



CLSM as a Pipe Bedding: Computing Predicted Load using the Modified Marston Equation

Jeff Boschert, P.E.¹ and John Butler²

¹National Clay Pipe Institute, 827 Judson Manor Drive, Saint Louis, MO 63141-6019; PH: (314) 229-3789; jboschert@ncpi.org

²National Clay Pipe Institute, 23835 Temescal Canyon Road, Corona, CA 92883-5043; PH: (909) 261-0662; jbncpi@att.net

ABSTRACT

Controlled Low Strength Material (CLSM), as a structural material for bedding vitrified clay pipe, is a mix consisting of Portland cement, fine aggregate, coarse aggregate, water, entrained air, and chemical admixtures to accelerate cure time. CLSM is gaining popularity as a bedding material for vitrified clay pipe (VCP) due to simplification of pipe installation, reduction in labor and inspection costs, and the benefit of a 2.8 load factor.

Computation of predicted backfill load on rigid pipe is performed utilizing the Marston Equation originally developed by Professor Anson Marston in 1913 and 1930. The variables of the Marston Equation consist of the depth of cover, the unit weight and type of the backfill soil and the width of the trench measured at the top of pipe. This design theory is still used today for rigid pipe design even though bedding system standards were yet to be adopted when it was developed. At that time, rigid pipe were generally laid on a hand-shaped trench bottom and imported bedding was rarely used.

Professor Marston theorized that the material at the sides of rigid pipe was so loose compared to the rigidity of the pipe that the support of any backfill load by the sidefill would be negligible resulting in a conservative design. The presumed inability of the sidefills to carry a significant share of the backfill load is not applicable when CLSM bedding is used since it neither settles nor compacts or shrinks significantly. CLSM will support a large portion of the backfill load, which would otherwise be carried by the pipe. Thus, utilizing the Marston Equation in its conventional form has proven to be inappropriate on CLSM projects.

The growing and successful use of CLSM as a bedding material led the clay pipe industry to conduct research on actual loads received by the pipe both in field installations and laboratory environments. This research demonstrates a load transfer mechanism in which the load on the pipe can be reduced by a ratio of the outside diameter of the pipe to the width of the trench at the top of the pipe (B_c / B_d) resulting in the Modified Marston equation.

INTRODUCTION

Description. Controlled Low Strength Material, CLSM, as a structural material for bedding Vitrified Clay Pipe, is a mix consisting of Portland cement, fine aggregate,

coarse aggregate, water, entrained air and chemical admixtures to accelerate cure time. CLSM, as discussed herein, is specifically the optimal mix design as defined by the NCPI. CLSM as a pipe bedding material meets the requirements of ASTM C12 Practice for Installing Vitrified Clay Pipe, Section 6, Bedding and Encasement, and the *National Clay Pipe Engineering Manual* (2006), Chapter 4, Part II, Structural Design. CLSM is placed from the bottom of the pipe to the top of the pipe completely encompassing the sidefills as shown in Figure 1.

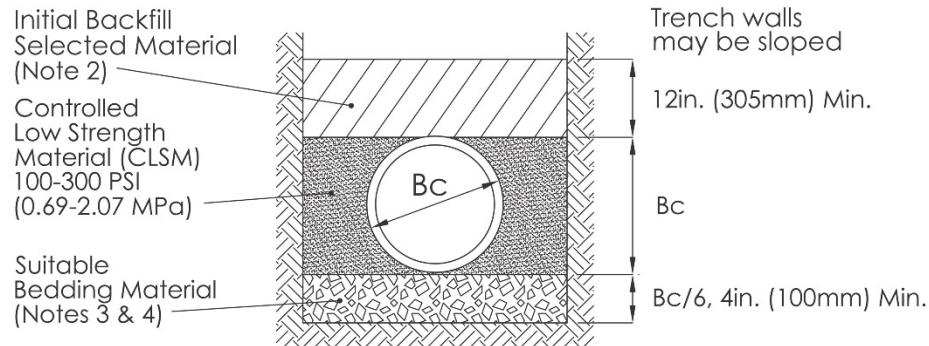


Figure 1 – Controlled Low Strength Material cross section

Advantages. CLSM is a cost effective method to achieve a load factor of 2.8. The flowability of CLSM allows the mix to flow around and along the pipe to provide circumferential support of the pipe barrel. When bedding a pipe without CLSM, shovel slicing or spading of the bedding material into the pipe haunches is essential for the total load factor to be realized. Utilization of CLSM, with a measured flowability of a 7 to 9-inch spread diameter, eliminates the need to shovel slice and the concern for insufficient haunch support. Using CLSM also minimizes the chance of bedding material migration and the French drain effect, a concern when using granular materials in an area with a fluctuating water table.

A rapid cure time allowing for earlier backfill can be achieved with an accelerated mix design. It is recommended that the cure rate be measured with a field penetrometer to attain a minimum of 500-psi reading prior to backfill loading. CLSM is used where deep or wide trench installations require a greater Load Factor than can be achieved using crushed stone encasement. CLSM made with the NCPI optimal mix design can be obtained from local ready-mix concrete plants.

DESIGN APPROACH

Historical perspective. NCPI has been aware of the ability to transfer backfill load from the pipe to the material at the sides of pipe since the loading tower tests that were conducted at the NCPI research laboratory in 1969. These tests showed very convincingly that the denser the sidefill material, the more backfill load it was capable of supporting. This was true for both rigid and flexible conduits.

Referring to the backfill loads on rigid pipe, Professor Marston stated that the material at the sides of rigid pipe was so loose compared to the rigid pipe that the support of any backfill load by the sidefill would be negligible. This premise was the basis for concluding that all of the weight of backfill would be transmitted to the pipe except for

that part which would be resisted by the friction between the backfill material and the trench walls. Eventually it was determined the load on the pipe reached a maximum limit in wide trenches. This discovery became the basis for transition width limits. Transition is the trench width where the backfill load equation for narrow trenches and the embankment equation for wide trenches yield the same load.

Original Marston rigid pipe backfill load design. The lack of any significant support of the trench backfill by the sidefills undoubtedly provided the basis for the concept of shear development between the interior prism of soil directly above the rigid pipe and the exterior prisms of soil directly above the sidefills (inverted arch action); see Figure 2. For a rigid pipe with limited sidefill support, the downward movement of the exterior soil prisms induces the central prism load directly over the pipe.

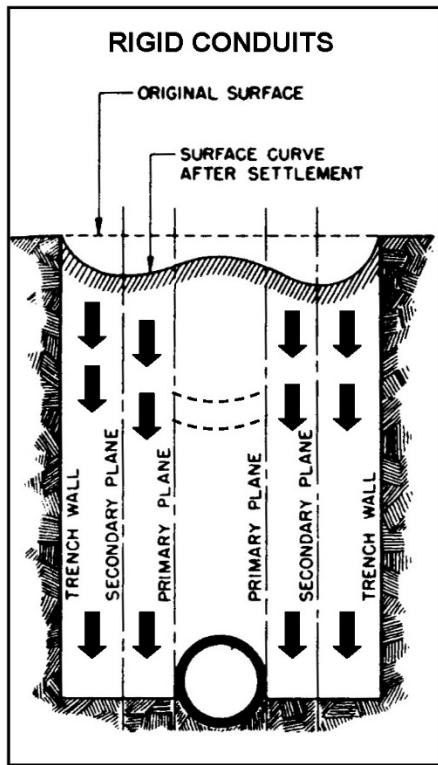


Figure 2 – Cross section of Interior And Exterior Soil Prisms

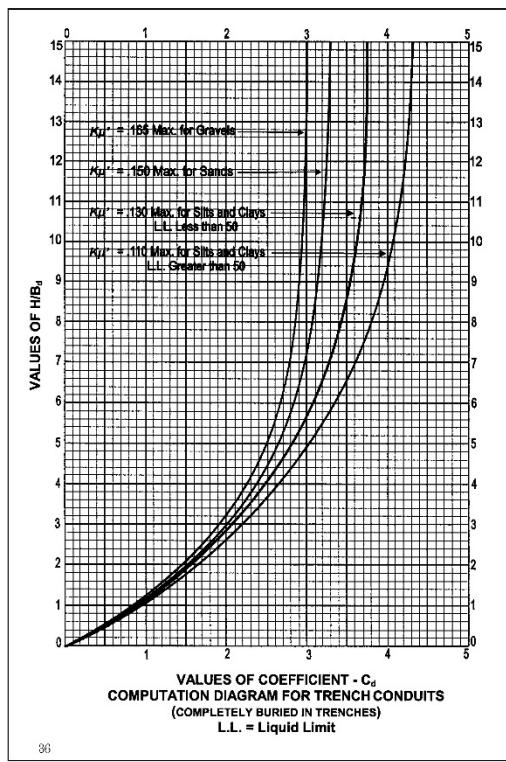


Figure 3 – Values of Coefficient – C_d

Since the height of backfill from the ground surface to the bottom of the trench would always be greater than the distance from the ground surface to the top of the pipe, it would naturally follow that downward shear forces would develop between the interior prism directly over the pipe, and the exterior prisms directly above the sides of the pipe. This, in turn, would give rise to the concept that the entire load in the trench is carried by the pipe less that amount resulting from friction between the backfill and the native trench wall. Thus, a load coefficient (C_d) was developed for the Marston Trench Load Equation.

Calculating C_d is a complex and laborious task so experimental data was used to generate a series of curves known as the load coefficient curves. For rigid pipe installed in narrow trenches, a curve was established for the various backfill soil types. One set of these curves is shown on page 36 of the *NCPI Engineering Manual* and above in Figure 3.

Backfill load distribution design (Modified Marston equation). With the experience gained by testing flexible corrugated metal pipe at Iowa State, Professor Spangler realized that the full trench backfill load was not actually applied to flexible pipe. Since it was common practice to compact the material at the sides of the corrugated steel pipe to keep it in shape, he reasoned that this compacted material not only restricted deflection of the pipe but it also must be supporting some of the backfill load.

Professor Spangler made the following statement in his classic 1951 textbook, *Soil Engineering*: “For the case of a flexible pipe conduit and thoroughly tamped sidefills having essentially the same degree of stiffness as the pipe itself, the value of W_c given by equation (25-3)(rigid pipe equation) might be multiplied by the ratio B_c / B_d ” (Breadth of conduit / Breadth of ditch) and, as a result, the flexible pipe load equation was generated. The equation takes the form $W_c = C_d w B_c B_d$. This has the effect of shifting a portion of the soil prism load above the pipe to the adjacent side prisms above the sidefills. This theory is described as arching or arch effect.

EXPERIMENTAL ANALYSIS

In the case where clay pipe is installed with CLSM sidefills from the bottom of the pipe to the top of the pipe; the clay pipe is rigid and, when set sufficiently prior to backfill, CLSM is also rigid. The backfill load is distributed with reasonable uniformity across the top of the pipe and the sidefills. Applying the same Spangler principal, the load on a clay pipe can be reduced by the ratio B_c / B_d . The standard Marston rigid pipe trench load equation becomes $W_c = C_d w B_d^2 \times B_c / B_d$ which can be simplified to: $W_c = C_d w B_c B_d$, thus a modification to the standard Marston equation.

The main reason for the high computed loads on rigid pipe is the presumed inability of the sidefills to carry any significant share of the backfill load. In CLSM installations, the CLSM neither settles nor compacts or shrinks significantly. It will support a large portion of the load that would otherwise be carried by the pipe. It only requires sufficient strength so that it does not move downward any distance greater than the top of the pipe when loaded.

To test this theory, data was collected and analyzed on three CLSM research projects. Two of the projects were field installations and the third was conducted in a laboratory setting. Actual load the pipe received was based upon readings from strain gauges, which were installed inside the pipe prior to loading. For the laboratory project, load applied to the pipe was taken directly from the actual load readings from the hydraulic unit. For the two field installations, load applied was calculated from (1) the standard Marston equation ($C_d w B_d^2$), (2) the Modified Marston ($C_d w B_c B_d$), and (3) Prism Load ($W_c = B_c w H$)).

The use of strain gauges on the pipe gives generally reliable readings for the actual load on the pipe. It was sometimes necessary to eliminate data that was unrealistic as gauges can become contaminated with moisture or other means that produce abnormalities.

Project #1, Agua Mansa, Riverside CA: This was the first field project where the objective was to determine an accurate Load Factor for the use of CLSM. The project used 39-inch VCP and was installed under contract to the City of Riverside, California. The project used six strain gauge instrumented pipe. Three were placed in a Crushed Stone Envelope (2.2 Load Factor) and three in CLSM.

The information derived was consistent. The strain data from the CLSM instrumented pipe was compared to the Crushed Stone instrumented pipe using a 2.2 Load Factor for Crushed Stone and arrived at a relative 2.8 Load Factor for CLSM based upon the reduced strain observed.

The strain readings were taken directly and converted using non-destructive pipe calibration charts to determine the load the pipe received in each of the bedding systems. Each of the field test pipe were calibrated in a 3-edge bearing machine for load vs. stress/strain characteristics with strain gauges positioned to measure circumferential tension in the invert.

Table 1 – Data Collection from Agua Mansa

39 inch VCP - Agua Mansa, Riverside, CA (1993)							
Load Factor Calculations From Field Results							
Days After Installation	5	11	19	31	39	45	61
Strain gauge reading: (Average of 3 pipe bedded in CLSM)	65	72	71	51	73	66	61
Load Received from Strain (LR)	1675	1950	1900	1150	1975	1725	1550
Calculated Backfill Load using Conventional Marston (LA): $W_c = C_d w B_d^2$	7900	7900	7900	7900	7900	7900	7900
Relative LA/LR	4.71	4.05	4.16	6.87	4.00	4.58	5.10
Calculated Backfill Load using Modified Marston (LA): $W_c = C_d w B_d^2 \times B_c/B_d$	5160	5160	5160	5160	5160	5160	5160
Relative LA/LR	3.08	2.65	2.72	4.49	2.61	2.99	3.33
Calculated Soil Prism Load (LA): $W_c = B_c w H$	7285	7285	7285	7285	7285	7285	7285
Relative LA/LR	4.35	3.74	3.83	6.33	3.69	4.22	4.70

LA = Calculated Load applied in lbs./ LF **LR** = Actual Load received in lbs./ LF

Relative LA/LR = ratio of Load Applied (calculated)/Load Received (invert tensile strain conversion to 3 edge bearing load)

Depth of Cover (H) = 15.5 Ft.; Trench Width (B_d) = 72"; Pipe OD (B_c) = 47"

Backfill soil unit weight (w) = 120 lbs/ cu. Ft.; Ku' = 0.130

Project #2, Mission Clay Products clay mine, Corona CA: 24-inch VCP was installed in an open trench at the Corona mine with a cover of 10-feet. Additional fill was placed over the backfilled trench for a total of 25-feet of cover. The primary purpose of this project was to compare the load on the pipe installed in CLSM at trench widths of 40-, 60- and 90-inch. A secondary purpose was to compare a Class B bedding to verify a comparative load factor.

The objective of comparing different trench widths for load on the pipe indicated that the trench width is not a significant factor for determining load when CLSM bedding is utilized in the sidefills. Marston considers trench width a significant factor for all bedding types when determining loads on the pipe.

Table 2 – Data Collection from the Corona Mine

24 inch VCP – Mission Clay Mine, Corona CA (2002)			
Average Load Calculations, 40", 60", 90 inch trench widths			
Trench width (inches)	40	60	90
Pipe Load Received from Strain, LR (lbs/ LF)	2840	2340	2640

LR = Load received in lbs./ LF

Depth of Cover (H)= 25.0 Ft.; Trench Width (B_d)= 40, 60, or 90"; Pipe OD (B_c)= 30"

Backfill soil unit weight (w) = 128 lbs/ cu. Ft.; $K_u^2 = 0.130$

The data suggests that the loads received on the pipe are quite low and the CLSM sidefills neutralized the effect of trench width.

Project #3, Laboratory load width plate testing: This testing was performed on 8-inch diameter pipe, 12-inches long, which were instrumented with strain gauges and installed in a steel box test cell. The box was 12-inches long (the direction of the pipe length), 34-inches wide (width of the widest load plate) and 26-inches deep. The pipe was placed on 8-inch deep crushed stone. CLSM was placed the full width of the box to the top of the pipe. Four-inches of dry sand was placed over the pipe to uniformly distribute the load being applied.

Four different widths of steel load plates were placed over the pipe/CLSM/sand and loaded by a hydraulic overhead test machine. The plates were 10-, 18-, 26- and 34-inches wide to simulate variable trench width.

The Load Applied readings were made directly from the bearing machine that was loading the various width plates. For each pipe, the Load Received measurement was made by converting the strain readings from the calibration curve. The load on the plates proceeded in the order of 34-, 26-, 18- and 10-inch. The load on each plate was terminated before structural failure of the pipe with the exception of the 10-inch test, which was continued through pipe destruction.

Values for the 34-inch wide plate are disregarded since the initial pipe strain readings went negative under load. The likely explanation for these negative readings is (1) the CLSM had not attained sufficient set prior to loading, and (2) the loading plate dimensions equaled the dimensions of the test cell. This combined condition would result in lateral compressive pressure on the pipe causing negative readings.

Load tests were performed on 4 separate pipe sections using the four plates of different widths. Reliable data could only be used from two of the tests. Pipe 4C and 1C were evaluated.



Figure 4 – Steel CLSM Test Cell



Figure 5 – Loading Plates



Figure 6 – 8-inch VCP Instrumented with a Strain Gage



Figure 7 – 8-inch VCP Test Pipe Installed in the Test Cell

Figures 4 – 7 show the test cell, loading plates, instrumented pipe and installed pipe. Identification and eventual control of the numerous variables resulted in the production of consistent data. The data indicates that when the same unit pressure is applied to the loading plates having different widths, the strain in the pipe is essentially the same.

Since the strain in the pipe was generally unaffected by the different plate widths (see Figures 8 and 9), it can be postulated that the influence of trench width was neutralized.

This was one of the key objectives of the research which in theory stated that when CLSM is used as bedding material to the top of the pipe, the influence of trench width may be nullified. This would result in the same backfill load on the pipe regardless of the width of the trench.

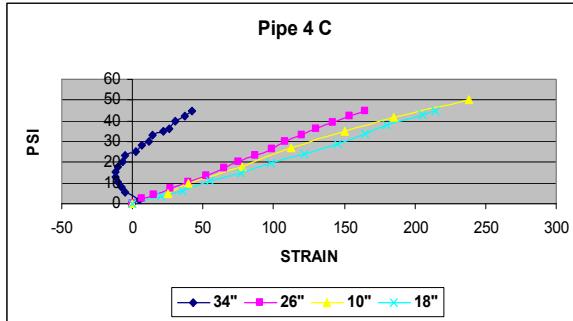


Figure 8 – 16 Hour CLSM Test

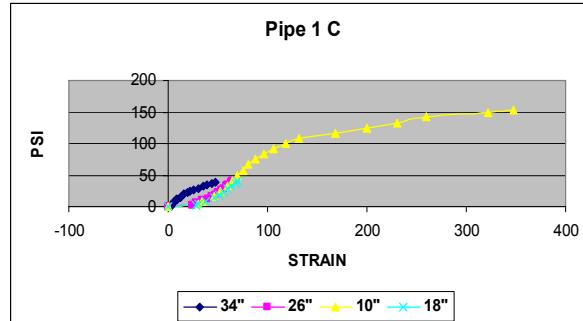


Figure 9 – 7-Day CLSM Test

These tests demonstrated that regardless of the width of the loading plate at the surface of the test cell, the same unit load yielded the same strain in the pipe. The total applied load increased as the width of the loading plate increased but the pipe did not receive a corresponding increase in strain.

Meta Analysis

Table 3 – Strain/ Load Data from the three projects used for Meta-Analysis Plot

META-ANALYSIS				
Experiment	Trench Width (inches)	Actual Load Received (lbs/ LF)	Load Applied $W_c = C_d w B_d 2$ (lbs/ LF)	Load Applied $W_c = C_d w B_d 2 \times (B_c / B_d)$ (lbs/ LF)
Laboratory Plate	10	2140	6000*	6000*
Laboratory Plate	18	1900	9720*	9720*
Laboratory Plate	26	1490	14040*	14040*
Corona Mine	40	2840	4690	3520
Corona Mine	60	2340	8640	4320
Corona Mine	90	2640	15770	5260
Agua Mansa (11 days)	72	1950	7900	5160

*Load Applied measured by calibrated hydraulic gauge

A Meta-Analysis was performed on the data collected from the three projects in an effort to determine similarities from the actual load received by the pipe and the calculated load applied options. The trench widths of 10-, 18- and 26-inches were taken as the trench width from the laboratory plate testing (loading plate dimensions). The trench widths of

40-, 60- and 90-inches were taken from the Corona Mine project and the 72-inch trench width was taken from the Riverside project (See table 3 above).

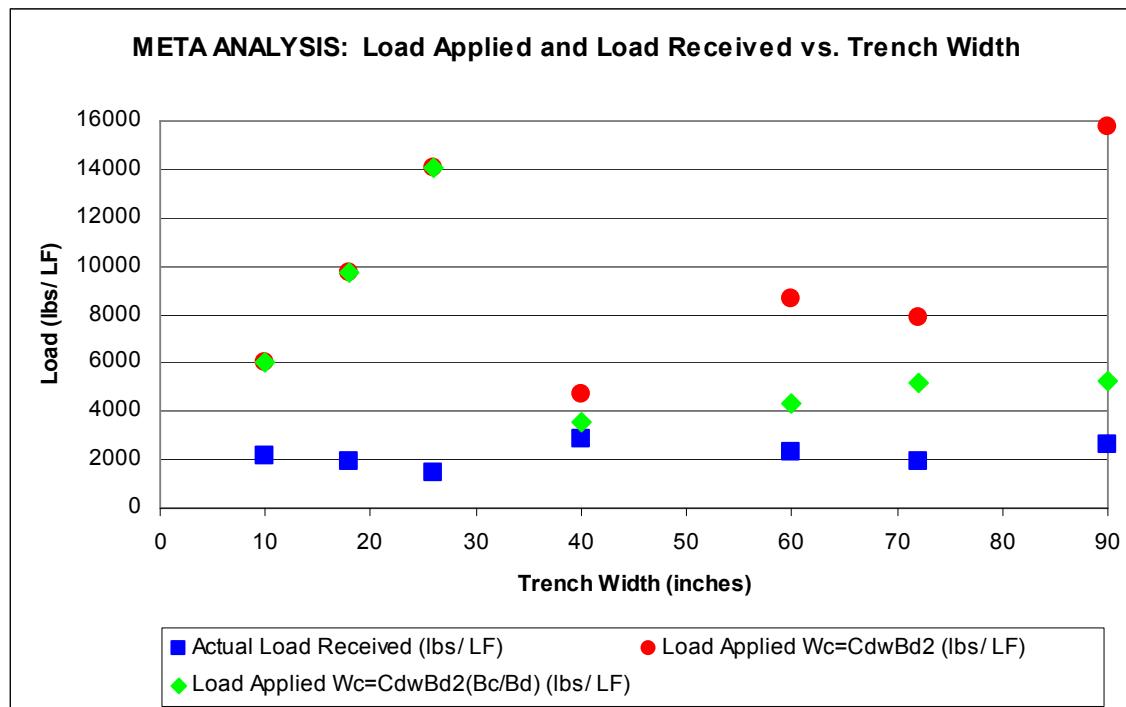


Figure 10 – Load Applied and Load Received vs. Trench Width

Data from the three experiments are shown in Figure 10. The actual Load Received (from calibrated strain gauges) is shown in blue (squares), and is essentially linear or invariant to trench width. The Load Applied calculated values for Marston (B_d^2) shown in green (diamonds) and Modified Marston (B_c/B_d) shown in red (circles) were plotted versus the trench widths. As the standard Marston (B_d^2) equation predicts a non-linear response to trench width, the data set for actual load received matches the Modified Marston calculated values far better than it does the conventional Marston calculated values. The experimental data thus confirms the appropriateness of Spangler's hypothesis in this application. If the material at the sides of the pipe keeps its shape, as does CLSM when properly set, it must also support a proportionate share of the backfill load.

RESULTS AND DISCUSSION

Marston factored the consolidation of the soil prism along both sides of the pipe as inducing load on the rigid pipe dependent upon the soil type, soil weight and trench width. Arching or inverted arching of the prism of soil directly above the pipe via shear of the exterior soil prisms above the sidefills is an inherent principle in the Marston theory.

When CLSM bedding is utilized in place of a granular material there is no side settlement of soil on each side of the pipe to induce additional prism load. The data collected from

these project reports shows that the CLSM sidefills support a portion of the load from the soil prism directly above the rigid pipe as well as the adjacent prisms.

Using either the conventional Marston rigid pipe equation or the Modified Marston equation to calculate the predicted load on a pipe installed using CLSM does not result in the actual load observed, both calculations being too conservative. The conventional Marston equation, however, is far too conservative and fails to accurately model the shape of the data's response to trench width. While still on the conservative side, Spangler's modification of the Marston equation provides a more accurate calculation for determining load for VCP bedded with CLSM sidefills.

Simply using the prism load ($B_c w H$) may seem applicable when using a rigid pipe and ‘rigid’ CLSM sidefills since, in theory, prism shear should not occur, but the data collection and analysis proves otherwise. In the 20+ years of VCP installations utilizing CLSM sidefills, the typical diameter range has been 24 inch and larger at cover depths over 20 ft. At these depths and diameters, the calculated prism load is greater than the conventional Marston (at a trench width = $B_c + 24$ inches) and is therefore inappropriate.

CLSM BEDDING SYSTEM CONSIDERATIONS AND INSTALLATION

Significant findings over the course of this research that are specific to CLSM installations include: a variable load/ bedding factor dependent on mix set time, optimization of mix designs, nullification of pipe flotation concerns, best practices for installation and placement, applicable field testing methods, and commencement of backfill. A few of these findings are discussed below; see the NCPI referenced documents for more detailed information.

Optimal mix design. This research demonstrates that the load factor for CLSM is dependent on the mix being set. CLSM as a bedding material for clay pipe provides the necessary circumferential support for the pipe to obtain a 2.8 load factor or higher. Common mix designs incorporate high amounts of both fly ash and water to achieve the needed flowability required for haunch support, but both of these components retard set time. In most cases on projects utilizing a CLSM bedding system, it is desirable for the mix to cure rapidly to facilitate initial backfilling at the earliest possible time. The CLSM mix design below contains an accelerator, an air entraining agent to reduce water needed, and zero fly ash. This design provides a rapid set time without sacrificing flowability or ultimate compressive strength:

Cement: _____ 188 pounds (Type I/II or II/V)

Fine aggregate: _____ 75% - 80% (by weight)

Coarse aggregate (3/8"): _____ 20% - 25% (by weight)

Water: _____ water necessary to meet flowability requirement

Accelerator: _____ 4% (as a percent of cement)

Air Entrainment: _____ 15%-20%

Flowability: _____ 8-inch +/- 1-inch spread diameter

(3-inch diameter by 6-inch long cylinder, ASTM D 6103)

Compressive strength: _____ 100-300 psi at 28 days

Flotation during placement. No field installations using CLSM have resulted in flotation of clay pipe. However, buoyancy calculations done using the Archimedes' Principle (that a body wholly or partly immersed in a fluid is buoyed up with a force equal to the weight of the fluid displaced by the body) indicate that the pipe should have floated. Further research to date supports the theory that clay pipe does not float because CLSM acts as a Bingham fluid. A Bingham fluid, also known as a Bingham plastic, is a viscoplastic material that resists movement at low values of shear stress in the fluid. Buoyancy forces generate shear stress in the CLSM. If the stress applied by the buoyant force does not exceed the shear yield stress of the CLSM, the pipe will not float.

Backfill commencement and set time. Measuring the penetration resistance using a penetrometer is a simple method for determining when the mix has set and backfill can commence. Penetrometer readings can be taken in the CLSM alongside the pipe. If it is not practical to use the penetrometer in the trench, CLSM may be collected in a cardboard box of approximately 12- x 12- x 9-inches for each 30-minute interval of pour and penetrometer measurements made from this accessible location. A 500-psi minimum reading is needed prior to backfill using a penetrometer with a 1-square inch by 1-inch long cylinder foot attached to the $\frac{1}{4}$ -inch diameter pin. The load readings on the penetrometer are penetration resistance and should not be confused with the compressive strength of the CLSM as measured by the standard concrete cylinder test.

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