UESI Pipelines 2025 Conference
Tampa, Florida | August 9–13, 2025
2025

Soil Migration and Buried Pipe

Amster Howard, M. ASCE[1] and Jeff Boschert, P.E., F. ASCE[2]

[1] Consultant, Lakewood, CO 80228; PH 303-949-5512; amsterhoward@comcast.net
[2] National Clay Pipe Institute, President; Chesterfield, MO 63017; PH (314) 229- 3789; jboschert@ncpi.org

ABSTRACT

Soil migration can create a problem for some buried pipelines. Migration is the movement of small soil particles into the voids of adjacent soils (i.e. crushed rock) that have large openings between particles. The particle movement is precipitated by gravity or the movement of water.

If there is enough fine-grained particles moving into these void spaces, the behavior of the larger particles can be affected. In the first part of a study conducted by the National Clay Pipe Institute (NCPI) in 2023, the soil migration changed the pipe embedment material from Class I to Class III (ASTM C12), which reduced the support for the pipe. Pipe movement and/ or loss of embedment support after installation can be an issue or even lead to a failure for either rigid or flexible pipe products. The study was continued in 2024 to expand on some of the test conditions.

The 2023 tests examined various combinations of fine-grained soils and cohesionless free draining crushed rock. A vitrified clay pipe (VCP) was laid on the surface of the crushed rock/ fine-grained soils in a wooden test box, the pipe loaded, and the pipe settlement measured. The load apparatus was a set up for conducting 3-edge bearing tests on VCP.

Conclusions from that study showed little effect from clean water or dirty water, an effective difference between uncompacted and compacted bedding, a significant difference using geofabric separator between soil and rock, and meaningful results for soil migration. The results were useful in evaluating physical testing equipment and procedures for future tests.

The 2024 study used a larger pipe, a larger steel soil box, better instrumentation, and used a confining pressure on top of the side fill soils to simulate the effect of backfill loading. The study also looked at using a geogrid, rather than a geofabric, as a separator between the soil and the crushed rock.

The second phase showed confining pressure on the bedding beside the VCP in the soil box reduced settlement and the first phase results should be tempered by that. The second phase tests also showed that adding about 20% soil to the crushed rock increased the pipe settlement about 20%, adding about 40% soil to the crushed rock increased the pipe settlement about 200%, that uncompacted bedding settled about 20% more than compacted bedding, and geotextile separators helped on compacted soil but not on uncompacted soil.

INTRODUCTION

Soil migration can create a problem for some buried pipelines, and some failures have been attributed to migration. As illustrated in Figure 1, migration is the movement of small soil particles into the voids of adjacent soils (i.e. crushed rock) that have large openings between particles. The particle movement is precipitated by gravity or the movement of water. If there is enough fine-grained particles moving into these void spaces, the behavior of the larger particles can be affected.

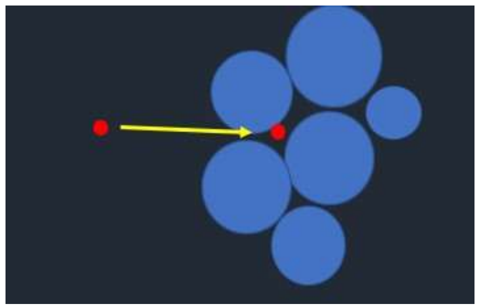

Figure 1: Fine Soil Particles Working into Voids of Adjacent Coarser Soil Particles

The National Clay Pipe Institute (NCPI) instigated a program in 2023 to evaluate the effect of migration on the soil support for buried pipe, specifically for vitrified clay pipe (VCP). However, the results would be applicable to all types of pipe materials. The 2023 tests were useful in pointing to trends, so a follow-up test program was conducted in 2024 with a larger pipe, larger soil container, and better instrumentation.

When coarse, open-graded material is placed as a bedding and/or embedment adjacent to a finer material, the finer material may move into the voids in the coarser material due to groundwater flow or gravity. For buried pipelines, migration of fine soil particles from the backfill, trench walls, and/or foundation into coarse bedding and embedment material may lead to less support for the pipe. Significant water flow may occur in pipeline trenches during construction when water levels fluctuate due to various dewatering activities. After construction, permeable underdrains or embedment materials may act as a French drain affecting groundwater levels and flow. Field experience has shown that migration may result in significant loss of pipe support and may contribute to flexible pipe deflections that may exceed design limits (Selig and McGrath 1994). For example, in Figure 2 if the *replaced foundation* material is a uniformly graded crushed rock and if the bedding and embedment soil is a clean sand, the sand could migrate by settling into the voids in the crushed rock, especially if water were trickling down through the embedment. An example of a uniformly graded crushed rock would be one where all particles are in the 3/4- to 1-1/2-inch *(19- to 37.5-mm)* size range. The loss of bedding and embedment material would reduce the support for the pipe. In similar fashion, if the *embedment* were a uniformly graded crushed rock, the fines and sand particles in the backfill could work their way down into the crushed rock voids. The side support for a flexible pipe (or the haunch support for a rigid pipe) would then be reduced from that of a clean, coarse-grained soil to a coarse-grained soil with fines. This reduces the embedment stiffness (pipe support) by half.

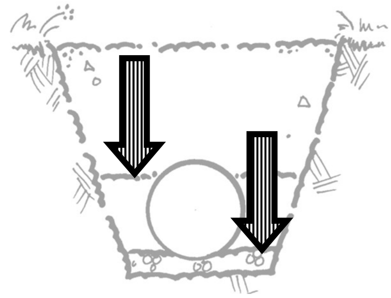

Figure 2: Vertical Migration of Soils (Howard 2015)

In the case illustrated in Figure 3, the fines from the trench walls could migrate into the voids of a clean, coarse-graded soil embedment changing the support characteristics of the embedment. The creation of large voids in the trench walls could also reduce the pipe support.

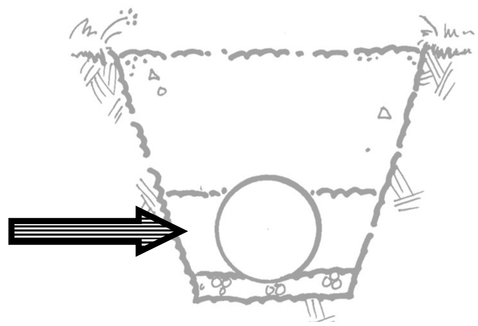

Figure 3: Horizontal Migration (Howard 2015)

Figures 4 and 5 illustrate the reality of migration of fines (Howard 2015). Clean, washed, crushed rock was used as an envelope around a pipe without a geotextile fabric wrap. Rainwater trickling down through the backfill carried the backfill fines into the crushed rock. Figure 4 shows the clean crushed rock before installation and Figure 5 shows the crushed rock after migration. Note in the later photo that each rock particle is coated with fines.

Figure 4: Clean Crushed Rock Before Installation

Figure 5: Crushed Rock After Migration of Backfill Soil

CASE HISTORIES

The following photographs are from projects where migration was found to be a problem.

Figure 6: Photographs of Various Installations Where Finer Soil has Migrated into Coarse Soil

REMEDIES FOR MIGRATION

When using open graded coarse soil particles in pipeline construction, migration may be controlled two different ways, using geotextiles or graded filters.

A graded geotechnical filter uses various soils ranging in gradation and permeability to prevent one material from migrating into another. The term *graded filter* means that the particle size distributions of the bedding, embedment, backfill, and adjacent materials must be compatible to minimize particle movement. Graded filters are commonly used in earth dams to control the water flow through the dam. An illustration of how a graded filter could be adapted for pipeline installation is shown in Figure 7.

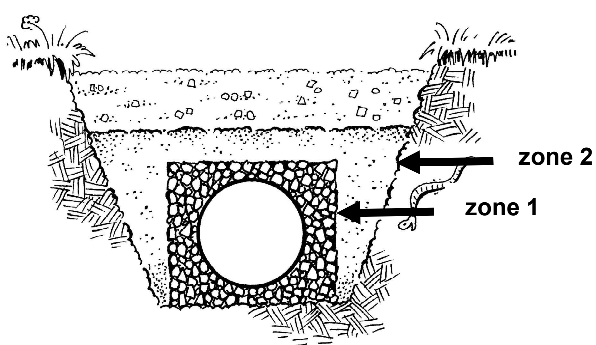

Figure 7: Zoned Filter Embedment

The gradation (particle-size distribution) of the Zone 2 material is selected so that the fine particles in the trench walls and in the backfill soil will not migrate into Zone 2. The gradation (particle-size distribution) of the Zone 1 material is selected that soil particles in Zone 2 will not migrate into Zone 1. Graded filters should be designed by a geotechnical engineer and are typically only practical for very large diameter pipe.

The most common method to control migration is the use of a geotextile along the boundary between the incompatible materials. The embedment soil is wrapped with a geotextile as illustrated in Figure 8. This is sometimes referred to as a *burrito wrap*, *stone burrito,* or *gravel burrito*.

A *geotextile* (geofabric, filter fabric, etc.) is a permeable fabric that can allow water passage but not allow soil particles to pass. There are different types of geotextiles used for different purposes. They can act as a filter, a separator between soil types, reinforcement in soft soils, or erosion protection. The two most common types are woven products (looks like fabric) or nonwoven products (looks like felt).

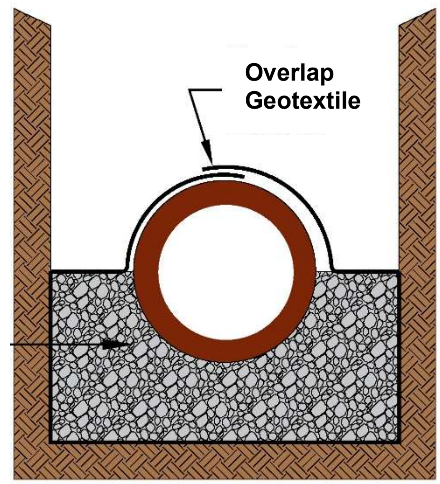

Figure 8: Geotextile Used to Prevent Migration
(Courtesy National Clay Pipe Institute)

The geotextile used in pipeline installation for migration issues should be a non-woven geotextile made from synthetic material. As used in Figure 8, the geotextile is placed on the bottom of the trench and up the sides of the trench wall. Then the bedding material is placed over the geotextile on the bottom and the pipe laid on the bedding. Nothing heavier than a person should be placed on the bedding or any impact allowed that would puncture the geotextile. Then the embedment is placed and compacted if required. Care must be taken during compaction to not tear or damage the geotextile. Then the fabric is overlapped across the top of the pipe and the embedment material encapsulating both the pipe and the embedment.

A third alternative to control migration is to use flowable fill in lieu of the crushed rock or clean gravel. This would eliminate the voids and thus migration.

TEST EQUIPMENT AND SOIL

The 2024 test set-up is shown in Figure 9 and is a 3-edge bearing test for VCP (ASTM C301). The foundation (bottom 4-inches) and bedding soil (top 4-inches) was placed in a 30-inch by 48-inch steel box followed by a two foot length of 24-inch diameter pipe placed on top of the bedding. The vertical load was applied to the full length of the pipe section with the 3-edge bearing test load machine. The settlement was measured on both ends of the pipe at the invert. A steel plate was placed on the soil beside the pipe as shown in Figure 10 and I-beams fastened to the steel box. Hydraulic jacks in between the plates and beams provided a surcharge load to the soil to provide a semblance of surcharge load (backfill load) on the bedding soil.

Figure 9: Test Set-Up with 24-inch diameter pipe and soil box

Figure 10: Surcharge Loading with Steel Plates/ Hydraulic Jacks on the Bedding Soil

The rock was 1-inch crushed rock with about 75% smaller than 3/4 inch, maximum particle size of 1-inch, and about 1% sand. The particles had a combination of rounded edges and fractured faces which qualified the rock as a Class II embedment material (ASTM C12), not a Class I (a Class I material has 100% fractured particles). The foundation soil was a clayey sand with 6% gravel with a maximum particle size of ¾-inch and contained about 35% fines.

TEST RESULTS: 4-INCHES OF ROCK ONLY

COMPARISON 2023 AND 2024 TESTS

The only 2024 test that was a repeat of the 2023 study utilized 4-inches of uncompacted rock with no surcharge. In 2023 the pipe settled 0.20 inches at 4,000 lbs load. In 2024 the pipe settled 0.16 inches at 4,000 lbs load. The 2023 test and the 2024 test settled about the same. In 2024, the load was continued to 8,000 lbs with a resulting settlement of 0.24

EFFECT OF SURCHARGE

In the 2024 tests the pipe was laid directly on an uncompacted rock bedding and the pipe loaded. Then the test was repeated with the surface of the rock beside the pipe having a surcharge load applied to both sides to simulate a backfill load, as shown in Figure 2.

The settlement of the pipe with the surcharge was 25% less than the settlement of the pipe with no surcharge.

EFFECT OF COMPACTION

In 2024, tests were conducted on uncompacted and compacted rock. The compacted rock settled 25% less than the uncompacted rock.

EFFECT OF WATER

The soil box was inundated for several of the tests to examine the effect of water on the pipe support material. Typically, the increase was about 10% except for the test with 4 inches of compacted rock which settled an additional 5%. The tests in 2023 (without surcharge load) settled about the same amount.

TEST RESULTS: 4-INCHES OF ROCK ABOVE 4-INCHES OF SOIL

EFFECT OF GEOFABRIC

Tests were conducted that used a geofabric separator between (typically) wet soil (bottom 4 inches) and uncompacted rock (top 4 inches). These tests included a thin geofabric, a thick geofabric, and a geogrid. The geogrid decreased the pipe settlement about 25%, the thin geofabric about 40%, and the thick geofabric about 70%. Figure 11 shows one of the geofabrics being placed between the soil and the rock.

The geogrid was a Tensar BX1100 with openings about 1-inch by 1-1/2 inch. The thin geofabric was bought off the shelf at Home Depot and there was no technical information on the wrapping.

Figure 11: Geofabric being Placed on top of the Soil

TEST RESULTS: 4-INCHES OF ROCK AND SOIL – VARYING MIXTURES

EFFECT OF MIGRATION

To evaluate the effect of soil migrating into the voids of the rock, soil was mixed with the rock so that the soil percentage of the total material was about 20%, 40%, and 50%. Increasing the percentage of soil increased the settlement of the pipe as follows:

0% soil	0.19 inches		
20% soil	0.23 inches	0.04/0.19 inches =	~20% increase
40% soil	0.56 inches	0.37/0.19 inches =	~200% increase
55% soil	1.69 inches	1.50/0.19 inches =	~800% increase

Uncompacted No. 67 stone (1/4 to 3/4 inch aggregate) has about 40% voids (porosity). The mixture with 20% soil probably still had particle to particle contact and the soil was lubricating the particles reducing the effect of the particle contact.

The mixture of 40% soil probably had most of the voids filled with soil reducing the particle to particle contact even more. Since the bedding for a buried pipe is confined by the surrounding foundation, trench walls, and pipe, the 40% soil probably best represents the worst case of migration and the subsequent loss of support for the pipe. The 40% value is significant in that the porosity of open graded aggregates is about 40% (ADS 2023). The voids in the rock are probably all filled with the soil so there is less particle-to-particle contact and more soil in between rock particles lubricating the surfaces and edges.

The mixture of 55% soil probably represents the No. 67 stone particles floating in a matrix of the soil as indicated by the 800% increase in settlement. While this condition may not happen in reality, the increase does indicate the significant effect the percentage of soil may have on pipe support.

In 2023 the crushed rock was inundated with clean water and dirty water with little increase in settlement. The dirty water represents less than 5% soil. The 20% increase with 20%

fines indicates that somewhere between 0% and 20% soil migration begins to affect the supporting strength. This effect was also noted in a separate study (Ibrahim 2015):

> "It is also found that on inundation of gravel soils containing plastic fines greater than 12% a considerable reduction in both the strength and the stiffness modulus is noticed."

The fines were described in the Ibrahim report were actually low plasticity fines. The Unified Soil Classification System (USCS) uses the presence of 12% fines as the boundary between "clean" gravel and sands (GW, SW, GP, SP) and "dirty gravel and sand" (GC, SC, GM, SM). The USCS groups are based on strength and compressibility, so the engineering properties are starting to be significantly affected at about 12% fines. It can be concluded that the stiffness of inundated cohesionless gravels will be reduced when the fines content is between 10% and 20%.

SUMMARY AND CONCLUSIONS

Load-settlement tests were conducted on a vitrified clay pipe supported by a variety of soil support conditions. The pipe was placed on a bedding of soil, or rock, or a combination of the two materials and the tests used surcharge loads provided by jacks on the bedding. The program used crushed rock (rock) as the main support for the pipe with various amounts of silty sand (soil) added that represents the soil migration into the voids of the rock. The results showed that:

1. Adding clean and dirty water (less than 5% soil) had little effect on the rock stiffness support for the installed pipe.
2. The soil started affecting the rock stiffness between 10% and 20% soil to rock ratio. With 20% soil, the pipe settled about 20% more than clean rock.
3. At 40% soil the void space in the rock was basically full of soil with reduced rock to rock contact. The pipe settled about 200% more than clean rock.
4. At 60% soil the rock was apparently floating in a sea of soil with no rock to rock contact. The pipe settled about 800% more than clean rock.
5. The compacted rock settled 25% less than the uncompacted rock.
6. Geotextiles were placed between the soil foundation and the rock bedding. Comparing these materials to no geotextiles, the geogrid decreased the settlement about 25%, the thin geofabric about 40%, and the thick geofabric about 70%.

REFERENCES

ASTM C12 *Standard Practice for Installing Vitrified Clay Pipe*

ASTM C301 *Standard Test Methods for Vitrified Clay Pipe*

ADS Pipe (2023), *Porosity of Structure Backfill*, Technical Note TN 6.30, Advanced Drainage Systems, Inc.

Howard, Amster (2015), *Pipeline Installation 2.0*, Relativity Publishing

Ibrahim, K (2015), *Effect of percentage of low plastic fines on the unsaturated shear strength of compacted gravel soil*, Ain Shams Engineering Journal, Volume 6, Issue 2