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# Optimal CLSM Mix Design
## As Developed by Means of Small Batch Testing

These tests were conducted to define the optimal mix for Controlled Low-Strength Material (CLSM) used in gravity sewer applications with vitrified clay pipe. Varying percentages of $^3/_8$-inch coarse aggregate, accelerator and entrained air were tested.

Multiple tests were run on plywood bases with six compartments 12-in x 12-in x 4-in.

The primary goal was to determine a mix design that would yield the fastest cure time over a maximum of six hours based on penetration resistance readings using a penetrometer.

### Batches

Batches were made on site using a ¼-yard portable concrete mixer. Three compartments of each batch were prepared.

1. Type II cement was used. (Type I not locally available)
2. Coarse aggregate (#4 crushed stone) - 15%, 20% and 25% by weight of total aggregate with fine aggregate (washed concrete sand) being the balance.
3. Accelerator: ASTM C494 Pozzolan based - 2%, 4%, and 6%.
4. Air entraining agent (BASF Rheocell Rheofill) - 15%, 20% and 25%.
5. Entrapped moisture in the aggregate was measured and subtracted from the total required water.
6. Potable water was used at ambient temperature.

### Method

Batches were made in the mixer as follows: ½ the water, fine aggregate, coarse aggregate, air entraining agent, accelerator, cement, and the balance of water to obtain flowability. After all contents were added, each batch was mixed for 15 minutes.

Flowability of all batches was 9 inches +/- 1-inch spread diameter using a 3-inch diameter by 6-inch long cylinder (per ASTM D 6103 – *Standard Test Method for Flow Consistency of Controlled Low Strength Material (CLSM)*).

Each batch was prepared, measured for air content, and placed into the three 12- x 12- x 4-inch thick compartments. Penetration resistance readings were recorded each hour using a ¼-inch diameter penetrometer. The penetrometer readings obtained for the three compartments were averaged and recorded for each batch.

## Observations and Conclusions

From these tests, it was decided that a 7-inch flowability mix (less water) versus the 9-inch mix should be evaluated using the Optimum Test Mix. The water used was reduced to 38 gallons per yard.

The use of 25% air and 6% accelerator caused foaming and lengthened the cure time.
The use of 15% air and 2% accelerator resulted in longer cure time.

## These tests determined the optimum percentage for each material

1. Coarse aggregate with a #4 size in the amount of 20% combined with 80% fine aggregate by weight is the optimum.
2. Air entrainment of between 15 to 20 % was found to be the optimum. Lesser and greater percentages yielded slower cure times.
3. Accelerator used at 4% was the optimum. Calcium Chloride is corrosive and was not considered performing as well as the accelerators specifically formulated for concrete and was therefore not used.
4. Washed concrete sand must be used. It is critical to know the moisture content before adding water for batch.
5. Additional water, above what is necessary for flowability, increases the cure time significantly.

## Optimal Mix Design as Determined From These Tests

| | |
|---|---|
| Cement | 188 pounds (type I/II or II/V) |
| Fine aggregate | 75% - 80% (by weight) |
| Coarse aggregate | 25% - 20% (by weight) |
| Water | Water necessary to obtain Flowability (7”-9” spread diameter) |
| Accelerator | 4% (as a percent of cement) |
| Air entrainment | 15%-20% |
| Flowability | 8-inch +/- 1 inch spread diameter<br>(3-inch diameter by 6 inch long cylinder, ASTM D 6103) |

- The specific gravity of the aggregate will vary by source location and needs to be taken into consideration to assure the mix yields one cubic yard of mix.
- *No testing was performed with Type I cement as it was not locally available.*
- *Entrapped air in the sand and rock were deducted to determine the water to be added.*

| CLSM Small Batch Results | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Test # | 3/8" Coarse Aggregate (%) | Accelerator (%) | Air Entrainment (%) | Penetration Resistance Readings | | | | | | Mix Temp. (°F) |
| | | | | 1 Hour | 2 Hours | 3 Hours | 4 Hours | 5 Hours | 6 Hours | |
| 1 | 15 | 2 | 15 | 0 | 0 | 20 | 60 | 85 | 105 | 71 |
| 2 | 15 | 2 | 20 | 0 | 0 | 30 | 55 | 80 | 98 | 71 |
| 3 | 15 | 2 | 25 | 0 | 0 | 15 | 30 | 50 | 80 | 74 |
| 4 | 15 | 4 | 15 | 0 | 0 | 28 | 55 | 90 | 120 | 75 |
| 5 | 15 | 4 | 20 | 0 | 0 | 25 | 60 | 95 | 122 | 78 |
| 6 | 15 | 4 | 25 | 0 | 0 | 15 | 30 | 88 | 103 | 74 |
| 7 | 15 | 6 | 15 | 0 | 0 | 15 | 45 | 55 | 83 | 75 |
| 8 | 15 | 6 | 20 | 0 | 0 | 20 | 20 | 43 | 70 | 71 |
| 9 | 15 | 6 | 25 | 0 | 0 | 10 | 15 | 45 | 62 | 72 |
| 10 | 20 | 2 | 15 | 0 | 0 | 20 | 55 | 80 | 110 | 73 |
| 11 | 20 | 2 | 20 | 0 | 0 | 25 | 50 | 80 | 110 | 72 |
| 12 | 20 | 2 | 25 | 0 | 0 | 20 | 45 | 75 | 98 | 70 |
| 13 | 20 | 4 | 15 | 0 | 0 | 25 | 55 | 84 | 123 | 79 |
| 14 | 20 | 4 | 20 | 0 | 0 | 30 | 65 | 91 | 125 | 83 |
| 15 | 20 | 4 | 25 | 0 | 0 | 15 | 35 | 83 | 109 | 73 |
| 16 | 20 | 6 | 15 | 0 | 0 | 5 | 15 | 45 | 78 | 68 |
| 17 | 20 | 6 | 20 | 0 | 0 | 5 | 15 | 50 | 79 | 71 |
| 18 | 20 | 6 | 25 | 0 | 0 | 5 | 10 | 45 | 68 | 69 |
| 19 | 25 | 2 | 15 | 0 | 0 | 15 | 25 | 43 | 82 | 72 |
| 20 | 25 | 2 | 20 | 0 | 0 | 15 | 35 | 55 | 88 | 73 |
| 21 | 25 | 2 | 25 | 0 | 0 | 10 | 25 | 46 | * | |
| 22 | 25 | 4 | 15 | 0 | 0 | 10 | 30 | 55 | 90 | 74 |
| 23 | 25 | 4 | 20 | 0 | 0 | 15 | 25 | 51 | 88 | 71 |
| 24 | 25 | 4 | 25 | 0 | 0 | 0 | 20 | 42 | * | |
| 25 | 25 | 6 | 15 | 0 | 0 | 0 | 10 | 20 | * | |
| 26 | 25 | 6 | 20 | 0 | 0 | 0 | 10 | 20 | * | |
| 27 | 25 | 6 | 25 | 0 | 0 | 10 | 20 | 20 | * | |
| **** The following are results for the 9-inch spread diameter mix** | | | | | | | | | | |
| 28 | 20 | 4 | 15 | 0 | 0 | 28 | 60 | 90 | 120 | 72 |
| 29 | 20 | 4 | 20 | 0 | 20 | 45 | 65 | 93 | 125 | 73 |
| **** The following are results for the 7-inch spread diameter mix** | | | | | | | | | | |
| 34 | 20 | 4 | 15 | 0 | 0 | 25 | 60 | 98 | 122 | 75 |
| 35 | 20 | 4 | 20 | 0 | 20 | 50 | 75 | 100 | 133 | 75 |
| NCPI Mix 8 | 0 | 4 CC | 17 | 0 | 0 | 0 | 40 | 60 | 90 | 73 |

* the readings for six hours were not recorded because the 5 hour readings were unacceptably small

** average of five batches