# Engineering Properties and Economics of Soil Cement Feedyard Surfacing

D. B. Parker, J. E. Mehlhorn, M. S. Brown, S. C. Bressler

**Abstract.** *Hard surfacing is being evaluated by open−lot beef cattle feedyard owners as a means to increase animal performance and improve manure quality. Soil cement, a compacted mixture of soil and Portland cement, has been used successfully for surfacing roads and airports. In this research, the engineering properties of soil cement and associated economics were evaluated using Amarillo fine sandy loam, one of the most common granular soils in the Texas Panhandle region. Soil cement specimens were prepared in compaction molds to determine the optimum moisture content and cement content for compaction. Specimens were subjected to simulated field conditions including exposure to manure for nine months. Specimens were then subjected to a series of tests: unconfined compressive strength, freezing−thawing, and wetting−drying. Unconfined compressive strength of soil cement increased linearly with cement content between 5% and 20% ($R^2$ = 0.99). At a cement content of 7.5%, the specimens disintegrated when exposed to field conditions for nine months, while the specimens at 15% cement remained intact. Exposure to manure for nine months did not affect unconfined compressive strength or mass lost during freezing−thawing and wetting−drying. The estimated total cost for installing a 15 cm thick soil cement surface was $582 per 100 $m^2$. The annual breakeven cost at a discount rate of 8% and payback period of five years was $146 per 100 $m^2$. Potential annual feed conversion benefits of $330 per 100 $m^2$ were estimated based on previous research, leaving soil cement an economically feasible option for further research and application.*

***Keywords.*** *Concrete, Earthen, Feedlot, Feedyard, Fly ash, Manure, Soil cement, Surface.*

Open−lot beef cattle feedyards in the Southern High Plains have traditionally been constructed with earthen surfaces except for the apron feed bunk and water trough, which are constructed of concrete. The primary reasons for using earthen pen surfaces are low cost and ease of construction compared to hard−surfaced pens. A major problem with earthen pens is that they often become muddy during high precipitation. As a result, animal health and performance may suffer, and manure management becomes a problem.

Manure deposited in open−lot feedyards is typically removed every 6 to 12 months by scraping the compacted manure from the soil surface with a front−end loader or box scraper. The manure is usually applied to cropland as a nutrient source. Taking care to remove only the manure pack and not the subsurface soil increases the manure value, decreases manure handling costs, and decreases pen surface construction repair costs.

There are several potential advantages to using hard−surfaced pens in open−lot feedyards. Manure is more easily removed from a hard surface while limiting the removal of subsoil. Hard−surfaced pens drain faster and are less prone to muddy conditions, which can cause wasted energy by cattle. Because hard−surfaced pens drain faster, significant odor events are less likely and less frequent. Manure scraped from a hard−surfaced pen has a lower ash content (i.e., soil) than manure scraped from an earthen−surfaced pen, making the manure more valuable to the farmer.

There are also some potential disadvantages with hard−surfaced pens. The most obvious is high capital construction costs, but there may also be concern with adverse effects on cattle hooves and legs. Hard surfacing and rough concrete have been implicated as potential factors affecting lameness in dairy cattle (Vokey, 2001; Stefanowska, 2001). However, hoof concerns should be less of an issue with open−lot beef cattle for two reasons. First, feedlot cattle spend only a few months in the feedlot, compared to multiple years for dairy cattle. The second and primary reason hard surfaces should not be a problem with open−lot feedlots is that there is a buildup of manure on the hard surface after a short time. In dairies, the manure is removed daily by flushing or scraping, but in open−lot feedyards the manure typically remains on the surface for 6 to 12 months. In a matter of a few days, the manure deposited on the hard surface creates a cushion similar to that of earthen−surfaced pens.

There are several alternatives for construction of hard feedlot surfaces: concrete, coal combustion byproducts, and soil cement. The first two have been used successfully in animal feeding operations. Concrete is commonly used as a surfacing medium in dairy operations, but it is too expensive to use in a large beef cattle feedyard. Coal combustion products, i.e., fly ash, hopper ash, flue gas desulfurization (FGD) material, and fluidized bed combustor (FBC) ash,

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have also been used in limited instances as feedlot surfacing materials. Fly ash, hopper ash, and FGD material have cementing properties and are used alone. FBC ash must be mixed with montmorillonitic clays to obtain the desired cementing properties (Greenlees et al., 1998).

In an unreplicated study, Amosson (1997) investigated the use of fly ash and hopper ash as surfacing materials in a commercial feedyard in the Texas Panhandle. Amosson found that fly ash was an adequate surfacing material, requiring no repairs over the two−year research period, but hopper ash required many repairs and was non−economical. Amosson determined that average daily gain was slightly better on the fly ash−surfaced pens (1.22 kg/d, 2.70 lb/d) as compared to the earthen−surfaced pens (1.12 kg/d, 2.47 lb/d). Amosson reported costs for a 15 cm thick fly ash pen surface of \$8.28/m$^2$.

In another experiment in the Texas Panhandle, Chirase et al. (1999) compared animal performance between fly ash−surfaced pens and traditional earthen−surfaced pens. Chirase found no statistical differences in animal performance between the two pen surface types, but other parameters such as feeding delivery methods and pen size may have confounded the results.

Dairies in Pennsylvania and California have been successfully paved with fly ash. Initial results suggest that cows kept on fly ash surfaces have less viral hoof infections and mastitis than cows on earthen surfaces (Suszkiw, 1999).

FGD material has been approved by the Ohio Environmental Protection Agency for use as a hard feedlot surface (Butalia and Wolfe, 1998). The FGD material can be obtained at no cost in Ohio. Costs for FGD were 65% less than the costs for concrete surfacing (Butalia and Wolfe, 1998).

Greenlees et al. (1998) compared a feedyard pen stabilized with FBC ash to a pen constructed with an earthen surface. The FBC ash was mixed with low−plasticity clay (CL), which was imported to the feedyard. Greenlees concluded that the soil stabilized with FBC ash was stronger than untreated soil, and the cost was one−tenth that of concrete paving.

Soil cement is a mixture of soil and measured amounts of Portland cement and water compacted to a high density (Adaska, 1990). Granular soils are preferred because they pulverize and mix more easily and require less cement than fine−grained soils. Cement concentrations range from 4% to 16% by dry weight of soil (Adaska, 1990). Mixture compaction and moisture content have a significant effect on soil cement strength. Soil cement is usually constructed at near−optimum moisture content and maximum dry density as defined by ASTM Test Method D 558 (ASTM, 1996a). Unconfined compressive strength is the most widely referenced property of soil cement (Adaska, 1990). Typical ranges of 28−day unconfined compressive strengths are 2750 to 6900 kPa (400 to 1000 psi) for sandy and gravelly soils, 2050 to 6200 kPa (300 to 900 psi) for silty soils, and 1700 to 4150 kPa (250 to 600 psi) for clayey soils (Adaska, 1990).

Soil cement has a variety of construction uses. It has been used successfully for road and airport stabilization projects (Adaska, 1990; PCA, 2002), for water−resource projects such as dam faces and pond liners (Hansen, 1991; Casias, 1991; PCA, 2002), for foundation stabilization under large structures (Adaska, 1990), and for wall systems in residential housing (i.e., rammed earth). However, soil cement has been used sparingly in animal feeding operations.

In this research, we evaluated the engineering properties and economics of constructing a feedyard surface using soil cement prepared with a regional soil source and Type I Portland cement. The objectives of this research were to:

- Determine how cement content and water content affect the unconfined compressive strength of soil cement.
- Determine how weathering and manure exposure affect the durability and unconfined compressive strength of soil cement.
- Determine the economic feasibility of surfacing a feedyard with soil cement.

## Materials and Methods

Amarillo fine sandy loam (fine−loamy, mixed, thermic Aridic Paleustalfs) was collected approximately 10 km east of Canyon, Texas. It is one of the most common granular surface soils in the region (NRCS, 1970). The soil profile at this particular location grades coarser with depth. Because coarser soils are better for soil cement, the soil used in the experiments was collected from a depth of 15 to 90 cm. This soil was classified as sandy loam per the USDA textural classification. The soil had 23.7%, 75.1%, 90.3%, and 98.5% passing No. 200, 100, 60, and 40 sieves, respectively. The soil had 79.4% sand, 18.5% silt, and 2.1% clay per the USDA classification. The soil was nonplastic per plastic limit and liquid limit tests (ASTM, 1996c) and was classified as SM per the Unified Soil Classification System (USCS).

Soil cement specimens were prepared by mixing the appropriate amounts of Type I Portland cement, soil, and water. Cement content was calculated as the weight of cement per weight of oven dry soil (Adaska, 1990). The soil cement was compacted in a 944 cm$^3$ cylindrical metal mold (Proctor mold) of 10.2 cm diameter and 11.5 cm height. Soil cement was compacted in three layers, with each layer receiving 25 blows from a 2.49 kg rammer dropped from a height of 30 cm (ASTM, 1996a). The soil cement specimens were extruded from the cylinder using a hydraulic ram.

To determine the optimum moisture content for compaction of the soil cement mixture, specimens were prepared at a variety of moisture contents for cement contents of 0%, 5.0%, 7.5%, 10.0%, 12.5%, and 15.0% (table 1). Plots of moisture content vs. density (compaction curves) were used to graphically determine the optimum moisture content and maximum dry density at each cement content.

Four specimens were prepared at optimum moisture content for each of the cement contents (5.0%, 7.5%, 10.0%, 12.5%, 15.0%, and 20%) (table 2). These specimens were cured in the laboratory at 21°C (70°F) for 28 days, and then

**Table 1. Moisture−density characteristics of soil cement mixtures.**

| Cement Content (%) | Optimum MC[a] (%) | Maximum Dry Density (kg/m$^3$) | Dry Density at −3% of Optimum MC (kg/m$^3$) | Dry Density at +3% of Optimum MC (kg/m$^3$) |
|---|---|---|---|---|
| 0.0 | 10 | 1950 | 1840 | 1840 |
| 5.0 | 11 | 1940 | 1720 | 1810 |
| 7.5 | 10 | 1990 | 1800 | 1860 |
| 10.0 | 11 | 1910 | 1730 | 1790 |
| 12.5 | 10 | 1920 | 1760 | 1860 |
| 15.0 | 10 | 1920 | 1840 | 1810 |

[a] MC = moisture content.

Table 2. Unconfined 28−day compressive strengths of lab−cured soil cement specimens at six cement contents.

| Cement Content (%) | Unconfined Compressive Strength | |
|---|---|---|
| | Mean[a] (kPa) | Standard Deviation (kPa) |
| 5.0 | 2937 a | 386 |
| 7.5 | 4423 b | 374 |
| 10.0 | 5759 c | 377 |
| 12.5 | 7738 d | 548 |
| 15.0 | 9748 e | 382 |
| 20.0 | 12235 f | 1971 |

[a] Means with different letters are significantly different at $\alpha = 0.05$ (Tukey's test).

the unconfined compressive strength was measured per standard methods (ASTM, 1996b).

Additional soil cement specimens were prepared to evaluate effects of weathering and manure exposure on soil cement durability and strength. Forty−five specimens each were prepared at 7.5% and 15% cement content, all at optimum moisture content (10%). Fifteen of the specimens of each cement content were randomly assigned to each of three treatments. Specimens in the first treatment (TRT 1) were stored dry in the laboratory for nine months (August to May). Specimens from the second treatment (TRT 2) were placed outside in oversized plastic containers with drain holes in the bottom for nine months. Specimens from the third treatment (TRT 3) were placed adjacent to the TRT 2 specimens, in similar plastic containers, but were partially covered (bottom and sides) with freshly scraped manure from the feedyard surface. Enough water was added to the plastic containers weekly to saturate the manure and wet the specimens. Freshly scraped manure was added to the TRT 3 containers every month as the manure settled around the specimens.

After the nine month period, five specimens from each treatment and cement content were subjected to unconfined compression tests (ASTM, 1996b), wetting−drying tests (ASTM, 1996d), and freezing−thawing tests (ASTM, 1996e). For the wetting−drying tests, specimens were subjected to 12 cycles of alternate submersion in water for 5 h followed by oven−drying at 71°C for 42 h. For the freezing−thawing tests, specimens were subjected to 12 cycles of alternate placement in a freezer at −23°C for 24 h followed by a thawing period of 23 h at 21°C. For both the freezing−thawing and wetting−drying tests, specimens were brushed between cycles with a wire brush on the sides and both ends per ASTM methods (ASTM, 1996d, 1996e).

Statistical analyses included linear regression, analysis of variance, and multiple range tests using Tukey's honestly significant different (HSD) comparisons. Tukey's test sets the experiment−wise significance level at 0.05, not the comparison−wise significance level. Statistical analyses were performed using SPSS Version 7.0 software.

An economic analysis was performed to implement a soil cement surface for feedyards, including material cost, labor, and equipment expense. Maintenance expense and surface life were not included in the economic analysis. Cost estimates for developing a soil cement feedyard surface were estimated based on using 15% cement mixed with local fill with a total surface thickness of 15 cm. Cost estimates were based on construction of 45.7 × 30.5 m pens, which is a common 100−head capacity pen used in commercial feedyards in the area. Equipment needs were based on recommendations from the *Soil Cement Construction Handbook* (PCA, 1995). Heavy equipment identified for construction included a grader, rotary tiller, water truck, pad roller, and steel wheel roller. Cost data was compiled based on equipment rates and costs from the *Rental Rate Blue Book* (Primedia, 1999). Once construction cost estimates were found, investment needs and discounted breakeven costs were calculated to determine the economic feasibility. Three discount rates (6%, 8%, and 10%) were used to calculate breakeven costs for pen construction. Payback periods were 2, 3, 4, and 5 years. Several different years were used due to the lack of long−term information available as to expected useful life of the soil cement surface.

## Results and Discussion

Moisture−density characteristics for the soil cement mixtures at different cement contents are presented in table 1. Maximum dry density ranged from 1,910 to 1,990 kg/m$^3$ (119 to 124 pcf). Optimum moisture content varied little as the cement content increased, which indicates that optimum compaction can be obtained at a moisture content of 10% regardless of cement content.

As expected, cement content had a significant effect on 28−day unconfined compressive strength (table 2). Unconfined compressive strength more than tripled from 5.0% to 20.0% cement content. The relationship between unconfined compressive strength and cement content was linear ($R^2$ = 0.99) (fig. 1). At the 15% cement content, the unconfined compressive strength was about half that of typical 20,680 kPa (3,000 psi) concrete. For comparison, the typical unconfined compressive strength of concrete is 13,790 to 41,370 kPa (2,000 to 6,000 psi) (Lindeburg, 1989).

After specimens were held for nine months, the mean unconfined compressive strength of the specimens stored in the laboratory was 4,739 kPa, as compared to 7,922 kPa for specimens stored outside exposed to water only (TRT 2) and 8,028 kPa for specimens exposed to manure and water (TRT 3) (table 3). The unconfined compressive strength of the nine−month laboratory samples was 4,739 kPa (table 3) compared to 9,748 kPa for the 28−day breaks (table 2). The

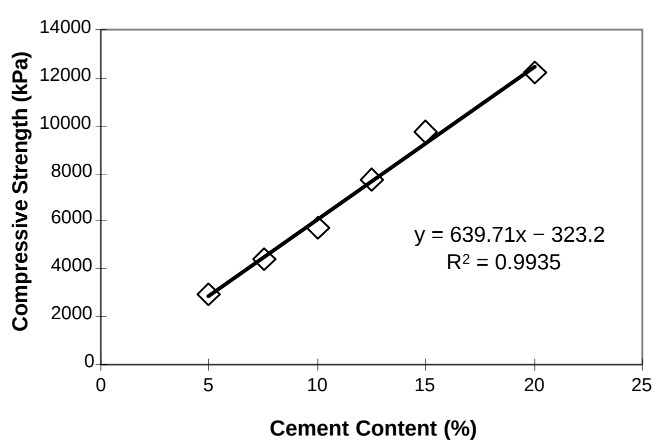


**Figure 1. Variation of unconfined compressive strength with cement content of soil−cement specimens compacted at the optimum moisture content of 10%. Data points represent averages of four specimens at each moisture content.**

**Table 3. Characteristics of soil cement specimens exposed to three treatments at cement contents of 7.5% and 15.0%.**

| | Mean Specimen Mass[a] | | Unconfined Compressive Strength | |
|---|---|---|---|---|
| | Initial (kg) | Final (kg) | Mean (kPa)[b] | SD (kPa) |
| 15.0% Cement Content | | | | |
| TRT 1: Stored in lab for nine months | 1.86 f | 1.78 cd | 4739 a | 1543 |
| TRT 2: Exposed to weather for nine months | 1.87 f | 1.78 de | 7922 b | 1793 |
| TRT 3: Exposed to weather/manure for nine months | 1.86 ef | 1.84 def | 8028 b | 2107 |
| 7.5% Cement Content | | | | |
| TRT 1: Stored in lab for nine months | 1.77 cd | 1.70 c | 2648 a | 657 |
| TRT 2: Exposed to weather for nine months | 1.77 cd | 1.45 a | NA[c] | NA |
| TRT 3: Exposed to weather/manure for nine months | 1.80 def | 1.55 b | NA | NA |

[a] Mean initial and final specimen masses with different letters are significantly different at $\alpha = 0.05$ (Tukey's test).
[b] Mean unconfined compressive strengths with different letters are significantly different at $\alpha = 0.05$ (Tukey's test).
[c] NA = not analyzed; samples disintegrated after nine months in the field.

unconfined compressive strengths of the TRT 2 and TRT 3 samples (table 3) compared favorably with the 28−day breaks (table 2); however, the cause of the lower shear strength in the nine−month laboratory samples is unknown.

At the 15% cement content, those specimens exposed to field conditions (TRT 2 and TRT 3) exhibited 0.05 to 0.06 kg mass lost per specimen for the wetting−drying test and about 0.10 kg mass lost per specimen for the freezing−thawing test (table 4). The mass lost from the specimens stored in the laboratory was significantly less (0.01 to 0.02 kg per specimen) than in the field, which indicates that exposure to field conditions accelerated the weathering of the soil cement. There were no significant differences between mean mass lost for TRT 2 and TRT 3, indicating that exposure to manure did not cause a difference in soil cement weathering.

All of the 7.5% cement specimens disintegrated after being exposed to the elements for the nine−month period. Therefore, wetting−drying and freezing−thawing tests could not be conducted on those specimens. This indicates that 7.5% cement is not enough for use as a feedyard surface with this soil. The 7.5% cement cylinders left in the laboratory for nine months had a mean compressive strength of 2,648 kPa (table 3), which is considerably lower than the 28−day compressive strength of 4,423 kPa (table 2). The exact cause of the lower strengths is unknown. Although the soil collected for the soil cement specimens in tables 2 and 3 was collected from within a 3 m area for both, the soil was collected at different times, so it is possible that soil variation could have been a factor in the variability in compressive strengths.

Greenlees et al. (1998) cited a required soil bearing pressure of 136 kPa (20 psi) for a typical 680 kg beef animal, corresponding to an unconfined compressive strength of 36 kPa. Greenlees et al. also stated that an animal in motion would require about twice that strength, or 72 kPa unconfined compressive strength. As soil increases in moisture content, its shear strength decreases correspondingly until eventually the soil is too soft to support the animal, and the animal sinks in the mud. At the 15% cement content, the unconfined compressive strengths of the soil cement were more than adequate for supporting animals.

Of more importance to the adequacy of a pen surface is the capability to withstand loading from heavy equipment. Manure is removed from open−lot feedyards about every six months using wheeled front−end loaders (e.g., Caterpillar 950G, Case 821C, John Deere 624G, and equivalent sizes), which have operating weights as much as 17,200 kg (38,000 lbs) and tire pressures of approximately 517 kPa (75 psi). At the 15% cement content, the unconfined compressive strengths of the soil cement were 4,739 to 9,748 kPa, which is considerably greater than the pressures exerted by the heavy equipment.

## Economics

Material costs for constructing the 45.7 × 30.5 m pens were estimated to be $4.76/m$^2$, with labor/equipment costs of $1.06/m$^2$. For a soil cement thickness of 15 cm, the total construction cost was estimated at $5.82/m$^2$, which is considerably less than costs for fly ash ($8.28/m$^2$) and concrete ($29.90/m$^2$). These preliminary estimates indicate that using soil cement pen surfacing will cost approximately $8,110 per pen.

At a payback period of 5 years and discount rate of 8%, the breakeven cost is $146 per 100 m$^2$ per year, or $2,031 per pen. Annual discounted breakeven costs per 100 m$^2$ of pen surface for discount rates of 6%, 8%, and 10% and payback periods of 2, 3, 4, and 5 years are shown in table 5.

Amosson (1997) reported a 9% increase in average daily gain for beef cattle on fly ash−surfaced pens compared to earthen−surfaced pens. However, because the difference was not statistically significant, the applicability of this number to economic projections is inappropriate at this time. The

**Table 4. Results of extreme−condition tests on soil cement specimens at 15% cement content, showing mass of specimen lost during wetting−drying and freezing−thawing tests.**

| | Wetting−Drying Test | | | Freezing−Thawing Test | | |
|---|---|---|---|---|---|---|
| Treatment | Initial Mass (kg) | Mean[a] Mass Lost (kg) | SD Mass Lost | Initial Mass (kg) | Mean[a] Mass Lost (kg) | SD Mass Lost |
| TRT 1: Stored in dry lab for nine months | 1.80 | 0.01 a | 0.004 | 1.78 | 0.02 a | 0.013 |
| TRT 2: Exposed to weather for nine months | 1.78 | 0.06 b | 0.020 | 1.74 | 0.10 a | 0.036 |
| TRT 3: Exposed to weather/manure for nine months | 1.81 | 0.05 b | 0.005 | 1.82 | 0.10 a | 0.112 |

[a] Means with different letters within a single column are significantly different at $\alpha = 0.05$ (Tukey's test).

National Research Council (1981) suggests that feedlot cattle housed in pens with 10 to 20 cm of mud would require between 5% and 15% more feed per unit of gain than cattle housed in pens with a dry surface. However, a hard−surfaced pen would be expected to accommodate a greater density of animals compared to traditional soil surface feedlot pens. Although few data are available, studies by Prawl et al. (1998) suggest that the combined effects of increased animal density, a cement pen surface, and partial shelter can decrease feed required per unit of gain by approximately 18%. Assuming diet costs of \$0.11/kg for dry matter, a 150−day feeding period, 9.5 kg/d dry matter intake (DMI) on earthen−surfaced pens, 8.1 kg/d DMI on hard−surfaced pens (15% lower DMI), a stocking rate of 7.2 animals per 100 $m^2$, two cattle turns per year, no independent effect of partial shelter, and similar average daily gains for soil cement and hard surfacing, then potential returns of about \$23 per animal fed, or \$330 per 100 $m^2$ per year, are projected from improved animal performance. This potential benefit greatly exceeds the 5−year breakeven cost of \$146 per 100 $m^2$; thus, it appears that hard−surfaced pens could have an application in beef cattle feedlots. Actual economic advantage of hard−surfaced pens will depend on savings in maintenance, construction costs, surface life, manure quality, and hidden marketing advantages.

## CONCLUSIONS

The following conclusions were drawn from this research:

- The optimum moisture content to achieve maximum dry density during compaction was 10% and varied little with cement content. A linear relationship was observed between unconfined compressive strength and cement content. The unconfined compressive strength of the soil cement with 15% cement content was about 9,700 kPa, which compares to 20,000 kPa (3,000 psi) for typical concrete slabs.
- Soil cement specimens with 7.5% cement content weathered excessively when exposed for nine months, while those with 15% cement content withstood weathering. Specimens exposed to manure weathered the same as those not exposed to manure. A cement content of 15% is recommended when preparing soil cement using this soil.
- The total cost for installing a 15 cm thick soil cement surface was estimated to be \$5.82/$m^2$, which compares favorably to costs for fly ash surfacing (\$8.28/$m^2$) and concrete (\$29.90/$m^2$). Potential returns from increased animal performance appear to outweigh costs of building hard−surfaced pens; however, benefits in animal performance, pen maintenance, and manure quality should be verified through future field studies.

**Table 5. Annual discounted breakeven costs per 100 $m^2$ of soil cement feedyard surface.**

| Discount Rate | Initial Cost | Payback Period | | | |
|---|---|---|---|---|---|
| | | 2 Years | 3 Years | 4 Years | 5 Years |
| 6% | \$582 | \$317 | \$218 | \$168 | \$138 |
| 8% | \$582 | \$326 | \$226 | \$176 | \$146 |
| 10% | \$582 | \$335 | \$234 | \$184 | \$153 |

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