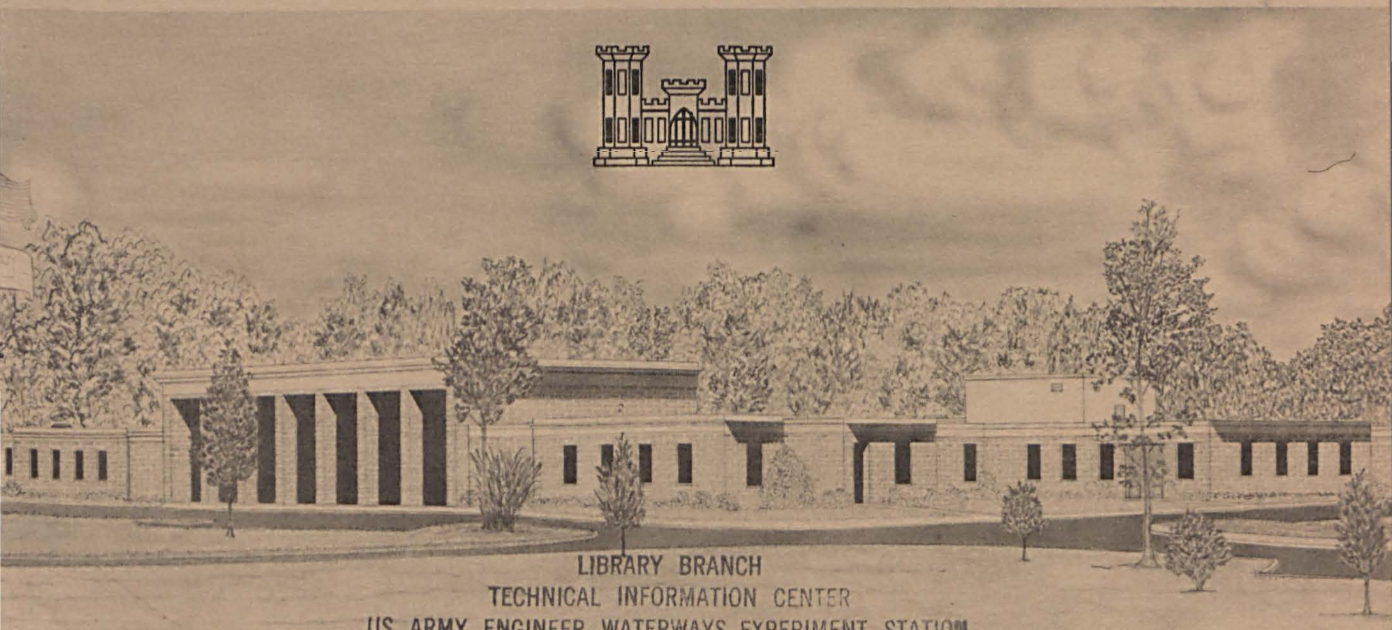
MISCELLANEOUS PAPER C-72-14

RECYCLED CONCRETE

by

A. D. Buck



May 1972

Sponsored by Assistant Secretary of the Army (R&D), Department of the Army

Conducted by U. S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi

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ARMY-MRC VICKSBURG, MISS.

FOREWORD

This work was funded by Department of the Army Project 4A061101A91D, Item BW, "In-House Laboratory Independent Research Program," sponsored by the Assistant Secretary of the Army (R&D).

The work was conducted in the Concrete Division (CD) of the U. S. Army Engineer Waterways Experiment Station (WES) under the direction of Messrs. B. Mather, R. V. Tye, Jr., and Mrs. K. Mather during the period 1 July 1971 to 30 April 1972. Mr. A. D. Buck was the project leader and prepared this report.

The Director of the WES during this period was COL Ernest D. Peixotto, CE. Mr. F. R. Brown was Technical Director.

CONTENTS

CONVERSION FACTORS, U. S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

U. S. Customary units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	By	To Obtain
inches	0.02540	metres
inches	25.4	millimetres
pounds (force) per square inch	0.00689476	megapascals
pounds (mass) per cubic yard	0.593277	kilograms per cubic metre
Fahrenheit degrees	5/9	Celsius or Kelvin degrees*
tons	0.09071847	kilograms
cubic yard	0.7645549	cubic metres

* To obtain Celsius (C) temperature readings from Fahrenheit (F) readings, use the following formula: C = (5/9) (F - 32). To obtain Kelvin (K) readings, use: K = (5/9) (F - 32) + 273.15.

SUMMARY

Supplies of natural mineral aggregates are diminishing even as their usage increases. Disposal problems exist because of steadily increasing accumulation of solid wastes. In light of these two situations an investigation was made to evaluate the use of crushed waste concrete similar to pavement concrete as concrete aggregates. If such use is practical, it will help to alleviate both problems mentioned.

A discarded concrete driveway that contained siliceous aggregates and a laboratory concrete beam that contained limestone as coarse and natural siliceous sand as fine aggregate were selected to represent pavement concretes. Portions of each kind of concrete were processed into aggregate sizes. Three rounds of three concrete mixtures were made to evaluate the driveway concrete as aggregate. Mixture 1, a control mixture, contained siliceous (chert) gravel and natural sand as aggregates. Mixture 2 contained crushed driveway concrete as coarse aggregate and natural sand as fine aggregate. Mixture 3 contained crushed driveway concrete as coarse and fine aggregate. One round of two other mixtures was made to evaluate the crushed concrete beam as aggregate. Mixture 4 contained limestone as coarse aggregate and natural sand as fine aggregate; these were aggregates from the same lots that were originally used in making the beam. Mixture 5 contained the crushed concrete beam as coarse aggregate and natural sand as fine aggregate.

Specimens from each round of each mixture were tested for compressive strength at different ages up to six months, for resistance to accelerated freezing and thawing, and for volume changes due to temperature changes or to moisture effects at a constant temperature.

The aggregate particles produced by crushing concrete had good particle shape, high absorptions, and low specific gravities by comparison with conventional natural mineral aggregates. Other results included:

_a_. The use of crushed concrete as coarse aggregate had no significant effect on the mixture proportions or workability of the mixtures by comparison with the control mixtures.

_b_. When the crushed driveway concrete was also used as fine aggregate in mixture 3, the mixture was slightly less workable and required more cement than control mixture 1.

_c_. The use of waste concrete as coarse aggregate results in concrete strengths that are 300 to 1100 psi lower than comparable strengths of control mixtures.

_d_. The use of the driveway waste concrete in mixtures 2 and 3 substantially improved frost resistance as indicated by an increase from DFE_{300} = 3 in control mixture 1 to DFE_{300} = 23 and 28 in the test mixtures.

e. The use of the crushed concrete beam as coarse aggregate in mixture 5 apparently lowered frost resistance slightly from DFE_{300} = 62 to DFE_{300} = 45 by comparison with control mixture 4.

f. The use of waste concrete as aggregate did not have any significant effect on the volume response of specimens to temperature or moisture effects.

A literature survey was made before and during the course of this work. A reference to work done in the USSR in 1946(1) was found. The present results agreed well with their results where comparisons were possible. While no United States references were found about the use of waste concrete as concrete aggregates, several United States references(2-4) were found about its use as aggregate in asphaltic mixtures and as base course material with good results.

While the present work does not provide information on the processing of concrete containing reinforcing steel into aggregate sizes, other United States work(2-4) indicated that this was practical.

It is concluded that the present results are promising for the use of recycled pavements or similar concretes as concrete coarse aggregate and perhaps as fine aggregate. If additional work tends to support this tentative conclusion, then existing specifications should be revised to permit and encourage the use of this material as concrete aggregate, to conserve existing supplies of natural aggregates, and to reduce the amount of solid waste that must be disposed of continually.

It is emphasized that the results in this work do not pertain to concrete from demolished buildings since the waste concrete used in this work was free of contamination by other materials such as sulfates. Recycled building concrete is likely to be contaminated by sulfates from plaster and gypsum wallboard, which creates a possibility of sulfate attack. The possible use of that kind of waste concrete as concrete aggregate should be evaluated in future work.

RECYCLED CONCRETE

PART I: INTRODUCTION

1. Existing supplies of natural aggregates are being depleted even as the demand for aggregates continues to rise. Since the remaining aggregate supplies are less and less accessible for convenient and economical use, the supply problem is compounded. There is a need now to develop replacements for conventional aggregates. If any of the materials that are now treated as solid wastes can be effectively utilized as aggregates, then the amount of waste that must be disposed of will be reduced and aggregate resources will be conserved at the same time.

2. This report covers tests and evaluation of waste concrete of two types for use as concrete aggregate. Waste concretes from pavements and from buildings should be considered separately as material for concrete aggregate because concrete from buildings is likely to contain calcium sulfates from plastering or gypsum wallboard which could raise the problem of sulfate attack if the recycled concrete were used in concrete accessible to moisture. Enough concrete of both kinds is demolished and wasted each year to make the reuse of either kind as aggregate of real benefit. The two concretes evaluated as aggregates in this investigation did not contain contaminating sulfates. One came from a driveway and the other from a test beam containing 3-in. maximum size aggregate. It would be interesting to test recycled concretes containing contaminating sulfates.

The sulfates might be present as discrete lumps of plaster or wallboard which could create localized expansion in concrete accessible to moisture.

PART II: LITERATURE REVIEW

3. A search of literature on the use of solid wastes as aggregate of any kind is continuing. Since the present interest was in the use of waste concrete as aggregate, special efforts were made to include work in European countries during the late 1940's and early 1950's. This selection was made because it is known that considerable amounts of debris produced by bombing and shelling were used in rebuilding in urban areas in European countries after World War II.

4. The majority of the foreign work that was found described the use of bricks and of material identified as rubble for aggregates during the rebuilding process. Since rubble is such a general term, references to it were of no direct value nor were those about bricks valuable at this time. The results of some Russian work(1) with waste concrete were found which will be discussed later.

5. Some references to the use of waste concrete as aggregate for asphaltic mixtures and as base course material in this country(2-4) were found. However, no references to the use in the United States of waste concrete as concrete aggregates were found.

PART III: PROCEDURE

Materials

6. Several tons of large pieces were obtained from a concrete driveway 6 in. thick that was being removed. This air-entrained concrete was about eight years old when it was removed; it had been made by a local ready-mix concrete plant, using natural chert gravel and natural sand as the coarse and fine aggregates, to a specified strength of 3000 psi at 28 days age. This sample was assigned CD serial No. WES-42 CON-1.

7. The processing used to produce aggregate of 3/4-in. maximum size from WES-42 CON-1 is described below:

a. A sledgehammer was used to break off pieces small enough to feed the laboratory jaw crusher and to remove wire mesh reinforcement. In some cases the wire mesh was removed by flexing it until it broke. Bolt cutters could have been used for the wire but were not needed.

b. The pieces were fed into a jaw crusher set to produce a product smaller than 2-1/2 in. Most of the wire mesh from inside the pieces shelled out and were removed by hand after this crushing.

c. The crushed pieces were then fed through a smaller jaw crusher set to produce a product smaller than 3/4 in.

d. The crushed material was then separated by sieving into the fractions shown below:

(1) Passing 3/4-in. and retained on 1/2-in. sieve.

(2) Passing 1/2-in. and retained on 3/8-in. sieve.

(3) Passing 3/8-in. and retained on No. 4 sieve.

All remaining wire mesh was removed by hand during the sieving operation.

e. All of the fines produced by this crushing and sizing operation were caught, combined, and saved.

8. A large unreinforced concrete beam (identified as B-3-13) that had been broken during testing in the laboratory was processed into the same sizes by the same methods that were used for the waste driveway concrete. The concrete in the beam contained aggregate of 3-in. maximum size and had been wet-screened from a mixture containing aggregate of 6-in. maximum size. The beam was 9-1/2 months old when it was made into aggregate; the aggregate was designated WES-42 CON-2. Twenty-five percent of the portland cement in the concrete mixture had been replaced by fly ash on a solid volume basis.

9. Since concrete aggregates are usually either siliceous or calcareous, the use of one waste concrete containing the siliceous aggregates chert gravel and natural sand and of another containing the calcareous coarse aggregate, limestone, and a siliceous natural sand, meant that the range of chemical classes of natural mineral aggregate found in waste concrete was covered by these two concretes.

10. The general particle shape and composition of the aggregates made from the two waste concretes was determined by inspection of representative portions of the crushed material.

11. The chert gravel and the natural sand that were used as coarse and as fine aggregate were identified as WES-1 G-5(16) and WES-1 S-4(50), respectively. These should be similar to the aggregates that had been used in the driveway concrete; sand from the same lot was used in making the concrete beam (B-3-13).

12. The limestone coarse aggregate used was identified as STL-20 G-1(2); aggregate from the same lot was used in the concrete beam (B-3-13).

13. Portland cement meeting the requirements of Federal Specification SS-C-192g for low-alkali Type II was used; it was designated RC-635. Cement from the same lot was used in beam B-3-13.

14. After selected physical tests of the aggregates, the materials that have been described were used in different combinations to make five concrete mixtures.

Mixtures

15. Three rounds of three concrete mixtures were made to evaluate the recycled concrete from the driveway as aggregate. The designations of the mixtures and aggregate combinations are shown below:

Mixture No.	Coarse Aggregate	Fine Aggregate
1	Chert gravel (WES-1 G-5(16))	Natural sand (WES-1 S-4(50))
2	Crushed concrete (WES-42 CON-1)	Natural sand (WES-1 S-4(50))
3	Crushed concrete (WES-42 CON-1)	Crushed concrete fines (WES-42 CON-1)

Mixture 1 was the control mixture for this series. All mixtures were proportioned as directed in CRD-C 114[5] which specifies the aggregate gradings, a water-cement ratio of 0.49, an air content of 6 ± 1/2 percent, and a slump of 2-1/2 ± 1/2 in. Although neither fine aggregate completely met the grading requirements of the test method, they were used without modification of grading for reasons that will be described later.

16. One round of two other concrete mixtures was made to evaluate the recycled concrete which contained limestone coarse aggregate. The designations of the mixtures and aggregate combinations are shown below:

Mixture No.	Coarse Aggregate	Fine Aggregate
4	Limestone (STL-20 G-1(2))	Natural sand (WES-1 S-4(50))
5	Crushed concrete (WES-42 CON-2)	Natural sand (WES-1 S-4(50))

Mixture 4 was the control mixture for this pair. These mixtures were also proportioned to conform with CRD-C 114[5] except for the sand grading as already mentioned.

17. The specimens made from each round of each mixture were:

No.	Size and Type
20	3- by 6-in. cylinders
3	3-1/2- by 4-1/2- by 16-in. beams
4	3- by 3- by 11-in. prisms with gage studs

Tests

18. The compressive strength of three 3- by 6-in. cores that had been drilled from representative portions of the old driveway

concrete was determined according to CRD-C 27.[5] The approximate compressive strength of the concrete beam was already known.

19. Specimens from each mixture were tested for compressive strength, frost resistance, linear coefficient of thermal expansion, and length changes due to changes in moisture content.

20. The compressive strength of three cylinders from each round of each mixture was determined at ages of 7, 28, 56, 90, and 180 days according to CRD-C 14.[5]

21. Three beams from each round of each mixture were tested in accelerated freezing and thawing in conformance with CRD-C 114.[5]

22. Three prisms from each mixture were tested to determine their linear coefficient of thermal expansion at 28 days according to CRD-C 39.[5] The test plan required testing only one round of specimens from each mixture, but the test was repeated for the third round of mixture 3 because of difficulties with loose inserts in the specimens from the first round.

23. One prism from each round of each mixture was stored in the moist room at relative humidity above 90 percent and temperature of 73 $\pm$ 2 F. The lengths were measured at 1, 28, and 90 days.

PART IV: RESULTS

24. Inspection of the coarse aggregate fractions of both crushed concretes (WES-42 CON-1 and 2) and of the sizes passing No. 4 sieve of the driveway concrete (WES-42 CON-1) showed that the coarse and fine aggregates did not contain excessive amounts of flat or elongated particles. The most common particle shape was pyramidal, a desirable situation.

25. Most of the particles in the coarse aggregate sizes of WES-42 CON-1 were individual chert particles or crushed portions of them with partial coatings of mortar adhering to the chert. At ages greater than six months to one year very strong bond develops between mortar and coarse aggregate in concrete made with the local chert gravel. The mortar coatings averaged about 1/8 in. thick but thinner and thicker coatings were present. In this category the original chert coarse aggregate usually formed the center of the particle. Small proportions of chert particles and of mortar particles were also present. The same types of particles were present in the fine aggregate sizes, with the amounts of mortar particles and of rock particles increasing at the expense of mortar-coated rock with decreasing particle size. The size passing No. 30 and retained on No. 50 sieve is made up largely of rounded quartz grains representing a concentration of this size in the original fine aggregate.

26. About 75 percent of the 1/2- and 3/8-in. sizes of WES-42 CON-2 is particles composed of rock with partial coatings of mortar, with the other 25 percent consisting of individual particles of

limestone. The proportion of rock particles rises to about 35 percent in the size retained on No. 4 sieve. The particles composed of rock with partial coatings of mortar differ from this type in the other concrete. In the recycled concrete with limestone coarse aggregate, it was less common for the limestone to form the center of the mortar-coated particles. The fine aggregate sizes of WES-42 CON-2 were not examined.

27. Tests in the program for which the concrete beam was made indicated that the compressive strength of the beam B-3-13 was about 8000 psi before it was processed to make WES-42 CON-2. The compressive strengths of three 3- by 6-in. cores drilled from different portions of the driveway concrete (WES-42 CON-1) and broken in the laboratory at about nine years are shown below:

Core No.	Compressive Strength, psi
1	6510
2	5500
3	5960
Average	5990

28. The absorption and specific gravity of the aggregates that were used are shown in table 1. The gradings of the natural sand and of the fines from the crushed driveway concrete (WES-42 CON-1) are also shown with the fine aggregate grading prescribed in CRD-C 114.(5) The absorptions and specific gravities of the natural sand, the chert gravel, and the crushed carbonate rock are within the usual range for these materials. The two crushed concrete coarse aggregates had high absorptions and rather low specific gravities. The crushed concrete fines used as fine aggregate had

absorptions of 7.6 and 9.0 (8.3 ± 0.7) in repeat determinations and low specific gravity. The relatively high absorptions and low specific gravities are to be expected in aggregates produced by recycling concrete, since the specific gravities of the original aggregates will be lowered by the specific gravity of the cement paste. While the specific gravities are expected to be lower and the absorptions higher than those of many natural mineral aggregates, the specific gravities will be above and the absorptions below those of many synthetic lightweight aggregates.

29. Table 1 shows that neither fine aggregate meets the grading requirements of CRD-C 114(5) and that the concrete fines depart more widely from the limits than the natural sand. When it was decided that the concrete fines would be used in the grading in which they were produced, it was also decided that the grading of the natural sand would not be brought within the limits. The concrete fines were used in the grading in which they were produced to see what effect this might have on the test results.

30. Properties of the freshly mixed concrete are shown in table 2. Mixture 3 which contained only crushed concrete as aggregate had lower slump and higher cement content than the other mixtures. This mixture appeared wet even though it was stiffer than its companion mixtures 1 and 2. Mixture 3 was used with a slightly low slump to avoid raising the cement content, to conserve on aggregate supplies, and to see what effects this might have on the test results. When natural sand was used as fine aggregate, there was

little difference in slump, air content, or cement content between the control mixtures and their companions, mixtures 2 and 5, respectively.

31. Compressive strengths of all mixtures are shown in table 3 and fig. 1 and 2 through 90-day tests. The 180-day data were not available when this report was prepared. Mixtures 2 and 5 containing waste concrete as coarse aggregate ranged from about 600 to 1100 psi lower than the control mixtures at corresponding ages. Mixture 3, with crushed concrete coarse and fine aggregates, is intermediate in strength between mixtures 1 and 2. Mixture 3 may have had higher strength than mixture 2, which had crushed concrete coarse aggregate and natural sand fine aggregate, because the water-cement ratio of mixture 3 was actually lower than that of mixture 2. The lower strengths of mixtures 2, 3, and 5 will be discussed later.

32. The results of the freezing-and-thawing tests are shown in table 4. Although the average DFE_{300} values of 3, 23, and 28 for mixtures 1, 2, and 3 are low, the increased resistance to freezing and thawing indicated by the mixtures containing crushed chert-gravel concrete (2,3) as aggregate is striking. Probable reasons for this will be discussed later. A reversed trend is shown by the average DFE_{300} values for mixtures 4 and 5, with the control mixture showing slightly higher DFE.

33. The linear coefficients of thermal expansion are shown in table 5. The value for control mixture 1 is as expected for concrete containing chert gravel and siliceous sand and the coefficients

of mixtures 2 and 3 are similar. The coefficient of mixture 4 is as expected for a limestone coarse aggregate with siliceous natural sand. The coefficient of mixture 5 is higher; the difference is probably significant but the value is still lower than the coefficients of the first three mixtures.

34. Length change of prisms stored in the moist room at high humidity and constant temperature is shown in table 6. The test mixtures have about the same amount of change as the corresponding control mixtures. The recorded values for mixtures 4 and 5 are believed to be too low since prisms made with limestone coarse and fine aggregate and a low-alkali Type II cement showed an average length increase of 0.006 percent at 28 days and 0.010 percent at 90 days in storage in the moist room in another program.

PART V: DISCUSSION

35. The intent in this work was to evaluate crushed waste concretes similar to concrete used in pavements for use as concrete aggregates. Pavement and building concrete should be considered separately since sulfate from plaster or wallboard is likely to be associated with building concrete and may create the problem of sulfate attack. This problem should not exist with pavement concretes in regions where the subgrade does not contain deleterious amounts of sulfate. The chert-gravel concrete from the driveway and the crushed limestone concrete from the laboratory beam used in this work are believed to be fairly similar to pavement concrete, except that the beam contained aggregate of 3-in. maximum size. One concrete contained chert gravel and natural sand and the other contained limestone and natural sand; both were free from contaminating sulfates and had compressive strengths of about 6000 and 8000 psi. Since the beam was not reinforced and the concrete from the driveway contained wire mesh, there are no results from this work on possible problems in processing concrete that contains steel bars. However, two references[2,3] and a personal communication on the use of recycled highway concrete as aggregate for asphaltic mixtures and as base course material indicate that processing of waste concrete that contains steel reinforcing bars is practical.

36. Strength, durability, and volume-change tests were made to see if there were substantial differences between test mixtures that contained crushed concrete as aggregates and control mixtures.

A comparison between some 1946 test results[1] on waste concrete from the USSR and our results is shown below:

Test Results

USSR	WES
1. New concrete will be no better than the waste concrete that is used as aggregate.	1. No comparison possible. Waste concrete used was of good quality.
2. The use of concrete fines as sand requires an undue increase in the cement content of a mixture.	2. Mixture 3 was the only one which contained concrete fines as sand. It required 47 lb per cu yd more cement than mixtures 1 or 2 with natural sand. This is not regarded as excessive.
3. Compressive strengths are lower when concrete is used as aggregate.	3. Concretes containing waste concrete as coarse aggregate range from 300 to 1100 psi lower in compressive strength than corresponding control mixtures.
4. The specific gravity of crushed concrete aggregate tends to be lower than that of natural aggregates.	4. Our work confirms this; in addition, the absorption tends to be high.
5. The cement factor can be lowered if the crushed concrete aggregate is moistened, not saturated, before use.	5. The coarse aggregates were inundated; the fine aggregates had moisture added 24 hours before mixing the concrete to satisfy their absorption. We cannot make this comparison.
6. For equal compressive strengths, the flexural strength of mixtures with crushed concrete aggregate is higher than for control mixtures.	6. No flexural tests were made.
7. Mixtures with crushed concrete aggregate stiffen rapidly but consolidate well with vibration.	7. No such difference noted with crushed concrete as coarse aggregate only, but mixture 3 with all aggregate crushed concrete was stiffer than the control even though it appeared wet.

Where comparisons are possible in the list above, the agreement between the Russian results[1] and the present work is excellent.

37. The mixtures containing crushed concrete as fine aggregate required more cement and were slightly stiffer; however, the increased cost for additional cement should be partly or wholly compensated by the advantage to be gained by using the crushed-concrete fine aggregate instead of having to dispose of it. Blending with natural sand, modification of mixture proportions, or use water-reducing admixtures might permit lowering the cement content and improve the workability when using crushed concrete as sand. None of the test data in this work rule out its use. Its use in an unusual grading did not seem to have any appreciable effect on the test results.

38. The reasons for the lower compressive strengths of mixtures containing crushed concrete as coarse aggregate as compared to mixtures containing only natural aggregates are not known at this time. Several explanations have been considered and rejected or cannot be proved at present. Explanations will be needed in the future. Adjustments of the mixture proportions might improve the strength of the test mixtures. It should be recalled that although the strengths were lower, they were satisfactory for many uses. It is hoped that slight adjustments of such mixtures will improve their strengths.

39. The improved frost resistance of mixtures 2 and 3, containing concrete as aggregate, compared to control mixture 1 from a DFE_{300} of 3 to 23 and 28 was substantial. It is thought that this improvement may have occurred because the old mortar which

coats many of the crushed concrete particles effectively seals off the voids in the frost-susceptible porous chert particles from taking up enough moisture to be damaged by freezing.

40. Comparison of data for test mixtures containing recycled waste concrete as coarse aggregate with data for control mixtures shows the following:

- a. There were no unusual problems in mixing or working with the test mixtures.
- b. The test mixtures have compressive strengths that are 300 to 1100 psi lower than the corresponding control mixtures at all ages tested through 90 days.
- c. The resistance to accelerated freezing and thawing is greatly improved when the waste concrete originally contained chert gravel coarse aggregate.
- d. The resistance to freezing and thawing is a little lower but essentially comparable when the waste concrete originally contained limestone coarse aggregate.
- e. Volume changes in response to temperature changes or to continued exposure to moisture at a constant temperature were similar and normal.

41. The findings for mixture 3 which contained waste chert-gravel concrete as coarse and fine aggregate were generally like the control mixtures except that cement demand was somewhat higher and workability slightly lower than with the control mixture.

PART VI: CONCLUSIONS AND RECOMMENDATIONS

42. The results indicate many reasons in favor of the use of crushed discarded concrete pavements or any other concrete not contaminated with sulfates as concrete aggregates. If additional work indicates that the lower concrete strengths obtained with waste concrete as coarse aggregate are not a serious problem, then all existing specifications should be revised to permit and encourage the use of crushed pavement or similar concrete as concrete coarse aggregate.

43. If, in addition, the mild undesirable effects of waste concrete fine aggregate on workability and cement content of concrete mixtures can be eliminated or reduced, then the use of this material should also be encouraged by specification revisions.

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NOTE: Three and four are different descriptions of the same thing.

Table 1

Specific Gravities, Absorptions, and Gradings of Aggregates

		Crushed Concrete WES-42 CON-1 Coarse	Crushed Concrete WES-42 CON-1 Fine	Crushed Concrete WES-42 CON-2 Coarse	Chert Gravel WES-1 G-5(16)	Limestone STL-20 G-1(2)	Natural Sand WES-1 S-4(50)
Bulk Specific Gravity Saturated Surface-Dry*		2.43 2.44	2.34	2.52	2.52	2.67	2.63
Absorption, %*		4.0 4.3	7.6 9.0	3.9	2.6	0.8	0.4
CRD-C 114 Grading Fine Aggregate Cumulative % Passing							
No. 4	100	-	100.0	-	-	-	98.1
No. 8	85±3		77.1				87.6
No. 16	65±5		58.7				74.4
No. 30	45±5		42.6				52.6
No. 50	21±5		23.5				25.6
No. 100	7±2		12.4				7.0
No. 200	-		6.6				1.2
Coarse Aggregate** Cumulative % passing							
3/4 in.	97-100						
1/2 in.	66±3						
3/8 in.	33±3						
No. 4	0.3						

* Determined according to CRD-C 107.(5) Duplicate determinations are reported where they were made.

** All coarse aggregates were proportioned according to this grading with 100 percent passing the 3/4-in. sieve.

Table 2

Selected Physical Properties of Five Concrete Mixtures*

	Slump, in.**	Air, %+	Actual Cement Content, lb/cu yd
Mixture 1: Chert gravel and natural sand.			
Round 1	2-1/4	6.0	461
Round 2	2-1/2	6.3	461
Round 3	2-1/2	6.3	461
Mixture 2: Crushed concrete coarse natural sand.			
Round 1	2-1/2	5.7	461
Round 2	2-1/2	5.8	461
Round 3	2-1/2	6.0	461
Mixture 3: Crushed concrete coarse and fine aggregate.			
Round 1	2-++	6.3	498
Round 2	2-	6.0	508
Round 3	2-	5.9	508
Mixture 4: Limestone coarse aggregate and natural sand.	2-3/4	6.0	508
Mixture 5: Crushed concrete and natural sand as aggregates	2-1/2	6.1	489

* Made according to CRD-C 114[5] using the slump and air content as controls. All mixtures had 0.49 water-cement ratio.

** The specified slump is 2-1/2 ± 1/2 in.

\+ The specified air content is 6 ± 1/2 percent.

++ 2- means slightly less than 2 in. but closer to 2 than to 1-3/4 in.

Table 3

Compressive Strength of Five Concrete Mixtures*

Identification: Mixture	Round	Compressive Strength, psi, at Ages Shown: 7-Day	28-Day	56-Day	90-Day
No. 1, Control: Chert-gravel and natural sand as aggregates	1	2810	4690	5010	5180
		3080	4100	5240	5150
		2760	4470	5230	5350
	Average	2880	4420	5160	5230
	2	2260	3620	4460	4930
		2390	3950	4200	4860
		2430	3960	4530	4890
	Average	2360	3840	4400	4890
	3	2550	3990	4490	5230
		2520	4210	4340	4920
		2490	4290	4750	5070
	Average	2520	4160	4530	5070
Average - 3 rounds		2590	4140	4700	5060
No. 2: Crushed chert-gravel concrete coarse aggregate and natural sand fine aggregate	1	1900	2890	3490	4060
		1850	2890	3320	3680
		1980	2870	3640	3970
	Average	1910	2880	3480	3900
	2	1980	3110	3390	4130
		1920	3170	3830	3750
		2070	3350	3650	3640
	Average	1990	3210	3620	3840
	3	2010	3110	3760	3740
		2080	3100	3490	3640
		2010	2940	3710	4310
	Average	2030	3050	3650	3900
Average - 3 rounds		1980	3050	3580	3880
No. 3: Crushed chert-gravel concrete coarse and fine aggregate	1	2520	3120	3790	4400
		2380	3370	3830	4120
		2430	3150	3750	4290
	Average	2440	3210	3790	4270

* Tested in accordance with CRD-C 14.(5)

Table 3 (Concluded)

Identification: Mixture	Round	Compressive Strength, psi, at Ages Shown: 7-Day	28-Day	56-Day	90-Day
No. 3 (Continued)	2	2230	3390	3720	4300
		2220	3730	4210	4510
		2190	3580	3850	4500
	Average	2210	3570	3930	4440
	3	2180	3350	3590	3920
		2210	3250	3680	4150
		2330	3680	3820	4290
	Average	2240	3430	3700	4120
Average - 3 rounds		2300	3400	3810	4280
No. 4, Control:** Limestone coarse aggregate and natural sand fine aggregate	1	3080	4340	5010	5230
		3150	4470	4840	5200
		3300	4720	4530	5540
	Average	3180	4510	4790	5320
No. 5:** Crushed limestone concrete coarse aggregate and natural sand fine aggregate	1	2570	4170	3280	4750
		2570	4100	4610	4610
		2600	4190	4120	4620
	Average	2580	4150	4000	4660

** Only one round was made of mixtures 4 and 5.

Table 4

DFE$_{300}$ of Concrete Beams in Accelerated Freezing and Thawing*

Round	Mixture No. 1. Control, Chert Gravel and Natural Sand	Mixture No. 2. Crushed Chert-Gravel Concrete Coarse Aggregate and Natural Sand	Mixture No. 3. Crushed Chert-Gravel Concrete Coarse and Fine Aggregate	Mixture No. 4. Control, Limestone Coarse Aggregate and Natural Sand	Mixture No. 5. Crushed Limestone Concrete Coarse Aggregate and Natural Sand
	DFE$_{300}$	DFE$_{300}$	DFE$_{300}$	DFE$_{300}$	DFE$_{300}$
1	4	33	30	66	34
	4	27	31	57	51
	3	23	28	63	50
Average	4	28	30	62	45
2	4	20	30		
	4	22	27		
	4	24	27		
Average	4	22	28		
3	2	18	27		
	2	20	21		
	2	19	27		
Average	2	19	25		
Average of 3 rounds	3	23	28		

* Tested in accordance with CRD-C 114.(5)

Table 5

Linear Coefficient of Thermal Expansion of Five Concrete Mixtures*

Round	Prism	Mixture No. 1. Control, Chert Gravel and Natural Sand	Mixture No. 2. Crushed Chert-Gravel Concrete Coarse Aggregate and Natural Sand	Mixture No. 3. Crushed Chert-Gravel Concrete Coarse and Fine Aggregate	Mixture No. 4. Control, Limestone Coarse Aggregate and Natural Sand	Mixture No. 5. Crushed Limestone Concrete Coarse Aggregate and Natural Sand
		Coefficient, Millionths/F	Coefficient, Millionths/F	Coefficient, Millionths/F	Coefficient, Millionths/F+	Coefficient, Millionths/F+
1	2	6.4	6.1	5.0	3.7	4.5
	3	6.3	5.9	5.7	3.6	4.7
	4	6.1	6.4	6.1	3.5	4.7
	Average	6.3	6.1	5.6	3.6	4.7
2**	10			5.7		
	11			5.2		
	12			6.1		
	Average			5.7		
	Average - 2 rounds			5.6		

* Tested in accordance with CRD-C 39.(5)

** A second round was made; the gage studs were chipped out and recemented with neat portland cement paste.

+ A few obviously faulty values were discarded. This only lowered the average coefficient values 0.2 and 0.3.

Table 6

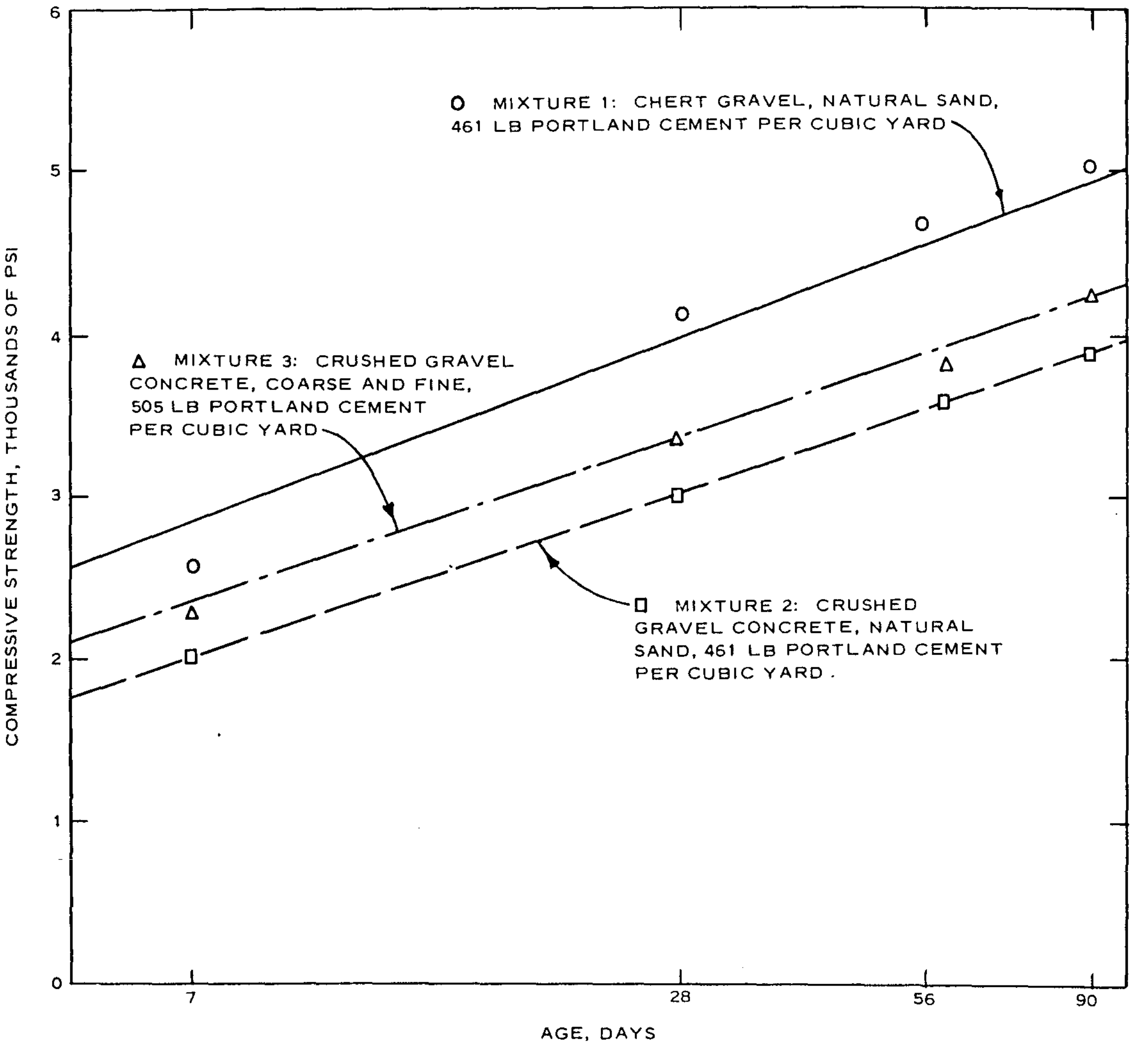
Length Changes of Concrete Specimens Stored at Constant Moisture and Temperature*

Round	Specimen	Mixture No. 1. Control, Chert Gravel and Natural Sand		Mixture No. 2. Crushed Chert-Gravel Concrete Coarse Aggregate and Natural Sand		Mixture No. 3. Crushed Chert-Gravel Concrete Coarse and Fine Aggregate		Mixture No. 4. Control, Limestone Coarse Aggregate and Natural Sand		Mixture No. 5. Crushed Limestone Concrete Coarse Aggregate and Natural Sand	
		Length Increase, %, at Indicated Age**									
		28-Day	90-Day	28-Day	90-Day	28-Day	90-Day	28-Day	90-Day	28-Day	90-Day
1	1	0.013	0.019	0.014	0.023+	0.017+	0.036+	0.003	0.001	0.003	0.002
2	5	0.016	0.018	0.010	0.011	0.007	0.009				
3	9	0.010	0.008	0.012	0.014	0.007	0.011				
	Average	0.013	0.015	0.012	0.016	0.010	0.019	0.003	0.001	0.003	0.002

* Specimens were stored in the moist room at over 90% R.H. and 73 ± 2 F.

** The initial reference length was measured at one day for mixtures 1 through 3 and at two days for mixtures 4 and 5.

+ Loose inserts.



6
5
4
3
2
1
0
7
28
56
90
AGE, DAYS
COMPRESSIVE STRENGTH, THOUSANDS OF PSI
O MIXTURE 1: CHERT GRAVEL, NATURAL SAND, 461 LB PORTLAND CEMENT PER CUBIC YARD
Δ MIXTURE 3: CRUSHED GRAVEL CONCRETE, COARSE AND FINE, 505 LB PORTLAND CEMENT PER CUBIC YARD
□ MIXTURE 2: CRUSHED GRAVEL CONCRETE, NATURAL SAND, 461 LB PORTLAND CEMENT PER CUBIC YARD.

Figure 1

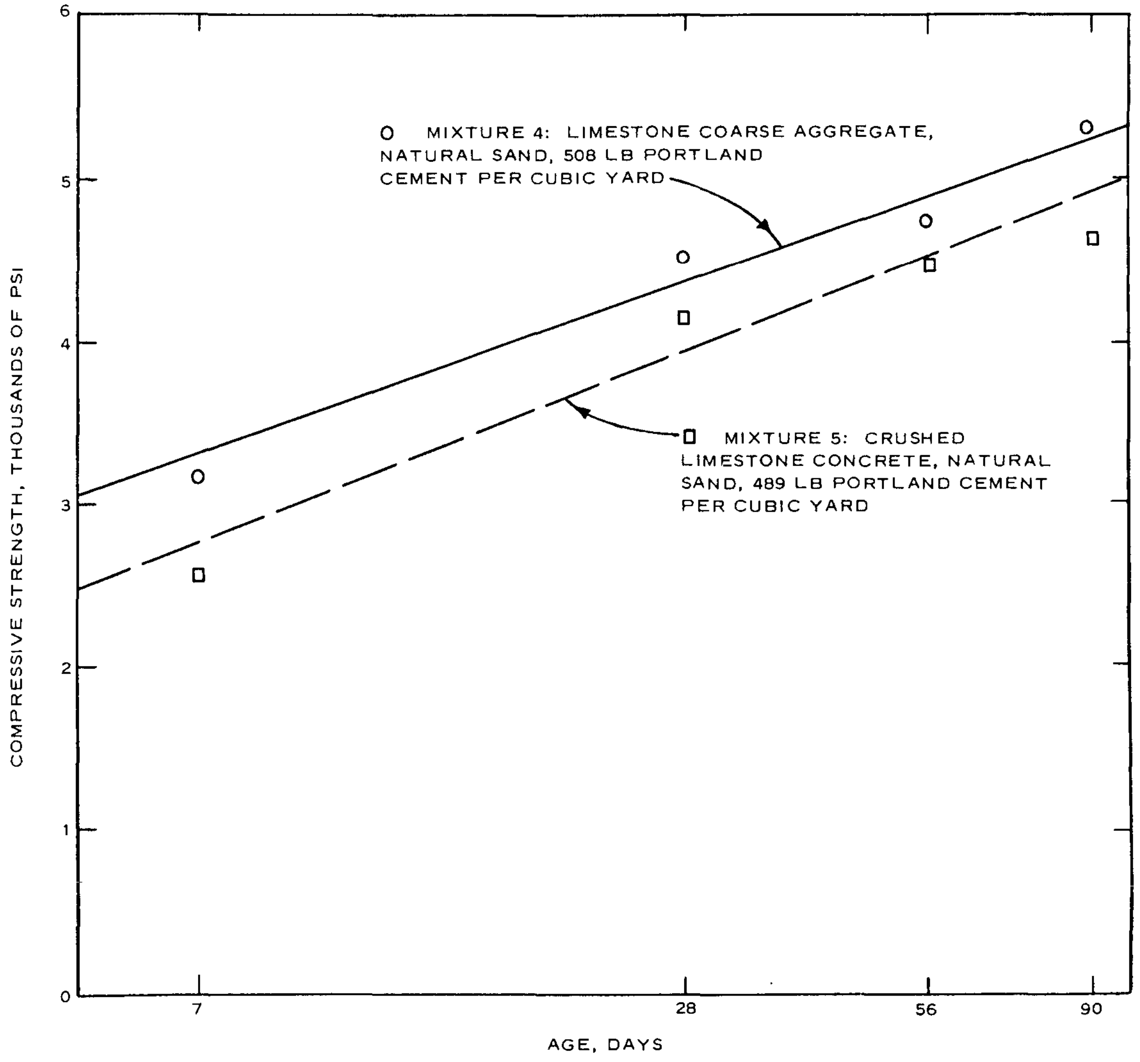

O MIXTURE 4: LIMESTONE COARSE AGGREGATE, NATURAL SAND, 508 LB PORTLAND CEMENT PER CUBIC YARD
□ MIXTURE 5: CRUSHED LIMESTONE CONCRETE, NATURAL SAND, 489 LB PORTLAND CEMENT PER CUBIC YARD
COMPRESSIVE STRENGTH, THOUSANDS OF PSI
0
1
2
3
4
5
6
7
28
56
90
AGE, DAYS

Figure 2

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13. ABSTRACT

Supplies of natural mineral aggregates are diminishing even as their usage increases. Disposal problems exist because of steadily increasing accumulation of solid wastes. In light of these two situations an investigation was made to evaluate the use of crushed waste concrete similar to pavement concrete as concrete aggregates. A discarded concrete driveway that contained siliceous aggregates and a laboratory concrete beam that contained limestone as coarse and natural siliceous sand as fine aggregate were selected to represent pavement concretes. Portions of each kind of concrete were processed into aggregate sizes. Three concrete mixtures were made to evaluate the driveway concrete as aggregate, and two other mixtures were made to evaluate the crushed concrete beam as aggregate. Specimens from each round of each mixture were tested for compressive strength at different ages up to six months, for resistance to accelerated freezing and thawing, and for volume changes due to temperature changes or to moisture effects at a constant temperature. The aggregate particles produced by crushing concrete had good particle shape, high absorptions, and low specific gravities by comparison with conventional natural mineral aggregates. Other results included: (a) use of crushed concrete as coarse aggregate had no significant effect on the mixture proportions or workability of the mixtures by comparison with the control mixtures; (b) when the crushed driveway concrete was also used as fine aggregate, the mixture was slightly less workable and required more cement than the control mixture; (c) use of waste concrete as coarse aggregate results in concrete strength 300 to 1100 psi lower than comparable strengths of control mixtures; (d) use of the driveway waste concrete substantially improved frost resistance; (e) use of the crushed concrete beam as coarse aggregate apparently lowered frost resistance slightly; and (f) use of waste concrete as aggregate had no significant effect on the volume response of specimens to temperature or moisture effects. It is concluded that the present results are promising for the use of recycled pavements or similar concretes as concrete coarse aggregate and perhaps as fine aggregate. It is emphasized, however, that the results in this work do not pertain to concrete from demolished buildings since the waste concrete used in this work was free of contamination by other materials such as sulfates. Recycled building concrete is likely to be contaminated by sulfates from plaster and gypsum wallboard, which creates a possibility of sulfate attack. The possible use of that kind of waste concrete as concrete aggregate should be evaluated in future work.

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Concrete aggregates						
Compressive strength						
Resistance to freezing and thawing						
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Waste concrete						

Unclassified

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