Louisiana Highway Research

# SHELL CONCRETE PAVEMENT

Louisiana Department of Highways – Research & Development Section

# SHELL CONCRETE PAVEMENT

by

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# SYNOPSIS

This report describes the testing performed with reef shell, clam shell and a combination of reef and clam shell used as coarse aggregate to determine if a low modulus concrete could be developed for use as a base material as an alternate to the presently used cement stabilized bases.

The tests in included, compressive, flexural and tensile strength, drying shrinkage, bond to reinforcing steel, freeze and thaw durability and dynamic modulus elasticity.

A total of twenty concrete mixes were evaluated, including two gravel and sand mixes for reference purposes. Cement contents of the mixes were 4.0, 5.0 and 6.0 sacks per cubic yard for each variable tested.

The results indicated that a 4.0 sack mix using reef shell as the coarse aggregate produced the lowest modulus of elasticity.

## INTRODUCTION

This project was undertaken in an effort to develop a low modulus, low cement content, shell concrete for use as a base material in areas where soil or aggregate type bases prove inadequate due to the unstable embankment material. Due to the large quantities of shell available in south Louisiana, it was felt that the development of a base of this type would be both economical and desirable.

## TEST PROGRAM

### Objectives

The objective of this study was to develop a concrete mix using shell and sand as aggregates that would result in a low modulus of elasticity, but yet have sufficient strength to bridge over unstable embankment materials. With a low modulus of elasticity, the concrete could withstand more deflection without cracking than could a very rigid high modulus concrete.

## MATERIALS

### Shell

Two sources of shell were used in this study. Source No. 1 was from the New Orleans area, and source No. 2 was from the Morgan City area. Both clam shell and reef shell were obtained from each source.

In order to determine the most economical shell to use, it was planned to obtain shell which would meet the present LDH specifications of not more than 10 percent foreign matter present in the shell, and also to obtain shell which had higher percentage of foreign matter. One of the objectives of this study would then be to determine the effects of this high foreign matter content on the concrete mix. The reasoning behind this was that if the shell containing large amounts of foreign matter could be used successfully, the price of the shell would be cheaper resulting in a lower cost concrete mix. However, after discussing this matter with the shell producers, it was found that the normal dredging operation results in double washing of the shell and a special effort would have to be made to produce shell having large quantities of foreign matter and no savings would be realized. For this reason, that aspect of the study was cancelled.

Concrete Sand

The concrete sand used in this study was obtained from a local supplier in the Baton Rouge area. The sand is a predominately siliceous material obtained from the Amite River.

Cement

Type I Portland Cement was used for all concrete mixes.

Admixtures

Chemical admixtures were used in all of the shell concrete mixes to entrain air, to reduce the required water, and to improve workability. The air entraining agent used was a neutralized vinsol resin, while the set retarding, water reducing agent was a calcium lignosulfonate.

Water

The water used for all concrete mixes was obtained from the city water supply of Baton Rouge, Louisiana.

## TEST PROCEDURES

All testing performed in this study was conducted in accordance with the following test procedures:

| | |
|---|---|
| AASHO T19-56 | Method of Test for Unit Weight of Aggregate |
| AASHO T22-60 | Method of Tests for Compressive Strength of Molded Concrete Cylinders |
| AASHO T27-60 | Method of Test for Sieve Analysis of Fine and Coarse Aggregate |
| AASHO T96-60 | Method of Test for Abrasion of Coarse Aggregate by Use of the Los Angeles Machine |
| AASHO T97-60 | Method of Test for Flexural Strength of Concrete (Using Simple Beam with Third Point Loading) |

| | |
|---|---|
| AASHO T 103-42 | Method of Test for Soundness of Aggregate by Freezing and Thawing |
| AASHO T104-57 | Method of Test for Soundness of Aggregate by Use of Sodium Sulfate or Magnesium Sulfate |
| AASHO T126-60 | Method of Test for Making and Curing Concrete Compression and Flexure Tests Specimens in the Laboratory |
| AASHO T160-60 | Method of Test for Volume Change of Cement Mortar and Concrete |
| ASTM C215-60 | Method of Test for Fundamental Transverse, Longitudinal, and Torsional Frequencies of Concrete Specimens |
| ASTM C291-61T | Method of Test for Resistance of Concrete Specimens to Rapid Freezing in Air and Thawing in Water |
| ASTM C496-64T | Method of Test for Splitting Tensile Strength of Molded Concrete Cylinders |
| LDH TR203-62 | Method of Test for Air Content of Freshly Mixed Concrete by the Pressure Method |
| LDH TR 207-64 | Method of Test for Slump of Portland Cement Concrete |
| Texas 425-A-62 | Comparing Concrete on the Bases of Bond Developed with Reinforcing Steel |

## TEST RESULTS OF AGGREGATE

Tests performed on the aggregate consisted of gradation, unit weight, abrasion, soundness (magnesium sulfate) and freeze and thaw soundness.

The gradation and unit weights of the aggregates are given in Table 1. The abrasion and soundness results are given in Table 2.

## CONCRETE

The combination of aggregate used in concrete mixes were as follows:

TABLE 1

GRADATION AND UNIT WEIGHT OF AGGREGATES

| U. S. Sieve | Percent Passing Sieve Indicated, By Weight | | | | | |
|---|---|---|---|---|---|---|
| | Shell Aggregate | | | | | |
| | Source No. 1 | | Source No. 2 | | | |
| | Clam | Reef | Clam | Reef | Sand | Gravel |
| 2 1/2 Inch | | | | 100 | | |
| 2 Inch | | 100 | | 99 | | |
| 1 1/2 Inch | 100 | 92 | 100 | 94 | | 100 |
| 1 Inch | 95 | 77 | 99 | 90 | | |
| 3/4 Inch | 66 | 65 | 77 | 88 | | 73 |
| 1/2 Inch | 23 | 43 | 34 | 82 | | 29 |
| 3/8 Inch | 14 | 34 | 17 | 74 | 100 | 11 |
| No. 4 | 9 | 18 | 5.7 | 55 | 97 | 0 |
| No. 8 | | | | | 88 | |
| No. 16 | | | | | 76 | |
| No. 30 | | | | | 62 | |
| No. 50 | | | | | 22 | |
| No. 100 | | | | | 2 | |
| Foreign Matter | 2.6 | 3.6 | 1.2 | 5.9 | 0 | 0 |
| DRY UNIT WEIGHT - LBS/CU FT | | | | | | |
| Loose | 51.5 | 49.0 | 57.0 | 63.0 | 104.0 | 89.0 |
| Rodded | 63.5 | 61.0 | 69.5 | 75.0 | 111.0 | 98.0 |

TABLE 2

LOS ANGELES ABRASION AND SOUNDNESS RESULTS

| | Los Angeles Abrasion Grade B - Per Cent Loss | Magnesium Sulfate Soundness Per Cent Loss | Freeze and Thaw Soundness Per Cent Loss |
|---|---|---|---|
| Aggregate 1 (Reef Shell-Source 1) | 41.5 | 6.34 | 10.97 |
| Aggregate 2 (Clam Shell-Source 1) | 36.0 | 6.04 | 22.89 |
| Aggregate 3 (Reef Shell-Source 2) | 44.9 | 1.26 | 6.13 |
| Aggregate 4 (Clam Shell-Source 2) | 34.2 | 1.08 | 13.43 |
| Aggregate 5 (Sand) | — | — | — |
| Aggregate 6 (Sand) | 18.4 | 3.56 | 3.60 |

1 - clam shell and sand
2 - reef shell and sand
3 - reef shell, clam shell and sand
4 - gravel and sand

Each of the above combinations were used in concrete mixes containing 4.0, 5.0 and 6.0 sacks of cement per cubic yard except for the gravel and sand mix which was tested at 6.0 sacks per cubic yard only. Admixtures were used in all shell mixes and in one sand and gravel mix. The designs used are given in Table 3. The mixes are identified with letters and numbers with CS meaning clam shell, RS meaning reef shell, RCS meaning a combination of reef and clam shell, GS meaning gravel and sand, and GSA meaning gravel and sand with admixtures. The cement content is designated by a 4, 5 or 6 and the source of the shell is identified by 1 or 2. For example CS 1-4 means a four sack mix containing clam shell from Source No. 1, and RCS 2-6 means a six sack mix containing reef and clam shell from Source No. 2.

The concrete was mixed in a 3.5 cu ft. revolving drum mixer. The aggregate and approximately two-thirds of the mixing was placed in the mixer and mixed for one minute. The cement and the remaining mixing water were then added and mixing continued for an additional four minutes. The concrete was then dumped from the mixer and the necessary tests and test specimens made.

The test specimens consisted of 6 x 12 inch cylinders for compressive and tensile strength, 6 x 6 x 20 inch beams for flexural strength, 3 x 4 x 16 inch beams for freeze and thaw testing, 2 x 2 x 11 1/4 inch cylinders for bond tests.

<u>Tests on Concrete Specimens</u>

Compressive strength, flexural strength, and tensile strength tests were performed at ages of 7 and 28 days, 3, 6 and 12 months. Three specimens were tested for each age with the average reported as the result of each particular test.

The specimens made for testing bond to reinforcing steel were tested at an age of 28 days. The Texas method was used for this study due to the large numbers of mixes involved, and because the Texas method allows the use of standard cylinders instead of cubes as required by the ASTM procedure.

The drying-shrinkage and popout tests were performed in accordance with the standard procedures. Dynamic modulus of elasticity was determined at 7 and 28 days, 3, 6 and 12 months on beams cured in the damp room. The highest value obtained was at 12 months and this value is the one reported. Table 4 lists the results for the above mentioned tests.

| Mix No. | Cement Lbs. | Aggregate | | Total Water Gals. | Admixtures | | Slump In. | Air Content Percent | Unit Wt. of Plastic Concrete Lbs./Cu. Ft. | Actual Cement Content Bags/Cu. Yd. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Fine Lbs. | Coarse Lbs. | | Air Entraining Ozs. | Water Reducer Lbs. | | | | |
| CSI-4 | 94 | 459 | 308 | 10.5 | 0.5 | 0.25 | 3 1/4 | 3.9 | 138.0 | 3.93 |
| CSI-5 | 94 | 345 | 262 | 8.0 | 0.5 | 0.25 | 3 3/4 | 4.0 | 138.4 | 4.88 |
| CSI-6 | 94 | 266 | 229 | 6.6 | 0.5 | 0.25 | 3 1/4 | 3.8 | 139.6 | 5.85 |
| RSI-4 | 94 | 451 | 278 | 10.5 | 0.5 | 0.25 | 3 1/4 | 3.9 | 133.6 | 3.96 |
| RSI-5 | 94 | 320 | 243 | 8.5 | 0.5 | 0.25 | 3 1/2 | 3.2 | 134.0 | 4.99 |
| RSI-6 | 94 | 258 | 195 | 7.3 | 0.5 | 0.25 | 3 1/2 | 4.0 | 133.6 | 5.95 |
| RCSI-4 | 94 | 454 | 191C<br>112R | 10.3 | 0.5 | 0.25 | 3 1/2 | 3.8 | 137.6 | 3.97 |
| RCSI-5 | 94 | 325 | 167C<br>98R | 8.2 | 0.5 | 0.25 | 3 1/2 | 3.5 | 138.0 | 4.96 |
| RCSI-6 | 94 | 263 | 136C<br>80R | 6.8 | 0.5 | 0.25 | 3 1/2 | 3.9 | 136.8 | 5.89 |
| CS2-4 | 94 | 491 | 280 | 10.3 | 0.5 | 0.25 | 3 1/2 | 3.9 | 138.8 | 3.95 |
| CS2-5 | 94 | 383 | 237 | 7.4 | 0.5 | 0.25 | 3 1/4 | 3.9 | 141.6 | 4.94 |
| CS2-6 | 94 | 296 | 208 | 6.2 | 0.5 | 0.25 | 3 1/4 | 4.0 | 141.2 | 5.87 |
| RS2-4 | 94 | 314 | 364 | 13.0 | 1.25 | 0.25 | 3 1/2 | 2.5 | 130.8 | 4.02 |
| RS2-5 | 94 | 217 | 309 | 10.4 | 1.25 | 0.25 | 3 1/4 | 3.0 | 131.2 | 5.01 |
| RS2-6 | 94 | 175 | 250 | 8.7 | 1.25 | 0.25 | 3 1/4 | 2.8 | 132.0 | 6.03 |
| RCS2-4 | 94 | 369 | 215C<br>158R | 11.1 | 1.25 | 0.25 | 3 1/4 | 2.5 | 140.0 | 4.07 |
| RCS2-5 | 94 | 264 | 187C<br>138R | 8.4 | 1.25 | 0.25 | 3 1/4 | 2.5 | 140.4 | 5.03 |
| RCS2-6 | 94 | 210 | 149C<br>110R | 7.4 | 1.0 | 0.25 | 3 1/4 | 2.7 | 140.0 | 6.05 |
| GS-6 | 94 | 197 | 323 | 5.5 | - | - | 3 1/4 | 1.2 | 147.2 | 6.02 |
| GSA-6 | 94 | 184 | 323 | 4.7 | 0.5 | 0.25 | 3 1/2 | 4.1 | 141.6 | 5.97 |

## CONCRETE TEST RESULTS

| Mix No. | Compressive Strength, P.S.I. 7 days | 28 days | 3 mo. | 6 mo. | 12 mo. | Flexural Strength, P.S.I. 7 days | 28 days | 3 mo. | 6 mo. | 12 mo. | Tensile Strength, P.S.I. 7 days | 28 days | 3 mo. | 6 mo. | 12 mo. | Drying Shrinkage Percent | Bond Strength P.S.I. | Popout Test | Dynamic Modulus of Elasticity P.S.I. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CS1-4 | 1372 | 1802 | 2132 | 2173 | 2111 | 257 | 333 | 423 | 402 | 393 | 109 | 150 | 149 | 169 | 182 | 0.053 | 899 | None | 4,338,770 |
| CS1-5 | 2049 | 2680 | 3026 | 3121 | 3086 | 310 | 460 | 393 | 503 | 477 | 176 | 200 | 216 | 202 | 220 | 0.058 | 1068 | None | 4,737,472 |
| CS1-6 | 2750 | 3504 | 3869 | 3821 | 3805 | 453 | 457 | 503 | 533 | 523 | 214 | 274 | 272 | 266 | 266 | 0.061 | 1212 | None | 5,085,096 |
| RS1-4 | 1260 | 1778 | 1908 | 1907 | 1896 | 297 | 403 | 560 | 417 | 440 | 119 | 155 | 165 | 209 | 172 | 0.061 | 885 | None | 3,927,898 |
| RS1-5 | 2014 | 2633 | 2697 | 2814 | 2898 | 413 | 490 | 573 | 508 | 460 | 191 | 215 | 240 | 247 | 239 | 0.075 | 1059 | None | 4,325,093 |
| RS1-6 | 2420 | 2714 | 3086 | 3122 | 3245 | 470 | 457 | 507 | 550 | 563 | 194 | 227 | 231 | 260 | 296 | 0.090 | 1108 | None | 4,602,541 |
| RCS1-4 | 1331 | 1767 | 1878 | 1979 | 2002 | 297 | 383 | 420 | 440 | 427 | 113 | 171 | 168 | 179 | 171 | 0.045 | 857 | None | 4,021,535 |
| RCS1-5 | 2226 | 2797 | 3097 | 2851 | 3262 | 367 | 490 | 497 | 547 | 510 | 175 | 218 | 218 | 228 | 227 | 0.060 | 1059 | None | 4,588,309 |
| RCS1-6 | 2686 | 3033 | 3403 | 3386 | 3598 | 430 | 480 | 503 | 650 | 623 | 213 | 208 | 245 | 278 | 254 | 0.069 | 1213 | None | 4,987,876 |
| CS2-4 | 1290 | 1649 | 2038 | 1902 | 2243 | 277 | 360 | 413 | 397 | 407 | 115 | 153 | 167 | 173 | 173 | 0.055 | 869 | None | 4,570,279 |
| CS2-5 | 2556 | 3138 | 3633 | 3687 | 3633 | 450 | 503 | 537 | 530 | 560 | 192 | 256 | 271 | 291 | 247 | 0.048 | 1200 | None | 5,241,590 |
| CS2-6 | 3174 | 3910 | 4298 | 4376 | 4616 | 530 | 573 | 617 | 567 | 537 | 241 | 266 | 302 | 263 | 258 | 0.045 | 1232 | None | 5,525,696 |
| RS2-4 | 931 | 1334 | 1543 | 1666 | 1714 | 257 | 380 | 417 | 437 | 420 | 78 | 127 | 170 | 164 | 181 | 0.091 | 645 | None | 3,082,571 |
| RS2-5 | 1431 | 1984 | 2179 | 2391 | 2485 | 353 | 400 | 537 | 500 | 523 | 152 | 174 | 226 | 223 | 226 | 0.115 | 832 | None | 3,493,738 |
| RS2-6 | 2332 | 2897 | 3027 | 3162 | 3180 | 443 | 500 | 580 | 540 | 577 | 203 | 223 | 249 | 247 | 251 | 0.124 | 967 | None | 3,869,879 |
| RCS2-4 | 1378 | 1714 | 2055 | 2144 | 2220 | 347 | 383 | 413 | 397 | 417 | 115 | 167 | 186 | 185 | 171 | 0.074 | 917 | None | 4,234,075 |
| RCS2-5 | 2055 | 2650 | 2909 | 2945 | 3321 | 403 | 547 | 533 | 510 | 573 | 160 | 235 | 263 | 231 | 242 | 0.072 | 1097 | None | 4,445,671 |
| RCS2-6 | 2791 | 3303 | 3940 | 3875 | 4152 | 488 | 607 | 593 | 593 | 617 | 211 | 239 | 313 | 267 | 285 | 0.074 | 1196 | None | 5,051,628 |
| GS-6 | 4304 | 5429 | 6413 | 6795 | 7226 | 593 | 800 | 880 | 910 | 840 | 335 | 366 | 438 | 520 | 451 | 0.039 | 1310 | None | 7,282,200 |
| GSA-6 | 4576 | 5548 | 6784 | 6518 | 7178 | 617 | 677 | 783 | 813 | 770 | 339 | 424 | 451 | 467 | 483 | 0.045 | 1259 | None | 6,826,355 |

The freeze and thaw tests were started when the specimens had reached an age of 28 days. The curing procedure for the specimens consisted of 24 hours of burlap curing while the specimens were in the beam molds, 6 days at 73±2°F and 100 percent humidity, 14 days at 73±2°F and 50 percent humidity and 7 days at 73±2°F and 100 percent humidity. At the conclusion of this curing cycle, the test specimens were tested for dynamic modulus of elasticity and placed in the freeze and thaw machine. The freeze and thaw machine produced eight cycles of freezing to 0±3°F and thawing to 40±3°F every 24 hours. The test specimens were removed from the freeze and thaw machine and tested for dynamic modulus of elasticity after approximately 20 cycles of freezing and thawing. This procedure was continued until the specimens had lost 40 percent of the original modulus of elasticity. At this point the specimens were considered to have failed. Table 5 gives the results of the freeze and thaw tests.

## DISCUSSION OF RESULTS

### Aggregate

The aggregate used in this study were subjected to freeze and thaw soundness tests, magnesium sulfate soundness tests, and Los Angeles abrasion tests in addition to the standard sieve analysis and unit weight determinations. The results of these tests indicated that clam shell had less loss when subjected to the Los Angeles Abrasion test and magnesium sulfate soundness test than reef shell, although the reef shell showed less loss when subjected to the freeze and thaw test. Gravel outperformed clam and reef for the abrasion and freeze and thaw tests, but the clam and reef shell from Source 2 had a lower loss when subjected to the magnesium sulfate soundness test than did gravel. No correlation was found in the results obtained from these tests. The only consistent results obtained was from the gravel which had a loss of 3.56 percent when subjected to the magnesium sulfate soundness test and 3.60 percent loss when subjected to the freeze and thaw soundness test.

### Compressive, Flexural and Tensile Strength

The compressive, flexural and tensile strength of the concrete mixes performed according to what would be expected in most cases. The clam shell produced higher strengths than the reef shell with the mixture of clam and reef generally falling in between the other two mixes. The few exceptions to this were probably due to normal expected variation in concrete testing.

The lowest strength results obtained was from the 4.0 sack mix containing reef shell from Source 2. However, all the strengths were higher than in obtained from our present cement stabilized bases.

Drying Shrinkage tests are given in Table 6. There was no consistent pattern established by the results. The only definite statement that can be made is that reef shell exhibited higher shrinkage than clam shell. Generally, the lower cement contents produced less shrinkage, although the mixes containing clam shell from Source No. 2 behaved entirely opposite from this with the lower cement factor producing the highest shrinkage and the highest cement content producing the lowest shrinkage. The reef shell from Source 2 gave the highest shrinkage of all mixes tested. The mixes containing a combination of reef and clam shell produced varied results. The 4.0 sack mix containing reef and clam shell from Source No. 1 had less shrinkage than the 4.0 sack mix containing clam shell only. The 5.0 and 6.0 sack mixes containing the combination material produced slightly higher results than the 5.0 and 6.0 sack mixes containing clam shell only. The combination mixes from Source No. 2 had shrinkage results that fell in between the results of the clam shell mixes and the reef shell mixes. However, there was only .002 percent difference between the shrinkage results of the 4.0, 5.0 and 6.0 sack mixes containing the combination of clam and reef shell.

The gravel and sand mix containing 6.0 sacks of cement and no admixtures had the lowest shrinkage of all mixes tested. The gravel and sand mix containing 6.0 sacks of cement with admixtures had the same shrinkage as the mix containing 4.0 sacks of cement per cubic yard with clam and reef shell from Source No. 1 and the mix containing 6.0 sacks per cubic yard with clam shell from Source No. 2.

## Bond Strength

The results of the bond strength tests are also given in Table 4. As stated earlier in the report, the Texas procedure was used to determine the bond to reinforcing steel.

As was the case with the drying shrinkage results, no consistent pattern was established with the bond strength results. Generally the clam shell mixes produced better bonding qualities although there were two exceptions to this. The mix containing 4.0 sacks of cement per cubic yard with a combination of reef and clam shell from Source No. 1 produced the highest bond strength of all 4.0 sack mixes, and the mix containing 6.0 sacks of cement per cubic yard with a combination of reef and clam shell from Source No. 2 produced a higher bond strength than the 6.0 sack clam and the 6.0 sack reef mixes from Source No. 2. The reef shell mixes generally produced lower results, with combination mixes falling in between the clam shell mixes and the reef shell mixes. The highest bond strength was obtained on the sand and gravel mixes.

TABLE 5

RESULTS OF FREEZING AND THAWING TESTS

| Mix No. | Per Cent of Original E At Approximately 300 Cylces | Durability Factor At 300 Cylces | Relative Durability Factor At Approximately 300 Cylces | Per Cent of Original E at Completion of Test |
|---|---|---|---|---|
| CS1-4 | 60.0 (73) | 15 | 125 | — |
| CS1-5 | 60.0 (220) | 44 | 367 | — |
| CS1-6 | 65.0 (200) | 65 | 541 | 60.0 (385) |
| RS1-4 | 60.0 (55) | 11 | 92 | — |
| RS1-5 | 60.0 (55) | 10 | 83 | — |
| RS1-6 | 60.0 (85) | 17 | 142 | — |
| RCS1-4 | 60.0 (43) | 9 | 75 | — |
| RCS1-5 | 60.0 (160) | 32 | 267 | — |
| RCS1-6 | 60.0 (64) | 13 | 108 | — |
| CS2-4 | 68.0 (300) | 68 | 567 | 60.0 (470) |
| CS2-5 | 82.0 (300) | 82 | 683 | 71.0 (525) |
| CS2-6 | 73.0 (300) | 73 | 608 | 60.0 (535) |
| RS2-4 | 60.0 (10) | 2 | 17 | — |
| RS2-5 | 60.0 (137) | 27 | 225 | — |
| RS2-6 | 90.0 (300) | 90 | 750 | 89.0 (500) |
| RCS2-4 | 60.0 (36) | 7 | 58 | — |
| RCS2-5 | 60.0 (152) | 30 | 250 | — |
| RCS2-6 | 60.0 (283) | 57 | 475 | — |
| GS-6 | 60.0 (62) | 12 | — | — |
| GSA-6 | 60.0 (83) | 17 | 142 | — |

Numbers in parentheses refer to cycles of freezing and thawing

## Popout Test

This test was performed to determine if any of the shell mixes would produce popout, but as can be seen from Table 4 no popout were observed on any of the mixes.

## Dynamic Modulus of Elasticity

The dynamic modulus of elasticity was determined from 3 x 4 x 16 inch beams cured in the moist room for a 12 month period. The highest modulus of elasticity was obtained at 12 months, and this value is shown in Table 4.

Thre results of this test were consistent with the clam shell mixes producing the higher modulus of elasticity, the reef shell mixes producing the lowest modulus, and the mixes containing the combination of reef and shell producing a modulus between the clam mixes and reef mixes. The lowest modulus obtained was from the 4.0 sack mix containing reef shell from Source No. 2. The highest modulus obtained from a shell mix was from the 6.0 sack mix containing clam shell from Source No. 2. The sand and gravel mixes produced the highest modulus of elasticity.

## Freeze and Thaw Test

The freeze and thaw test performed on the concrete mixes consisted of rapid freezing in air and thawing in water. The test specimens were 3 x 14 x 16 inch beams, and dynamic modulus of elasticity was used to determine the rate of deterioration of the concrete. The results of the freeze and thaw tests are shown in Table 5.

The clam shell mixes outperformed the reef shell and combination reef and clam shell mixes in all cases but one. The five sack mix containing reef shell from Source No. 2 performed better than any other mix having retained 90.0 percent of its original modulus of elasticity after 300 cycles of freezing and thawing and 89.0 percent after 500 cycles of freezing and thawing. Only five mixes out of the twenty tested reached 300 cycles before losing 40 percent of their original modulus of elasticity. The five mixes were CS 1-6, CS 2-4, CS 2-5, CS 2-6, and RS 2-6. Three of these mixes, CS 2-5, CS 2-6, RS 2-6, exceeded 500 cycles before obtaining a loss of 40 percent of the original modulus of elasticity.

The higher cement content mixes did not outperform the lower cement content mixes in every case. The five sack mix containing reef shell from Source No. 1, and the five sack mix containing reef and clam shell from Source No. 2 outperformed the comparative mixes containing six sacks of cement per cubic yard. In addition, the four sack mix containing reef shell from Source No. 1 was superior to the five sack mix containing the same shell by five cycles of freezing and thawing.

A comparison between the two sources indicate that generally Source No. 2 gave better results than Source No. 1. The three exceptions to this were mixes RS 2-4, which gave the lowest results of all mixes tested, RCS 2-4 and RCS 2-5. All but five of the shell mixes gave higher results than the sand and gravel mix used as the reference. These five mixes all had cement contents of four and five sacks per cubic yard as compared to a six sack mix for the sand and gravel.

## CONCLUSIONS

The results obtained from this study warrant the following conclusion:

1. Concrete made using clam shell as the coarse aggregate generally produced higher compressive, flexural and tensile strength than did concrete made using reef shell as the coarse aggregate. The combining of reef and clam shell in a mix generally resulted in a reduction of strength from that received when clam shell was used as the coarse aggregate. In most cases, the shell from Source No. 1 produced higher strength than the shell from Source No. 2.

2. Concrete made using clam shell as the coarse aggregate had less drying shrinkage than did concrete made with reef shell as the coarse aggregate. Concrete made using reef shell from Source No. 2 produced the highest shrinkage of all mixes tested.

3. Concrete made using clam shell as the coarse aggregate resulted in higher bond strengths than concrete made using reef shell as the coarse aggregate.

4. The lowest modulus of elasticity was obtained from concrete made with reef shell as the coarse aggregate.

5. Generally, concrete with clam shell as the coarse aggregate resulted in a more durable mix than reef shell. The only exception to this was mix RS 2-6 which had the best durability of all mixes tested. Most shell concrete mixes outperformed the sand and gravel reference mix when subjected to the freeze and thaw test.

## RECOMMENDATIONS

The results of this study appear to warrant a field evaluation of shell concrete.

Since one of the prime objectives of this study was to develop a low modulus of elasticity concrete with sufficient strength to serve as a base material, it appears evident that a four sack mix using reef shell as the corase aggregate should be evaluated along with a four sack mix using clam shell. Although the reef shell concrete did not perform as well in most cases as the clam shell concrete, it is the author's opinion that the lower modulus of elasticity obtained from this mix is desirable and that when all properties are considered the concrete will perform in a satisfactory manner. However, the final decision will have to be made after a field investigation is complete.

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