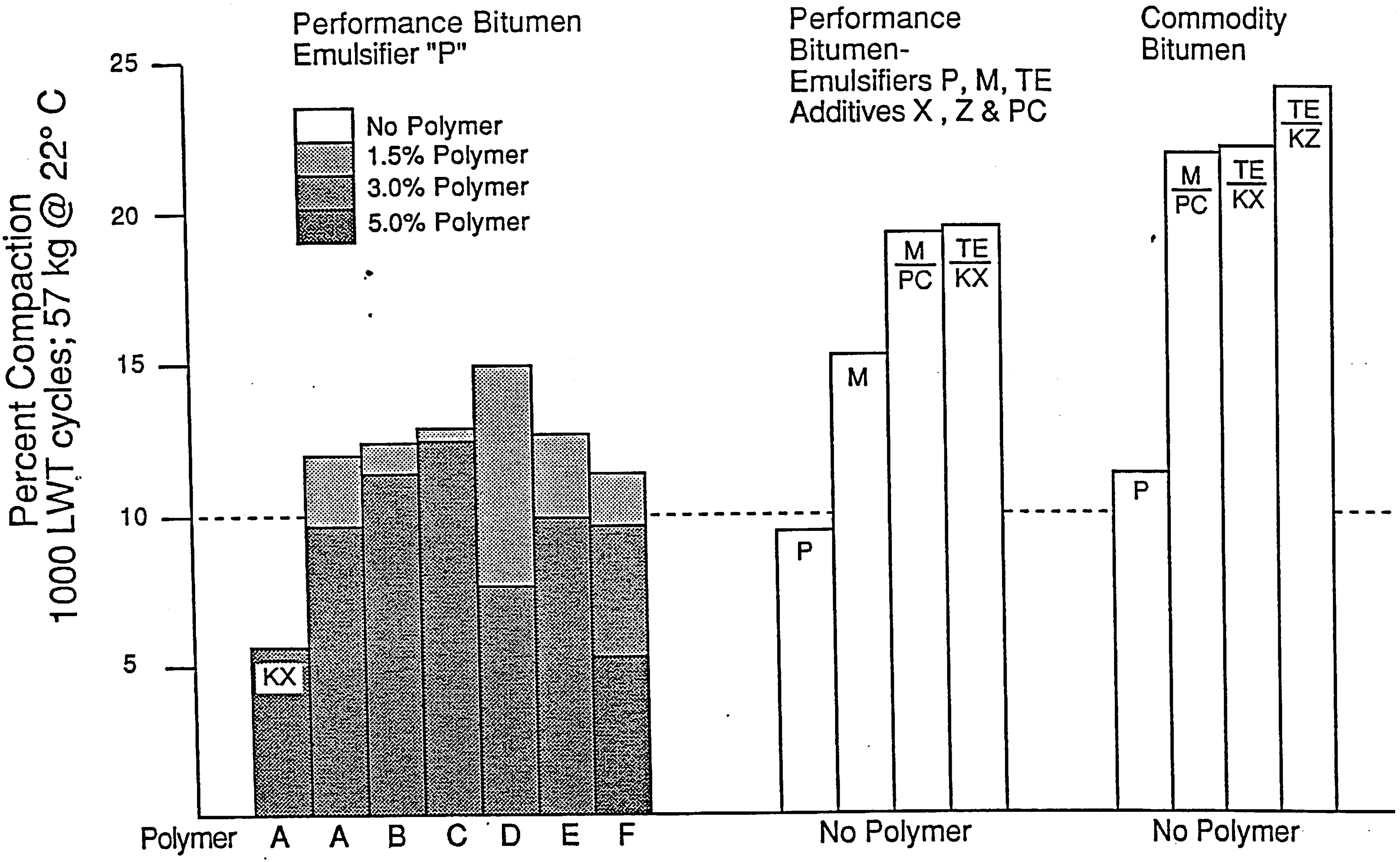

Figure19 **Effect of Polymer type, Bitumen type, Emulsifier type, and Mix additives at 12% emulsion content on Compaction**