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Emerging Bedding, Padding and Related Pipeline Construction Practices

to

Pipeline and Hazardous Materials Administration

Contract DTRS56-03-T-0005

and

Interstate Natural Gas Association of America

January 2005

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Emerging Bedding, Padding, and Related Pipeline Construction Practices

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by

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This project assessed enhancements in safety and productivity possible through recently developed construction practices, and identified and evaluated opportunities for cost reduction, improved pipe protection, and decreased construction created pipe/pipe coating damage that could be realized with new or emerging pipe support and padding/backfill practices. Data were gathered subject to the practical constraints imposed by use of construction equipment and the contractor's permission to enter or approach the ditch for "hands-on" measurements and close-up observation. Coating damage resistance was found to be a major factor in the viability of bedding and padding practices and specifications, as existing coatings were found to be tough and durable and so were resistant to damage under conditions typical of well-controlled bedding and padding operations. Thus, the significance of bedding and padding practices designed to avoid damage was found to be limited where adequately damage-resistant coatings were used. Performance-based specifications for coatings and construction practices appear viable for such scenarios, with validation needed to make this a widely accepted approach. Some areas have been identified for future development, including combination crusher/padding machines and continued evolution of damage-resistant coatings.

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Table of Contents

Page

Acknowledgements iii
Executive Summary ix
Introduction 1
Objectives 4
Approach 5
Definitions 5
Scope and Metrics 6
Construction-Imposed Constraints 8
Task Structure and Report Organization 9
Results – Tasks One and Two 9
  Metrics and Site Protocols 9
  Field Reporting Format 11
  Site Selection Criteria 11
  Sites Selected and the Pipeline Projects 12
Observations, Data, and Discussion – Tasks Three and Four 20
  Project One 21
  Project Two 33
  Project Three 43
  Project Four 46
  Industry Experience and Commentary 50
  Observations and Trends 56
Summary and Major Conclusions 67
Recommendations 70
References 71
Appendix A – Operation and Function of Ozzies Padder and the Dynapad Machine A-1
Appendix B – Field Measurement Protocol B-1
Appendix C – Reporting Format C-1
Appendix D – Soils Reports D-1
Appendix E – Viscoelastic Aspects of Bench Design and Structural Performance E-1

List of Figures

Page

Figure 1. Comparison between vintage and modern bedding and padding equipment 3
- a) 1950s vintage auger loaded cylindrical-screen machine
- b) modern integral in-line loader and flat single-screen padder
- c) modern independently loaded vertical multi-screen padder

Figure 2. Views on two spreads of Site One 14
- a) lowering-in for a sag tie-in in hilly terrain
- b) lowering-in for a tie-in in flatter terrain
- c) prior to sag tie-in in hilly terrain
- d) padding a sag after a tie-in in rolling hills

Figure 3. Views on three spreads of Site Two 15
- a) lowering-in on flat terrain
- b) lower-in before a tie-in in flatter terrain
- c) after a sag tie-in in rolling hills
- d) lowering-in in hilly terrain
- e) rock shards on working side of shot ditch
- f) wheel-hoe ditch through softer flat terrain
- g) lowering-in through rolling terrain
- h) lower-in after a corner tie-in in flat terrain
- i) after corner tie-in in flat terrain
- j) sprayed in-situ breakers on a gradual slope

Figure 4. Views on two spreads of Site Three 18
- a) prior to lowering-in through wetland
- b) lowering-in through rolling terrain
- c) lowering-in downhill prior to creek crossing
- d) starting to lower-in down a steep slope
- e) sandbag breakers down a gradual slope
- f) broadened ditching through a corner

Figure 5. Views on two spreads of Site Four 19
- a) lowering-in in some of the flatter terrain
- b) construction through rolling hills
- c) in-situ foam breakers in hilly terrain
- d) in-situ foam breaker on a gradual slope
- e) laid in on sandbags prior to a steep hill
- f) trenching through some of the sharper rock

Figure 6. Views of the fill material deposited by Dynapad.....24
- a) axial sequential deposit of increasingly coarser fill material deposited
- b) layered backfill, with increasing depth of cover as the layers are added

List of Figures (continued)

Page

Figure 7. Aspects of bedding and padding with Dynapad and elements of the KNI System 25
- a) typical coverage after one pass
- b) flow of fines enveloping the pipe-string
- c) overview for image in part d)
- d) view of coating below the first layer of fill
- e) warning tape installation
- f) beginning to lay-in geotextile fabric
- g) lowering-in onto sandbags
- h) lower-in onto patent-pending foam benches
- i) overview of pipe settled onto foam benches
- j) closer view of pipe settled onto foam benches

Figure 8. Aspects of bedding and padding with Ozzies Padder 32
- a) technique and coverage for first pass
- b) flow of fill material enveloping the pipe-string
- c) technique and laying of a second pass
- d) view of cover from two passes
- e) rock in the wake of the padder
- f) view of coating below the cover

Figure 9. Further observations on bedding and padding at Project Two 37
- a) sprayed-in-situ benches
- b) foam pillows installed at a corner
- c) reverse-rock shield at work lowering-in
- d) three Ozzies Padders in tight tandem
- e) tandem of augers and blades making grade
- f) view of padded and covered pipe-string
- g) angle of repose and natural size selection
- h) as in part g), but the runoff of spoil from an auger
- i) reverse-rock shield at work lowering-in
- j) three Ozzies Padders in tight tandem
- k) a second pass, filling and building cover
- l) a restart, similar to any start-up scenario

List of Tables

Table 1. Matrix of construction scenarios targeted for evaluation 7

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Executive Summary

Increased demand for fuels and other hydrocarbons has begun to deplete transmission pipeline supply basins near early markets, requiring longer pipelines to increasingly remote supply basins located typically in challenging geographic and climatic conditions. Shifting population centers and related markets such as distributed power generation have likewise driven this process. This has prompted evolution of new or emerging construction practices, as well as developments in thinner and stronger line pipe, and new coatings. Coupled with developments in construction equipment and practices to deal with these challenges, such improvements could add value through increased safety and reliability due to reduced extent and/or severity of construction related coating damage that necessitate repairs.

This project assessed enhancements in safety and productivity possible through recently developed construction practices, and identified and evaluated opportunities for cost reduction, improved pipe protection, and decreased construction created pipe/pipe coating damage that could be realized with new or emerging pipe support and padding/backfill practices. Data were gathered subject to the practical constraints imposed by use of construction equipment and the contractor's permission to enter or approach the ditch for "hands-on" measurements and close-up observation.

On-site measurements and observations made in reference to the many spreads visited lead to the following general conclusions:

- The performance of bedding and padding machines is dictated by the properties of the soil and soil mechanics, in addition to design and operating features that might be unique to a given padding machine. Differences in performance characteristics between integral in-line load and screen machines and independently loaded stacked vertical-screen machines preclude a one-size-fits-all basis for machine selection.
- Coating damage resistance is becoming a major factor in the viability of bedding and padding practices and specifications, as existing coatings were found to be tough and durable and so were resistant to damage under conditions typical of well-controlled bedding and padding operations.
- The relative significance of bedding and padding practices designed to avoid damage tends to be of limited value where adequate damage-resistant coatings were used. Performance-based specifications for coatings and construction practices appear viable in this context, with validation needed to make them widely accepted.
- Dynapad develops a layered backfill, grading and placing three tiers of fill material. But, whether this enhances integrity depends at least on the damage resistance of the coating.
- Where appropriate skill is practiced, an Ozzies Pipeline Padder (and likely other similar designs) can bed and pad without undue damage to pipeline coatings, at least for the coatings and trench conditions addressed in this project. Significant to this conclusion is the skill of the operator, the coating used, and the screen size involved.
- The KNI assertion that the washout occurs due to horizontal or vertical trench instability is viable, but there is little practical field data to identify when or where trench instability is an issue. Use of geotextile as laid by Dynapad is unproven to stabilize vertical washout, and inconsistent with other somewhat proven applications to control washout using geotextile fabric.

- Analytical considerations indicate the complicated response of foam structures make it very difficult to selectively control bench "failure" – as suggested for the KNI patent-pending precast foam bench. This scenario is further complicated given the locally variable conditions and loadings typical of most ditches.
- Some areas have been identified for future development, the focus of which is combination crusher/padding machines and the evolution of damage-resistant coatings. Work underway in Europe is particularly significant in this context.
- Some technology-starved areas exist in regard to some aspects of pipeline construction considered herein, for which several recommendations are included in the report.
- Forums organized around topics such as ditch stability, new technology, and other topics noted in this report might be effective in defining issues for future consideration, if any.

A number of less general but still important conclusions follow from the measurements and observations made at the five sites considered. These are detailed in the summary and conclusions section of the report, and justified in the observations and trends developed based on the field observations and measurements.

Introduction

The gas and liquid pipeline infrastructure began to develop as these products were recognized as merchantable. While other forms of transportation existed, pipelines were eventually recognized as the safest and most economical means to move these products from supply basins to markets. Supply basins were initially located in nearby markets, as early finds of these resources were located in sites such as Pennsylvania. As demand grew and the nearby resources began to deplete, wells went deeper and supply basins tended to be increasingly remote. This scenario continues today, with current interest in moving domestic supplies from areas like Alaska to the lower forty-eight.

As the supply basins became increasingly remote, a system of pipelines developed to transport products to the various market centers. This has developed a cross-country infrastructure of pipelines that runs throughout the US and connects with border countries. Early construction traversed the plain states, with limited construction into and through wet or swampy areas as well as hilly or mountainous areas where such features lay between the supply basin and the market.

Early construction made use of backhoes and various ditching practices, with the pipeline built along and lowered onto the ditch bottom as a string. As construction usually traversed farm fields, the ditch bottom was smooth and so could serve as the foundation for the pipeline. Likewise, native soil could be returned to the ditch as bedding and padding for the pipeline, as well as cover for the pipeline. A-frames used to lower-in the pipe-string gave way to side-booms beginning in the 1930s, while machine-made bends replaced couplings and other field-bending practices used to change the direction of the pipeline beginning in the 1940s. As the threat of corrosion was recognized, over-the-ditch coating methods were developed, with such coatings widely used beginning in the 1940s[1].

Construction up and down hills or through rocky areas used practices similar to those used for construction across flat country and soft ground, along with schemes developed or adapted to move or anchor up and down hills, protect the pipeline from rock damage, or screen native backfill for acceptable fill material, or use replacement fill materials. Techniques used to move or anchor in hilly or mountainous terrain evolved with the demands of the pipeline industry, adapting equipment typically developed for other off-road applications. Approaches to deal with rocky ditches and native backfill addressed the perceived threat to the pipeline. One early approach to deal with rocky ditches simply replaced backfill below and around the pipeline with select backfill that was free of material considered a threat to the pipeline. A related practice used sandbags stacked periodically below and along the pipeline to raise it off the ditch-bottom, which allowed select backfill to flow under the pipeline. Another early approach used wood cribbing around the pipeline as protection from rock damage. As these schemes relied on logical methods to avoid or limit rock and related damage, variations on these methods using modern materials and more streamlined practices evolved, some of which continue in use today.

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[1] For details on construction practices and the related aspects see Appendix G of Reference 1. A timeline for the introduction of developments associated with pipelines can be found in Appendix H of Reference 1.

* Numbers in superscript parenthesis refer to the list of references compiled at the end of this report.

Variations in technology that have continually evolved from the early practices are outlined in written histories associated with pipeline construction[e.g., 2,3)*]. Likewise such variations can be found via Internet web searches. For example, the key words "rock shield" in relation to transmission pipelines lead to several modern variations that rely on a variety of practices typically involving wraps based on a variety of modern polymers deployed over a range of schemes[e.g., see 4-7)]. Likewise, the key words "bedding and padding" tied to transmission pipelines lead to at least eight websites detailing a range of competitive equipment[e.g., see 8-15)], each of which typically claims to be the best in one or more important aspects such as cost or effectiveness.

An example of the evolution of bedding and padding equipment can be seen in comparing Figure 1a, which shows a 1950s vintage padding machine[(16)], with Figures 1b and 1c, which show two of the more recent machines whose function is similar. Whereas existing, emerging, and new bedding and padding equipment largely rely on screening technology, where flat screens are deployed in various ways, angles, and sizes, using one or more screens loaded by various schemes, the 1950s machine used a rotary screen. Because of this flat mode, the modern machines load via conveyers whereas the 1950s vintage machine used an auger, as can be seen in Figure 1a.

The evolution of bedding and padding equipment can be tracked through "feature sections" in pipeline industry trade magazines, which document such equipment, along with related trenching and other construction equipment. Such sections in trade magazines and supplier websites also address coatings used by the pipeline industry to help limit corrosion along with the use of cathodic protection (CP) schemes. Early, thick and compliant bitumen/tar-based, over-the-ditch pipeline coatings seemed well suited to protecting pipelines from construction-related damage, although over time these have been replaced by typically much thinner coatings.

As time passed, demand increased for petroleum products, which motivated an increase in both pipeline diameter and line pipe grade. This led to increased throughput and decreased construction cost and time. But it also facilitated a decrease in wall thickness, which increased the diameter to thickness ratio that occasional led to denting where the pipeline sat on sandbags used in construction. This motivated the search for alternatives to the stiff support provided by sandbags used as standoffs from the ditch bottom during construction. As supply basins moved to more remote regions and population shifts moved markets, routings through more mountainous regions motivated alternative approaches to dealing with rocky terrain.

Developments in machined trenching that could cut through even hard rock provided a neatly formed and well-defined ditch alternative to the earlier practice that shot a wide often ill-controlled trench through rock. This alternative technology also developed an ample supply of rock fines that provides a viable backfill alternative to the large sharp rock shards that often resulted where rock was shot. Moreover, the well defined narrow ditch limited the amount of fill needed in contrast to an ill-formed shot ditch, and provided an otherwise undisturbed construction site, all of which provide cost advantages over historical practices. Problems with over-the-ditch coatings that disbonded over time because their volatile content evaporated motivated development of alternative coating methods. These new mill-applied fusion-bonded epoxy and mill or field applied tape-applied coatings reduced time on the spread and improved metal-loss protection, and reduced costs through reduced CP demand. However, while polymer-based thin film and tape-applied coatings have the advantage of being tough and resistant to tearing or disbonding, they might be prone to spalling or cutting under

a) 1950s vintage auger loaded cylindrical-screen machine

b) modern integral in-line loader and flat single-screen padder (Ozzie 200)

c) modern independently loaded vertical multi-screen padder (KNI) on sideboom

Figure 1. Comparison between vintage and modern bedding and padding equipment

point contact. The industry has addressed possible backfill damage to such coatings, although the results tend to be viewed as commercial property[e.g., see 17], and such work continues[18]. Likewise, technology is evolving to determine the extent of construction-related coating damage[19].

Improvements in pipe making and coatings coupled with developments in bedding and padding practices for hard, rocky ground could add value through increased safety and reliability due to reduced extent and/or severity of construction related coating damage that necessitates repairs. And, given the occasional rocks are found in softer ground, it is reasonable to conclude such improvements could bring similar benefit for such scenarios to the extent that rock is present. Benefits may also accrue for spreads involving periodic runs of rocky soil or hard rock, which otherwise require imported material for bedding and padding, or use of equipment that crushes and/or screens native spoil as required. Such benefits would be maximized where the equipment is suitable for continuous use, with equal or greater rate of forward progress as compared to usual practices, as otherwise nonproductive periods and the cost of moving it along the spread would offset their potential value. Potential benefits also could be claimed when formulating integrity-management plans (IMPs) for pipelines running through high consequence areas (HCAs) where practices that produce enhanced safety and reliability through reduced extent and/or severity of construction related damage are used. Where this occurs, it will be useful for regulators to have a basis to evaluate the value of construction practices in reference to integrity. Reference 2 defines the requirements of such IMPs, and provides definitions or related regulatory guidance.

Objectives

The stated objective of the Government project funded through the US Department of Transportation (DoT) Pipeline and Hazardous Materials Administration (PHMSA) project was to assess the merits of modifications to construction equipment and practices to enhance safety and productivity achieved through use of recent developments. The stated objective of the cost-share for the PHMSA project funded through the Interstate Natural Gas Association of America (INGAA) was to identify and evaluate opportunities for cost reduction, improved pipe protection, and decreased construction created pipe/pipe coating damage that could be realized with new or emerging pipe support and padding/backfill practices. Both projects had interests focused on specific developments by KNI Inc. (hereafter KNI) in comparison to existing technology.

These objectives couple concern for safety and reliability of the as-constructed pipeline in balance with aspects related to productivity during construction. To be comprehensive, the extent to which safety and productivity are enhanced through recently developed pipe support and padding/backfill practices must be evaluated relative to existing practices, and do so for the range of ditching conditions where the benefits of such enhancements could be evident. Meeting this objective will provide a technically sound basis to determine which practice is optimal as a function of right-of-way (RoW) specific issues, and it will establish a basis for determining the safety-related value of such practices.

Approach

Evaluating safety and reliability in balance with construction productivity requires field data that involve metrics that reflect safety and characterize productivity and possible cost reduction. This necessitates an empirical approach that uses field observations as the basis to gather data, which then are evaluated to meet the project's objectives.

Given the project's objectives involve productivity as well as safety and reliability, observations must be directed at opportunities to improve productivity, or reduce cost in balance with improved quality in operations associated with ditching and pipe-laying. Metrics of productivity are needed, along with metrics of safety and reliability. Field data consistent with the metrics must then be gathered to characterize qualitative and/or quantitative measures of the extent to which current or emerging practices could be improved or new practices developed to enhance safety and value-based quality, in balance with reduced cost and enhanced productivity, for construction situations from hard rock through soft soil.

Definitions

The approach just outlined involves the empirical comparison of current and emerging or new practices and equipment in terms of productivity as well as safety and reliability. However, as yet the timeline for current versus emerging or new has not been defined, nor has productivity nor safety and reliability.

Consider first definition of a timeline to discriminate current versus new or emerging technology. The most relevant definition of timeline follows from the realization that each contractor makes use of known and thereafter proven practices and equipment. Practices and equipment become favored through an experience-based trial and error process, and thus reflect the portfolio of prior work and circumstances encountered by contractors along the rights-of-way they work. On this basis, practices and equipment that become favored reflect the equipment that is either owned or available for a given job, the circumstances known or anticipated along the rights-of-way, the negotiated value for extras, and a host of other parameters. It follows that construction practices and equipment that are considered "known or proven" are contractor-specific, and also specific to the anticipated circumstances along a given routing. Thus, what is new versus emerging versus existing reflects equipment or practices that might differ contractor to contractor, which for a given contractor might be routine and another neither known nor proven. On this basis, what is taken as new or emerging versus existing when generalized across the industry reflects equipment or practices that are neither known nor in widespread use across the industry.

For purposes of this project, the timeline for new or emerging is measured in reference to the introduction of technology that produces layered-backfill for purposes of bedding and padding. In reference to Figure 1, a major step in developing screening technology to separate select backfill came with the shift from a rotary screen to the use of a flat screen. As most equipment now advertised for such purposes relies on flat screens deployed in various ways[2], a criterion other than screen orientation is needed to discriminate timeline and what constitutes emerging or

[2] Virtually all machines use large, flat screens, the exception being one machine using a long, narrow rotary screen.

new. One major feature that differs between the various screen-based machines that could be used to discriminate a timeline in planning these projects is the ability to create "layered backfill", which is graded from fine near the pipeline to increasingly coarser moving away from the pipeline. As the benefits of layered-backfill are central to the interests of both the INGAA Foundation and PHMSA, this criterion was chosen to discriminate between new, emerging, and existing technology. In this context, layered-backfill as produced in the manner of Reference 10 is used to discriminate between widely used screening-based equipment. As layered backfill defines the timeline for "emerging" technology, while developments that enhance the process beyond layered backfill comprise "new" technology. It follows that flat screening-based technology that does not produce layered backfill comprises "current" bedding and padding technology, as would rock shield and such long-known protective schemes.

Consider now safety and reliability defined in terms that can be measured in the real-time under constraints typically associated with commercial pipeline construction. For present purposes these definitions are established in reference to pipeline integrity as perceived in IMPs[e.g., 19-21]. Safety and reliability in this context are defined in reference to "threats" to pipeline integrity, and the hierarchy of significance of these threats. Threats to integrity are typically assessed in reference to pipeline incident experience, which is tracked in the US on Office of Pipeline Safety (OPS) reporting forms that are specific to gas versus hazardous liquid service[22]. This experience is documented on the OPS website[23], and widely discussed in the literature[24,25].

While the hierarchy of significance of threats is specific to the pipeline's service, for present purposes one can reasonably conclude that external corrosion and mechanical damage are universally important. Safety and reliability in this context involve initial coating quality and the absence of line pipe shape change caused by construction damage. Thus, for present purposes safety and reliability are defined specifically in reference to coating quality and the absence of line-pipe shape change caused by construction damage. Within this definition, construction equipment or practices that do not reduce as-applied coating quality is viable. Likewise, construction equipment or practices that do not cause a permanent change in pipeline shape is viable. As-produced coating quality and pipeline shape define the reference against which quality and shape are judged. Abnormalities introduced in construction involving coating quality and permanent change in line-pipe shape are defined in accordance with usual conventions and the API 5L specification[26]. Terms specific to this report that could require clarification include:

- Coating Anomaly – Any deviation in the properties of the coating found by inspection, such as jeeping or visual observation.
- Flaw – A permanent deviation in the pipeline shape properties according to API 5L.

Scope and Metrics

The approach noted above evaluates current versus new or emerging developments associated with bedding and padding or related protection for construction situations ranging from hard rock through soft soil in reference to reduced cost and enhanced productivity, safety, and reliability. This open-ended scope was contractually focused in reference to three site visits to gather data with the expectation of comparing the just-noted two current technologies with the emerging layered-backfill technology.

The work scope proposed addressed the matrix of equipment and construction situations as identified in Table 1. The emerging layered-backfill technology was addressed in reference to KNI equipment known as Dynapad[10]. Existing technology that was to serve as the reference for comparison to existing practices was through comparison to Rock Shield[4-7] in one of its several commercial forms and the Ozzies Padder[13]. The decision to use the Ozzies Padder as the reference for current technology reflected the view in planning this project that this equipment was in widespread use. Comparison of these practices was proposed in the framework of the 3-by-3 matrix of situations in Table 1, with eight combinations proposed for consideration. Appendix A presents aspects of the function and operation of the Ozzies Padder and Dynapad.

New technology was considered in regard to pipe support methods, for which sandbags were taken as the reference for comparison. New technology was also considered to the extent it became evident during the course of the project, and was available for observation and/or evaluation. Aspects considered to varying degrees included geotextile fabric to stabilize the ditch, in-the-ditch markers as a means to limit mechanical damage[3], in-the-ditch crusher technology and related mobile crushers as alternatives to existing equipment, and alternative practices for use with trench breakers on hills as a means to stabilize the ditch.

Table 1. Matrix of construction scenarios targeted for evaluation

Machine/System	Construction Situation		
	Rock[4]	Mixed	Soil
Dynapad	√	√	√
Rock Shield	√	√	
Ozzies Padder	√	√	√

Six parameters were targeted as quantitative metrics of quality in planning these projects, which could be used to infer relative measures of safety and reliability including:

- absence of permanent pipe shape change or mechanical damage,
- absence of coating damage,
- extent of fill compaction below the pipe,
- quality of support and its effect on future pipeline functionality,
- quality of bedding, padding, and backfill around pipe, and
- implications for reduced maintenance or operations costs and integrity management.

The first and third of these metrics are identical regardless of the support system, be it sandbags or other benches designed to avoid pipeline contact with the bottom of the trench. The second

[3] For discussion of such markers and their value in reducing third-party contact, see Reference 27.

[4] In planning, rock was taken as situations where the ditch needs to be shot, or cut with rock trenching equipment – the definition of mixed was recognized to depend on the spreads available, with the expectation that it would reflect frequent encounters with significant rock content in sizes three inches and larger – while soil referred to bottomland or rich organic farm acreage with light clay, but again depended somewhat on the spreads available.

and fourth metrics reflect the interaction between the support scheme used during construction and the initially uncompacted bedding below the pipeline.

Three parameters were considered in the planning as absolute quantitative metrics related to productivity, including:

- forward speed,
- volumetric fill rate, and
- padding conditions (soil type/geology, topography, geography).

These metrics were evaluated for a range of construction situations that ranged from soft ground through increasingly challenging situations, ending with construction through hard rock.

Construction-Imposed Constraints

Data that can be gathered over the range of construction situations in Table 1 is constrained in reality by the equipment in use, which reflects the contractor's assessment of benefit in reference to productivity and safety consistent with the specifications for this project as set forth by the pipeline company he was working for. Empirical observation of the metrics noted above requires "hands-on" access to the pipeline during construction. Thus, data that can be gathered also are constrained by site safety rules, OSHA requirements related to ditch/trench safety, and safety considerations related to the heavy equipment in operation along the ditch. Physical entry into the ditch is determined by downtime for equipment, which is further constrained according to directions from the contractor along the RoW. In all cases, safety requirements were set forth by the contractor in a safety briefing prior to entry to the RoW, which required compliance with all safety-related directives indicated from time to time by the contractor.

As entry to the RoW was subject to approval of the contractor and his presence therein, safety and other conditions dictated by the contractor for site access were adhered to. These requirements typically limited hands-on observations to a few minutes prior to startup each day, to downtimes during tie-ins but only at sites remote to the tie-in, and to about 15 minutes during the break periods and at the end of the day's construction. Because the desire was to observe and evaluate construction as it normally occurs, being onsite but out of sight was essential to ensure typical practices were utilized. Being onsite for a period of several days to in some cases a week or more helped to ensure usual practices were observed.

As differences between soil types and the presence of rock could affect the comparison between proven versus emerging or new practices and equipment, comparative data would ideally be developed under identical field conditions. However, as the equipment or practices used on adjacent spreads was the choice of the contractor, the ideal scenario of head-to-head comparison was virtually impossible to achieve in practice. Nevertheless, an effort was made to obtain data under conditions where the comparison occurred under "comparable conditions." Soil sampling was done by commercial laboratories as a guide to the nature of the materials involved. But as this reflects disturbed samples, and soils by their nature are variable, little can be said with certainty as to the direct comparability of sites. For this reason, productivity is reported for each site visited in terms of forward progress and related metrics, along with an indication of the equipment on site and the practices in use.

The final practical constraint involves the project's timeline, and the need to find construction projects that are consistent with this timeline and the unique needs of this project.

Task Structure and Report Organization

Meeting the project objectives for this work scope was accomplished in reference to four technical tasks and a reporting task, as follows:

1. identify spreads that illustrate the problems encountered and the capabilities of current and emerging technologies and practices,
2. develop field protocols to quantify the above-noted metrics,
3. gather qualitative and quantitative data characterizing the above-noted metrics, through field observations and discussions with industry experts, observing the strengths and weaknesses of current, emerging, and new equipment or practices,
4. evaluate and trend the data and compare current versus emerging or new bedding and padding methods, and related construction technologies, and,
5. report the results quantifying improved pipe protection and decreased construction created pipe/pipe coating damage achieved with emerging or new pipe support and padding/backfill equipment and practices.

The report develops in the sequence of the just noted tasks. The next section focuses on the results, beginning consideration of the sites and spreads, and continuing with consideration of the protocols developed for on-site measurement. Thereafter, each of the spreads visited are discussed along with a summary of the results. The next section evaluates the data and identifies and discusses trends, leading to the last section which summarizes the work and presents the project's conclusions. The details in all cases are relegated to appendices. As noted earlier, Appendix A presents aspects of the operation and function of the Ozzies Padder and the Dynapad machine. Appendix B presents the field measurement target protocol, whereas Appendix C presents the target report format. Appendix D presents the soils reports as determined for selected sites while Appendix E presents results developed to help better understand the structural performance of benches made of polymeric (viscoelastic) foam.

Results – Tasks One and Two

Metrics and Site Protocols

The objectives of Tasks One and Two were to develop practical field measures to characterize the high-level metrics indicated in the section titled Scope and Metrics and then develop protocols to consistently capture the data and report it.

Productivity can be directly measured in regard to forward speed by estimating forward daily progress through odometer estimates made along the right of way coupled with a daily estimate of the time spent in bedding and padding. Productivity also can be directly measured in regard to volumetric fill rate using forward speed coupled with periodic estimates of average trench depth and width. In contrast, soil type and ditching characteristics cannot be so simply quantified, nor can the size of the aggregate present. Moreover, variability evident along a given RoW effectively precludes characterizing soil type unless sampling is done according to a statistical design, which would lead to costs well beyond that possible within this project. Accordingly, soils were sampled to a limited extent using standard sieve methods and a geological assessment of the materials present, using commercial laboratories located near the spreads.

High-level metrics involving construction-related potential benefits for safety and reliability focused on permanent shape change and mechanical damage, along with coating quality. Parameters associated with potential benefits involving improved benching practices considered the effect of pipe support on pipeline functionality and fill compaction. Five qualitative measures were used to characterize these high-level metrics in regard to safety and reliability. Visual observations were used to identify obvious flaws in regard to denting and other local permanent changes in pipe shape such as mechanical damage. Likewise visual observations were used along with touch to identify possible flaws in coating quality. These sensory-based measures in most cases were backed up by widespread checks in coating quality using a local jeeping capability that was functional even though part of the pipe had been bedded or partially padded. Results developed in this project were evaluated in light of literature discussion and data on full-scale simulated contact, oral communications, standardized testing, and related analysis considering the effect of backfill mass, angularity, and other factors on coating damage.[e.g., 28-34]

Visual observations were made under the pipe whenever construction conditions permitted such, to identify the extent of bedding flow under the pipe, which occasionally was photographed to document these observations. As If a small gap was observed immediately below the invert of the pipe as the bedding process advanced along the pipe-string, one can state that a gap exists at least initially at this location. However, based on soil mechanics considerations[35], continued flow of bedding material under the pipe appears to be forced by the weight of the padding and subsequent backfill, particularly in less viscous fill materials. Order-of-magnitude analysis is introduced later to supplement visual observations of the role of bench compression and failure on the extent of fill compaction below the pipe, and its effect on pipeline functionality. Finally, visual observations were made in regard to the extent of compaction, which were supported by observations of impact penetration in these areas when permitted by the contractor. The sum of these observations and analyses results were used to contrast the quality of bedding, padding, and backfill around the pipe for the variety of equipment and practices evaluated across the range of soil conditions considered.

A protocol was developed to consistently implement the empirical observations and measurements, a copy of which is presented in Appendix B. While not a formal part of the protocol as they reflect random infrequent occurrences, from time to time larger rocks can slip from the spoil pipe being worked for fill material suitable for bedding and padding. Contact when it occurs with pipe-string is announced by a gong-sound that propagates along the pipe-string and motivates examination of the coating for damage and immediate in-situ repairs. The stronger this contact, and more likely the damage, the louder the sound that announces contact. In the case where contact occurred, care was taken to observe the size of the rock and its angularity, the likely elevation above the pipe based on the location of the padding or other supporting equipment, and the nature of the coating damage if any was evident. Finally, where the opportunity occurred along the RoW to evaluate the sensitivity of the coating to backfill damage more broadly than addressed in the protocol, data were developed. This involved evaluations made on short lengths of pipe apparently discarded after a tie-in, which were not yet cleared from the RoW. Where such scrap was found, various sizes of rock and/or degrees of angularity were used in an ad hoc evaluation of the sensitivity of the coating to impact, penetration, and/or scratching.

Field Reporting Format

A reporting structure was developed to ensure the consistent recording of the measurements and observations developed in reference to the protocol for empirical observations and measurements presented in Appendix B. An example of the reporting structure form developed for use in field reporting is presented in Appendix C. Where results were developed beyond the field measurement and observation protocol, they were recorded independent of this form.

Site Selection Criteria

The selection of spreads began with the award of contract. It was idealistically planned to develop a list of potential sites within two months after award of contract based on FERC-approved construction underway nationally. Input to this process came via the INGAA Planning and Studies Committee ad hoc group monitoring the startup of this project, INGAA Foundation member-company representatives, and industry articles that document such construction[(e.g., 36)]. Initial criteria planned for selecting spreads included a minimum length of 10 miles[5], along with consideration of the routing and soil and rock anticipated on the spread. Another factor in selecting spreads involved the construction equipment and practices employed by the contractor, the desire being to observe as many elements noted in Table 1 on different spreads of the same construction project. As indicated in Table 1 the desire was to include a range of soil and rock situations, tabulated therein as rock, mixed, or soil. The desire also was to consider Dynapad in comparison to Ozzies Padder (or other padders) and Rock Shield[6]. Consequently, the potential suitability of FERC-approved spreads included evaluation of likely soil types based initially on USGS maps – with follow-up planned to include pipeline company survey data and discussions with the contractors to identify their preferred equipment and practices.

A cursory review of FERC-approved pipelines on the books and under a construction contract while planning this project indicated a two-year-long contracting period, with three site visits targeting projects involving multiple spreads to maximize the value gained from each visit. Superimposed on selecting projects and spreads was the complicating effect of visits during periods of winter construction, as the time of year can influence the effectiveness of some construction equipment and practices, and alter the properties of pipeline coatings. Thus, the time of year that construction was projected to occur through rocky areas became a potentially important factor in selecting sites. This introduced the need for some potential compromise when selecting spreads when experience indicated seasonal differences might override the other considerations.

Of these considerations, correspondence with KNI during planning indicated its Dynapad machine and related technology would be present for evaluation on a variety of spreads[(37)]. On

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[5] The minimum length of 10 miles was noted in the proposal as one approach to average out the effect of soils variability on productivity and safety and reliability. As time passed it became evident that the inherent variability in soils and geological formations was large enough in some areas that it could not be averaged-out so simply. More importantly, it also became evident that overall construction productivity was dominated by the effects of hills, which primarily reflects the need for tie-in welds to join the segments of pipeline strung together between areas where curvature reversed. As such, the minimum length of 10 miles became a secondary consideration.

[6] Formally revision to the INGAA proposal requested Table 1 address three technologies, although there was clear interest in these aspects. The PHMSA proposal specifically names the technologies noted in Table 1.

this basis, equipment in use was anticipated to be a secondary factor. However, the reality was that only a very few spreads could be identified where it would be used with certainty along with its related new technology. It became clear during spread selection that when Dynapad was used there was only limited or no use of what was perceived by KNI to be new technology, such as their foam benches or geotextile fabric[7]. The decision to use such technology remained that of the pipeline owner, and his contractor, with reticence to employ new technology reflecting the view that it either was untested or unproven – or there was reason to question its safe use or value.

Consequently, the primary consideration in spread selection became the contractor's planned use of equipment, with the site selection process reduced to consideration of spreads where Dynapad and other new or emerging technology was in use. The second important factor was the incremental knowledge gained from a visit to a given spread. As reality limited the spreads where all elements of Table 1 were active, the planning process was reduced to selecting between a few projects that occasionally were marginally suited to the needs of the project. As the data so generated were limited, the number of spreads targeted was increased beyond the three sites addressed in the project's planned scope with a view to bridging some gaps in the database, with budget reallocated accordingly.

With a view to broaden the database and provide maximum exposure for new or emerging technology, selected contractors, service providers, and pipeline companies were contacted in the Spring of 2004. None indicated activity was then underway that would incrementally broaden the scope of the equipment or systems that were of interest. Nevertheless, this opportunity was held open over the course of the ensuing construction season, but again no opportunities became apparent that would alter trends that were emerging by that time.

Finally, it is appropriate to note the process of selecting and accepting spreads is influenced by the need to meet programmatic milestones. For this project this aspect was secondary to the desire to address the technical concerns that underlie the range of soil types and existing and emerging construction practices noted in Table 1. The mileage for the construction projects observed as part of this project account for approximately ten-percent of the slightly more than 12000 miles slated for construction starting in 2003 and continuing over the next three years[(36)].

Sites Selected and the Pipeline Projects

Task One delivered a series of sites that reflected routings and construction practices consistent with the expectations of Table 1. A total of five sites were developed and visited, as detailed in the ensuing paragraphs. Photographs that characterize features typical of these sites and aspects of the bedding and padding, support systems, and the breakers for the related construction projects follow later as Figures 2 through 5. Additional photographs that further characterize these aspects of the construction projects follow later in Figures 6 through 9.

Project One

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[7] Foam supports (also termed benches, pillows, cushion-cradles) have been available to the pipeline industry in precast form since at least the early 1960s[(38)], and in-situ sprayed form since the 1980s[(e.g., 39,40)].

This project involved construction of a large diameter pipeline coated with fusion-bonded epoxy (FBE) running through the North-Eastern US. Construction through rocky areas on multiple spreads by different contractors used Dynapad and Ozzies Padders, which made this a potentially useful site. This also was an attractive site as the owner and the contractor on one spread agreed to the use of preformed foam benches and the use of geotextile fabric, at least over a short run of the pipeline. The spreads involved construction in soils of mixed clay and rock through quite hilly terrain. Figure 2 presents a sequence of photographs that capture features along the RoW, from the ditching through the construction and restoration for this project.

The ditch on all spreads was created with backhoes and because of the large rocks present had variable width and occasionally uneven depth. Because of this, and the larger diameter of the pipeline, there was a significant amount of material required to meet the bedding and padding specifications. Spoil piles were created over an existing pipeline along some portions of the construction. While there were differences in the mix of soil and rock in these spreads, the difference was not significant. Rock sizes ranged from usual rounded stone and boulders, in sizes that in some cases were up to several feet across. The relative fraction of usable material in the spoil piles that lay near the ditch that was acceptable according to company specification was roughly 60 to 75 percent by volume, depending on location along the right of way.

These spreads were well suited to the purposes of this project as they involved two different machines for padding pipelines, both of which were designed to extract fines from native backfill located adjacent to the pipeline. The downside for these spreads involved the short notice of their availability just prior to initiating the project contract. This limited the time on these spreads and the preparations possible for these visits.

Project Two

This project involved construction of a large diameter pipeline through the South-Western US that was coated with FBE. Four spreads, labeled herein as A through D, were considered for the period of the visit. The right of way ranged from hard rock in some areas, through sand in others. Figure 3 presents a sequence of photographs that capture features along the RoW, from the ditching through the construction and restoration for this project.

The ditch on spreads involving softer soils and sandy conditions was created with backhoes, while that through the rock used mechanical trenching, although a few short sections were shot. The transition from rock into more workable soils appeared to occur rather abruptly in most cases. Where the ditch was machine cut, it was rectangular and sized consistent with regulatory requirements and company specifications, and the spoil was rich with fill material of a consistent size and shape that comprise acceptable backfill. In the short sections where the rock was shot, the ditch was randomly shaped with depth to comply with regulations and width much wider than required by company specifications, and was without useful spoil. Trenching through the softer soils provided rich spoil. The depth of the trench was consistent and as required by regulations. The width also was rather consistent and wider than required, being apparently controlled largely by the strength characteristics of the soil. Generally, the spoil piles were laid away from the existing pipeline.

Where the ditch size matched regulations and company specification, the required backfill was minimized, but where the ditch size was variable and much greater than necessary, there was a

a) lowering-in for a sag tie-in in hilly terrain

b) lowering-in for a tie-in in flatter terrain

c) prior to sag tie-in in hilly terrain

d) padding a sag after a tie-in in rolling hills

Figure 2. Views on two spreads of Project One

a) lowering-in on flat terrain

b) lower-in before a tie-in in flatter terrain

c) after a sag tie-in in rolling hills

d) starting to lower-in through hilly terrain

Figure 3. Views on three spreads of Project Two

e) rock shards on working side of shot ditch

f) wheel-hoe ditch through softer flat terrain

g) lowering-in through rolling terrain

h) lower-in after a corner tie-in in flat terrain

i) after corner tie-in in flat terrain

j) sprayed in-situ breakers on a gradual slope

Figure 3. concluded

significant amount of material required to bed and pad the pipeline. In areas that involved a machined ditch or the construction was through softer soils, the relative fraction of usable material in the spoil piles created was virtually 100 percent. In contrast, in the short sections where the rock was shot there was virtually no useful material. However, more than ample useful material was available from the spoil piles adjacent to these sections.

Construction on multiple spreads by different contractors used Ozzies Padder and an Outlaw padder in rocky areas, making this a potentially useful site. This also was an attractive project as contractors were using sprayed foam benches and foam padding up the walls during lowering-in. The spreads involved construction through quite hilly terrain, which necessitated many tie-in welds to join previously welded pipe-strings. These spreads were well suited to the purposes of this project as they involve two different machines for padding pipelines, both of which were designed to extract fill material from native backfill located adjacent to the pipeline.

Project Three

Project Three is part of the construction underway through mountainous terrain in the East-Central part of the US. The construction involved moderate diameter line pipe coated with polyethylene tape. Figure 4 presents a sequence of photographs that capture features along the RoW, from the ditching through the construction and restoration for this project.

Construction through rocky sections used Dynapad for bedding and padding, but the company and contractor were not interested in using KNI's preformed foam benches or geotextile fabric, even over a short run of the pipeline. The spreads involved construction in soils of mixed clay and flat and rounded rock through moderately hilly terrain.

The ditching was done using backhoes and occasionally had variable width and uneven depth. The soil varied from soft clay largely free of rock, through material that ranged from rounded boulders through flat rocks. The ditch was occasionally quite wide in contrast to the requirements of the minimum company specifications, and also showed some large variations in depth. For this reason in some places there was a significant amount of material required to bed and pad the pipeline. There were long runs free of rock, and a few stretches that were quite rocky, with the transition between these areas being quite abrupt. There were differences in the mix of soil and rock in these spreads, which depending on the location were quite significant. Where rock was present, the sizes ranged from smaller rounded stone and boulders, to flat rock that occasionally was several feet across. The relative fraction of usable material that was acceptable according to company specification where rock was present was roughly 60 to 70 percent by volume.

These spreads were well suited to the purposes of this project as they presented the opportunity to observe Dynapad to balance the quite extensive opportunity to observe the Ozzies Padder provided by the second project.

Project Four

This construction runs through spreads in the mid-West of the US and involved moderate diameter line pipe coated with FBE. Figure 5 presents a sequence of photographs that capture

a) prior to lowering-in through wetland **b) lowering-in through rolling terrain**

c) lowering-in downhill prior to creek crossing **d) starting to lower-in down a steep slope**

e) sandbag breakers down a gradual slope **f) broadened ditching through a corner**

Figure 4. Views on two spreads of Project Three

a) lowering-in in some of the flatter terrain

b) construction through rolling hills

c) in-situ foam breakers in hilly terrain

d) in-situ foam breaker on a gradual slope

e) laid in on sandbags prior to a steep hill

f) trenching through some of the sharper rock

Figure 5. Views on two spreads of Project Four

features along the RoW, from the ditching through the construction and restoration for this project.

The project involved spreads where the bedding and padding in rocky areas was done using an Ozzies Padder. The spreads involved construction over moderate rolling hills in soils of mixed clay and rock, through some heavily rocky areas. Where rock was present, the sizes ranged from smaller rounded stone and boulders over a broad range of sizes, through some large flat and quite angular sharp rock. The project involved spreads where the bedding and padding was done using an Ozzies Padder. The spreads involved construction over moderate rolling hills in soils of mixed clay and rock, through some heavily rocky areas. Where rock was present, the sizes ranged from smaller rounded stone and boulders over a broad range of sizes, through some large flat and quite angular sharp rock.

Ditching on all spreads was done with backhoes with spoil piles created either side of the ditch. Because of the large rocks found in some stretches, the ditch had variable width and depth, with occasionally quite deep sections. Because of this, there occasionally was a significant amount of material required to bed and pad the pipeline. There were significant differences in the mix of soil and rock along these spreads, which depending on the location were quite significant. The relative fraction of usable material that was acceptable according to company specification where rock was present was roughly 50 to 60 percent by volume.

These spreads were well suited to the purposes of this project as they involved use of foam-sprayed trench breakers, which for some would be considered new technology, and provided for observations of bedding and padding under wet conditions.

Project Five

This construction also was located through portions of Eastern US where the topography and geology were similar to that of Project Four. Because this construction was concurrent in time with Project Four, and in reasonable proximity to it, a visit to these multiple spreads could be accomplished under the same travel plan. This construction planned to use Ozzies Padders where rocky conditions necessitated bedding and padding. As this construction ran through similar conditions as Project Four where Dynapad was used to deal with its rocky areas, a visit to this project was potentially useful. These spreads anticipated soils of mixed clay and rock in quite hilly terrain. Unfortunately, while these spreads ran through areas comparable to Project Four, this construction did not present enough rock to necessitate use of bedding and padding equipment, nor was there much opportunity to significantly add to the prior observations. Consequently, after a brief site visit to assess the potential value of further observations, the visit was abandoned.

Observations, Data, and Discussion – Tasks Three and Four

The objective of Task Three was to gather qualitative and quantitative data characterizing the metrics identified earlier, through field observations and discussions with industry experts, observing the strengths and weaknesses of current, emerging, and new equipment or practices. The objective of Task Four was to evaluate this data, and develop trends. Photographs that characterize features along the spreads that provided this data can be found in Figures 2, 3, 4, and 5 for Projects One to Four, respectively.

Project One

As indicated earlier, this construction involved large diameter line pipe that in the vicinity of the construction visited apparently used dual-layer Scotchkote coating. The ditch on all spreads was created with backhoes and because of the large rocks present had variable width and occasionally uneven depth. Because of this, and the larger diameter of the pipeline, there was the potential to need a significant amount of material to meet the bedding and padding specifications. The active spreads were being built by different contractors, which where rock was encountered were using either an Ozzies Padder or a Dynapad machine. Because these spreads were active through areas involving rock encountered just as this project was initiated, the planning and time on-site was limited. Because of the scheduling of this visit relative to the project startup, this work was done prior to completion of the protocol and reporting forms presented in the appendices, and in part served as a guide to improve what had been anticipated for these aspects. The majority of the observations reflect operations with largely dry spoil. In contrast to areas where the spoil was dry, in limited areas where the spoil was wet the bedding and padding process was slowed for both contractors.

Dynapad Spread

Equipment and Personnel

- One Dynapad padder
  - One backhoe serving the padder
  - One bulldozer
  - Four people involved in bedding and padding operations, and related restoration.
    - One operator on Dynapad
    - One operator for the backhoe
    - One operator for bulldozer
    - One site manager walking with equipment

Supports (Sandbags)

- The typical number of sandbags varied from support to support, ranging from three to six in the soft soil areas. More sandbags were used in instances where rises, sags, and turns occurred, to accommodate inconsistencies in ditch depth and places where bends in the pipe-string apparently did not neatly match the ditch profile.
- The center-to-center distances varied widely from terrain to terrain. In rocky and hilly sections the bags were spaced more consistently.

Supports (Foam Benches)

- Foam benches were set over the ditch bottom on a short stretch of the RoW in advance of lowering-in through that section. These benches were precast and apparently made of polyurethane foam whose formulation was not made available. All benches had a fixed thickness, width and length, being the order of several feet long and roughly one foot square. Shims were also available. As these benches were light-weight and easily handled, discussion on site indicates their placement is simple and requires only a light truck and two laborers (driver and setter). By virtue of their apparently disorganized placement prior to lowering-in, a laborer would be needed to reset them while lowering-in. Their constant thickness and width would result in inconsistent support to the pipe

because of the variable depth of the trench due to the presence of large rock encountered during ditching. This necessitated use of foam shims, which likewise are placed during lowering-in.

Breakers

- There was no opportunity to observe breakers during the short time on the spread.

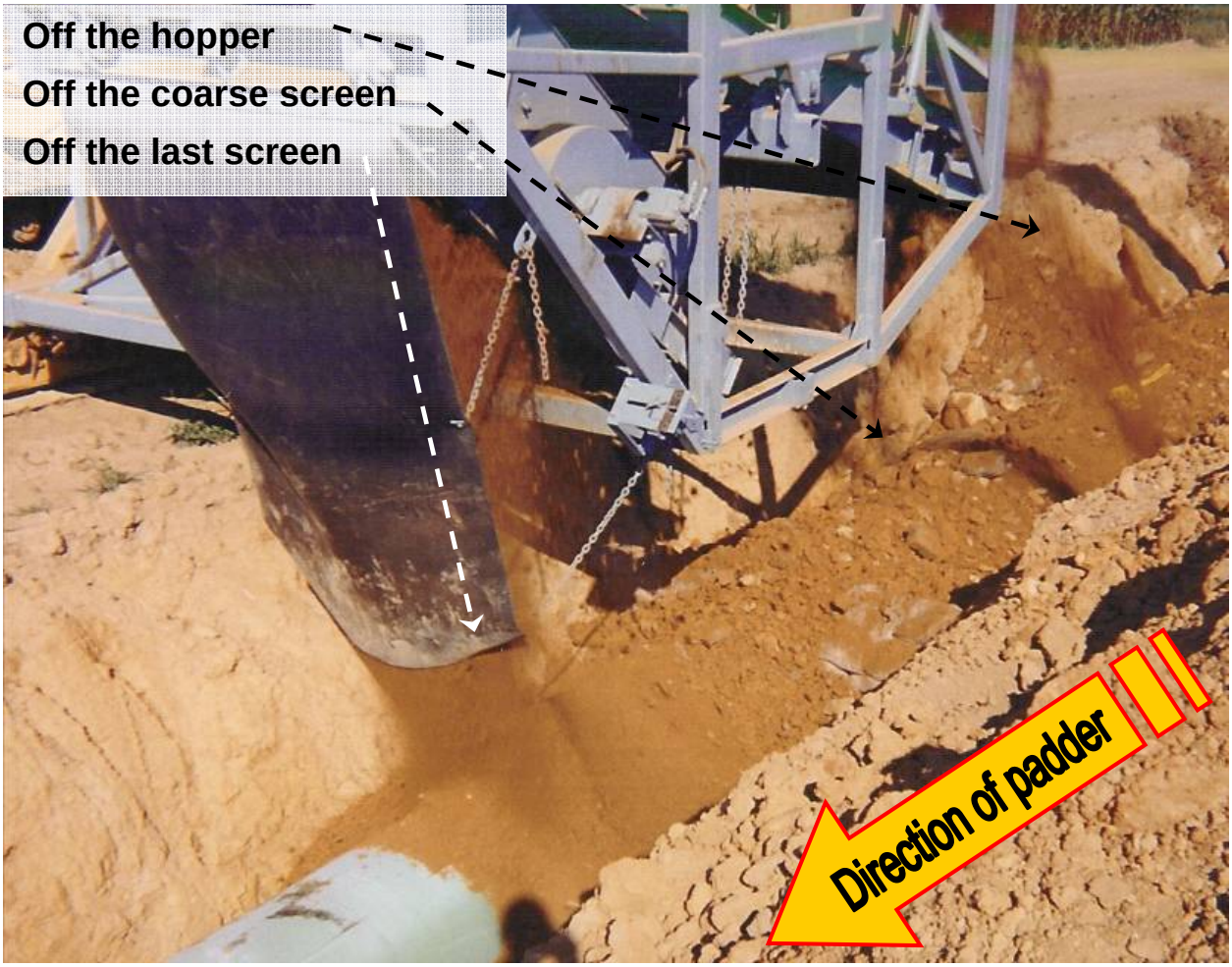
Bedding and Padding Operations

- The Dynapad machine is an inclined vertically stacked processor of spoil that uses multiple screens to separate and grade spoil and deposit successively coarser fill material over the pipe-string. Details of its operation and function can be found in Appendix A. The design causes the finest fill material to fall first onto the pipe-string, with coarser material deposited sequentially along the pipe-string. Where ample fines are accessible to the backhoe feeding the machine, the deposit off the last screen can create a layer whose depth ranges from six to twelve inches deep (on average), which is followed by successive layers of increasingly larger fill material and rock, the last comprising material that did not pass the bars above the hopper. Because the hopper is fed by backhoe, spoil can be selected whose maximum size suited the requirements for the job. Figure 6 illustrates the axially sequential deposit of coarser fill material developing layered backfill from Dynapad. Figure 6a shows the process underway in steady-state operation while Figure 6b is a view of the results after a start-stop cycle for one bedding and padding run.
- The size of the trench relative to the pipe was measured in several areas where the pipe had been lowered-in. In some places the width of the ditch was two to three times the diameter of the pipeline. This was much wider than the minimum width based on company specifications, which based on discussions with help on-site typically required twelve inches more than the outside diameter of the pipe on either side of the pipe-string.
- Based on limited site observations, the Dynapad was used over stretches where rock was present. The decision to use the padder was that "rock was present," although the contractor's representative had no quantitative basis for the decision, which apparently is the usual scenario. Stretches of soil where minimal to no rocks were present were padded with backhoes from the spoil pile based on comments from the crew, with the grade and other restoration not observed but likely done by bulldozer.
- Forward progress was measured over several rocky stretches, which varied depending on the geology and topography/geography. Through flat and straight stretches relatively rich in fines, Dynapad produced 216 and 350 feet per hour on average in two stretches, but slowed to about 170 feet per hour where the backhoe reached for good fill material.
- Because of the reach of the backhoe, the Dynapad could feed its hopper from a wide range of spoil, which for this spread permitted the pipe-string to be padded in one pass. The layered backfill from this single pass developed bedding, padding, and cover for the pipe-string of at least two feet, with upwards of three feet deposited in some locations.
- The ability to select fines by loading independently through a backhoe means that with appropriate spoil selection startup can proceed with only fines deposited into the ditch. Backhoe operator skill in this context is essential to limit damage to the coating until forward progress develops the layer onto which the coarser fines and other material can be deposited subsequently.

- Because the last screen deposits fines onto an already existing layer once steady-state operation develops, and because the spoil was dry, the fill material flows freely onto, around, and underneath the pipe leaving little unfilled area except below the invert. Continued flow of the fill material appeared to fully fill this area, and also compact the backfill by virtue of the weight of the overburden, leaving little to no discernable void.
- The padding operation involved one Dynapad padder, one backhoe, and one bulldozer. No tie-ins were done while on-site, so there was no way to observe how such areas were dealt with.

Layered Backfill, Coating Condition and Possible Damage

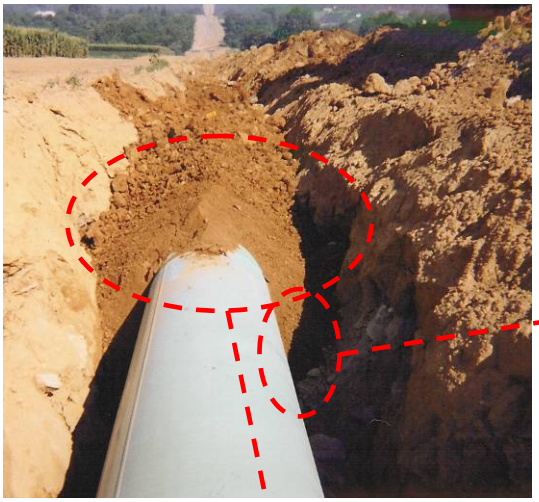
- Because of the limited preparation time, there was no opportunity to obtain jeeping equipment. However, during start-stop cycles, the contractor allowed entry to the ditch, which facilitated periodic evaluation of coating quality as well as the nature of the layered backfill. For this job the light-weight Dynapad could work on either the shoulder of the ditch, with access to the main spoil pipes deposited over two hot pipelines operating in this RoW. The initial screen's mesh size and gravity feed of the material that drop to and impact the pipe off the last screen are anticipated to minimize coating damage and develop a compactable layer because of the rather small size of the fines deposited off the first screen. This was observed, along with the anticipated layered backfill created by successive deposits due to the multi-screen design of this machine. This is evident in Figure 6b.
- The fill material off the fine screen dropped around the pipe, with the hopper fed until the pipe-string was covered, after which the fill material were observed to flow forward enveloping the pipe-string over a distance of several feet. No operator "technique" was necessary for Dynapad, as the amount of fill material available at startup did not require forward motion to supply feed for the hopper, nor was operator technique needed to ensure that material adjacent to the pipe-string was comprised of fines. However, skill is necessary on the part of the backhoe operator as high-quality fill material must be found to ensure nothing comes off the hopper or the coarse screen until the first layer is created. Flow of the fill material forward along the pipe-string once the pipe-string is enveloped is controlled by soil mechanics through the angle of repose for the soil[35], which depends on the nature of the soil, including the size and to a lesser extent the shape of the fill material. The extent of this flow as it enveloped the pipe for Dynapad is evident in Figures 7a and 7b. A bedding and padding machine that provides for these aspects should supply well compacted fill that flows around the pipeline, with the least chance for coating damage. Forward flow of the backfill and the natural selectivity for coarser material to roll down the slope created by the angle of repose has been understood for decades as fundamental to success in bedding and padding[41,42], and a design parameter for such equipment. A major advantage of the Dynapad lies in its use of independent loading that facilitates selection of spoil that is rich in fines without the need to move forward along the ditch, as this facilitates startup of the bedding and padding process without concern for coarser material contacting the pipe-string.
- Whether or not damage is done depends on the resistance of the coating to impact and other forms of contact as well as the energy and the nature of the contact. Nevertheless, a machine that limits contact is a hedge to avoid coating damage during construction. So long as adequate cover is developed over an initial section of the pipe, and subsequent fill



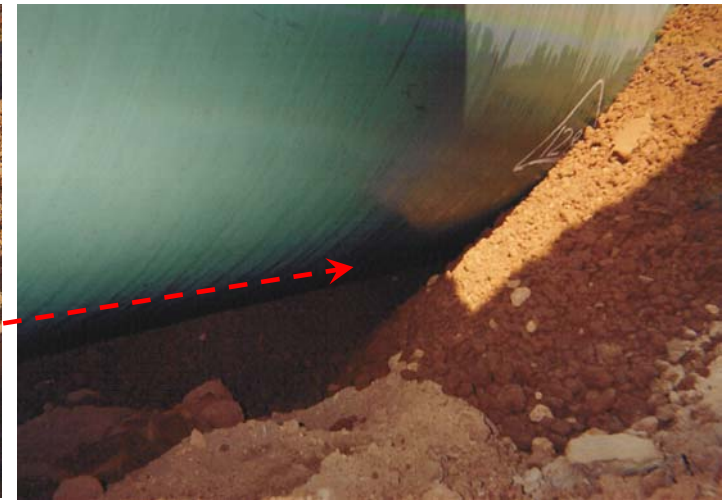
a) axial sequential deposit of increasingly coarser fill material deposited

b) layered backfill, with increasing depth of cover as the layers are added

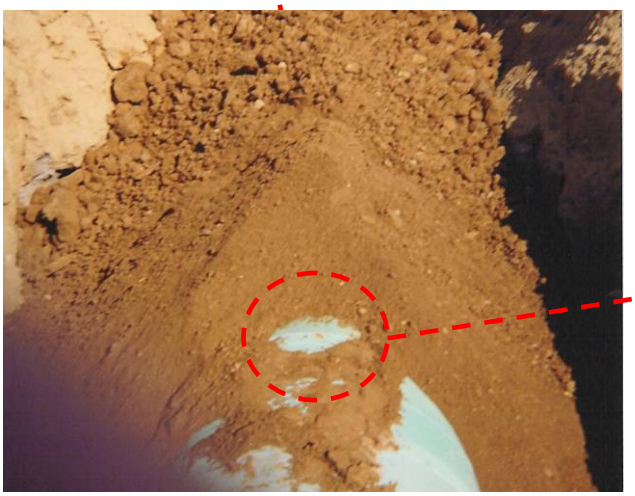
Figure 6. Views of the fill material deposited by Dynapad



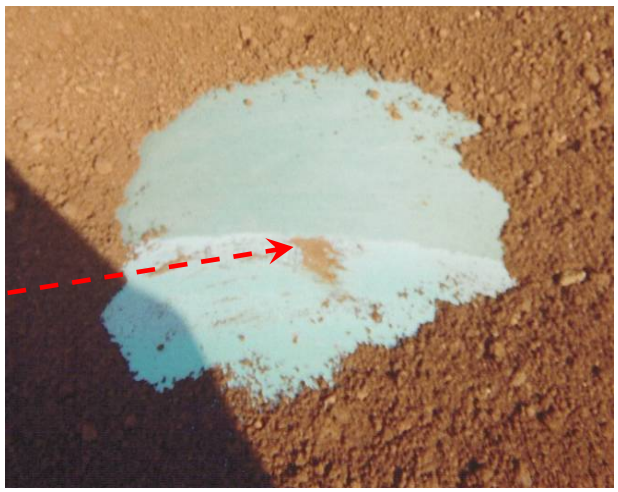
a) typical coverage after one pass



b) flow of fines enveloping the pipe-string



c) overview for image in part d)



d) view of coating below the first layer of fill

e) warning tape installation

f) beginning to lay-in geotextile fabric

Figure 7. Aspects of bedding and padding with Dynapad and elements of the KNI System

g) lowering-in onto sandbags

h) lower-in onto patent-pending foam benches

i) overview of pipe settled onto foam benches

j) close-up view of pipe settled onto foam benches

Figure 7. concluded

material flows forward and envelops the pipe, the fill added should cause no chipping or other coating damage. Success in this context is largely dependent on fill that flows freely, which occurs most easily for dry fine fill material.

- Physical inspection showed the initial layer deposited was comprised largely of earth for this jobsite. The leading edge of the fill material was loosely compacted, but a foot back where additional material overlaid the fines, physical inspection of the fill deposited over the crown of the pipe-string showed the deposit was compacted.
- Physical inspection where the fill over the crown of the pipe was removed as possible during period stop-start cycles showed a coating that looked as it did prior to the bedding and padding process, with no evidence of nicks or chips. The views in Figures 7c and 7d illustrate the nature of periodic visual inspection that was possible on this spread. Padding material was not obtained for sampling at this site due to the limited time available to facilitate such studies. Other views of interest are in Figures 7e to 7j.
- The depth of the padding developed because the hopper can be filled without forward progress coupled with the double layering of increasingly coarser fill material kept large rocks coming off the back of the hopper from reaching the crown of the pipe-string, and appeared to likewise limit this during subsequent backhoe-backfill operations. Figures 7e and 7f present views of the ditch after it has been filled, as does Figure 7a.
- While not specifically observed, the Dynapad operator indicated that on a good day, and with a skilled backhoe operator, upwards of 9000 feet could be covered over flat stretches during a typical day-long shift. This claim cannot be substantiated, and is included only for the sake of completeness.
- In stretches through sag areas where because of the topography the spoil was wet, the hopper appear to be prone to clog, which slowed the process and limited the flow of fill material, with some clumping being evident in the material deposited off the last screen. Similar operation with wet spoil was confirmed by discussion with the operator.
- Areas where the ground was hilly revealed that the design of Dynapad limits its motion to one direction unless its mainframe was rotated. Likewise, if it is traversing hills with widely varying angle, the efficiency of the machine could vary. However the machine provides for adjustment to level the mainframe. Other concerns can be remedied by working machines in opposite directions such that gravity causes the large rocks to roll toward the already padded pipe. Such is the case for all machines, becoming more acute as the incline-angle of the screen increases.

Backfill Operations

- The backfill process was accomplished with a backhoe drawing fill material from the spoil piles. The padding had sufficient depth to preclude large rocks from reaching the crown of the pipe-string.
- A bulldozer was apparently used to top-off the trench after the backhoe was finished.

Ozzies Padder Spread

Equipment and Personnel

- One Ozzies Padder
- One bulldozer creating windrows of spoil serving the padder

- One backhoe as required to supply the bulldozer as needed
- Four people involved in bedding and padding operations, and related restoration.
    - One operator on the Ozzies Padder
    - One operator for the backhoe
    - One operator for bulldozer
    - One site manager walking with equipment

Supports (Sandbags)

- Although the contractor was different on this spread, practices associated with sandbag benches were similar to the Dynapad spread. Foam benches were not used over any portion of this spread.

Breakers

- As for the Dynapad spread, there was no opportunity to observe breakers during the limited time on the spread.

Bedding and Padding Operations

- The Ozzies Padder is an in-line integrated loader and processor of spoil that couples a single inclined shaking screen fed by a conveyer located behind an articulated mouth at the front of the machine. The screen for this job had a clear spacing of about two inches on a side. The articulated mouth provides limited manipulation to broaden access and/or aid selection of backfill material. The machine operates on the shoulder of the ditch parallel to the pipe-string, feeding select fill to the ditch by a conveyer table collecting fill material from the screen and delivering it to the ditch. This table can be extended from the machine toward the ditch. Access to spoil is controlled by the fill material available from a linear track through the spoil windrow. Spoil available in the windrow was enhanced on this spread by "roaching" using a bulldozer to add fines material where possible and narrow the windrow to better match the mouth of the padder. Material rejected is dumped off the screen in the wake of the machine, leading to diminished returns if a second or third pass is required – unless material is added to the windrow or the windrow reshaped with spoil that was not used on a prior pass. For this spread, the largest Ozzies Padder was used, the weight of which kept it off the main spoil pile that during trenching was placed over two adjacent hot lines in this RoW. This affected efficiency, as it limited the supply of available spoil. Other factors include the large diameter of this pipeline and the uneven larger ditch due to the rock, both of which contribute to the amount of acceptable material required to meet company-specified cover. Bedding and padding reaching the pipe appeared to be homogenous in size and constituents throughout the cover. The cover appeared to be softer and penetrated more easily by large rocks that occasionally are placed over the cover as the ditch is backfilled, although the observations supporting this in contrast to Dynapad are limited.
- The size of the trench relative to the pipe was measured in several areas where the pipe had been lowered-in. In some places (other than where tie-ins were made) the width of the ditch was more than two but much less than three times the diameter of the pipeline. This was wider than the minimum width based on company specifications, which based on discussions with help on-site typically required twelve inches more than the outside diameter of the pipe.

- Based on limited site observations, the Ozzies Padder was used over stretches where rock was present. Again, the decision to use the padder was that "rock was present," although there was no clear quantitative metric for the decision. Discussion indicated that areas where minimal to no rock was present were filled with backhoes from the spoil pile, with the grade and other restoration done by bulldozer.
- Forward progress was measured over one straight stretch rich in fines, which on average indicated the Ozzies Padder produced 300 feet per hour. Where multiple passes were needed as the spoil was low in fill material and the ditch was broad, productivity dropped in proportion to the number of passes made. Production in such cases slowed to 192 feet per hour to a low of 76 feet per hour for two stretches observed, with a backhoe used to transfer spoil to the side of the ditch being padded and the spoil being roached by a bulldozer for the lowest of these rates. However, where the spoil was rich in fines, a single pass provided bedding, padding, while a second was used to provide cover for the pipe-string, the latter reaching depths of one to two feet. Figure 8 presents views of the padding process for Ozzies Padder.
- Once the bedding and padding process was started, fill material off the screen flowed freely underneath the pipe, with little unfilled the area except below the invert. Continued flow of backfill appeared to fully fill this area, and also compact the backfill by virtue of the weight of the overburden, leaving little to no discernable void. This is evident by the flow out from under the pipe-string over the course of the first pass, as shown in Figure 8a, and the extent of the fill that fully occupies the space below the pipe, as shown in Figure 8b. In steady-state operation, the fill either is placed onto the material deposited with the first pass, or is projected off the ditch-wall or into the space between the pipe and ditch to limit contact with the pipe-string, the latter being evident in Figure 8c. The larger material rolls off these fines ahead of what remained close to the pipe, and into the ditch bottom. Excellent photographs of this behavior were captured under good lighting for the second project, and are shown later where that project is discussed. Consequently, while not inherently designed to produce layering of the deposited fill, in steady-state operation the coarser material "rolled" ahead of the fines to fill areas remote to the pipe, while fines remained near the pipe. However, such did not occur during startup when the generally uniform fill material fell or was projected off the conveyer table randomly onto the pipe. During this startup and over the first few feet of travel larger rocks that passed the screen could fall directly onto the pipe-string.
- During the startup phase, the fill material serving as bedding flowed freely underneath the pipe, with little unfilled area except that below the invert. Continued flow of the fill material appeared to completely fill this area, and also compact the backfill by virtue of the weight of the overburden, leaving little or no discernable void.
- No tie-ins were done while on-site, so there was no chance to observe this aspect.

Backfill, Coating Condition, and Possible Damage

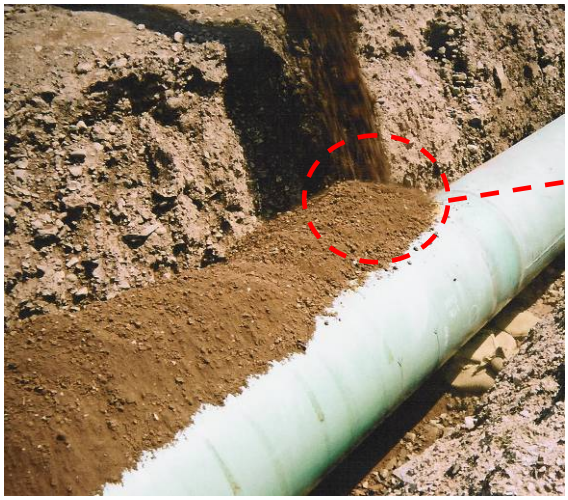
- Because of the limited preparation time, there was no opportunity to obtain jeeping equipment. However, the start-stop cycles associated with repositioning of the machine for a second or third pass, the contractor allowed brief entry into the ditch to periodically evaluated coating quality as well as the nature of the backfill. For this job the Ozzies Padder worked the line of the lesser spoil piles laid on the side of the ditch away from the two hot pipelines, or occasionally from an elevation several feet above the shoulder of the

ditch, up to as much as about six feet for the operations observed. Based on one startup observed, fill material passing the screen was allowed to impact the pipe, with occasional impacts occurring squarely at the crown. However, while not inherently designed to produce layering of the deposited fill, during steady-state operation the coarser material "rolled" ahead of the fines to fill areas remote to the pipe, while fines remained near the pipe. Industry experts associated with companies that sell or operate such equipment note this inherent property of the fill material as a key to the success of such equipment[e.g., 37,38,39,40]. It follows that little damage is anticipated during steady-state operation because the already present fines limit direct contact and the larger material rolls harmlessly down to the ditch bottom. However, damage might be anticipated during startup and the first few feet of the bedding and padding operation unless the spoil is roached selectively to limit this problem.

- Operators and personnel working with the Ozzies Padder note that the richest zone of fines tend to lie toward the bottom and center of the spoil[43,44], such that an effort is made to articulate the mouth of the padder into this area during the startup phase. Also during startup, this operator indicated damage can be limited by directing the flow from the conveyer table against the far wall of the ditch, filling that side with overflow onto the top of the pipe-string, followed by flow onto the now covered crown to fill the side adjacent the padder, such that the flow into the trench does not impact the pipe.
- Thus, in spite of direct contact even on the crown of the pipe as noted above, operator technique is central to avoiding coating damage during construction. Operator "technique" gained through experience or training is particularly important to maximize the amount of fines available at startup and minimize possible damage by directing flow away from the crown of the pipe at startup, but is much less important during steady-state operation. Avoiding damage during startup can be complicated by the fact that forward motion is needed to supply feed to the screen.
- As discussed for Dynapad, flow of the fill material forward along the pipe-string once the pipe-string is enveloped is controlled by soil mechanics through the angle of repose for the soil[35], which depends on the nature of the soil, including the size and to a lesser extent the shape of the fill material. Thus, as noted earlier, any bedding and padding machine that satisfies these aspects should supply well compacted fill that flows around the pipeline, with the least chance for coating damage. Forward flow of the fill material and the natural selectivity for coarser material to roll down the slope created by the angle of repose has been understood for decades as fundamental to success in bedding and padding[41,42], and a design parameter for such equipment. While an important parameter, whether or not damage is done depends on the resistance of the coating to impact and other forms of contact as well as the energy and the nature of the contact. Nevertheless, a machine that limits contact is a hedge to avoid coating damage. So long as adequate cover is developed over an initial section of the pipe, and subsequent fines flow forward and envelop the pipe, the fill added should cause no chipping or other coating damage. Success in this context is largely dependent on fill that flows freely, which occurs most easily for dry fine fill material. Figure 8c illustrates one technique often used for the second pass on this spread, while Figure 8d shows the ditch after the second pass is completed (viewed in the direction of padder advance). This figure also illustrates the type of material in the fill mix, which here runs from fine earth through small rounded

stones and occasionally sharper rocks. Figure 8e illustrates the rock typically excluded by this padder on this job, which the photo shows included some large rocks.

- Physical inspection showed the steady-state layer deposited by the Ozzies Padder was a mix of small stones and earth for this jobsite. The leading edge of the fill material was loosely compacted, as was the material a foot or more back, in spite of additional material being overlaid. While physical inspection of the fill deposited over the crown of the pipe-string showed limited compaction, the weight of the eventual overburden deposited during final backfill and restoration is very likely to achieve high compaction. Because the contractor recognized the importance of the startup phase there was reticence to stop the process to permit ditch entry. Consequently, it was not possible to determine either the nature of this deposit nor observe the pipe's surface under conditions characterized by this aspect of the process. But this is not a big issue, as were such results available they could not be generalized beyond the specific situation observed because the results in this phase of the process are dependent on operator experience and skill.
- Physical inspection where the fill over the crown of the pipe was removed was possible for steady-state operation at the conclusion of a padding run, or a stop-start cycle. Such examination showed a coating that looked as it did prior to the bedding and padding process, with no obvious evidence of nicks or chips. Figure 8f shows one patch exposed near the leading edge of the cover on the crown. There was no evidence of chips, and the shine of the finish coating remained when the dust was washed off.
- Padding material was not obtained for sampling at this site due to the limited time available to facilitate such studies.
- The depth of the padding developed is a clear function of the fraction of fill material available and forward speed.
- While not specifically observed, the Ozzies Padder operator indicated that upwards of 7500 feet could be covered over flat stretches during a typical day-long shift on a good day, and with a skilled bulldozer operator (that perhaps was supported by a backhoe operator). This claim cannot be substantiated, and is included here for the sake of completeness.
- Where the Ozzies Padder runs through a sag where because of the topography the spoil was wet, the screen appeared to be prone to clog, which slowed the process and limited the flow of fill material. Some clumping also was evident in the material deposited as it rolled down the leading face of the bedding and padding.
- Areas where the ground was hilly revealed that the design of the Ozzies Padder limits its motion to one direction unless the feed table is shifted, as allowed for in its design. If it is going up a steep hill, there is the possibility of large rocks falling off the screen on top of the already padded pipe-string. Such applies to all padders, becoming more acute as the incline angle of hill increases.



a) technique and coverage for first pass **b) flow of fill material enveloping the pipe-string**

c) technique and laying of a second pass **d) view of cover from two passes**

e) rock in the wake of the padder **f) view of coating below the cove**

Figure 8. Aspects of bedding and padding with Ozzies Padder

Backfill Operations

- The backfill process was accomplished with a backhoe drawing fill material from the spoil piles, operating in conjunction with a bulldozer to top-off the trench. The padding appeared to have sufficient depth to preclude large rocks from reaching the crown of the pipe-string.

Project Two

Spread A

This involved a large diameter line pipe with dual-layer Nap-Gard coating. This pipe was laid in a largely machine ditched trench, although some short sections involved shot rock.

Equipment (padding operation)

- Three Ozzies Padders – two model 200, one model 300
- Two Outlaw padders (support for Ozzies Padders)
- One auger dozer (backfill)
- Two bulldozers (backfill and roaching)
- Approximately 14 people were involved in operating this equipment or supporting its operation

Equipment (lowering in)

- Four side booms

Equipment (other)

- One paddle hoe (backfill for leveling later by bulldozers)
- Numerous small water trucks (counted eight at one time; others in route returning and leaving, several large water trucks - Clark County requirement for dust control)
- One foam truck – crew of three, technician (company), foamer and driver (contract)

Supports (Foam Benches Only)

- Polyurethane foam (two-part) supplied by subcontractor Pedero Pipe Support Systems (Alberta, Canada) www.pedero.com . This foam was used as site-formed pillows, as well as sprayed in-situ across ditch-bottoms as benches, and also used sprayed in-situ on the ditch walls as a "reverse-rock shield," protecting the pipe from contact with the ditch-wall during construction. Typical views of these three items are found in Figures 9a, 9b, and 9c, respectively.
- Bench spacing on straight runs was about 18 feet (paced by the operator), with height ~18 inches, width ~12 inches, and length equal to the width of trench. The height and width are approximate indications of actual size. As the benches were spray-formed from the top of the trench, these dimensions varied. The operator indicated he attempted to track a continuous profile consistent with the topography, which was achieved to varying degrees. Spacing tended to be closer at corners, over-bends, and sag-bends, with the reverse-rock shield applied in a heavier layer in the corners.
- Discussion with the technician of one truck indicated they can spray-form foam benches at a rate of about two miles per day on average – or about 587 benches at 18 foot spacing.

This rate seems high, as it corresponds to a bench every ten minutes over a 10-hour working day, without consideration of time to re-supply raw foaming materials. Moreover, it is faster than the observed production rate at least as evident during our observation period.

- Discussion with Peter Ellis (Operations Manager and son of company President) indicated the following facts about their process:
  - Two basic types: open cell and closed cell. Closed cell much better, open cell structure is more porous/pervious.
  - Foam temperature due to exothermic chemical reaction was approximately 175°F.
  - The foam "solidifies" in seconds, with strength developed over its cure time, which was one to two hours.
  - The design density was set at 2.2 lbs/ft^3, leading to great compressive strength (although localized failures evident from time to time suggests otherwise). Design density is based solely on diameter/wall thickness (weight) of pipe.
  - Decomposes under UV light (sunlight) and water saturation (reference to breakers), but this is a long-term process. The almost immediate discoloration of the outer surface of the benches was explained on-site as sunlight-induced.
  - Density can be altered by design, but not at the site as the chemical makeup for this property is established and then batched into barrels at the home plant, from where the material is trucked to the jobsite.
- Although the benches (pillows) can be sprayed from the trench top, pre-made or shot into plastic/tarp bags, this job used both in-situ sprayed benches and pillows.
- This spread also used sprayed foam as a reverse rock shield, a layer of foam up to a few inches thick was sprayed up the rock on the trench wall opposite the side from where the pipe was strung.

Lowering-in with relation to benches and reverse rock shield

- Throughout flat straight pipe runs the benches supported the pipe more or less uniformly and with moderate compression in the vicinity of the support.
- Where changes in direction occurred (at corners or vertical bends), cases existed where all benches were not uniformly compressed, and spans existed where the benches showed little evidence of compression, and so carried little pipe weight. This caused the adjacent benches to be more severely compressed. Potential causes for this include:
  - Bench heights not uniform from one to the next, and
  - Bench heights not uniform along their length.
- As these just noted causes for periodic support are equally plausible throughout straight runs where the support was more or less uniform, other potential causes are more likely responsible. More likely causes include:
  - Problems in matching the bend orientation to the ditch profile,
  - Pipe elevation change not matching trench elevation change, or
  - Problems in making tie-in welds.
- However, as the benches are polymeric and so exhibit viscoelastic response, these benches will facilitate continued settlement such that the pipe will settle into the padding over time. Thus, so long as there is sufficient clearance off the trench-bottom and the

bench strength is adequate throughout construction, periodic support is not a practical concern. See Appendix E for further discussion.

- The reverse-rock shield was most effective where it sprayed fully up the side of trench.

Additional Observations for Lowering-In

- Contractor's opinion was that the foam benches were much quicker and less manpower intensive than more traditional sandbag method.
- The bench crew was found to be much faster than pipe could be lowered in, as this crew indicated it was often miles ahead of lowering-in.
- On spreads with significant hills and valleys, causing pipe to be strung and joined into many sections, the rather tedious process of tie-in welds appeared to dictate construction progress, with other issues apparently secondary drivers for completion of the spread.

Bedding and Padding Operation

- Three Ozzies Padders were on-site, with a larger 300 model working in front of smaller 200 models. A double tandem scheme was common, with the third smaller padder available as backup for double tandem use, or for use in a triple tandem, or for dealing with tie-ins and other specialty areas. Each Ozzies Padder had a single screen with a clear pitch passing one-inch aggregate per company specifications. See Appendix A for discussion of the operation and function of the Ozzies Padder, which are relevant here, and are reinforced as noted by observations specific to this spread.
- Pipe height over the trench floor at randomly chosen measurement sites indicated distances of 10, 8, 9, 12, and 7 inches.
- Size of the ditch relative to the pipe was varied depending on the type of soil and whether a turn was involved. Straight sections and areas through softer rock were made by a trenching machine that produced a consistent width the order of four feet, which satisfied required minimum width of 12 inches greater than the outside diameter of the pipe. Short straight sections apparently done by a backhoe were about five feet across. Areas through turns, tie-ins, and short sections involving hard rock that was greater shot were much wider than this. The width at the top of the ditch in these areas often was many times the diameter of the line pipe.
- The rate of progress varied relative to spoil and trench width and depth. For example, one hour and 15 minutes was taken to cover a 0.2 mile long stretch through a wide turn. In contrast, the same amount of time was needed to cover a 0.6 mile long straight stretch using one padder along a ditch that was consistently four feet wide. Another similar stretch of 0.9 miles took four hours to complete.
- Where the three available Ozzies Padders worked in triple tandem, three bedding and padding passes could be accomplished in the time required for one, without the need to backtrack to affect the required coverage. Because the spoil pile created by machine ditching was almost all fines, there was no problem in fines supply through these areas. At times, the rear padder would back up somewhat to ensure cover over a section of the pipe higher off the trench floor or where the spoil was heavy in larger rock content.
- In observing the extent of fill, once both sides of the pipe were padded, coverage looked complete, as the fill extracted from the spoil was fine enough to flow in and leave no observable voids.

- The depth of padding above the pipe averaged in the range of 12 to 18 inches.
- Padding material was obtained with a total of four samples, with the laboratory analysis included in Appendix D.
- Because the padding sequence typically involved tandem padders, occasionally followed by auger-dozers, all working linearly in a tight formation, no jeeping was possible as the pipe was fully covered in one pass, without access to areas available during start-stop cycles, or the period where the padder was repositioned for a second or third pass. Figure 9d illustrates an example of three padders in a tight-tandem arrangement working the widened ditch at a corner, while Figure 9e shows a similar tandem arrangement of augers working to close the now padded and covered ditch, to restore the grade. Figure 9f is a view just prior to the practices of Figure 9e.

Additional Observations for Bedding and Padding

- During stretches where there were large rocks present in spoil and the spoil height was large, large rocks were occasionally knocked onto the pipe by the tracking of the padders. While the crew included laborers working along the ditch to intercept such rocks (as can be seen in Figure 9a), and thereby limit contact to the pipe, from time to time the rocks were too large to be stopped by the two-man shovel crew assigned this task. In such cases, the tandem of padders stopped and the assisting crew patched the pipe with a thick application of two-part epoxy, covered by a tape-over, so bedding and padding could resume without concern for the cure time or the possibility padding material would move the patch or adhere to it when they resumed. At least five such patching operations were observed in one day-long shift, although this appeared extreme in contrast to other days.
- On one occasion over the period of observation, a large rock moved by the tracking of the padder rolled down the spoil pile onto a section covered by at least 12 inches of padding. The cover displaced somewhat, but this large and heavy rock did not come close to contacting the line pipe's surface.
- In severe to extreme rock conditions, as occurred with shot rock, the padders were supplied by bulldozers that roached the windrow to supply adequate padding material, with additional fill material coming from the nearby machined-ditch spoil.
- One short ring of pipe discarded from a tie-in provided the opportunity to assess the sensitivity of the dual-layer Nap-Gard to contact with rock. While not scientific, these ad hoc experiments using small rocks located in the RoW provide insight into the resistance of this coating to impact and scraping. The results of these impacts and scrapes showed this coating to be quite resistant to damage, at least at the moderate daytime temperatures of southern Nevada during February when it was in the high 60s (in °F). More formal evaluation of coating damage resistance under parametric contact conditions would develop a quantitative understanding of what contact conditions are problematic, and facilitate developing and validating value-based (performance) specifications to maximize safety in concert with productivity.
- As discussed in regard to Project One, flow of the fill material forward along the pipe-string once the pipe-string is enveloped is controlled by soil mechanics through the angle

a) sprayed-in-situ benches

b) foam pillows installed at a corner

c) reverse-rock shield at work lowering-in

d) three ozzies padders in tight tandem

e) tandem of augers and blades making grade

f) view of padded and covered pipe-string

Figure 9. Further observations on bedding and padding at the Project Two

g) angle of repose and natural size selection **h) as in g), but the runoff of spoil from an auger**

i) reverse-rock shield at work lowering-in **j) three Ozzies Padders in tight tandem**

k) a second pass, filling and building cover **l) a restart, similar to any start-up scenario**

Figure 9 (concluded)

of repose for the soil[35], which depends on the nature of the soil, including the size and to a lesser extent the shape of the fill material. Forward flow of the fill material and the natural selectivity for coarser material to roll down the slope created by the angle of repose has been understood for decades as fundamental to success in bedding and padding[41,42], and a design parameter for such equipment. Figures 9g and 9h illustrate the angle of repose, and also the natural selectivity for coarser material to roll down the slope that comprises the angle of repose. The angle of repose in these figures is evident as the slope that in both cases is about 30 degrees (with due provision for the perspective embedded in the photo). Notice in contrasting Figures 9g, which reflects the flow of fill material into the ditch, and Figure 9h, which reflects flow off the blade/auger of a dozer, that this response in not a consequence of padding or any other process, it simply characterizes soil mechanics.

- Consideration of the Ozzies Padder spread for Project One pointed to the use of operator skill or technique as a requisite of limiting contact with the pipe as a means of avoiding damage to the coating. Three techniques noted then included: 1) laying-in fill material between the pipe and ditch-wall, without direct pipe contact; 2) directing the flow off the ditch wall; and 3) laying-in the padding over fill material already present via techniques one and two. So long as adequate cover is developed, and subsequent fines flow forward and envelop the pipe, the fill added does not hit the pipe directly and so does no chipping or other coating damage. These same techniques were practiced by the operators padding the several spreads for this project. Figure 9i illustrates technique one on a broad corner ditch to create the first pass for this corner. As Figure 9j shows, this technique can be used to lay fill material onto the ditch bottom, which then pipes up side of the pipe and spills onto or over the crown of the pipe-string. Figure 9k shows the second pass being built-up with the third technique, where fill material is flowed onto the cover over the crown from the first pass, which then flows forward to envelop the pipe-string. Finally, Figure 9l shows a restart of padding, where the first technique is used following the spoil being roached to enrich the pile somewhat.

Backfill Operations

- Immediately following the padders, an auger dozer and two bulldozers performed the backfill operation (Figure 9e). From the above-noted observation where a large rock rolled down on the padding, this backfilling procedure would avoid larger rocks coming into contact with the pipe.
- A “paddle” hoe was behind the backfill operation pulling dirt from the original spoil for subsequent leveling at a later time.

Spread B

This involved large diameter line pipe with dual-layer Nap-Gard coating. This pipe was laid in a largely machine ditched trench, although some short sections involved shot rock.

Equipment (padding operation – several locations noted)

- Four Ozzies Padders – two model 200s, two model 300s
- Two Outlaw padders
- Two bulldozers (backfill and roaching)

- Approximately 16 people were involved in operating this equipment or supporting its operation

Equipment (lowering in)

- Four side booms

Equipment (other)

- One paddle hoe (moved backfill for leveling later by bulldozers)
- Numerous small water trucks (required for dust control)
- Two foam trucks – crew of three, technician (company), foamer and driver (both contract employees), and Peter Ellis (Company Operations Manager)

Supports (benches)

- See discussion for Spread A.

Additional Observations for Supports

- A couple of sections used dirt as the material for the benches. When an inquiry was made into this, the reply from Peter Ellis indicated an agreement was reached to allow this because the site boss did not want to lay anybody off, so a make-work job involving benches was created. Company Operations Manager indicated the dirt benches comprised approximately 15 percent of the total, presumably over the length of the spread.

Breakers

- Like the benches, breakers were made using sprayed-in place polyurethane foam.
- These were approximately one foot across at the top tapering out to approximately two feet at their base.
- Some breakers were observed with vertical and horizontal splits in the top section. Crew commentary indicated Pedero personnel made the needed repairs.
- Pedero's website provides reference information and photographs typical of their supports and breakers, which showed more closely spaced breakers than observed at this site. As ditch stabilization depends on many factors, further comment on this aspect absent more details is irrelevant.

Observations of lowering-in with relation to benches

- Comments for Spread A apply here

Additional Observations on Supports

- Some benches seemed less robust as compared to those for Spread A. While this "looks bad", there was no indication it was problematic.

Bedding and Padding Operations

- Notes for Spread A apply here, with the following differences.
- Four Ozzies Padders were used, with two 300 models and two 200 models involved. These padders tended to work independently, which meant that padding required multiple passes through roached spoil to attain the required bedding and padding cover. The 200 model Ozzies Padder often needed three passes to achieve this condition. When a 300

model padder worked in tandem following a 200 model, the required cover was achieved in one tandem pass.

- Where the 200 model padder was used independently, the first two passes impacted the sidewall of the pipe as the voids between the sidewall and the trench were filled to overflow the crown, with one side filled first and then the second side. The third pass supplied cover across the full width of the pipe, with cover depths ranging from 18 to 24 inches.
- See discussion of the Ozzies Padder presented in Project One – Ozzies Padder Spread as well as Appendix A for details of the operation and function of this padder, which apply equally here, and are reinforced as noted by observations specific to this spread.
- Limited straight runs where ditched by backhoe were up to six feet across. In general, ditches in the vicinity of turns and areas involving shot rock were wider as compared to Spread A.
- Forward progress on this spread was difficult to assess, as the several padders on this spread generally worked independent of each other. Accordingly, total forward progress was assessed by considering the padding accomplished by all four padders, which was estimated at about four miles over a three-day period involving a total of four padders. This leads to about a mile per 10-hour shift per padder.
- Padding material typical of that involved was obtained for three samples, with the laboratory report included in Appendix D.
- Because the padding technique involved a start-stop cycle wherein the padders were repositioned for a second or third pass, it was possible to enter the ditch to jeep on two occasions. This was done by driving a four foot copper rod into the ground above the trench. A grounding wire from the portable jeep was connected to this and then thrown into the trenching location. Jeeping was done after climbing down a breaker and then walking the ditch. The first location involved a length of about 32 feet, which comprised the length of the grounding wire in both directions from the copper rod. One coating nick exposing metal was found at approximately the 11 o'clock position, which was about ¼ inch in diameter. This chip was possibly due to a larger rock that rolled down the spoil and contacted the unpadded pipe, which went un-repaired, as other evidence similar features was found along the 32 feet measured. This chip also could be due to handling or other contact, although such is usually repaired in jeeping prior to bedding and padding. The second stretch jeeped was approximately 100 feet in length. This process was aided by a top-side laborer that removed and reset the copper rod while traversing this length of pipe. This jeeping did not identify any coating faults over this stretch. In both cases, this jeeping reflects steady-state bedding and padding operations.

Additional Observations of Bedding and Padding

- Two Outlaw padders also were used locally along this spread, specifically for runs that required bedding and padding very steep grades and tie-ins that previously were bypassed by the Ozzies Padder. Based on limited observations and crew comments, these machines were slower than an Ozzies Padder, apparently because of their design. These padders were supported on and loaded by tracked backhoes, and made use of a bulldozer that roached spoil. This operation involved a crew of four.

- Cover achieved by the Outlaw ranged from 18-24 inches in depth. The unique nature of their use precludes forward progress results under conditions even remotely similar to that for the other machines.
- As was noted for Project One, the observations for this project indicated operator skill or technique is important for the Ozzies Padder, with the results here indicating the only time the spoil directly hit the pipe was during startup. During this time contact was primarily along the sidewalls when the flow into the void between the pipe and ditch wall was being filled. It was noted that the operator works the spoil to fill the ditch at startup, after which spoil flows out across the top of the pipe then begins to proceed forward along the pipe-string. In this approach, spoil coming off the conveyor only hits the pipe during the initial fill, with operation later dropping fill material onto already existing fill that then flows out over the pipe. This provides a couple of inches of fill that can cushion the fall of the smaller aggregate passing the screens used, and thus limits damage to the coating.

Backfill Operations

- Backfilling involved one bulldozer pushing in backfill to restore the grade. A "paddle" hoe was present for later leveling purposes but this process was not witnessed in real time.

Spread C

Work finished on this spread in the week before our visit. Its topography and geography looked similar to Spread D.

Spread D

This construction involved large diameter line pipe with dual-layer Nap-Gard coating. This pipe was laid in a trench dug either by a ditching machine or a backhoe through relatively soft sandy soil.

- This spread was flat for most of its distance and the soil contents were fine akin to sand, which precludes the need for bedding and padding.
- Not surprisingly, no padders were apparent on this spread, although the crew indicated there might have been one somewhere along its length.
- The fill operation was completed by a bulldozer that moved fine spoil back into the trench as is the usual practice. The pace after ditching through lowering-in was comparable to the other spreads, but since there was no bedding and padding operation, the pace through this phase was like that observed in the other spreads during the backfill operation. On this basis, bedding and padding does slow the overall process. But where the topography required many tie-in welds to join the many segments strung and welded between geographic features and crossings, the tie-ins appeared to dictate completion.
- No benches of any kind were necessary, as the usual practice wherein the pipe is laid on the trench bottom was appropriate. The trench bottom was water compacted.
- Some stretches of trench were cut out using the "wheel" hoe (trenching machine), while other sections used a backhoe. The trenches were about 5 feet wide by 8 feet deep where the "wheel" hoe was used and wider when a backhoe was used.

Lessons Learned for Subsequent Visits

- When booking hotels for different spreads, getting one near where the actual work is being done on the spread versus where their offices are would significantly cut down on travel time and allow more time to be spent at the site itself.
- A compact/collapsible ladder would greatly increase ability to enter the trenches for jeeping tests. This allows quick/safe entry and exit and the ability move the copper rod for longer jeeping runs.
- Acquire a longer grounding wire for jeep to increase distance of jeeping before having to reset the copper rod.
- Bring a broom to quickly sweep off spoil from top of pipe to facilitate removing dirt.
- Determine applicable OSHA regulations for entering a trench.
- A voice recorder could increase frequency and detail of notes taken in field versus a journal.
- Ground markers of some sort to more accurately mark locations for distance covered by padders during a time period (hours/day, etc.). If the terrain is flat and free of landmarks, once the equipment is moved and pipe has been backfilled it can be difficult to relocate the exact stop-start locations, especially several days later.

Project Three

This project involved moderate diameter line pipe apparently covered by multi-layer tapecoat.

Equipment (padding operation)

- One Dynapad padder
- Two backhoes (both as padders and/or as backfill)
- One bulldozer
- Nine people were involved in operating this equipment or supporting its operation
    - One operator on Dynapad
    - One operator each for backhoes
    - One operator for bulldozer
    - One Dynapad padding assistant walking with equipment
    - One laborer per backhoe

Equipment (lowering in)

- Four side-booms (three shown, one holding up pipe at tie-in)
- One long sandbag truck (for benches) – driver, four laborers (two on truck, two in trench) and foreman. They were somewhat ahead of lowering-in crew.
- One Bulldozer
- One Marachi – halftrack vehicle with supplementary sandbags, ladders, miscellaneous equipment etc.

Equipment (other)

- One long sandbag truck – driver, four to six laborers and foreman (breakers)
- One metal skid for skids (dragged by a bulldozer)

- One bucket-type hoe, one clamshell hoe (dredging trench in front of lowering-in and behind jeepers and coating crew)

Supports (benches)

- The typical number of sandbags varied from support to support, ranging from three to six in the sandy soil areas but predominantly three were used. Higher numbers of sandbags was used in instances where rises, sags, and turns were prevalent to accommodate pipe bends not exactly following the trench elevation contours or radius of turn and in the stretches containing rocky soil. Also, road tie-ins used an increased number of sandbags.
- The center-to-center distances varied widely with the terrain, with spacing from approximately six feet up to a high of ~30 feet, while in very rocky and hilly sections the spacing was tight and relatively consistent averaging six to ten feet.

Additional Observations for Supports

- One truck was positioned ahead of the lowering-in crew that was busy setting the sandbags for the benches. The first two days on site involved terrain that was sandy and mixed with rocky stretches. When the soil consisted mostly of fines the benches used a few sandbags that were separated by larger distances, while in other places the pipe simply laid on the trench floor. In the rocky stretches, the sandbag count and frequency increased to match the terrain.
- Differences in terrain led to differing arrangements of sandbags. Where three or fewer sandbags were used, their use seemed less functional. But, as just noted this occurred where rock was absent, and so was not consequential.

Breakers

- The breakers at this spread were constructed using sandbags. The typical number of sandbags required for a typical breaker was about 225. The foreman stated it took approximately 30 minutes for a crew of four to construct this, which seems a viable estimate. The largest breaker observed used over 900 sandbags.
- Typical breakers were 15 inches wide, and stopped about one foot below the trench top. The breakers appeared to be well constructed and uniform.

Observations of lowering-in with relation to benches

- Lowering-in involved four side booms with at least two hands walking the process. The trailing was responsible for directions to keep the pipe-string either centered in the trench or on the benches when present, while the lead ensured all was in place to continue. Where the trench was flat and rock-free, the pipe was laid directly on the trench floor.
- Some sections were fully strung and the pipe joints welded except for road tie-ins, as was permitted by local conditions, while other sections involved more segmented strings and so more frequent tie-ins.
- Sandbag footprints varied greatly. The sandbags themselves were in the 10 by 15 inch range, with a footprint consisting of 10 inches by 30 inches.
- There were instances where the pipe-string sat slightly above the benches. However, it can be anticipated that elasticity in the pipe-string and compression in adjacent benches will facilitate eventual settling onto the bedding.

Observations of Bedding and Padding Operations

- The Dynapad was used throughout where the presence of rock necessitated bedding and padding.
- Practices similar to those discussed for Project One – Dynapad Spread were used, with discussion there and in Appendix A equally applicable here, and reinforced or expanded as noted herein by observations specific to this project.
- As for Project One, Dynapad provided a layer of fines about 12 inches deep on average, followed by a small rock layer and thereafter larger rocks.
- In most trench areas where the soil was fine and without rock, the pipe was laid directly on the trench floor. Occasionally in these areas, stacks of three sandbags were used as supports, being spaced along the pipe-string at quite large distances.
- In rocky areas, more sandbags were used and spaced more closely together to develop the required offset from the trench bottom, with clearance that ranged up to 22 inches, but more typically was about 10 inches whereas the specifications targeted eight inches.
- The size of the trench relative to the pipe was measured in several sites. These measurements indicated trench widths from the order of four feet up to seven feet, with depths from seven to more than nine feet. Trench width easily met the required minimum width of 12 inches greater than the outside diameter of the pipe, with 18 inches required when there is rock in the ditch or water crossings (creeks, streams, rivers) are involved. Likewise, the depth easily met the specified minimum cover, as the measured depth was typically greater than seven feet.
- At the time of the visit, construction involved short stretches where rock was present interspersed in longer stretches with little to no rock evident. The padder was in the short rocky stretches, while the remainder was padded with backhoes from the spoil pile.
- Two short rocky stretches were timed with the Dynapad covering 175 feet in 30 minutes for one stretch and 217 feet in 20 minutes for the second stretch. The combination of the fines, two layers of small rock and spoil spilling over the back of the hopper as it is being loaded from the backhoe affected coverage of at least two feet with upwards of three feet deposited in some areas.
- Observing the extent of the fill under the pipe showed the fill material flowed freely underneath and filled the area underneath with no discernable voids.
- The padding operation involved one Dynapad padder, two backhoes and one bulldozer with a total of six personnel (equipment operators and two laborers). There was another padder on site, but it was relegated to mopping of tie-ins and other spot areas.
- Because backfill via backhoe immediately followed the bedding and padding process, there was no start-stop cycle to admit jeeping the pipe for nicks in the coating. But as noted previously, the design of this machine layers fines adjacent to the pipe with increasingly larger material away from the pipe, which limits the chance of rock contact and so virtually precludes rock damage.
- Padding material was obtained with one sample from an area consistent with most in the area of observation. The laboratory soils report is in Appendix D.

Additional Observations for Bedding and Padding

- The depth of the padding coupled with the double layering of different sized rocks was sufficient to keep large rocks coming off the back of the hopper and from backfill operations from impacting the pipe.
- The operator for the Dynapad stated that on a good day with the backhoe operator keeping up he was capable of doing about 9000 feet over flat stretches. However, this estimate cannot be verified in reference to the data gathered from this site, which at best indicated 651 feet per hour or about 6510 feet in a continuous 10-hour long padding shift.
- Where the spoil is wet, the same problems evident in limited observations for Project One were again apparent. There was some evidence of blockage that slowed progress, and the fines were prone to clumping that becomes evident from the start of processing the wet spoil. The design of the hopper area on a Dynapad also appeared susceptible to clogging from roots and other debris in the spoil pile. If roots were left to build up enough, it was remarked that they would need to be burned out.

Backfill Operations

- The backfill process was accomplished with a backhoe with fill material obtained predominantly from the spoil pile.
- The padding appeared to be of sufficient depth that any large rocks from the backfill would not come in contact with the pipe.
- A bulldozer was used to top-off the trench after the backhoe was finished.

Additional Observations for Backfilling

- There were times especially near tie-in areas where a backhoe was used for padding when the spoil contained significant rock, opening the door to rock contact. As such, overall coating quality is controlled by more than the bedding and padding machine used.

Project Four

This project involved moderate diameter line pipe whose wall had a Dura-Bond coating. The ditching was done by backhoe.

Equipment (padding operation)

- One Ozzies Padder – model 200
- Two backhoes (one backfill, one roaching)
- One bulldozer
- Nine people were involved in this aspect of operation
    - Two operators on Ozzies Padder (one learning the operation of the machine)
    - One operator each for backhoes and bulldozer
    - One Ozzies Padder padding assistant walking with equipment
    - Three laborers

Equipment (lowering in)

- Three side booms

Equipment (other)

- One foam truck – crew of three, technician, foamer, and driver from Offshore Joint Services (OJS)
- One skid truck
- One bulldozer

Supports (benches)

- Polyurethane foam was initially used at this site but was discontinued before my arrival. Its use was stopped subject to procedural requirements.
- Sandbags were used while I was there but I was told that they would probably be going back to foam benches at a later point.
- The typical number of sandbags per support was five, ranging from four to seven. In some cases, more sandbags were used in instances where rises and sags were prevalent, to accommodate pipe bends not exactly following the trench elevation contours. Also, a greater number of sandbags were used at all tie-in locations due to a deeper trench being dug at these locations.
- Typical configuration of a five sandbag arrangement was two abreast; two abreast above that and the fifth sandbag straddling center position on top.
- The sandbags were bought from a local company at a $1.25 a piece. Trucks would drive the RoW depositing sandbags for benches, which per comment on site was to occur every 20 feet. The lowering in crew would place the sand bags as they proceeded. Extra bags were to be available where needed. I did not witness this, but estimate from prior observations at other sites two people were placing bags in trenches for supports.
- In one stretch, the distances between successive sandbag placements were as follows: 18.5 feet, 16 feet, 19 feet, 18.5 feet, 20.5 feet, 12 feet, 19.5 feet, and 16 feet. Another shorter stretch showed spacing at 16.5 feet, 17.5 feet, and 18.75 feet.

Additional Observations for Supports

- It was stated that the placement of the sandbag supports was to be every 20 feet. The measurements indicated that the majority of the distances came in under this distance. This in turn will decrease the load per bench and help decrease the possibility of ovalization or denting of the pipe.

Breakers

- Open cell polyurethane foam was used, which allows the passage of water, for the breakers. The company providing this service was OJS.
- Technician stated that the foam temperature reached 135 degrees during curing. The technician was unable to provide density or compressive capacity.
- Typical breaker dimensions were 12 inches wide and four feet to 4.5 feet high. They were spaced using the following company specifications: for slopes at 5-15 degrees space at 300 feet apart, from 15-30 degrees space at 200 feet apart and over 30 degrees space at 100 feet.

Additional Observations on Supports

- There was evidence of splitting in the breakers seen once or twice at Project Two. The one split observed on the Project Four spreads was caused by the raising of the pipe to add additional sandbags at one location.

Lowering-in with relation to benches

- The lowering-in was done well ahead of the padding crew so this could not be easily observed given the project's focus was bedding and padding. It was however apparent that the pipe-strings that were jointed were quite segmented, driven apparently by the topography and routing, which led to many rises and sags, some of which were quite steep. The tie-ins at roads crossed (there were many in the stretch attended) were not completed. There were also many portions along the route that were not yet welded. .
- A typical sandbag footprint was the order of 15 inches by 36 inches.
- A rough estimate indicates that at least 95 percent of the pipe was properly seated on the benches. Only a few instances were observed where there was space between support and pipe and it was never more than one bench in span.

Bedding and Padding Operations

- The padding operation involved one 200 model Ozzies Padder, two backhoes and one bulldozer accompanied by nine personnel. There was another padder on site but it was relegated to mopping up of tie-ins and other spot areas.
- The Ozzies Padder's screen pitch for this job was two inches by two inches. The techniques to limit contact between the fill material and the crown of the pipe-string used by the operator on this project were the same as those discussed previously in reference to Project One and Project Two.
- See discussion of the Ozzies Padder in Appendix A and the section in Project One – Ozzies Padder Spread for details of the operation and overall strengths and weaknesses of this padder, which apply equally here, and are reinforced as noted by observations specific to this project.
- For this project, the majority of the time fill material from the padder was directed by the operator to fall between the pipe and trench wall, with the fill material spilling over the top of the pipe and eventually around the other side of the pipe. A final pass would meet the required cover over the pipe.
- Clearance heights from bottom of pipe to trench floor ranged up to 19 inches, although inaccessible locations such as near tie-ins showed even larger clearances.
- The typical ditch width was five feet wide, with the narrowest being three feet - eight inches. The typical ditch depth was six feet, with slightly deeper instances measured. These greatly exceeded the specified minimum trench width and depth.
- The rate of progress for the Ozzies Padder varied widely depending on the fill circumstances encountered. For example, a one-day shift on one occasion covered about 600 to 700 feet, while this same period on another day covered about 2400 feet. Often the terrain was hilly and muddy, which hampered forward progress.
- The number of passes to achieve the required bedding, padding, and cover varied as expected. A minimum of three was required to obtain adequate cover, with as many as six required in the worst case. The high number of machine passes was necessary due to

the extent of mud prevalent at the site. The wet and clumped dirt/mud coated the screen and did not pass easily through the screen. The required cover was six inches, with the padding applied easily exceeding this requirement, with cover depths ranging from eight to 12 inches typically, and sometimes even deeper.

- The extent of the fill under the pipe was as for cases where the spoil was dry, evidently because the fill material that easily passed the screen had properties comparable to cases where all fill material was dry. The fill flowed freely below the pipe and filled the area underneath with no discernable voids.
- While the majority of the time, the fill material introduced from the padder was directed by the operator to hit in between the pipe and the trench wall, there were instances of the padding material landing on the crown of the pipe. Such occurred for short stretches as the operator redirected the flow. When the operator was traveling over a double-stepped ditch shoulder, which was necessitated due to the contours of the hill and the direction of pipe travel, the likelihood of hitting the pipe was much more prevalent. Jeeping was done whenever possible for such scenarios, but these opportunities were constrained by safe entry to the trench and time in the trench. Entry occurred only at the foam breakers due to trench depth. If the breakers were too far from the point of interest, too little time was available to get into the ditch, perform the jeeping, and then get out without inhibiting padder progress. About 400 of such padding operations were jeeped, with only one instance of chipped coating identified. This chip was found where fill material from the two-inch-square clear screen pitch dropped directly onto the crown of the pipe. Small areas of chipped coating are easily dealt with by the CP system. Nevertheless, such chips reflect reduced coating quality as compared to a pipe-string installed free of such features.
- Padding material was obtained for three samples as reported in Appendix D.

Additional Observations for Bedding and Padding

- One of the main factors controlling padding progress was the extreme muddiness. A second key factor was the fact that the RoW was only 50 feet wide, which allowed space for only the trench and one lane. This appeared to cause several problems:
    - If any equipment had to move in front of or behind of another vehicle for any reason, everyone had to move out for the other to get in and then the procedure was reversed to return to the original layout.
    - During the period observed, the Ozzies Padder could not work the spoil pile so it was getting its padding supply from a backhoe roaching the adjacent RoW.
- The Ozzies Padder, like any screen-based system, does not handle extreme muddiness very well. In addition to slowing progress, dealing with the mud required a twice per day cleaning that required three to four people and led to 1½ hours downtime twice per day. Mud was observed to buildup underneath the conveyor belt and chain to a thickness up to about five inches, which was so compacted that its removal required it be chipped away with a shovel.
- One possible concern associated with any padding machine was occasionally evident where the cover was observed to take on the shape of the pipe, or form a crown over the centerline where the cover is deeper than on either side. Where the depth is minimal and measured over the centerline there is a chance the flanks are not adequately covered.

Moreover, there is a tendency for larger material placed over the cover during backfill to fall toward the space between the pipe and ditch wall, possibly wedging into such areas, or enabling large rocks to be resting closer than desired to the pipe-string.

Backfill Operations

- The backfill process was accomplished with a backhoe drawing from the spoil pile when it could be reached, or from fill material lying on either side of the RoW.
- The padding appeared to be of sufficient depth to keep any large rocks entering the ditch during backfill from contacting the pipe when deposited by the backhoe.
- A bulldozer topped-off the trench after the backhoe was finished.

Industry Experience and Commentary

In addition to discussions with construction and operating company personnel during the site visits, a meeting was hosted at Battelle with Mr. Carl Turnage of Ozzies, while discussions with Mr. Ed Klaymar of KNI were held at various locations typically associated with INGAA meetings or construction spreads. Discussions also were held with Mr. Jim Jackson and others of CRC-Evans, and with various pipeline company personnel via telephone interview and Email dialog. Aside from the comments made by Mr. Jim Jackson of CRC-Evans, the most significant of these reflect dialog with Mr. Henry Yamauchi representing experience gained with pipelines operated by Westcoast Energy Inc.

Such discussions can reflect the commercial interests where equipment suppliers are involved, or the specific experience of an individual that might be dated or otherwise biased by the characteristics of a given construction job when dealing with individuals. Nevertheless, some valuable insight was developed, as follows.

Mr. Jim Jackson – CRC-Evans

When asked about the productivity of the various padding machines, Mr. Jackson noted that none of the padding machines work well in wet material, especially not clay. This observation verifies the rather limited experience developed in this project. In contrast, for one job in the California desert where the spoil consisted of river rock and dry material rich in fines, he noted they were able to pad over 8,000 feet in less than seven hours. He further noted favorable comparison for the Ozzies Padder (a competitor padder), stating it was a very high production machine. Such rates outstrip anything observed in this project, and provide credibility for upper bound rates cited for Dynapad at 9000 feet per day. What is clear from this is that productivity is strongly dependent on the fill conditions being bedded and padded.

When asked how pipelines were padded in the “old days” – Jim mentioned that they had their tricks. For example, they would use the spoil in the ditch as a “ramp” to roll padding material down the slope toward the bottom of the pipe. This way they would not directly impact the pipe with large rocks. But, as was observed, the success of this technique had a lot to do with the contractor performing the work. This early technique remains the basis of the practices used by Ozzies Padder’s operators during startup, as they seek the richest area of fines in the spoil pile and direct that fill at the side of the ditch opposite the padder until it fills. Thereafter, they apply material directed onto the spillover from the first side padded or into the still unfilled space between the pipe and other ditch wall. Once the ditch is initially filled, they direct material onto the already covered pipe with forward motion of the excess cover rolling down the ramp created

by the angle of repose of the fill material. Jim also provided some interesting history and related discussion, including the photo shown earlier in Figure 1a.

Mr. Carl Turnage – Ozzies Padder

The meeting with Carl Turnage at Battelle also was productive, as it included some history and an overview of the construction process, which was supported by videos that included reference to foam benches and other aspects considered by some to be new technology. Carl addressed issues as perceived by Ozzies, from productivity through new technology.

A key theme of Carl's was construction productivity in reference to meeting or beating the planned date to bring the pipeline into operation. Carl noted that bedding and padding productivity was an important factor in this timeline, but also emphasized other aspects of construction such as the ditching technique, where he compared blasting to a machine ditching. Carl also spoke briefly about contract requirements and how they and subcontract provisions can affect how a job is approached.

Carl indicated that tie-in welds could control construction productivity for spreads with many crossings and hills and valleys that force jointing many segments of pipeline that then must be tied together, noting the tie-in weld as the limiting factor. This observation reinforces the same conclusion drawn first for this project, while observing the several hours dedicated to each tie-in on Project Two – Spread A. In such cases the entire spread effectively came to a halt while tie-ins were completed. This means that while productivity and costs related to bedding and padding are important, they are not controlling – and might be secondary to other more significant drivers depending on the spread profile and routing. Evidence of this can be seen for Project Two - Spread A, where up to three Ozzies Padders ran in tandem, leading to three times the cost for equipment simply to achieve productivity, which otherwise was largely suspended when a tie-in was needed.

When Carl narrowed consideration of productivity to bedding and padding, he noted the amount of fines available as the primary driver, which underscores the presence of supporting equipment and personnel to roach for spoil on spreads where Ozzies Padders were observed for this project.

In reference to new and emerging technology Carl mentioned combination crusher/padding machines, but noted they are currently very slow – a clear drawback given his emphasis on productivity. He mentioned the Grub crusher (CRC-Evans/Laurini) that runs along the bottom of as a viable alternative to bedding. He noted the machine ditch works well, using a hammer type system to crush rocks in the bottom of the ditch. He further stated that "the industry is going toward bottom padding in the ditch before laying down the pipeline so that it will better conform to the shape of the ditch", indicating that "Ozzies Padder will be running a machine laying bottom padding, followed by a machine behind the stringing operation to add the additional padding".

Carl went on to note that Ozzies is looking into the use of a bucket-type padder that has an auger device in the bottom of the bucket to break up mud/clay material. They also are looking at using a crushing machine with their padding machine to make better use of the spoil pile. His comment reflects the diminishing returns as a second or third passes is made through the same spoil. This aspect was identified in reference to the Ozzies machine, beginning with the first project visited. He noted that combining a crusher with the padder will enhance the amount of

fines, and minimize the need to have to haul away the large rocks upon completion of the padding job. However, again he pointed to the downside that currently is reduced productivity.

He also commented on rock shield technology, specifically in reference to polymer (fiberglass or polyurethane) pipeline coatings, which variously includes fibrous cushioning materials. His comments reflected a competitor's position, as they indicated large rocks can still damage pipeline, and also noted this technology tends to shield the pipeline from CP. While a competitor's perspective, these views tend to be shared by the industry, as there was little evidence of pipe-applied polymers used for rock protection in the projects visited. Moreover, personnel from at least two pipeline operating companies noted these same concerns. Polymer foam breakers as well as foam pillows are also likely to shield the pipeline from CP. In spite of this, such technology was developed and first used in Canada where near-neutral pH as well as high pH stress-corrosion cracking (SCC) is prevalent, without apparent concern.

In regard to benches and breakers, Carl warned that foam does get hot and if not properly mixed can get hot enough to burn the pipe. He also commented on denting the bottom of the pipe caused by sandbags, where the bags were not spaced or placed properly. These comments served to confirm project team observations, and comments made by others during the course of this project.

In closing, Carl commented that it costs anywhere from $2 to $4 per foot to perform the padding operation – with the cost depending on the number of tie-ins, terrain along the spread, timing; and other factors. Measured against a cost to construct a mile of pipeline including materials that ranges the order of a million dollars, the cost of bedding and padding is not quite noise, but nor is it big. Carl closed noting that Ozzies has padded 1,000's of miles with their machines, starting with the Iroquois Pipeline about 1988, and indicating we would be more than willing to add further to this discussion as the need presented.

Mr. Ed Klaymar – KNI Inc.

Mr. Klaymar's primary focus in conversation is the same as the message evident in written text presented on behalf of KNI[10], which focuses on pipeline support, bedding and padding, and trench stability, along with the quality of the fill material deposited – aspects considered by KNI to comprise their layered backfill "system." Key themes include the merits of layered backfill in reference to limited damage to the pipeline coating, and the stability of the ditch as affected via geotextile fabric deposited above the layered backfill, and the fact these can be installed at no added cost as compared to other bedding and padding construction practices. He also alludes to foam benches as an element of his construction system associated with the Dynapad bedding and padding machine. Because an objective of this project was to evaluate the KNI layered backfill system, this section summarizes discussions with KNI in conjunction with commentary on the system based on the data and observations of this project, and the technical literature to the extent it speaks to these topics.

In regard to pipe supports, material supplied by KNI indicates its new, patent pending, pipe support method overcomes the cost and quality disadvantages of the pipe support methods in current practice. According to their literature and site observations at Project One, KNI's system uses foam benches designed to be strong enough to support the pipe after it has initially been lowered into the trench. It claims that, in contrast to current methods, the benches are constructed to fail when the additional cumulative loading produced by complete backfill and

hydrostatic testing is applied. While this is possible, calculations that support this claim are absent, nor are tables provided that indicate changes in bench design necessary to achieve this as a function of backfill density, product density, ditch depth, and pipe diameter and wall thickness. Analysis presented in Appendix E and related considerations noted therein indicate the design compliance and related properties such as the time constant of the support material must depend on these parameters.

Achieving the behavior claimed requires uniform support for and loading of the benches, a feature that is unlikely or practically very difficult to achieve given the variability in typical trenching for pipeline construction. This variability can be offset if the benches are individually shimmed, appropriately spaced, and uniformly supported by the ditch bottom in an unloaded state, such that they can develop uniform contact by the pipeline during and after lowering in. However, this will greatly slow productivity and has the potential to involve significant cost and inventory control issues. Significantly, there was no evidence of concern for such factors and inventory control where these benches were in limited use on Project One. The claims further note that pipelines installed according to this method will be supported by the padding material beneath the pipe, leading to full compaction, which is certainly the case if the installation achieves uniform support and compresses adequately under the imposed loads. Whether uniform compaction greatly reduces the problem of padding wash-out as claimed could not be confirmed directly, as detailed controlled studies to evaluate this aspect could not be found in the open literature. However, while the literature does not address this issue directly, soil mechanics texts do suggest that, when the soil is not fully compacted precluding the existence of pores and constrained on all directions, water ingress is possible. This implies that where water is present along the ditch bottom it could eventually permeate the once vertically compacted fines. On this basis, it is not clear that soil initially compacted in one dimension will remain resistant to washout when sufficient water is present. [8]

It also is worth noting that the sprayed in-situ foam benches in use in Canada since the 1980s are from a practical perspective as likely capable of claims similar to those posed by KNI, particularly in reference to uniform bottom support. Moreover, as the size and shape of supports sprayed in-situ offers theoretically infinite adjustment, supports sprayed in-situ likely are more easily "aligned and shimmed" by spraying materials as needed as compared to precast blocks that do not match the ditch bottom and so must be shimmed from both sides. However, as the structural and failure response of any design built of viscoelastic, time-compliant material depends on the stress imposed[(46)], the design of such benches and the open- or closed-cell foam used must reflect backfill density, transported product density, ditch depth, and pipe diameter and wall thickness, and have a time constant consistent with a timeline consistent with subsequent bedding, padding, backfilling, and hydrotesting. Presently it is known that the Pedero products involve concern for at least some of these parameters, as the foam density among other parameters is dependent on the pipe dimensions and the product transported. However, no such data was made available by KNI following the visit to Project One, nor is such data evident in the KNI literature on their patent-pending benches. Finally, as the benches delivered to the Project One had fixed width, it is not apparent how variables such as differing

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[8] A limited GRI-funded study[(45)] was located that provides the potential to evaluate aspects of KNI technology, however as yet the necessary follow-up evaluation of this initial field work has not yet been initiated.

fill density or ditch depth were to be addressed, nor was their evidence these were considerations in the foam design, as the benches bore no designation to discriminate such parameters.

The KNI literature also speaks to concerns involving settlement into the bedding, and related compaction. While a concern of this project, nothing could be found in the literature that directly quantified the relationship between the initial quality of pipeline support and its effect on future pipeline functionality. A related exception was anecdotal evidence of the effect of overly stiff and ill-placed sandbags in causing ovalization and denting. Significantly, sandbags made using the traditional burlap sack would only be as stiff as the burlap bag was strong, and its seams resistant to splitting. On this basis, one might conclude the use of modern stronger decay-resistant polymeric materials for bagging, as has been observed for some spreads, could further complicate the effects of ill-placed sandbags. For example, burlap bags might have split under the action of the weight of the water during long-term hydrostatic tests, or the weight of an in-line inspection tool, making this a short-term concern for burlap bags and promoting settlement into the bedding. However, their stronger modern counterparts might survive retaining any local pipe distortion. In the same vein, the modern materials are not prone to deteriorate over time, as would burlap bags. This leads to the possibility that any ill-placed sandbags made of strong polymeric materials resistant to rot will continue to cause distortion of the pipe's cross-section and the pipe-string's profile, whereas the burlap bags would rot leading to eventual settlement into the bedding. As results to evaluate such aspects could not be found in the open literature, little can be said in regard to their possible significance over the long term.

The merits of layered backfill have been discussed with Mr. Klaymar in reference to limited damage to the pipeline coating achieved via layered backfill, which grades and places tiers of fill material prior to backfilling. According to those discussions and related product literature, the three in-line screening stages of the Dynapad cover the pipe first with high quality padding material, after which a layer of small sized stone follows, which is followed by a third layer of larger sized stone. Their literature claims a much higher level of pipe protection than current padding and backfill methods and further claims it virtually eliminates construction created pipe and pipe coating damage. This claim, which is made in passionate terms in discussions with Mr. Klaymar, has been verified at all sites visited where Dynapad was used, with no evidence of damage evident in any case. However, whether this finer-quality layered fill material affects improved integrity and reliability of the pipeline as compared to other padders depends at least on operator skill and experience in regard to the Ozzies Padder, the nature of the coating used in regard to its resistance to damage, and the eventual presence of adequate and reliable CP. Corrosion that might ensue at such coating defects becomes a threat to integrity only where the CP is unreliable or inadequate, neither of which is a practical concern early in the life of a new pipeline. However, such chips can become a concern later in the life if, when, and where the CP system becomes unreliable or inadequate – both of which are regulatory issues.

Finally, KNI technology was discussed in reference to the stability of the ditch as affected via geotextile fabric deposited above the layered backfill. Discussions and their literature indicate that the Dynapad has been adapted to install this geotextile fabric between the padding material and the first layer of sized stone, which is claimed to stabilize the backfilled trench and the protective padding layer for the life of the pipeline. Whether or not this added layer of geotextile fabric functions as claimed could not be confirmed, as detailed controlled studies to evaluate its function could not be located in the literature[8]. Likewise, their literature claim that this low cost of the geotextile fabric will be more than offset by eliminating currently required construction

counter measures such as trench breakers also could not be evaluated as detailed controlled studies to evaluate its function could not be located in the literature[8].

According to KNI literature and related discussions, backfilled trenches require stabilization in reference to padding washout that occurs in one of two forms. One involves erosion along the trench as water flows where a gradient is present along the conduit created by trenching harder impervious rock and later filled by the pipeline, the select fill materials nearby, and the backfill above. Discussions with the industry personnel indicate this form of washout is known selectively within the industry. Personal observations by the authors likewise validate this form of washout. The KNI literature further asserts a second form of washout can occur if the padding material saturates with water sufficiently to cause a "change-of-state." This scenario is quite plausible as it has analogs in nature. KNI asserts that where excess water accumulates and stagnates in the bottom of the trench, the padding material changes state from a solid to a liquid (mud). While not addressed in the KNI literature, freeze thaw cycles that tend to move rocks toward the surface will also be active for rock that lie at or above the frost line, more so in areas and over depths where many such cycles are experienced annually.

As problems with flowing water are significant where there is a gradient driving the flow, the industry has controlled flow effects by installing breakers across the full width and depth of the trench, which functions as a dam. But, while breakers limit flow and displacement of the fill material by erosion, they set up conditions that contain the moisture, such that where sufficient water is present to change the properties the second form of washout seems plausible. When such conditions reach a depth that affects the fill material bridged above the pipeline, it is conceivable that heavier rocks placed in the backfill could migrate toward the pipe-string or the trench floor. An indication of the practical significance of the change-of-state washout can be inferred in reference to the known buoyancy of natural-gas transmission pipelines. The buoyancy of natural gas pipelines is apparent as such pipelines are known to rise through the soil of soft water soaked flats or other areas that make them buoyant unless retained by swamp-weights or the weight of a concrete coating. Consequently, the second form of padding wash-out – if a significant problem – should be evident on such systems through humping above these pipelines akin to the "speed-bumps" that occur occasionally in soft water soaked flats. As most operators don't generally report this problem, one can conclude that while plausible it has yet to become an industry issue.

While apparently not an industry-wide concern, the KNI literature asserts that the change-of-state wash-out is readily found immediately above trench breakers. This assertion has potential credibility if the claim in KNI literature that one (un-named) major transmission company specifies a French drain system be installed on the trench floor immediately above trench breakers so collected water can be drawn off through the breaker can be substantiated. It gains further credibility in that at least one company with pipelines through very hilly and mountainous country is experimenting with a method to control water between their breakers, as considered in regard to discussions with Mr. Henry Yamauchi reported subsequently.

The final aspect considered with KNI was future directions and developments involving bedding and padding, and related construction aspects. Mr. Klaymar noted that the high costs required to implement current construction specifications are driving the development of new generations of rock trenchers and pipe coatings. He noted the hope that either a rock trencher/crusher would be developed that could economically grind the rock into useful fill material, and/or new coatings could be developed that were more resistant to chipping and other rock damage, making issue of

backfilled rocks moot. He also alluded to costs associated with maximum rock size restrictions now being included in prescriptive company backfill specifications, stating that much cost is incurred in segregating and removing the oversized rocks from the RoW. Finally, he alluded to expensive trench breakers that are installed where the pipeline trench is excavated on hills, suggesting an alternative such as his geotextile fabric is needed to stabilize the ditch. While such an alternative would be welcomed, it is not clear how a thin but tough fabric could stop heavy rocks from sinking if indeed the properties of the mud had the viscosity of a liquid such as water.

Mr. Henry Yamauchi – Westcoast Energy Inc

After a friendly exchange of greetings, Mr. Yamauchi outlined their current experiment with a drain system something akin to that alluded to in the KNI literature, although as yet the practice is still experimental. He stated "recently, some pipe, 914 mm OD, was installed in a shot rock, blasted ditch. The pipe was embedded in sand with minimum of 250 mm on bottom and 300 mm above the the pipe, followed by placement of non-woven geotextile fabric Nylex 4553 on the select sand padding, extending 150 mm up the sidewall of the ditch. Since we had previously experienced some padding losses, which could have contributed to pipe dents on the bottom of the pipe discovered by internal inspection tool, particularly in shot rock ditches, due to water migration into the soft ditch line, we decided to contain the sand-pad for this project by placement of geotextile fabric above the padding, followed by placement of excavated material over the geotextile fabric."

He continued, "We have previously used ditch blocks, with drainage lines to intercept and direct water out of the covered ditch. (He did not indicate they specified this practice.) Depending on drainage pattern, this method worked satisfactorily but at a substantial cost. Installation of ditch blocks with drainage pipe costs approximately $8,000 Cdn. per set. Depending on drainage pattern and precipitation area, many ditch blocks with drainage lines are required to control water flow in the ditch line. A roll of geotextile fabric Nylex 4553, 15 feet wide by 300 feet long, costs about $500 Cdn. This would cover about 600 lineal feet of ditch."

As Westcoast's pipelines operate through very hilly and mountainous country where change-of-state is plausible, his conversation lends credibility to both mechanisms for washout noted in the KNI discussions. But in contrast to the KNI practice, the geotextile fabric used in this experiment lies above the padding and below the pipeline, a placement scenario much different than what can be achieved with the Dynapad machine where the fabric is placed above the padding.

Observations and Trends

This section begins with general observations. For present purposes, general observations reflect a recurrent consistent position or trend. This observation or opinion must be evident throughout the spreads visited, or in the comments from individuals whose observations or opinions became evident on the spread, or were sought in meetings and other forms of correspondence or phone dialog. Recurrent, consistent patterns comprise trends, the most significant of which are noted later in this section. Where limited data or observations exist, but the outcome is experience-proven and/or logical, the corresponding pattern is considered a trend. Finally, as head-to-head comparisons could not be made between the practices and equipment considered because of practical field constraints, no attempt is made to compare equipment or practices one against the other in this section.

Productivity and Cost Reduction

- Integral in-line loader and screen machines operate well in situations where the spoil contains rich to adequate fill material. They become less productive, even when run in tandem, where the spoil provides diminished fill material, as multiple passes become necessary and roaching for fill material can slow this process. When the spoil left in the wake of the padder contains heavy boulders or rock, enhancing that spoil by roaching can be inefficient and the fines added can be difficult to extract because of the significant amount of larger rocky material left in the wake of that pass.
- When dealing with spoil that contains very large rocks or debris such as roots, stacked systems will likely lag the integral in-line machines, as the hoe operator must presort this material to avoid blocking the hopper – but where the spoil contains limited fill material and there is limited large rock and debris, the independently loaded stacked screen machine is likely to outpace its integral in-line counterparts.
- Ditch width and height are important parameters, with width being most significant in regard to the fill material required in contrast to the specified minimum parameters. Wide uncontrolled ditches limit productivity, and can become a controlling parameter in applications where limited fill material is available in the spoil.
- In applications involving rock that can be either shot or machine ditched, the balance of factors such as speed and cost in creating the ditch and spoil produced is likely balanced or significantly offset by the speed, cost, and construction convenience afforded by the controlled ditch size, the more workable ditch shoulder, the extensive and available rich spoil, and the ability to use the ditch as a reverse rock shield in conjunction with sprayed foam benches. Where it is "possible" to machine ditch the rock in lieu of blasting, factors from productivity through economy and safety indicate subsequent construction is facilitated and productivity enhanced.
- Lighter and more portable vertically stacked machines appear more cost-effective where the run needing the padding equipment is short, in contrast to cases where the run is long, which justifies the large equipment and mobilization/demobilization costs. Thus, lighter and more portable vertically stacked machines appear more practical and cost-effective for short looping or replacement jobs, and in rights-of-way that are narrow or involve space limitations for heavy equipment because of the presence of hot pipelines, or the location of the spoil.
- New technology is on the horizon that couples crushing with loading and bedding and padding, which as productivity issues are resolved, will obviate the concern for rock.
- Construction productivity and decisions related to machine selection are controlled by more than the forward progress of the bedding and padding crew. Where construction involves many tie-ins because of routing or topography, the tie-in welds appear to be the rate controlling step.
- Where productivity is in balance with cost, particularly when Ozzies Padders are used, equipment cost and cost related support for the padder, including roaching to enhance the spoil, appear to be secondary to productivity.
- The only opportunity to enhance productivity or reduce cost comes in reference to Ozzies Padder, where longer conveyer tables could provide access to more spoil or richer spoil, and eliminate the need to roach rock that in the wake of the prior pass was screened quite efficiently.

Crews and Equipment

- Crews and the amount of equipment involved with and working in support of the vertically stacked independently loaded machine were typically smaller than for the integrated in-line machine. But, as the projects and spreads being compared reflected different lengths and geology, other factors are at play such that this observation may not be general.

Benches and Breakers

- Sprayed foam benches offer support that is in intimate contact with the ditch bottom, which can be sized and shaped to address local differences in ditch depth, backfill density, product density, pipe diameter, and wall thickness, and thus could develop structural response that facilitates controlled settlement onto the padding.
- Traditional practices based on sandbags appear less productive to set than foam benches, and involve the potential to locally ovalize or dent the pipe where the bags are overly stiff or poorly placed. Contractor opinion was that the foam benches were much quicker and less manpower intensive than the more traditional sandbag method.
- The transition from burlap to synthetic bags opens the door to potential short- and long-term problems not historically experienced with burlap.
- Precast foam benches appear to be easier to get to the spread and into the ditch, but are more difficult to set on an uneven ditch bottom to achieve something close to controlled loading and to keep in that position through lowering-in.
- Because precast benches have a constant width in the direction of the pipe-string, it will be difficult to achieve their potential design goals while accommodating practical realities such as uneven ditch bottoms, differing fill densities, differing ditch depths, and differing pipe thickness (weight) where class changes, crossings, etc occur. Different widths, and other properties are possible, but this leads to inventory issues, which coupled with the uncertainty of what size to provide where along the RoW makes them somewhat less attractive.
- Foam versus sandbag breakers share the same productivity issues noted for benches. Such breakers must be sprayed to achieve a fit to variable trench width and depth and pipe placement.

Benches after Lowering-In

- For flat straight pipe runs, where the benches were well placed the pipe settled uniformly onto the benches, with moderate compression in foam pads or similar displacement in sandbags in the vicinity of the support.
- Problems were typically experienced where vertical or horizontal changes in direction occurred, as fewer benches were uniformly loaded, and short spans were evident. The worst problems occurred for vertical bends (sag- and over-bends).
    - Potential causes include:
        - Bench heights not matched to the line of the pipe-string, and
        - Bench heights not horizontal over their width in the ditch.
    - More likely causes include:
        - Problems in matching the vertical or horizontal bend orientation to the ditch, and
        - Problems in making tie-in welds.

    - Such problems have limited practical significance when dealing with polymeric benches whose viscoelastic deformation response promotes settlement of the pipe into the bedding material. Such is the case even where highly uneven loads during lowering-in cause foam benches to split, as even split benches continued to support loadings, as in no case was there evidence the pipe settled onto the ditch floor during our time on-site.
- The bench crew was found to be much faster than pipe could be lowered in, as this crew was often miles ahead of the lowering-in operation.
- On spreads with significant hills and valleys, causing pipe to be strung and joined into many sections, the rather tedious process of tie-in welds appeared to dictate construction progress, with other issues apparently secondary drivers for completion of the spread.

Bedding and Padding – Dynapad

- Dynapad is an inclined vertically stacked processor of spoil that uses multiple shaking screens to separate and grade spoil, and by arrangements within the unit deposits successively coarser fines sequentially into the RoW. Dynapad is gravity-fed, operating over the pipe-string while attached to and suspended there from a "mast" attached to a conventional side-boom. Provisions are included to maintain the screening unit or "mainframe" more or less horizontal, and to rotate this unit.
- The positioning of the screens and the internal operation of the mainframe of Dynapad causes the smallest fines to fall first onto the pipe. Increasingly coarser material is deposited sequentially over a few feet along the pipe-string. The incline angle of the screens coupled with movement of the screens and gravity controls the size of the material passing the screen. These parameters also cause the larger material to shift along the screen until it eventually falls onto the next screen or the pipe-string.
- Where ample fines are accessible to the backhoe feeding Dynapad, the deposit off the last screen can create a layer of cover whose depth ranges from six to twelve inches deep (on average), which is followed by successive layers of increasingly larger fines and rock, the last comprising material that did not pass the bars above the hopper. Because the hopper is fed by backhoe, spoil can be selected whose maximum size suited the requirements for the job.
- Dynapad was used over stretches where rock was present, but not otherwise. Stretches of soil where minimal to no rocks present were padded with backhoes from the spoil pile with usual practices for pipeline construction.
- Forward progress measured over several rocky stretches indicated the Dynapad produced 350 feet per hour on average, with some variation evident in speed depending on spoil conditions. Other data over two short rocky stretches indicated 175 feet in 30 minutes for one stretch and 217 feet in 20 minutes for the second stretch, the best of which indicates 6510 feet in a 10-hour long shift.
- Because of the reach of the backhoe, the Dynapad can feed its hopper from a wide range of spoil, which for this spread permitted the pipe-string to be padded in one pass. The layered backfill from this single pass developed bedding, padding, and cover for the pipe-string of at least two feet, with upwards of three feet deposited in some locations.
- The ability to select fines by loading independently through a backhoe means that with appropriate spoil selection skill startup can proceed with only fines deposited into the

ditch. Backhoe operator skill in this context is essential to limit damage to the coating until forward progress develops the layer onto which the coarser fines and other material are subsequently deposited.

- Because the last screen deposits fines onto an already existing layer once steady-state operation develops, and because the spoil was dry, the fill material flows freely onto, around, and underneath the pipe leaving little unfilled area except below the invert. Continued flow of the fill material appeared to fully fill this area, and also compact the backfill by virtue of the weight of the overburden, leaving little or no discernable void.
- Dynapad typically involved use of the padder, one backhoe, and one bulldozer. Dynapad worked on either shoulder of the ditch depending on the locations spoil piles and the needs of the loading backhoe. The small controlled size of the material that drops first onto the pipe coupled with the layered nature of the backfill limits coating damage and develop a compacted layer. This layered backfill was observed consistently.
- No operator "technique" was necessary during start up or otherwise for Dynapad, but during startup "skill and experience" are required by the backhoe operator. During this phase the hoe operator must identify spoil free of unacceptable fill material to limit rock contact until a layer of cover develops over the crown of the pipe. A major advantage of the Dynapad lies in its ability to deposit fill material without the need to move forward along the ditch, as this facilitates startup of the bedding and padding process and limits concern for coarser material impacting the pipe if the initial fill material is appropriately selected.
- Physical inspection showed the initial layer deposited by Dynapad is comprised largely of earth. The leading edge of the fill material was loosely compacted, but a foot back where additional material overlaid the fines, physical inspection of the fill deposited over the crown of the pipe-string showed the deposit was compacted.
- Physical inspection where the fill over the crown of the pipe covered by Dynapad was removed as possible during period stop-start cycles showed a coating that looked as it did prior to the bedding and padding process, with no evidence of nicks or chips.
- In areas where the spoil was wet, the hopper of Dynapad appeared to be prone to clog, which slowed the process and limited the flow of fill material, with some clumping being evident in the material deposited off the last screen.
- Areas where the ground was very hilly revealed that the design of Dynapad limits its motion to one direction unless its mainframe was rotated. While traversing hills with widely varying angle, its efficiency could vary, as is true of all machines. This machine provides for adjustment to level the mainframe to limit this concern. Other related concerns can be remedied by working machines in opposite directions such that gravity causes the large potentially damaging rocks to roll back off the hopper toward the already padded pipe. Such is the case for all machines, becoming more acute as the incline becomes steeper.

Bedding and Padding – Ozzies Padder

- Ozzies Padder is an inclined in-line integrated loader and processor of spoil. It couples a single shaking screen fed by a conveyer through a chute to a loader located at the front of the machine. As for Dynapad or any screen-based system, the incline angle of the screen coupled with movement of the screen and gravity controls the size of the material passing

the screen. These same parameters cause the larger material to shift along the screen until it is deposited on the shoulder of the ditch in the wake of the Ozzies Padder. The chute on the Ozzies Padder lies behind an articulated "mouth" at the front of the machine that provides limited manipulation to broaden access and/or aid selection of backfill material. The machine operates on the shoulder of the ditch parallel to the pipe-string, feeding select fill to the pipe-string by a conveyer table that collects fill material from the screen and delivers it to the ditch by extending the table from the machine toward the ditch.

- Because the spoil processor is in-line and integrated to its loader, access to productive spoil is controlled by the fines available from a linear track through the spoil windrow. For this reason, the spoil available in the windrow was enhanced by "roaching" the spoil using a bulldozer, adding material where possible and narrowing the windrow to better match the mouth of the padder.
- Where the fines available from the spoil are limited, a second pass, and sometimes a third pass, is needed to provide the specified bedding depth and padding cover. As the machine efficiently separates useful material, little satisfactory fill material remains after a pass through the windrow. This leads to diminished returns from a second or third pass unless new material is roached into the windrow or the windrow is reshaped with spoil that was not used on a prior pass.
- For in-line integrated machines like the Ozzies, efficiency is controlled by the conveyer table length, as this facilitates access to spoil further from the ditch, and also by the amount of fines that are available in the windrow of spoil.
- Bedding and padding efficiency is influenced by the quality of the ditching, as heavier Ozzies machines must remain well off the edge of the ditch. The weight of heavier Ozzies machines can limit its use where the main spoil pile is placed over adjacent hot lines in the RoW. This too limits efficiency, as it limits the supply of available spoil. Ditch quality also affects the volume of fill material needed to complete the bedding, padding, and cover.
- Bedding and padding reaching the pipe from an Ozzies Padder appears to be homogenous in size and constituents throughout the cover.
- The Ozzies Padder was used over stretches where rock was present. Stretches of soil where minimal to no rocks were present were padded with backhoes from the spoil pile, or other usual construction practices.
- Forward progress was variable, depending on the size of the ditch as well as the quality and availability of the spoil. Measured progress in straight runs through several rocky stretches indicated the Ozzies Padder produced 300 feet per hour on average. Where multiple passes were needed, productivity dropped in proportion to the number of passes made. Where the spoil was rich in fines, a single pass provided bedding, padding, and cover for the pipe-string to depths that reached up to two feet in some cases. The best productivity observed was estimated on average at a mile per 10-hour shift.
- Progress varied relative to trench width and depth. For example, one hour and 15 minutes was taken to cover a 0.2 mile long stretch through a wide turn. In contrast, the same amount of time was needed to cover a 0.6 mile long straight stretch using one padder along a ditch that was consistently four feet wide.

- Ozzies machines working in tandem over rich spoil were highly productive, offsetting the need and time lost while repositioning a single padder for multiple passes.
- In observing the extent of fill once both sides of the pipe were padded, coverage looked complete, as the fill extracted from the spoil was fine enough to flow in and leave no observable voids.
- The depth of padding above the pipe averaged in the range of 12 to 18 inches.
- Once the bedding and padding process had achieved steady state production, fill material off the screen flowed freely underneath the pipe, with little unfilled the area except below the invert. Continued flow of backfill appeared to fully fill this area, and also compact the backfill by virtue of the weight of the overburden, suggesting there was little or no discernable void. The fines in the fill appeared to drop onto the already deposited material and remain in place, whereas the larger material rolled off these fines ahead of what remained close to the pipe, and into the ditch bottom. Consequently, while not inherently designed to produce layering of the deposited fill, in steady-state operation the coarser material "rolled" ahead of the fines to fill areas remote to the pipe, while fines remained near the pipe. Industry experts associated with companies that sell or operate such equipment note this inherent property of the fill material as a key to the success of such equipment.
- The behavior during startup differs from steady state, as the generally uniform fill falls from or was projected off the conveyer table randomly onto the pipe unless the operator intervened to better direct the flow. During uncontrolled startup and over the first few feet of travel larger rocks that passed the screen could fall directly onto the pipe-string. During the startup phase, the fill material serving as bedding flowed freely underneath the pipe, with little unfilled area except that below the invert. Continued flow of the fill material appeared to fully fill this area, and also compact the backfill by virtue of the weight of the overburden, leaving little or no discernable void. Startup had rock whose size approached the clear pitch of the screen, contacted the pipe-string, with occasional impacts occurring squarely at the crown unless care was taken to avoid it.
- It follows that little damage is anticipated for the Ozzies Padder during steady-state operation because the already present fill material limit direct contact and the larger material rolls harmlessly down to the ditch bottom. However, damage might be anticipated during startup and the first few feet of the bedding and padding operation unless the spoil is roached selectively to limit this problem and the operator is careful to direct the flow into the space between the pipe and ditch wall.
- Operators and personnel working with the Ozzies Padder noted techniques used to limit impact to the pipe from fill material. First, as the richest zone of fines typically lies toward the bottom and center of the spoil windrow, an effort is made to articulate the mouth of the padder into this area during startup. This increases the fines present in the stream of fill material. Second, operators direct the flow from the conveyer table either into the space between the near-wall of the ditch and the pipe, or against the far wall of the ditch, filling until overflow onto the top of the pipe-string. This is followed by flow onto the now covered crown to fill the side adjacent the padder, such that the flow into the trench does not impact the pipe.
- Thus, operator "technique" gained through experience or training is important to the effective and damage-free use of the Ozzies Padder.

- Physical inspection showed the steady-state layer deposited by the Ozzies Padder was typically a mix of small stones and earth. The leading edge of the fill material was loosely compacted, as was the material a foot or more back, in spite of additional material being overlaid by other spoil.
- Physical inspection where the fill over the crown of the pipe was removed at the end of a padding run showed a coating that looked as it did prior to the bedding and padding process, with no obvious evidence of nicks or chips.
- Where because of the topography the spoil was wet the Ozzies Padder screen and loader appeared to be prone to clog or pack with fill material, which slowed the process and limited the flow of fill material. Some clumping also was evident in the material deposited as it rolled down the leading face of the bedding and padding.
- Where the ground was hilly the design of the Ozzies Padder limits its motion to one direction, although its direction can be reversed by changing the side the conveyor table feeds to. If working down a steep hill, there is the possibility of large rocks falling off the screen and rolling past the padding operation onto bare pipe. As noted earlier, such concerns can be remedied through use of machines working in opposite directions such that gravity causes large rocks to roll back off the screen toward already padded pipe.

Bedding and Padding – General

- Forward flow of the fill material and the natural selectivity for coarser material to roll down the slope created by the angle of repose has been understood for decades as fundamental to success in bedding and padding, and a design parameter for such equipment. This forward flow once the pipe-string is enveloped is controlled by soil mechanics through the angle of repose for the soil, which depends on the nature of the soil, including the size and to a lesser extent the shape of the fill material. Any bedding and padding machine that provides for these aspects should supply well compacted fill that flows around the pipeline, with the little chance for coating damage.
- While contact with the pipe is necessary for damage, whether or not damage is done depends on the resistance of the coating to impact and other forms of contact as well as the energy and the nature of the contact. Nevertheless, a machine that limits contact is a hedge to avoid coating damage. So long as adequate cover is developed over an initial section of the pipe, and subsequent fines flow forward and envelop the pipe, the fill added should cause no chipping or other coating damage. Success in this context is largely dependent on fill that flows freely, which occurs most readily for dry fine fill material.

Rock Impact and Coating Quality in Relation to Safety, Reliability, and Cost Reduction

- Some heavier modern coatings, such as dual-layer Nap-Gard or Scotchkote products, appear highly resistant to impacts with sharp rather large aggregate falling from distances the order of six to eight feet. For example, jeeping over 400 feet where aggregate passing a two-inch square screen projected off a conveyer table and falling such distances onto the crown of a larger-diameter pipe-string revealed only one coating chip. Other ad hoc experiments on a discarded ring of pipe showed the coating to be quite resistant to damage, at least at moderate temperatures.
- The available results indicate that coating damage resistance is a major factor in the viability of bedding and padding procedures, as tough durable coatings can resist damage.

Damage resistance limits the relative significance of bedding and padding practices designed to avoid damage where such coatings are used. Developing performance-based specifications for coatings and construction practices seems viable in this context, with validation needed to make them as effective as possible in balance with longer-term concerns related to coating quality.

- More formal evaluation of coating damage resistance under parametric contact conditions is necessary to develop a quantitative understanding of what contact bedding and padding or related construction practices are viable versus problematic as a function of coating type and thickness, and factors affecting their properties such as temperature, thereby maximizing productivity without jeopardizing safety. Consideration should be given to typical as well as extreme conditions, as construction sites seldom involve only routine scenarios. The viability of coatings should also consider longer-term behavior, where soil movement can lead to scratching/scraping loadings not evident in construction.
- The role and effectiveness of CP should be a consideration in developing and validating any one-size-fits-all construction specification that involves coating quality.
- Once the viability and durability of various coatings are quantified in reference to construction practices and subsequent in-service loadings, up-front cost for such coatings can be weighed in balance to potential cost-reduction achieved over the pipeline's life-cycle in reference to reduced maintenance involving aspects such as recoating, pipe replacement, reduced CP demand, more consistent interpretation of direct-assessment measures, etc).
- A forum organized around coating damage resistance and longer-term durability would identify needs/benefits, if any, along with related drivers and so define a path forward, providing value to all stakeholders.

Rock Shield

- This generic class of products saw limited use on the spreads visited, possibly because various concerns exist for the use of polymer-based coatings[9].
- The use of "reverse rock shield" in the form of foam sprayed on the rock local to each bench appeared to provide effective protection during lowering in, avoiding concern for CP shielding where such foams are applied directly to the pipe-string.

Trench Stability

- Data are limited to nonexistent in reference to practical field conditions where trench stability due to water flow along the ditch or vertical migration in the ditch would be an issue.
- There is evidence that companies operating through hilly or mountainous terrain with significant rainfall potential experience trench stability problems due to flow along the ditch or vertical migration in the ditch – but there is no clear evidence to indicate the significance or extent of this concern or to identify factors that control when it becomes practically important.

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[9] While it was not evident in the small sample of sites visited, it does remain in use in various forms. An example of a slat-based approach wrapped around a protective overlay is illustrated on the first page of Reference 36.

- Where vertical trench stability appears to be a problem based on experience, select backfill might be a consideration, with rocks larger than a few inches excluded. But, as the data are limited to support such actions, this decision must reflect cost-benefit considerations.
- A forum organized around trench stability might be effective in defining the issues, if any. Potential considerations include geology, topography, and breaker spacing, and company-specific experience. Needs/benefits, if any, along with related drivers could identify a path forward, and so provide value to all stakeholders.

Future Developments

- "The industry is going toward bottom padding in the ditch before laying down the pipeline so that it will better conform to the shape of the ditch" according to Mr. Turnage, for which combination crusher/padding machines appear viable, although they currently are very slow.
- The hope that either a rock trencher/crusher and/or new coatings that were more resistant to chipping could be developed, making issue of rocks moot, was expressed by Mr. Klaymar.
- A forum organized around necessary/beneficial developments and related drivers and constraints might be effective in defining the issues, if any, and identifying a path forward with potential value to all stakeholders. Some useful aspects to consider include incorporation of technology to limit time on the spread and maintenance costs, or enhance operations, or facilitate integrity management. One possibility is deploying marker tape that is sufficiently wide and tough to cover the trench and be obvious to an excavator thereby limiting future contact with the pipeline. Another is capturing pipeline position through increasingly faster and more accurate GPS, or capturing and benchmarking girth-weld locations and local survey features for use in future in-line inspection (ILI) or other maintenance. Yet another is periodically capturing images of the soil, for use in future integrity management activities, or integration into analysis that use such data to assess the possibility of SCC. While some such aspects might add slightly to costs today, their future value for data integration and systemic integrity management is significant from several perspectives.

The KNI System – Layered Backfill

- Layered backfill does develop through use of Dynapad, which grades and places three tiers of fill material – fines, smaller sized stone and fines, and a third layer of larger sized spoil material. This was verified at all sites visited where Dynapad was used, with no evidence of apparent damage in any case.
- Whether this finer-quality layered fill material affects the integrity and reliability of the pipeline as compared to other padders depends at least on operator skill and experience in regard to the other padder, the nature of the coating used in regard to its resistance to damage, and the eventual presence of adequate and reliable CP.
- Corrosion that might ensue at such coating defects becomes a threat to integrity only where the CP is unreliable or inadequate, neither of which is a practical concern early in the life of a new pipeline. However, such chips can become a concern later in the life if, when, and where the CP system becomes unreliable or inadequate – aspects that are regulatory issues.

The KNI System – Pipeline Support Method

- Limited observations on Project One indicates this pipeline support comes in the form of precast foam benches, but literature documenting this and their design as a function of backfill density, product density, ditch depth, and pipe diameter and wall thickness to selectively control their failure was not available.
- Viscoelastic theory and related considerations (Appendix E) indicate the structural and failure response of foam structures is complicated with stress imposed locally as well as nominally being important factors that affect their behavior. Consequently, selectively controlling bench "failure" under locally different backfill density and ditch depth typical of most trenches, and uneven loadings during lowering-in and due to limited practical control over local alignment of the pipe will be complicated and difficult at best.
- However, use of compliant materials with a suitable foam density and viscoelastic time constant, as has been done beginning in Canada since the 1980s using a sprayed in-situ foam bench, appears viable for the spreads observed. Pipelines so installed should settle onto their bedding, as continued time-dependent compression develops.

The KNI System – Ditch Stability and Geotextile Fabric

- KNI suggests ditch stability is compromised in the horizontal direction due to water flow along the trench bottom, which is most prevalent where the gradient due to hills is present, and also notes vertical instability occurs due to change-in-state under water saturation. Both forms of instability appear feasible and experienced to some degree, as vertical instability might be due to freeze-that cycles. However, the extent of vertical instability and related padding washout is unknown, and its practical industry-wide significance is as yet unproven, although it is selectively credible based on limited data.
- As yet the use of geotextile as laid above layered backfill by Dynapad is unproven in stabilizing vertical washout[8].
- However, one company has limited sand washout under some circumstances by placing a non-woven geotextile fabric (Nylex 4553) on the padding, and extending it up the sidewall of the ditch. This placement is in strong contrast to the location associated with geotextile fabric laid by Dynapad.
- A forum organized around this topic might be effective in defining the issues, if any. Issues such as geology, topography, and breaker spacing are potential topics, along with company-specific experience.

Modifications that Merit Consideration

- Unless independently evaluated but not broadly known or reported, consider alternatives to the rot-resistant higher strength polymeric replacement for conventional burlap noted on some spreads for making sandbags.
- As modern coatings in heavy application appear resistant to impacts with sharp rather large aggregate as it enters the ditch in well-controlled bedding and padding, consider widespread use of such coatings where rock is anticipated. A ranking of coating resistance would enhance such decisions. As this requires data that define coating

performance, consider supporting this through related experiments to quantify coating damage resistance under practical field conditions in lieu of standardized industry tests that bear little resemblance to the field[10].

- As coating damage resistance can be a major factor in the viability of bedding and padding procedures, consider developing and validating performance-based specifications for both the coatings and construction practices.

Summary and Major Conclusions

Increased demand for transported fuels and other hydrocarbons has depleted supply basins near early markets, leading to increasingly remote supply basins that occasionally are located in challenging geographic and climatic conditions. Shifting population centers and related markets such as distributed power generation have likewise forced pipeline construction onto challenging routes across mountains and through other geographically difficult areas. This has led to the evolution of new or emerging construction practices, as well as developments in thinner and stronger line pipe, and new coatings. Such improvements coupled with developments in bedding and padding practices for hard, rocky ground could add value through increased safety and reliability due to reduced extent and/or severity of construction related coating damage that necessitate immediate or longer-term repair.

This project assessed enhancements in safety and productivity possible through recently developed construction practices, and identified and evaluated opportunities for cost reduction, improved pipe protection, and decreased construction created pipe/pipe coating damage that could be realized with new or emerging pipe support and padding/backfill practices. The extent to which safety and productivity were enhanced through recently developed pipe support and padding/backfill practices were evaluated relative to existing practices, for the range of ditching conditions where the benefits of such enhancements could be evident.

Safety and reliability have been evaluated in balance with construction productivity using field data and observations and metrics that reflect safety and characterize productivity and possible cost reduction. Empirical comparison of current and emerging or new practices and equipment in terms of productivity as well as safety and reliability helps establish what works best and under what conditions. For purposes of this project, the timeline for new or emerging is measured in reference to the introduction of technology that produces layered-backfill, as this comprises the last major step in flat screening technology to separate select backfill, in contrast to the prior major step that involved the shift from a rotary to flat screening. Safety and reliability were defined in reference to threats to pipeline integrity, and the relative significance of these threats. This led to parameters that minimize external corrosion and mechanical damage as measures of enhanced safety and reliability, which from a construction perspective translate to changes in pipe shape damage as practical field measures.

Data were gathered subject to the practical constraints imposed by use of construction equipment and the contractor's permission to enter or approach the ditch for "hands-on" measurements and

[10] Current work funded through the PRCI is evaluating bedding and padding optimization. Reference 47 addresses the results of this proprietary work, which as of the release date of this report is not yet available for purchase.

close-up observation. Accordingly, safety and other conditions dictated by the contractor were complied with.

On-site measurements and observations made in reference to the five sites considered lead to the following general conclusions.

- The performance of bedding and padding machines is dictated by the properties of the soil and soil mechanics, in addition to design and operating features that might be unique to a given machine.
- Differences in performance characteristics between integral in-line loader and screen machines and independently loaded stacked vertical-screen machines preclude a one-size-fits-all basis for machine selection. Economics and many other factors dictate overall productivity on the spread and constrain decisions – for example, where many tie-ins are involved because of routing or topography, the tie-in welds appear to control, and this is but one such factor.
- Coating damage resistance is a major factor in the viability of bedding and padding procedures, as tough durable coatings were resistant to damage under loading conditions characteristic of bedding and padding.
- The significance of bedding and padding practices designed to avoid damage is limited in practice where damage-resistant coatings were used. Performance-based specifications for coatings and construction practices seem viable in this context, with validation needed to make them as effective as possible, in balance with longer-term concerns related to coating quality.
- The potential for cost reduction due to improved bedding and padding procedures cannot be assessed independent of the coating used, because as just noted the significance of bedding and padding practices designed to avoid damage is limited in practice where damage-resistant coatings were used. This means that selection of bedding and padding practices depend on the coating system used as well as the conditions known or anticipated along the construction routing.
- The potential for cost reduction reflect not only the coatings performance during construction but also on the coatings survivability in-service. Long-term durability and reliability means reduced maintenance associated with avoided metal loss, as well as reduced costs and problems associated with other threats like possible SCC at coating failure sites or service induced damage such as dents and/or gouges. It follows that an up-front investment in quality coating brings the potential for immediate value through enhanced resistance to construction-related damage almost independent of the bedding and padding practice, plus longer-term cost-reduction and increased safety related to avoided corrosion, possible SCC, and mechanical damage.
- The behavior of the fill material is also a critical bedding and padding parameter, as forward flow of the fill material and the natural selectivity for coarser material to roll down the slope created by the angle of repose lead to flow of fill under and around the pipe-string. Forward flow once the pipe-string is enveloped is controlled by soil mechanics through the angle of repose for the soil, which depends on the nature of the soil, including the size and to a lesser extent the shape of the fill material. Any bedding and padding machine that provides for these aspects should reasonably supply compacted fill that flows around the pipeline, with the little chance for coating damage. Industry

personnel associated with companies that sell or operate such equipment note this inherent property of the fill material is a key to the bedding and padding success.

- The presence of select material under the pipe and the exclusion of larger rock from the immediate vicinity of the pipeline should lead to a reduction in rock dents and other such mechanical damage during construction. While not directly quantified in the project as such results follow from post-construction ILI and other such data, anecdotal information gathered from contractors indicates such benefits are common when the investment and effort is made to quantify such factors.
- Some technology-starved areas exist in regard to the aspects of pipeline construction considered, for which several recommendations follow in the next section.

A number of less general but still important conclusions follow from the measurements and observations made at the five sites considered. These include:

- Where it is "possible" to machine ditch the rock in lieu of blasting in reference to all factors from productivity through economy and safety, subsequent construction is facilitated and productivity enhanced.
- Sprayed in-situ foam offers support that is intimate with the ditch bottom, can be sized and shaped to address local differences in ditch depth, backfill density, transported product density, pipe diameter, and wall thickness, as well as structural response that facilitates controlled settlement onto the padding. When sprayed onto the trench wall above the support, sprayed foam offers reversed rock shield, protecting against very likely damage in tight ditches during lowering-in.
- The transition from burlap to synthetic bags could open the door to potential short- and long-term problems beyond those experienced with burlap.
- Problems in matching horizontal and vertical ditch profile to pipe profile at tie-ins tends to cause uneven loading on benches that can cause their failure, however in no case was there evidence of pipe to ditch contact that involved damage to the coating.
- Dynapad developed layered backfill, grading and placing three tiers of fill material. But, whether this enhances integrity and reliability depends at least on the damage resistance of the coating.
- Where appropriate skill is practiced, an Ozzies Padder (and presumably other similar designs) can bed and pad without undue damage to pipeline coatings, at least for the coatings and trench conditions addressed in this project. Significant to this conclusion is the skill of the operator during startup through steady-state operation, the coating used, and the screen size involved.
- Data regarding horizontal and vertical trench stability in the presence of water and related washout are limited to nonexistent, nor is there much practical field data to identify conditions where trench instability due to flow along the ditch or vertical migration in the ditch would be an issue.
- Some areas have been identified for future development. These focus combination crusher/padding machines and the continued evolution of coatings resistant to damage, making the issue of rocks moot.
- Analytical considerations indicate the complicated structural and failure response of foam structures make it very difficult to achieve selectively control bench "failure" – as

suggested for the KNI patent-pending precast foam bench – given the locally different conditions and loadings typical of most trenches.

- Use of geotextile laid above layered backfill by Dynapad is unproven to stabilize vertical washout. Control of sand washout under some circumstances by placing a non-woven geotextile fabric (Nylex 4553) on the padding, and extending it up the sidewall of the ditch involves placement in strong contrast to the location associated with Dynapad.
- Forums organized around topics such as ditch stability and new technology, might be effective in defining the issues, if any.

Recommendations

- Data concerning coating damage resistance are limited in reference to contact conditions and what size/depth chip or scrape is a short- or long-term threat. A formal evaluation of coating damage resistance under parametric contact conditions should be considered to quantify this in reference to contact bedding and padding or related construction practices are viable versus problematic as a function of coating type and thickness, and factors affecting their properties such as temperature, thereby maximizing productivity without posing a practically significant short- or long-term threat or burden on maintenance. Such testing and evaluation should represent the scenario as it occurs in practice as opposed to using simple standardized tests that are designed to facilitate comparing laboratory resistance under laboratory simulated scenarios, and also avoid direct acceptance of suppliers literature.[(e.g., 33,34)]
- Because tough durable coatings were observed to resist damage, damage resistance becomes a major factor in the viability of bedding and padding procedures. As the viability of coatings becomes better characterized, consideration should be given to performance-based specifications for coatings and construction practices, with validation drawn from the results of the above noted parametric coating evaluation. The role and effectiveness of CP should be a consideration in developing and validating any one-size-fits-all construction specification involving performance-based coating and bedding and padding practices.
- Some data indicate that horizontal and vertical trench stability and related washout pose a threat yet little is known to identify conditions where trench instability due to flow along the ditch or vertical migration in the ditch would be an issue. Consideration should be given to a forum organized around this topic to define the issues, if any, and identify a relevant path forward.

References

1. Clark, E. B., Leis, B. N., and Eiber, R. J., "Integrity Characteristics of Vintage Pipelines," Final Report to the INGAA Foundation, Battelle, October 2004.
2. Share, J., "Sheehan Pipe Line Moves into 2nd Century of Service," Pipeline and Gas Journal, Feb, 2003 (www.undergroundinfo.com/PGJ/pgj_archive/February03/sheehan).
3. Anon., Pipeline Construction, Petroleum Extension Service, University of Texas, Cat. No. 4.00030, 1984.
4. Rock Shield at www.pedero.com/pages/rockshield.htm.
5. Rock Shield at www.tapecoat.com/pages/tcrock.html.
6. Rock Shield at www.crc-evans.com/division/concrete/2e.html.
7. Rock Shield at http://www.conwedplastics.com/products_pipesaver.html.
8. CRC-Evans: www.crc-evans.com/division/pipeline (variety of inclined flat screen machines and crushers, including in the ditch units – look like Laurini machines).
9. EZ: www.ezpadding.com/home (dozer-mounted self loading via rotary paddles, with rotary screen).
10. KNI: advertised at www.dynapad.com (sideboom mounted (rubber-tire option available) backhoe loaded vertically stacked inclined flat screen machine, couples with geotextile stabilizer/ warning tape installation and precast foam benches) Literature provided independent of their advertised website addresses the KNI system in regard to the supports, layered backfill/Dynapad, screening, and other related aspects.
11. Laurini: www.laurini.com/superscreen (variety of inclined flat screen machines and crushers, including in-the-ditch units).
12. Outlaw: www.outlawpadding.com/padding_machine (backhoe mounted and loaded screen plus bucket).
13. Ozzies Padder: www.ozzies.com (integral loader and single inclined screen in-line machine).
14. Somico: www.somico.com/padding (sideboom mounted, backhoe loaded vertically stacked inclined flat screen machine – looks like Dynapad - plus integral loader and single inclined screen in-line machine).
15. Superior: via webinfo.wwmachine.com/equipmentsearch.aspx, then search on padding machines – currently yields two sizes of superior padders (Ozzies Padder-like integral loader and single inclined screen in-line machine).
16. Jackson, J., CRC-Evans, private communication, in his follow-up to a phone conversation with Battelle project staff, Feb. 2003.
17. Anon., "Pipeline Coatings/Backfill Testing," Advantica Circular, Issue 12, Winter 2003 (spadeadam@advantica.biz) – Completed study reported under Project Number GRI 8704 to become available through www.PRCI.com.
18. Masilela, Z. and Pereira, J., "Using the direct current voltage gradient technology as a quality control tool during construction of new pipelines," *Eng. Failure Analysis*, Vol 5, No. 2, 1998,p. 99-104.
19. Anon., United States Department of Transportation, Research and Special Projects Agency web site, http:\\primis.rspa.dot.gov/comm; see also http:\\primis.rspa.dot.gov/iim; see also

related legislative action and regulatory requirements in Code of Federal Regulations, Title 49-Transportation, Part 192 and Part 195 in sections specifically regulating IMPs.

20. Anon., ASME Code Supplement on Integrity Management for Pressure Piping, B31.8S, Revision 1, 2002, ASME.
21. Anon., "Managing System Integrity for Hazardous Liquid Lines," 1st Ed., API Standard 1160-2001, November 2001.
22. Anon., United States Department of Transportation, Transmission Pipeline Incident Reporting, http:\\ops.dot.gov/forms.htm#7000-1/2.
23. Anon., United States Department of Transportation, Transmission Pipeline Incident Databases, Office of Pipeline Safety web site, http:\\ops.dot.gov.
24. Kiefner, J. F., Mesloh, R. E., and Kiefner, B. A.; " Analysis of DOT Reportable Incidents For Gas Transmission and Gathering System Pipelines, 1985-1997", PRCI, PR-218-9801, 1999: see also Jones, D. J., Kramer, G. S., Gideon, D. N., and Eiber, R. J., "An Analysis of Reportable Incidents for Natural Gas Transmission and Gathering Lines 1970 through 1984," PRCI Catalog No. L51499, March 1986.
25. Trench, C. J., "The U. S. Oil Pipeline Industry's Safety Performance," Report to Association of Oil Pipe Lines and the American Petroleum Institute's Pipeline Committee, February 2003.
26. Anon., "Specification for Line Pipe", API Specification 5L, April 1995.
27. Leis, B. N. and Hopkins, P., "Mechanical Damage Gaps Analysis", in Volume I -Pipeline Technology, Science Surveys Ltd., 2004, pp 1921 - 1943.
28. Espiner, R., Thompson, I. and Barnett, J., "Optimization of Pipeline Coating and Backfill Selection," NACE03 Paper 03046, 2003.
29. Schmitz-Pranghe, N. and von Baeckmann, W., "Polyethylene Extrusion Coating of Buried Steel Pipe," Corrosion 77, Paper No 142 NACE International, 1977.
30. Williamson, A., et al., "The Resistance of Advanced Pipeline Coatings to Penetration and Abrasion by Hard Rock," 2nd International Pipeline Conference, ASME International, Calgary, October 2000.
31. Clough, N., et al., "The Buried Pipeline: An Engineered Approach," Onshore Pipeline Cost Reduction Conference, Amsterdam: also Clarion Technical Conferences, Houston, April 2000.
32. Edmondson, S., "Measuring the Ability of Dual Powder Systems and Three Layer Polyolefin Coatings to Withstand Damage," 14th International Conference on Pipeline Protection, Barcelona, October 2001.
33. ASTM G14-83: Standard Test Method for Impact Resistance of Pipeline Coatings. ASTM, 1983.
34. ASTM G17-83: Standard Test Method for Penetration Resistance of Pipeline Coatings, ASTM, 1983.
35. Lambe, T. W. and Whitman, R. V., Soil Mechanics, John Wiley, 1969.
36. Ives, B., "Operators Schedule 12300 Miles for Construction," PipeLine and Gas Technology, February 2003, pp. 16-19.
37. KNI email from Ed Klaymar to Battelle, dated June 18 2002, stating KNI would "obtain 3 or 4 spreads in which it would be committed to utilize our full methods on portions of the

spreads. Furthermore, these spreads will already have been committed to utilize the Dynapad Layered Backfill Machine on the complete spread."

38. Anon., "Foamed Padding Cuts Padding Costs," Pipe Line News, July 1962, pp. 44-45.
39. Anon., discussion at www.pedero.com/pages/, circa February 2003.
40. Yamauchi, H., Westcoast Energy Inc., private communication, discussion of innovations in Canadian transmission pipeline construction, October 2003.
41. Jackson, J., CRC-Evans, private communication, discussion of bedding and padding history and practices during his visit to Battelle, February 2003.
42. Tunrage, C., Ozzies Padder, private communication, discussion of bedding and padding history and practices during his visit to Battelle, March 2003.
43. Anon., private communication, operator of the Ozzies Padder on the Project One spread, July 2002.
44. Anon., private communication, lead-hand and operator of the lead Ozzies Padder on the Project Two Spread A, February 2003.
45. Ferguson, T. A., "An Evaluation of a New Ditch Backfill Method for Use When Laying Pipelines in Rocky Terrain," Gas Research Institute, GRI-97-0260, 1997.
46. Pipkin, A. C., Lectures on Viscoelasticity Theory, Springer-Verlag – Volume 7 in Applied Mathematical Sciences, 1972.
47. Thompson, I., Private communication, with the principle investigator of PRCI/GRI 8704, to become available through www.PRCI.com, January 2005.

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Appendices
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Bedding and Padding
and Related Construction Practices "

Appendices

This section contains details in support of the body of this report in the form of five appendices as follows:

Appendix A – Operation and Function of Ozzies Padder and the Dynapad Machine
Appendix B – Field Measurement Protocol
Appendix C – Reporting Format
Appendix D – Soils Reports
Appendix E – Viscoelastic Aspects of Bench Design

Appendix A outlines the operation and function of the Ozzies Padder and Dynapad machine based on observations made during this project. Appendix B presents the field measurement target protocol, while Appendix C presents the target report format. Appendix D presents the soils reports as determined for selected sites whereas Appendix E presents results done to better understand the structural performance of benches made of polymeric foam.

References cited in the body of the report are numerous, and few additional references appear in these appendices. For this reason it is convenient to retain the numbering system used in the body of the report. When new references are cited, they appear in the appendices as footnotes. Footnotes used herein are numbered independently from the body of the report. In contrast, where figures appear here in that are not addressed in the body of the report, it is impractical to retain the numbering system from the body of the report. Where figures or tables presented in the body of the report are cited, use is made of the same number used in the main text. Where new figures or tables are introduced, they are numbered with a scheme that couples a letter prefix corresponding to each appendix coupled with the figure or table number as appropriate.

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Appendix A – Operation and Function of Ozzies Padder and the Dynapad Machine

Operation

Dynapad Machine

Dynapad is an inclined vertically stacked processor of spoil that uses multiple screens to separate and grade spoil, and by arrangements within the unit deposits successively coarser fill material sequentially into the RoW. Dynapad is a gravity based machine from its feed stock to its delivery. It operates over the pipe-string while attached to and suspended there from a "mast" connected in its currently advertised configuration to a conventional side-boom. In the past it also has been suspended from a front-end loader.

Provisions made via design are available to maintain the screening unit or "mainframe" more or less horizontal, and to rotate this unit to reverse operating direction. Information as to its design and history including the patent process can be found online through an internet thread that relates to its designer, L. John Morris, and patent under the name of Edward J Klaymar. The shaking or vibrating screens are steeply inclined in optimal use, to limit dynamic screen blinding, being fed by conveyer from a holder that collects fill material from a hopper. The holder is present to maintain supply to the conveyor.

Primary separation occurs above the hopper through use of steel bars with a clear spacing that passes material about five inches on one dimension. These bars run across the full length of the hopper, and serve to reject rocks and clumps of fill material larger than this size. The rack of bars can be raised toward a vertical position to dump debris blocking entry into the already padded and covered ditch. This helps limit static blinding of this primary screen. Material longer in one dimension than the spacing of the bars is avoided by spoil selection done by the backhoe operator feeding the hopper. As such the first screen is not mechanical but human.

Spoil passed through the bars is transferred from the holder onto a conveyor belt onto increasingly finer screens for deposit into the ditch. The clear pitch of the first screen is designed to pass material the order of two inches on a side, measuring about 2.25 by 2.25 inches, while the clear pitch for the second screen measured about 1.5 by 2.25 inches, the latter dimension being parallel to the trench. The positioning of the screens and the internal operation of the mainframe causes the smallest fill material to fall first onto the pipe-string. Thereafter, increasingly coarser material is deposited sequentially over the length of several feet along the pipe-string. Thus, soil and rock larger than the last screen but smaller than the first fall onto fines passed by the last screen, while material not passed by the bars falls onto the previously deposited padding as it drops off the back of the hopper.

The incline angle of the screens coupled with movement of the screens and gravity controls the size of the material passing the screen, such that the material passed tends to be smaller than the clear pitch of the screens. These parameters also cause the larger material to shift along the screen until it eventually falls to the next screen or onto the pipe-string. Where ample fines are accessible to the backhoe feeding the padder, the deposit off the last screen can create a layer of cover whose depth ranges from six to twelve inches deep (on average), which is followed by successive layers of increasingly larger fill material and rock, the last comprising material that

did not pass the bars above the hopper. Because the hopper is fed by backhoe, spoil can be selected whose maximum size suited the requirements for the job. Figure 6 illustrates the axially sequential deposit of coarser fill material developing layered backfill from Dynapad. Figure 6a shows the process underway in steady-state operation while Figure 6b is a view of the results after a start-stop cycle in a bedding and padding run on Project One.

Ozzies Padder

The Ozzies Padder in heavier-duty models is an axially-in-line integrated loader and processor of spoil. It couples a single shaking or vibrating screen that is fed by a conveyer through a chute to a loader located at the front of the machine. These machines operate on the shoulder of the ditch parallel to the pipe-string, feeding select fill passed by the screen to the pipe-string by a conveyer that collects fill material and delivers it to the ditch by extending a table from the machine toward the ditch.

The axial structure of the Ozzies Padder involves a loader comprising a "mouth," chute, and inclined conveyer articulated from a crawler. This loader deposits spoil onto a declined screen attached to the crawler, which separates acceptable fill material from the rejected spoil. Acceptable fill material is deposited onto a conveyer that runs along a table that extends to either side of the machine. The articulated loader provides limited manipulation, which in conjunction with the crawler broadens access and/or aids selection of spoil. Because of the axial structure and the limited articulation, the angle of the screening unit cannot be simply modified to deal with slope differences along hills. However operating direction can be reversed by design by switching the side the fill material is conveyed to. Information as to its design and history can be found online, where its patent is under the name of Mark Osadchuk.

As for any screen-based system, the incline angle of the screen coupled with movement of the screen and gravity controls the size of the material passing the screen. These same parameters cause the larger material to shift along the screen, which is deposited on the shoulder of the ditch in the wake of the padder. The screen size is job-specific, being chosen according with the specifications, with clear screen spacings available from less than one inch to several inches, as needed. Because the spoil processor is in-line and integrated to its loader, access to acceptable fill material is controlled by the fines available from a linear track through the spoil windrow. For this reason, the fines available in the windrow are enhanced by "roaching" the spoil using a bulldozer, adding material where possible and narrowing the windrow to better match the mouth of the padder. Very large rock (boulders), several feet across, is selectively removed during this process. But, in contrast to the Dynapad machine where large rock was selectively avoided by the backhoe operator, many large rocks (some up to two feet across) remained in the windrow.

This heavy-duty machine efficiently separates large rock and unacceptable spoil from the useful material, with the unsuitable material dumped in the wake of the machine. When the fines available in the spoil fail to provide the required bedding, padding, and cover in one pass, a second or third pass can be needed. Because the machine very efficiently separates useful material from the spoil, little useful material remains after a pass through the windrow, leading to diminished returns from a second or third pass unless material is added to the windrow or the windrow reshaped. The unusable material from prior passes is left in the wake of the padder can complicate this process, thus slowing progress.

It follows that efficiency in padding is controlled by the length conveyer table, to facilitate access to spoil further from the ditch, and the amount of fill material that are available from the windrow of spoil. Efficiency is also influenced by the quality of the ditching, as heavier versions of this machine must remain well off the edge of the ditch. For some jobs, the weight of the larger Ozzies Padders can limit its access to rich spoil when the main spoil pile during trenching is placed over adjacent hot lines in the RoW. This too can effected efficiency. Other factors include the large diameter of this pipeline and the uneven larger ditch due to the rock, both of which contribute to the amount to acceptable material required to meet company-specified cover.

Bedding and padding reaching the pipe for the Ozzies Padder appears to be homogenous in size and constituents throughout the cover. The cover appears to be soft and also appears to be penetrated more easily by large rocks, although the observations supporting this in contrast to Dynapad are limited.

In-Service Use, Typical Practices, and Results

Dynapad Machine

The Dynapad machine is used over stretches where rock is present, although the decision of whether rock is present or absent lacked a quantitative basis. Because the presence of this padding machine slows progress as compared to when it is not used, stretches where rock is absent are constructed using typical construction procedures.

The Dynapad machine is used in conjunction with a backhoe that gathers spoil and loads the machine's hopper, and one bulldozer that both roaches spoil and tops off the ditch in the wake of the Dynapad machine. Because of the reach of typical backhoes, a wide range of spoil can be selected to avoid debris or large rock from either the main or secondary spoil piles. Because spoil can be added without forward motion, bedding, padding, and deep cover can be accomplished in a single pass.

At start-up, fill material off the fine screen drops around the pipe, with the hopper fed until the pipe-string is covered, after which the fill material flows forward enveloping the pipe-string over a distance of several feet. The ability to select fines by independent loading via backhoe means that, with appropriate spoil selection, startup can proceed with only fines deposited into the ditch. Backhoe operator skill is essential in this context to ensure rich fines enter the hopper until the pipeline is initially covered, limited damage to the coating from fill material falling directly onto the crown of the pipe-string. However, no Dynapad operator "technique" is necessary as the amount of fill material available at startup does not require forward motion to supply feed for the hopper, nor was technique needed to ensure that material adjacent to the pipe-string was comprised of fines. However, skill is necessary on the part of the backhoe operator as high-quality fill material must be found to ensure nothing comes off the hopper or the coarse screen until the first layer is created.

Once the pipe-string is covered, forward progress can begin with less concern for spoil selection, as once the pipe is covered coarser fines and other material are deposited sequentially onto the already covered pipe-string. Flow of the fill material forward along the pipe-string once the pipe-string is enveloped is controlled by soil mechanics through the angle of repose for the soil[35], which depends on the nature of the soil, including the size and to a lesser extent the shape of the fill material. The extent of this flow as it enveloped the pipe for Dynapad is evident in

Figures 7a and 7b. Forward flow of the backfill and the natural selectivity for coarser material to roll down the slope created by the angle of repose has for decades been understood to be fundamental to success in bedding and padding[41,42].

Because the last screen deposits fines onto an already existing layer once steady-state operation develops, and where the spoil is dry, the fill material flows freely onto, around, and underneath the pipe leaving little unfilled the area except below the invert. Continued flow of fill material appears to completely fill this area, leaving little or no discernable void[1]. Where the spoil is wet, the hopper appears to be prone to clog, which slowed the process and limited the flow of fill material, with some clumping being evident in the material deposited off the last screen. Nevertheless, apparently because the fill material passing the fines screens is dryer than the material that clumps, flow of the fine fill material continues down and around the pipe much as it does for dry spoil.

The design of Dynapad facilitates a change in the direction of operation by rotating its mainframe. Likewise, the mainframe can be adjusted to keep it level such that the screens work at or close to their design inclination.

Ozzies Padder

Ozzies Padder is used over stretches where rock is present, although the decision of whether rock is present or absent lacked a quantitative basis. Because the presence of this padding machine slows progress as compared to when it is not used, stretches where rock is absent are constructed using typical construction procedures.

The Ozzies Padder is used in conjunction with a bulldozer that roaches spoil and shapes the spoil windrow with a backhoe when needed to add reach or help enrich the spoil, and as needed another auger-dozer or bulldozer is used to top off the ditch. Less support is needed when the spoil is rich in fines, which limits the need to reshape and enrich the spoil as occurs when multiple passes are needed to meet specified bedding, padding, and cover requirements. In contrast, when access is limited to the main spoil pile for various reasons, a backhoe is used to transfer spoil to the side of the ditch being padded, while the spoil is roached by the bulldozer.

Absent the ability to layer the padding as occurs for Dynapad, technique is required with Ozzies Padder to avoid impacting the pipe with the flow of fill material during start-up. Operators and personnel working with the Ozzies Padder note that the richest zone of fines tend to lie toward the bottom and center of the spoil, such that an effort is made at startup to articulate the mouth of the padder into this area during the startup phase of the operation. Also during startup, operators limit contact with the pipe by directing the flow of fill material from the conveyer table into the space between the adjacent ditch-wall and the pipe, filling that side with overflow onto the top of the pipe-string, followed by flow onto the now covered crown to fill the ditch side opposite the padder. Thus, operator "technique" is important to maximize the amount of fines available at startup and minimize possible contact with the pipe-string. This can be complicated by the fact that forward motion is needed to supply feed to the screen. Thus, during startup and the first few

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[1] Conclusive observation is in all cases complicated by the forward motion of the bedding and padding process, the forward flow of the fill material, limited space between the pipe and the ditch-wall and bottom, and the limited light. This observation of filled space reflects views captured photographically under such conditions.

feet of the bedding and padding operation, areas rich in fines must be sought in the spoil to limit contact of the pipe by larger but still acceptable fill.

As discussed earlier, flow of the fill material forward along the pipe-string once the pipe-string is enveloped at start-up is controlled by soil mechanics. Forward flow of the fill material and the natural selectivity for coarser material to roll down the slope created by the angle of repose is fundamental to success in bedding and padding. Figure 8c illustrates one technique often used for the second pass on this spread, while Figure 8d shows the ditch after the second pass is completed (viewed in the direction of padder advance). This figure also illustrates the type of material in the fill mix, which here runs from fine earth through small rounded stones and occasionally sharper rocks. Figure 8e illustrates the rock typically excluded by this padder.

Once the pipe is enveloped, fill material can be added during steady-state operation to any area of the covered pipe during start-up, because the already present fines limit direct contact and the larger material rolls harmlessly down to the ditch bottom. Such views are common on the Ozzies Padder website. During the steady-state bedding and padding process, fill material off the screen flows freely underneath the pipe, with continued flow of backfill completely filling this area. The backfill compacts by virtue of the weight of the overburden. This is evident by the flow out from under the pipe-string over the course of the first pass, as shown in Figure 8a, and the extent of the fill that fully occupies the space below the pipe, as shown in Figure 8b. Other excellent photographs of this behavior are included in Figure 9. Physical inspection shows the steady-state layer deposited by the Ozzies Padder is typically a mix of small stones and earth, the ratio of which is dictated by the feed-spoil. Inspection where the fill over the crown of the pipe shows a coating that looked as it did prior to the bedding and padding process, with no obvious evidence of nicks or chips. Figure 8f illustrated one patch exposed near the leading edge of the cover on the crown of the pipe-string. There was no evidence of chips, and the shine of the finish coating remained when the dust was washed off. The depth of the padding developed is a clear function of the fraction of fill material available and forward speed.

The design of Ozzies Padder facilitates a change in the direction of operation by switching the side from which the ditch is fed. However, there is no adjustment to the screen to keep it close to optimum function.

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Appendix B – Field Measurement Protocol

What follows are field guidelines as developed prior to the visit to the second project. This protocol evolved in light of the experience gained at the first project, and continuously thereafter as what could or could not be expected on-site became increasingly defined.

Roles and Responsibilities

Develop visual observations over the course of the day, and comment on those observations according to the Schedule of Activities. Obtain items to support the Schedule of Activities attached, and make arrangements for local laboratory support as outlined in the same schedule. Direct the lab to hold the samples for up to six months.

Target Schedule of Activities

Prior to site visits:

Obtain and read the padding/backfill and pipe support project specifications during transit to the primary site, and note critical dimensions that characterize bedding and padding, and backfill procedures.

At each site:

- Determine the pipe diameter, wall thickness, grade, and coating
- Identify and record the manufacturer names, and their equipment designations for all equipment used, for each of the operations observed
- Photograph typical aspects of each operation

Observe and Characterize Pipe Support

Sand bags if used for support –

- count the number of sand bags per bench and photograph what appears typical,
- measure the center-to-center distance between benches, and
- through discussions with the foreman, determine crew size, equipment used, and number of benches set per day, as basis to estimate bench cost.

Observe lowering-in

- estimate the cross-section area of several benches to estimate support pressure and
- determine if every bench appears to be supporting the pipe uniformly? If not, are there spans, and how big: How often? Photograph what appears typical.

Screened subsoil mounds for support rather than sand bags –

- measure the time to create several supports and photograph what appears typical,
- measure the center-to-center distance between supports, and

- through discussions with the foreman, determine crew size, equipment used, and number of supports set per day, as basis to estimate cost per support.

Observe lowering-in

- estimate the cross-section area of several supports to estimate support pressure and
- determine if the pipe settles onto the supports equally or unequally between a typical set of supports If not, are there spans, and how big: How often?

Bedding and Padding Operations

- determine the number of screens and measure screen mesh size openings
- measure the height of pipe over trench floor in several sites to determine the extremes and what is typical along a joint of pipe, and for five or so randomly chosen joints,
- determine the size of the ditch relative to the pipe and contrast to specs,
- observe rate of forward progress as a function of typical operation over the course of the day, and report extremes as well as average progress ,
- determine the number of passes to affect coverage to suit the specs, and measure typical cover over the pipe, and photograph what is typical,
- observe the extent of fill under the pipe, as opportunities are present, as for example when the crew completes a pass, or breaks for lunch, and photograph what is typical,
- photograph the native backfill and estimate the size and roughly estimate the range of rock sizes present,
- identify the pieces of equipment involved, their sizes, and the man power employed for padding as the basis to estimate costs,
- measure size of padding material and obtain a sample for lab sieve test,
- locate local lab and determine sample characteristics in terms of particle size distribution – obtain 4 to 6 such samples per site, using judgment to represent the range of geological conditions experienced (purchase a pail and a supply of heavy-duty bags for this purpose – satisfy the local lab's requirements on sampling practices,
- observe and determine if padding material introduced into the trench impacts the pipe after one or two passes are made and pipe is not covered, walk the crown of the pipe and use holiday detector (jeep) to check for bare metal exposures. Do this for each different type of padding machine in use on the spread. Note: Exposures are most likely to occur from clock positions 9 to 11 and 1 to 3, or in the vicinity of 30° to 45° from the square padding impact point – see Figure B1 for clues as to location, and
- when the crew has stopped a padding run, from the vicinity of the toe of the padding (where the pipe is just uncovered), back onto the increasingly deeper cover, drop a small ball that weighs a few ounces (e.g., use white golf balls) onto the pipe from a fixed height, such as your waist, targeting a spacing of ~ 3 inches for a distance of about 24 inches. Leave the golf balls in place – locate rulers to serve as vertical and horizontal scales, and

photograph each site to capture the relative penetration and degree of compaction typical of each different type of padding machine in use on the spread.

Backfill Operations

- observe backfill process to document backfill rocks falling through the padding and contacting, or coming into close contact with the pipe and
- estimate the nature of the backfill relative to the presence of rocks, their sizes, and proximity to the pipe wall.

Check out variances

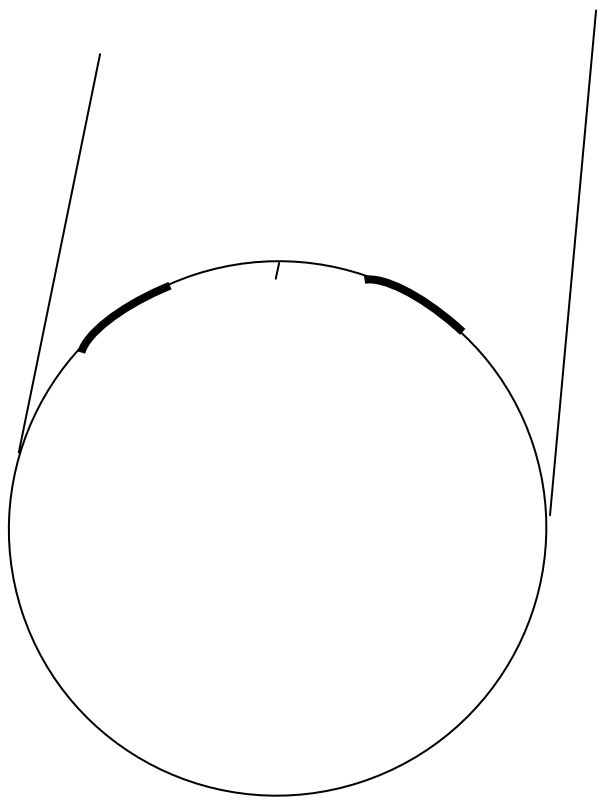
Through discussion with spread management determine

- what happens in extreme rock conditions and
- in what type of conditions are padding machines not used.

On the Ride Home

- while still fresh in your mind, use this time as necessary to make notes or documentation in addition to that made daily on the spread.

Figure B1 follows



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Appendix C – Reporting Format

Line Pipe Description – diameter, thickness, grade, coating and unique descriptors

Pipeline and Right-of-way Description – owner, general location or routing, transported product

Spread Description – topography and geography, and general practices in use, the nature of ditching, type and quality of spoil, etc.

Equipment and Personnel – list all relevant equipment and support personnel, management, etc.

Supports – Report the support scheme and details relating to materials, type of construction, and aspects indicative of cost and quality. Address distances, sizes, features, and consistency versus variability, etc. Address measures related to productivity and quality as they effect construction and might impact long term pipeline functionality. Report influence on pipe shape and or aspects related to damage to pipeline (denting/ovalization) and coating. Characterize and quantify, or provide qualitative data.

Breakers – Report the support scheme and details relating to materials, type of construction, and aspects indicative of cost and quality. Address distances, sizes, features, and consistency versus variability, etc. Address measures related to productivity and quality as they effect construction and might impact long term pipeline functionality.

Bedding and Padding Operations – Report and discuss equipment and its function/operation, when and why it is effective, strengths/weakness, measures of productivity, quality in reference to bedding and padding, such as flow around and compaction, fines, necessary technique/skill, possible enhancement through modifications, etc. Characterize and quantify, or provide qualitative data. Assess the role of the trenching, in reference to productivity in trenching and any relationships to same or subsequent functionality or integrity of the pipeline. Address distances, sizes, features, and consistency versus variability, etc, all as a function of the trench and spoil conditions, and the amount of equipment and personnel involved. As relevant address layered backfill, and always report coating condition and possible damage, whenever possible using jeeping practices. Take pictures often, and of everything. Physically inspect everything noted, and document. Measure depths, compaction, etc, and qualify as a function of conditions. Do so for all aspects from trenching, through final backfill operations.

Prepare notes for field reports nightly.

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Appendix D – Soils Reports

This appendix includes soils sampling of spoil recovered from the spoil piles along the RoW prior to the bedding and padding operation. As this sampling represents material obtained by randomly filling a two and one-half gallon pail, there is a natural tendency to obtain samples that are representative as well as maximize the material available for evaluation. Likewise, there is a limitation in regard to the maximum size boulder or rock based on what the pail could hold. These facts taken together have limited the samples to sizes biased to smaller material, as where larger material was involved it is not represented by this sampling practice. In all cases the work was done by commercial laboratories. As the body of the report indicates, results were developed from seven samples for Project Two (four sites on Spread A and three sites on Spread B), three sites on the Project Four, and one site on the Project Three. For reference, sieve sizes other than those noted in inches as fractions down to 3/8-inch reflect even sizes in SI units spaced along a logarithmic scale. For reader convenience, these are translated to fractions of an inch, that to be useful must be reported to three decimal places. These are reported in pairs as (sieve number / inch fraction): #4 / 0.187, #8 / 0.093, #16 / 0.071, #30 / 0.024, #50 / 0.012, #100 / 0.006, #200 / 0.003.

The reports are presented on the ensuing pages.

SUMMARY REPORT OF SOIL AND AGGREGATE TESTS

Date of Report: 2/24/03
Project Number: 273-001
Sample Number: 11619

Soil Symbol: GM
Date Sampled: N/R
Date Received: 2/20/03
Sampled By: Client

Soil Classification: Light brown silty gravel with sand

SOIL AND AGGREGATE PROPERTIES	Test Method ASTM	Results	Specifications	Pass or Fail
Liquid Limit, LL	D4318			
Plastic Limit, PL	D4318			
Plasticity Index, PI	D4318			
Fractured Faces, %	NDOT T230			
R-Value, RV	D2844			
Cleanness Value, CV	NDOT T228			
Sand Equivalent, SE	D2419			
Fine Aggregate Void Content, %	AASHTO T304			
LA Abrasion, % loss 100 Rev's	C131			
LA Abrasion, % loss 500 Rev's	C131			
Clay Lumps and Friable Particles	C142			
Lightweight Pieces, %	C123			
Uncorrected Max. Dry Density, pcf	D1557			
Uncorrected Optimum Moisture, %	D1557			
Corrected Max. Dry Density, pcf	D1557			
Corrected Optimum Moisture, %	D1557			
Bulk Specific Gravity, +3/4"	C128			
Bulk SSD Specific Gravity	C128			
Apparent Specific Gravity	C128			
Absorption, %	C128			

SIEVE ANALYSIS - ASTM C136,C117		Specification Limits		
Sieve Size	Percent Passing	Min.	Max.	Pass or Fail
6"				
3"	100			
2"	96			
1 1/2"	92			
1"	84			
3/4"	78			
1/2"	69			
3/8"	63			
#4	52			
#8	46			
#16	43			
#30	40			
#50	38			
#100	32			
#200	18			

Comments:

Reviewed By: Marlen Pistoni

Date: 2-24-03

SUMMARY REPORT OF SOIL AND AGGREGATE TESTS

Date of Report: 2/24/03
Project Number: 273-001
Sample Number: 11619

Soil Symbol: GM
Date Sampled: N/R
Date Received: 2/20/03
Sampled By: Client

Soil Classification: Light brown silty gravel with sand

SOIL AND AGGREGATE PROPERTIES	Test Method ASTM	Results	Specifications	Pass or Fail
Liquid Limit, LL	D4318			
Plastic Limit, PL	D4318			
Plasticity Index, PI	D4318			
Fractured Faces, %	NDOT T230			
R-Value, RV	D2844			
Cleanness Value, CV	NDOT T228			
Sand Equivalent, SE	D2419			
Fine Aggregate Void Content, %	AASHTO T304			
LA Abrasion, % loss 100 Rev's	C131			
LA Abrasion, % loss 500 Rev's	C131			
Clay Lumps and Friable Particles	C142			
Lightweight Pieces, %	C123			
Uncorrected Max. Dry Density, pcf	D1557			
Uncorrected Optimum Moisture, %	D1557			
Corrected Max. Dry Density, pcf	D1557			
Corrected Optimum Moisture, %	D1557			
Bulk Specific Gravity, +3/4"	C128			
Bulk SSD Specific Gravity	C128			
Apparent Specific Gravity	C128			
Absorption, %	C128			

SIEVE ANALYSIS - ASTM C136,C117		Specification Limits		
Sieve Size	Percent Passing	Min.	Max.	Pass or Fail
6"				
3"	100			
2"	96			
1 1/2"	92			
1"	84			
3/4"	78			
1/2"	69			
3/8"	63			
#4	52			
#8	46			
#16	43			
#30	40			
#50	38			
#100	32			
#200	18			

Comments:

Reviewed By: Marlen Fatoni

Date: 2-24-03

SUMMARY REPORT OF SOIL AND AGGREGATE TESTS

Date of Report: 2/24/03
Project Number: 273-001
Sample Number: 11619

Soil Symbol: GM
Date Sampled: N/R
Date Received: 2/20/03
Sampled By: Client

Soil Classification: Light brown silty gravel with sand

SOIL AND AGGREGATE PROPERTIES	Test Method ASTM	Results	Specifications	Pass or Fail
Liquid Limit, LL	D4318			
Plastic Limit, PL	D4318			
Plasticity Index, PI	D4318			
Fractured Faces, %	NDOT T230			
R-Value, RV	D2844			
Cleanness Value, CV	NDOT T228			
Sand Equivalent, SE	D2419			
Fine Aggregate Void Content, %	AASHTO T304			
LA Abrasion, % loss 100 Rev's	C131			
LA Abrasion, % loss 500 Rev's	C131			
Clay Lumps and Friable Particles	C142			
Lightweight Pieces, %	C123			
Uncorrected Max. Dry Density, pcf	D1557			
Uncorrected Optimum Moisture, %	D1557			
Corrected Max. Dry Density, pcf	D1557			
Corrected Optimum Moisture, %	D1557			
Bulk Specific Gravity, +3/4"	C128			
Bulk SSD Specific Gravity	C128			
Apparent Specific Gravity	C128			
Absorption, %	C128			

SIEVE ANALYSIS - ASTM C136,C117		Specification Limits		
Sieve Size	Percent Passing	Min.	Max.	Pass or Fail
6"				
3"	100			
2"	96			
1 1/2"	92			
1"	84			
3/4"	78			
1/2"	69			
3/8"	63			
#4	52			
#8	46			
#16	43			
#30	40			
#50	38			
#100	32			
#200	18			

Comments:

Reviewed By: [signature]

Date: 2-24-03

SUMMARY REPORT OF SOIL AND AGGREGATE TESTS

Date of Report: 2/24/03
Project Number: 273-001
Sample Number: 11619

Soil Symbol: GM
Date Sampled: N/R
Date Received: 2/20/03
Sampled By: Client

Soil Classification: Light brown silty gravel with sand

SOIL AND AGGREGATE PROPERTIES	Test Method ASTM	Results	Specifications	Pass or Fail
Liquid Limit, LL	D4318			
Plastic Limit, PL	D4318			
Plasticity Index, PI	D4318			
Fractured Faces, %	NDOT T230			
R-Value, RV	D2844			
Cleanness Value, CV	NDOT T228			
Sand Equivalent, SE	D2419			
Fine Aggregate Void Content, %	AASHTO T304			
LA Abrasion, % loss 100 Rev's	C131			
LA Abrasion, % loss 500 Rev's	C131			
Clay Lumps and Friable Particles	C142			
Lightweight Pieces, %	C123			
Uncorrected Max. Dry Density, pcf	D1557			
Uncorrected Optimum Moisture, %	D1557			
Corrected Max. Dry Density, pcf	D1557			
Corrected Optimum Moisture, %	D1557			
Bulk Specific Gravity, +3/4"	C128			
Bulk SSD Specific Gravity	C128			
Apparent Specific Gravity	C128			
Absorption, %	C128			

SIEVE ANALYSIS - ASTM C136,C117		Specification Limits		
Sieve Size	Percent Passing	Min.	Max.	Pass or Fail
6"				
3"	100			
2"	96			
1 1/2"	92			
1"	84			
3/4"	78			
1/2"	69			
3/8"	63			
#4	52			
#8	46			
#16	43			
#30	40			
#50	38			
#100	32			
#200	18			

Comments:

Reviewed By: [signature]

Date: 2-24-03

SUMMARY REPORT OF SOIL AND AGGREGATE TESTS

Date of Report: 2/24/03
Project Number: 273-001
Sample Number: 11621

Soil Symbol: GM
Date Sampled: N/R
Date Received: 2/20/03
Sampled By: Client

Material Use: N/A
Soil Classification: Brown silty gravel with sand

SOIL AND AGGREGATE PROPERTIES	Test Method ASTM	Results	Specifications	Pass or Fail
Liquid Limit, LL	D4318			
Plastic Limit, PL	D4318			
Plasticity Index, PI	D4318			
Fractured Faces, %	NDOT T230			
R-Value, RV	D2844			
Cleanness Value, CV	NDOT T228			
Sand Equivalent, SE	D2419			
Fine Aggregate Void Content, %	AASHTO T304			
LA Abrasion, % loss 100 Rev's	C131			
LA Abrasion, % loss 500 Rev's	C131			
Clay Lumps and Friable Particles	C142			
Lightweight Pieces, %	C123			
Uncorrected Max. Dry Density, pcf	D1557			
Uncorrected Optimum Moisture, %	D1557			
Corrected Max. Dry Density, pcf	D1557			
Corrected Optimum Moisture, %	D1557			
Bulk Specific Gravity, +3/4"	C128			
Bulk SSD Specific Gravity	C128			
Apparent Specific Gravity	C128			
Absorption, %	C128			

SIEVE ANALYSIS - ASTM C136,C117		Specification Limits		
Sieve Size	Percent Passing	Min.	Max.	Pass or Fail
6"				
3"	100			
2"	95			
1 1/2"	91			
1"	84			
3/4"	74			
1/2"	61			
3/8"	50			
#4	36			
#8	28			
#16	24			
#30	21			
#50	19			
#100	16			
#200	12			

Comments:

Reviewed By: [signature]

Date: 2-24-03

SUMMARY REPORT OF SOIL AND AGGREGATE TESTS

Date of Report: 2/24/03
Project Number: 273-001
Sample Number: 11619

Soil Symbol: GM
Date Sampled: N/R
Date Received: 2/20/03
Sampled By: Client

Soil Classification: Light brown silty gravel with sand

SOIL AND AGGREGATE PROPERTIES	Test Method ASTM	Results	Specifications	Pass or Fail
Liquid Limit, LL	D4318			
Plastic Limit, PL	D4318			
Plasticity Index, PI	D4318			
Fractured Faces, %	NDOT T230			
R-Value, RV	D2844			
Cleanness Value, CV	NDOT T228			
Sand Equivalent, SE	D2419			
Fine Aggregate Void Content, %	AASHTO T304			
LA Abrasion, % loss 100 Rev's	C131			
LA Abrasion, % loss 500 Rev's	C131			
Clay Lumps and Friable Particles	C142			
Lightweight Pieces, %	C123			
Uncorrected Max. Dry Density, pcf	D1557			
Uncorrected Optimum Moisture, %	D1557			
Corrected Max. Dry Density, pcf	D1557			
Corrected Optimum Moisture, %	D1557			
Bulk Specific Gravity, +3/4"	C128			
Bulk SSD Specific Gravity	C128			
Apparent Specific Gravity	C128			
Absorption, %	C128			

SIEVE ANALYSIS - ASTM C136,C117		Specification Limits		
Sieve Size	Percent Passing	Min.	Max.	Pass or Fail
6"				
3"	100			
2"	96			
1 1/2"	92			
1"	84			
3/4"	78			
1/2"	69			
3/8"	63			
#4	52			
#8	46			
#16	43			
#30	40			
#50	38			
#100	32			
#200	18			

Comments:

Reviewed By: [signature]

Date: 2-24-03

SUMMARY REPORT OF SOIL AND AGGREGATE TESTS

Date of Report: 2/24/03
Project Number: 273-001
Sample Number: 11619

Soil Symbol: GM
Date Sampled: N/R
Date Received: 2/20/03
Sampled By: Client

Soil Classification: Light brown silty gravel with sand

SOIL AND AGGREGATE PROPERTIES	Test Method ASTM	Results	Specifications	Pass or Fail
Liquid Limit, LL	D4318			
Plastic Limit, PL	D4318			
Plasticity Index, PI	D4318			
Fractured Faces, %	NDOT T230			
R-Value, RV	D2844			
Cleanness Value, CV	NDOT T228			
Sand Equivalent, SE	D2419			
Fine Aggregate Void Content, %	AASHTO T304			
LA Abrasion, % loss 100 Rev's	C131			
LA Abrasion, % loss 500 Rev's	C131			
Clay Lumps and Friable Particles	C142			
Lightweight Pieces, %	C123			
Uncorrected Max. Dry Density, pcf	D1557			
Uncorrected Optimum Moisture, %	D1557			
Corrected Max. Dry Density, pcf	D1557			
Corrected Optimum Moisture, %	D1557			
Bulk Specific Gravity, +3/4"	C128			
Bulk SSD Specific Gravity	C128			
Apparent Specific Gravity	C128			
Absorption, %	C128			

SIEVE ANALYSIS - ASTM C136,C117		Specification Limits		
Sieve Size	Percent Passing	Min.	Max.	Pass or Fail
6"				
3"	100			
2"	96			
1 1/2"	92			
1"	84			
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3/8"	63			
#4	52			
#8	46			
#16	43			
#30	40			
#50	38			
#100	32			
#200	18			

Comments:

Reviewed By: [illegible]

Date: 2-24-03

Date: [illegible]

SUMMARY REPORT OF SOIL AND AGGREGATE TESTS

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Sand Equivalent, SE	D2419			
Fine Aggregate Void Content, %	AASHTO T304			
LA Abrasion, % loss 100 Rev's	C131			
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Lightweight Pieces, %	C123			
Uncorrected Max. Dry Density, pcf	D1557			
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Corrected Max. Dry Density, pcf	D1557			
Corrected Optimum Moisture, %	D1557			
Bulk Specific Gravity, +3/4"	C128			
Bulk SSD Specific Gravity	C128			
Apparent Specific Gravity	C128			
Absorption, %	C128			

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3/8"	63			
#4	52			
#8	46			
#16	43			
#30	40			
#50	38			
#100	32			
#200	18			

Comments:

Reviewed By: [illegible]

Date: 2-24-03

Date: [illegible]

SUMMARY REPORT OF SOIL AND AGGREGATE TESTS

Date of Report: 2/24/03
Project Number: 273-001
Sample Number: 11619

Soil Symbol: GM
Date Sampled: N/R
Date Received: 2/20/03
Sampled By: Client

Soil Classification: Light brown silty gravel with sand

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Sand Equivalent, SE	D2419			
Fine Aggregate Void Content, %	AASHTO T304			
LA Abrasion, % loss 100 Rev's	C131			
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Uncorrected Max. Dry Density, pcf	D1557			
Uncorrected Optimum Moisture, %	D1557			
Corrected Max. Dry Density, pcf	D1557			
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Bulk Specific Gravity, +3/4"	C128			
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Absorption, %	C128			

SIEVE ANALYSIS - ASTM C136,C117		Specification Limits		
Sieve Size	Percent Passing	Min.	Max.	Pass or Fail
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3/8"	63			
#4	52			
#8	46			
#16	43			
#30	40			
#50	38			
#100	32			
#200	18			

Comments:

Reviewed By: [signature]

Date: 2-24-03

Date: 2-25-03

SUMMARY REPORT OF SOIL AND AGGREGATE TESTS

Date of Report: 2/24/03
Project Number: 273-001
Sample Number: 11619

Soil Symbol: GM
Date Sampled: N/R
Date Received: 2/20/03
Sampled By: Client

Soil Classification: Light brown silty gravel with sand

SOIL AND AGGREGATE PROPERTIES	Test Method ASTM	Results	Specifications	Pass or Fail
Liquid Limit, LL	D4318			
Plastic Limit, PL	D4318			
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Apparent Specific Gravity	C128			
Absorption, %	C128			

SIEVE ANALYSIS - ASTM C136,C117		Specification Limits		
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#16	43			
#30	40			
#50	38			
#100	32			
#200	18			

Comments:

Reviewed By: [signature]

Date: 2-24-03

T

DATE: October 16, 2003 OUR REPORT NO.: 101-30105-2

TEST DATA

Visual Classification SILTY CLAYEY GRAVEL (GC-GM)

SAMPLE #81

Method of Test

Rammer: Method of Preparation:

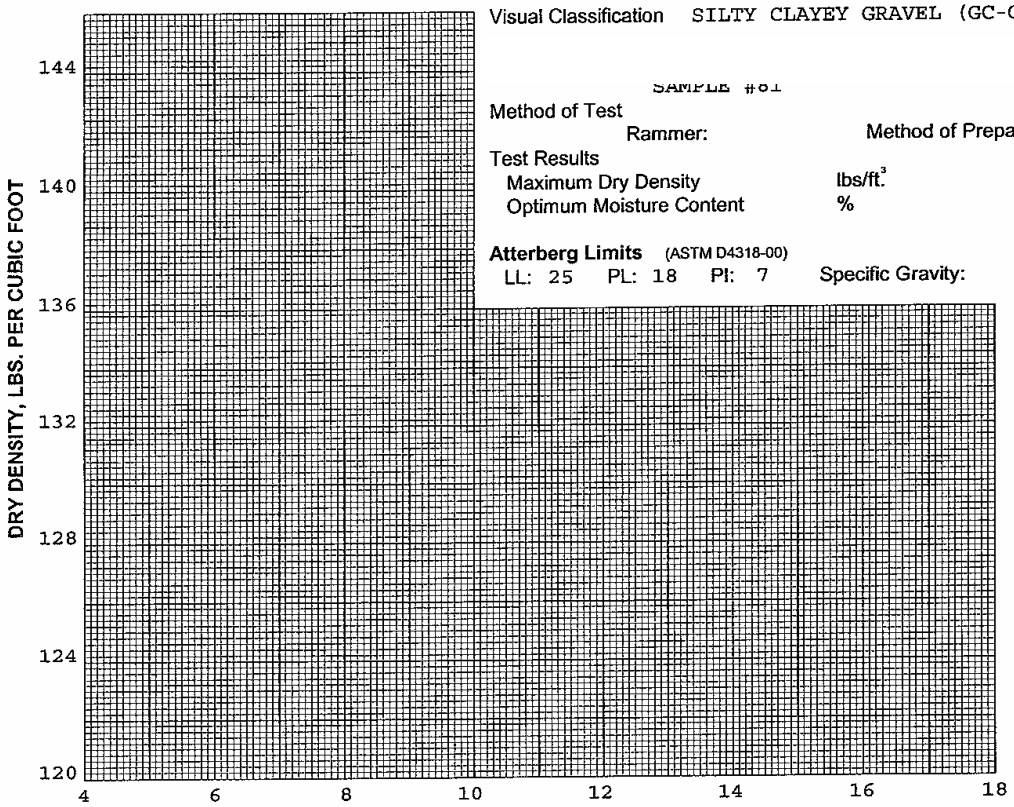
Test Results

Maximum Dry Density lbs/ft.^{3}

Optimum Moisture Content %

Atterberg Limits (ASTM D4318-00)

LL: 25 PL: 18 PI: 7 Specific Gravity:



Grain Size Analysis
(ASTM C136-01 and/or C117-95)

Sieve Size	Percent Passing
1-1/2"	81.2
1"	75.8
3/4"	71.7
1/2"	66.5
3/8"	63.3
No.4	58.7
No.8	55.3
No.16	53.1
No.30	52.1
No.50	50.5
No.100	48.5
No.200	45.6

REMARKS: DENSITY DETERMINATION NOT REQUESTED

Respectfully submitted,

DATE: October 16, 2003 OUR REPORT NO.: 101-30105-3

TEST DATA

Visual Classification SILTY SAND WITH GRAVEL (SM)

Method of Test

Rammer: Method of Preparation:

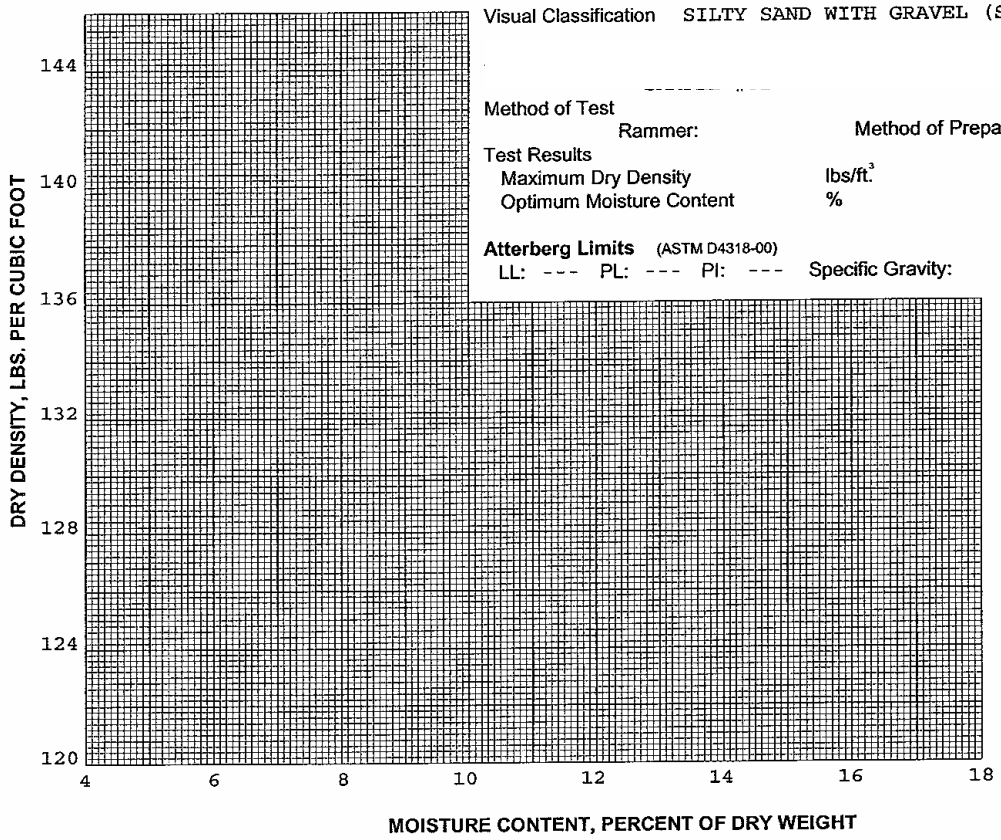
Test Results

Maximum Dry Density lbs/ft.^{3}

Optimum Moisture Content %

Atterberg Limits (ASTM D4318-00)

LL: --- PL: --- PI: --- Specific Gravity:



Grain Size Analysis
(ASTM C136-01 and/or C117-95)

Sieve Size	Percent Passing
1-1/2"	97.2
1"	92.6
3/4"	89.8
1/2"	87.3
3/8"	85.0
No.4	79.8
No.8	76.1
No.16	72.5
No.30	68.3
No.50	58.9
No.100	42.1
No.200	35.1

REMARKS: THE SAMPLE WAS DETERMINED TO BE NON-PLASTIC

Respectfully submitted,

DATE: October 28, 2003 OUR REPORT NO.: 101-30105-4

TEST DATA

Visual Classification BROWN GRAVELLY SILT WITH SAND

Method of Test

Rammer: Method of Preparation:

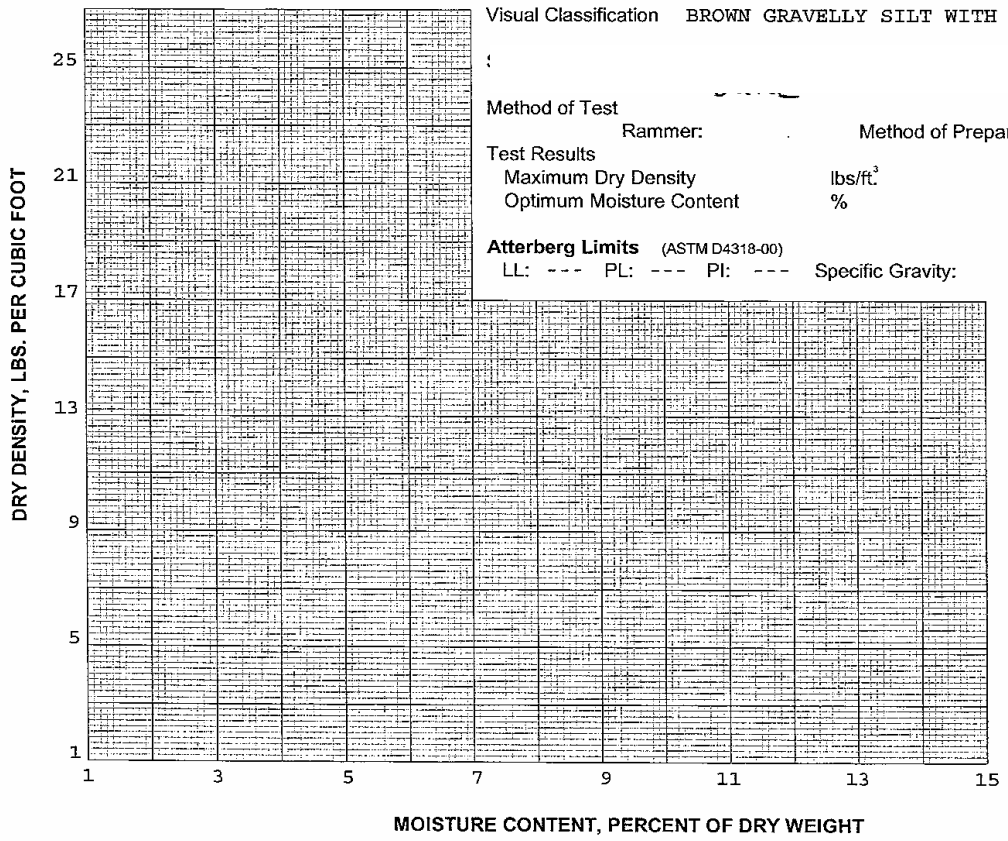
Test Results

Maximum Dry Density lbs/ft.^{3}

Optimum Moisture Content %

Atterberg Limits (ASTM D4318-00)

LL: --- PL: --- PI: --- Specific Gravity:



Grain Size Analysis
(ASTM C136-01 and/or C117-95)

Sieve Size	Percent Passing
1-1/2"	79.1
1"	67.8
3/4"	63.6
1/2"	60.6
3/8"	58.7
No.4	53.9
No.8	49.1
No.16	42.4
No.30	35.8
No.50	28.9
No.100	23.2
No.200	19.2

REMARKS: THE SAMPLE WAS DETERMINED TO BE NON-PLASTIC.

Respectfully submitted,

Appendix E – Viscoelastic Aspects of Bench Design and Structural Performance

With a view to better understand the behavior of foam benches, numerical analyses have been done to characterize the loading and dimensional sensitivity to achieve uniform loading on benches, which is central bench design "to fail when the additional cumulative loading produced by complete backfill and hydrostatic testing is applied" as in the KNI claim. Analyses also have been done to characterize the structural response of a bench whose size is consistent with some seen in the field, supporting loads that also are typical of what occurs in service. The analysis has been done to gain insight into structural performance under idealized conditions, which then can offer guidance for more realistic field scenarios. Such analyses are in no way a basis to design foam support systems. No attempt has been made to be exact or comprehensive as details on foam flow and fracture behavior, as the necessary properties are lacking or inadequate. Structural response is considered only in terms of mechanical properties taken as representative of the compliance for structural foam. No attempt is made to characterize the failure or fracture of the foam.

In viscoelastic materials, the stress-strain response is time-dependent, as indicated in Figure E1. Under a rapid increase in stress, such as the compression stress imposed on the supports due to the weight of the pipe, the compression strain and therefore the compressive deformation of the bench increases quickly at first and then continues at a reducing rate as time passes. In reference to Figure E1, the imposed stress is illustrated in the upper view, while the resulting displacement or strain response is illustrated in the lower view. As this time-dependent compression of the bench continues following lowering-in, the load originally carried by the bench can eventually be transferred in part to the soil. Depending on the extent of the fill below the pipe, the soil's properties, and the properties of the bench, the weight of the pipeline, its transported product, and the overburden are supported by the benches and the soil reacting against the lower quadrant of the pipe.

At lowering-in, the benches support only the pipe's dead weight, whereas eventually the weight of its transported product and the weight of the overburden are shared by the benches and the soil reacting against the lower quadrant of the pipe. The vertical loads at these various stages involve the pipe's deadweight, the transported product weight, and the weight of the overburden. All loads are uniformly distributed along the pipeline's length, and except at unmade tie-ins, the pipeline behaves as a continuous beam. A simple spreadsheet analysis facilitates such calculations, which here consider the linear elastic response of the steel pipe relative to the loadings imposed. For the sake of illustration, consider a 24-inch diameter steel pipeline with a 0.281-inch wall thickness. For this illustration, the cover is taken as

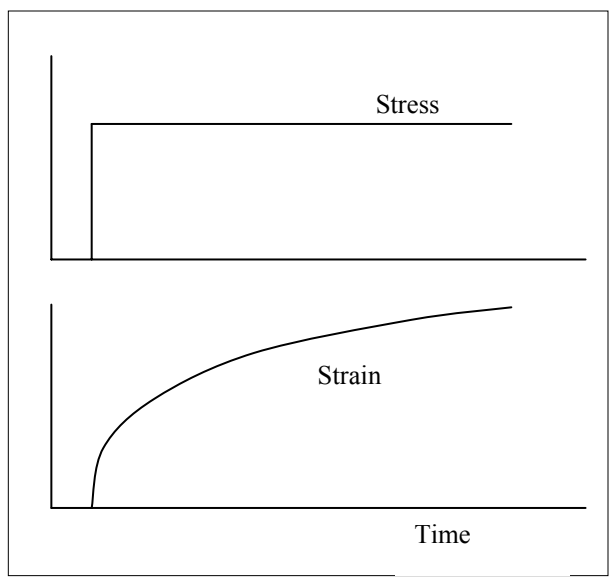


Figure E-1. Idealized viscoelastic compression creep response

36 inches of backfill with density equal to 120 pounds per cubic foot, the depth of the backfill is measured from the top of the pipe to the surface of the trench, and the benches are set 20 feet (480 inches) on center.

Table E-1 compares the effects of typical vertical forces acting on a buried pipeline in terms of the displacements induced at the center of the spans between the benches. These results reflect conditions shortly after construction, as they neglect possible support from the soil that could react against such loading along the lower quadrant of the pipe. Such results reflect the largest vertical displacements that develop in the pipe-string, and so represent an upper bound for the differential displacement that could develop between adjacent supports, all else being equal. The vertical deflection at the center of the pipe due to the weight of the pipe alone is ~0.019 inch, which is the case at lowering-in. After the ditch is bedded and padded, and backfilled and the grade restored, the related loading causes the deflection to increase by ~0.194 inch. After the pipe is filled with water for hydrotesting, this deflection increases again by ~0.052 inch.

Bench design "to fail when the additional cumulative loading produced by complete backfill and hydrostatic testing is applied" as in the KNI claim requires the loading to be reasonably well known. Otherwise, it is impossible to size benches and select their properties to deform consistently under load. Considering for the sake of argument the loading can be determined adequately for such design, achieving those "known" loads requires construction to the same level of precision that underlies the design. In reference to Table E1 and the just noted displacements, construction must be controlled quite precisely given the very small deflections that develop due to the line-pipe's dead load, or other associated loads. That is bench design "to fail when the additional cumulative loading produced by complete backfill and hydrostatic testing is applied" as in the KNI claim requires that the benches must be precisely set and leveled to ensure failure occurs in accordance with the design assumptions. Assuming this is possible and the bench is designed to fail during the hydrotest after the grade is restored, Table E1 indicates construction must control the relative elevation of adjacent benches to within a total maximum (mid-span) deflection the order of 0.019 + 0.052 + 0.194 = 0.265 inch for the above-noted example.

Table E1. Vertical forces acting on an example buried pipeline under idealized conditions

Parameters	Weight			Totals
	Steel Pipe	Water in Pipe	Soil on Pipe	
Depth of Burial, inches			36	
Pipe Outside Diameter, inches	24			
Wall Thickness, inch	0.281			
Span between Benches, inches	480			
Elastic Modulus, psi	29,000,000			
Density, pounds per cubic inch	0.283	0.037	0.069	
Load per Unit Length, pounds per inch	5.9	16.0	60.0	81.9
Vertical Compression Force on each Bench, pounds	2,847	7,670	28,800	39,317
Span Deflection, Pipe	0.019	0.052	0.194	0.265

Analysis like that illustrated in Table E1 has been setup in a spreadsheet format, considering other typical pipeline geometries and support spans. Such analyses considered the vertical loads in terms of line-pipe's dead weight, the weight of the contained water during hydrotesting or the transported product in service, and the weight of the backfill for some assumed soil density. Taken in conjunction with typical pipeline geometries and support spans, such results indicate the elastic vertical bending of the pipe leads to deformations the order of 0.01 inch to 0.50 inch. Significantly, the load and related stress developed in a bench varies from zero to near collapse over this range of vertical displacements. Consequently, the relative position of adjacent benches must be controlled to within a ***fraction of this order*** to achieve the design loading of the benches, and thereby reasonably target uniform stresses to control failure of the benches in keeping with the KNI claim.

Prior to lowering-in, such control is at best impractical unless the benches are set in intimate contact with the ditch across their bottoms. Thereafter, levels must be shot to ensure their elevation matches the profile of the pipe-string – as strung and as welded, which means the actual profile of the pipe-string including joint-to-joint variability must be known with corresponding accuracy and precision. Alternatively, during lowering-in shims could be added, but this cannot be a haphazard process, as it is essential to preselect the shim thickness to a fraction of the order of 0.01 inch to 0.50 inch to achieve the design hypothesis of the KNI claim. In practice, this requires intimate contact over the bottom of the bench, which is plausible for sprayed in-situ benches, and an array of shims sized to fractions of dimensions the order of 0.01 inch to 0.50 inch. While this might be plausible in theory, it seems impractical in real-time at the rate lowering-in progresses. Finally, one might consider adding shims after lowering-in. But, given the nature of viscoelastic materials and collapsible structures such as foam causes them to deform rapidly initially, and thereafter show decreasing deformation with time, as indicated in Figure E1 and by the form of Equation E1, shimming after lowering-in is not practical.

Consider now numerical analyses of the stresses and deformation response of a viscoelastic bench, such as the bench illustrated prior to loading by the pipe in Figure E2. The view in Figure E2 involves two planes of symmetry, such that only one-quarter of the bench is illustrated. The view in Figure E2 reflects a bench shaped in reference to the desire to achieve more uniform stress in consideration of the desire to control collapse or failure of the bench. Two aspects have been considered in this context. First, loading of a bench whose shape is a rectangular section beam as is typical of field use bench by the circumference of a pipe will cause very high contact stresses where contact first occurs. In addition, high friction-induced shear will develop along the bench's surface along the pipe's circumference as the pipe settles into the bench, whereas local compression will decrease. As both aspects complicate design to control the collapse or failure of the bench according to the KNI claim, a circular seat has been considered. Second, a compliant rectangular beam will bend significantly local to the load and lead to trench-bottom lift-off at the ends of the bench. Accordingly, load will not be carried by portions of the bench other than in the pyramid-shaped compression zone that develops due to the pipe load. For this reason, the design evaluated here has removed material in the region of trench-bottom lift-off with a view to achieve more uniform stresses.

The smaller prismatic shapes evident in mesh presented in Figure E2 indicate the elements used in the finite-element model of the "idealized" bench. The shapes of these elements after loading reveal the deformation (and strains) that develop in this bench under load. These deformed shapes are evident in Figure E3, along with the overall shape of the bench. Figure E3 also serves

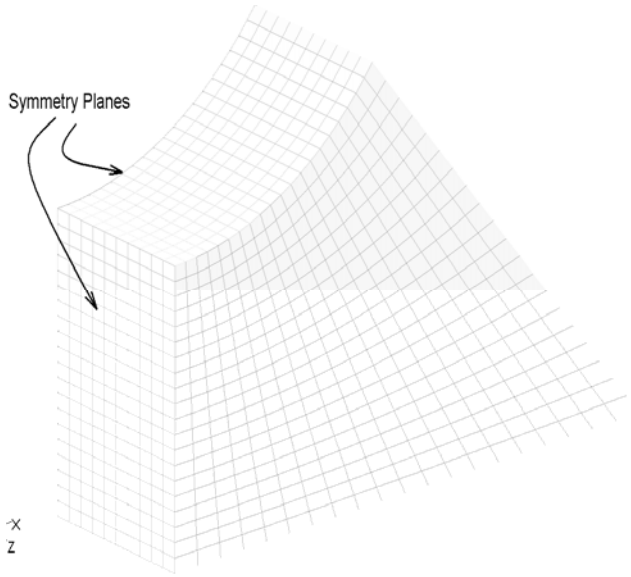


Figure E2. Undeformed mesh

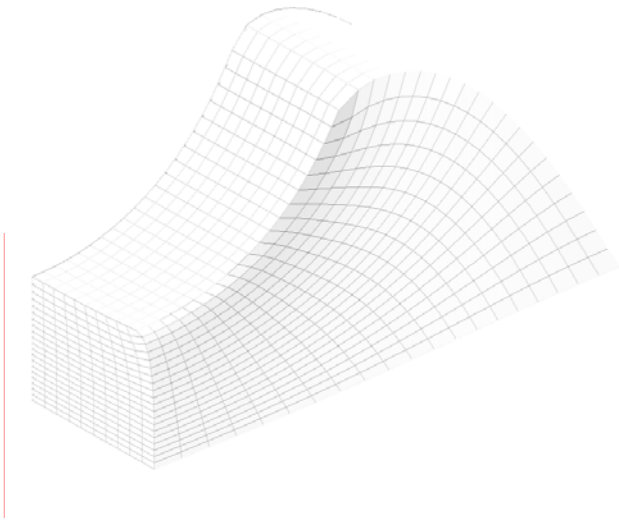


Figure E3. Deformed mesh

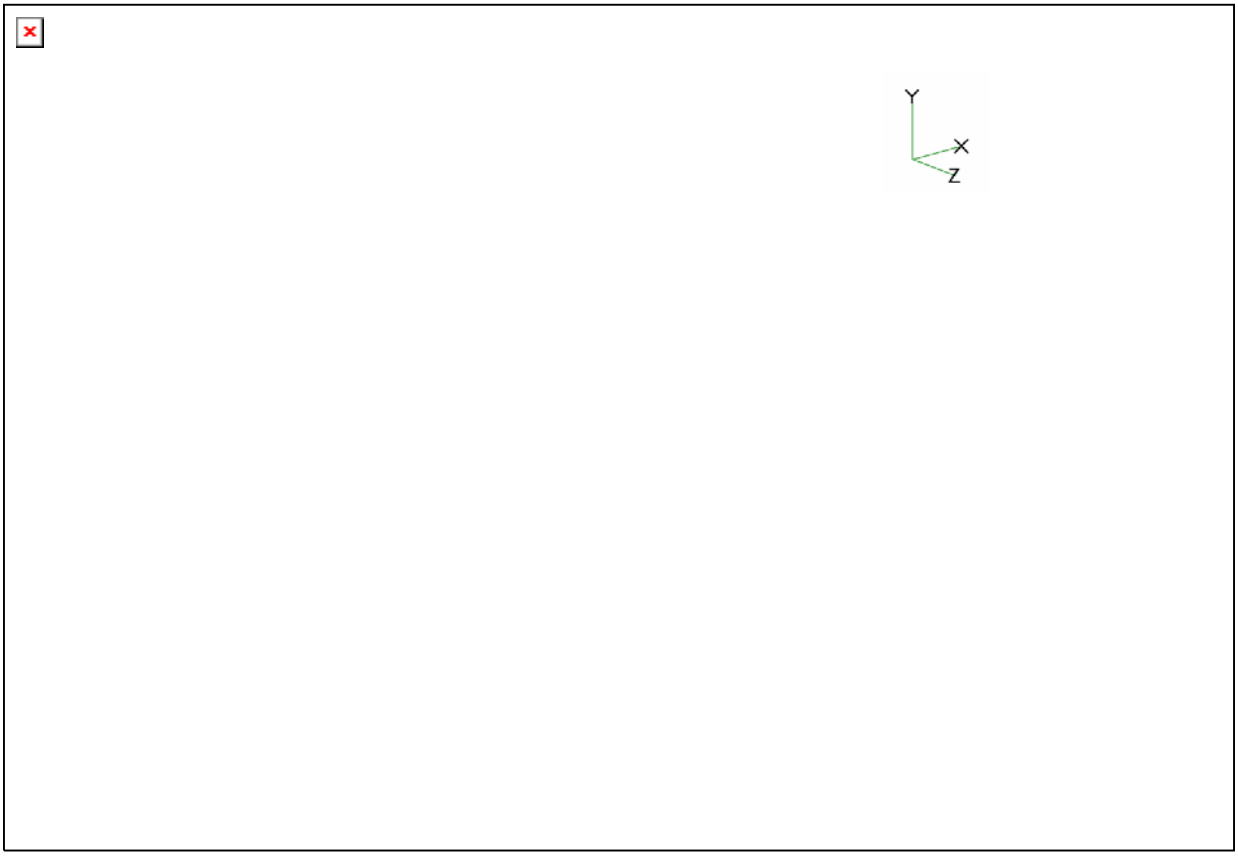


Figure E4. Contours of maximum principal stress referenced to the undeformed mesh

to illustrate aspects of the bench-shape discussed above. Contrasting the element shapes in Figure E3 with those in Figure E2 also provides insight into where the stresses will be highest. Note the through-thickness bulging and other distortion evident immediately below the pipe. In contrast, out toward the exterior lower edge of the bench there is virtually no change in shape, as this area carries virtually no compression, and indeed shows limited local lift-off from the ditch bottom. Were a rectangular shape evaluated without a cut-out for the pipe, the contact stresses would be very large at the center of contact, and decrease to quite low levels toward the extremes of contact. Such results indicate the insertion of shims after contact has initiated between the bench and pipe is of little practical value.

The view in Figure E4 shows the contours of maximum principal stress at selected stress levels. As can be seen, the stress varies significantly from the free-surfaces of the bench into the bench, apparently as constraint develops within the bench. This strong free-surface effect and the quite complex distribution of maximum principal stress indicates that bench design "to fail when the additional cumulative loading produced by complete backfill and hydrostatic testing is applied" as in the KNI claim will be difficult if not impossible – even if idealized and well characterized loading can be achieved. The magnitudes of the stress contours that develop in response to a pipe centered on a bench uniformly supported below by the ditch indicates the stresses are very high immediately adjacent to the pipe loading. The stresses diminish rapidly to much smaller and more uniform levels away from the contact-induced stresses. This response suggests the loads are resisted largely by compressive reaction, with little contribution of shear. On this basis, material in the bench not on or near the path between the load and the reaction from the trench floor plays a very limited role in structural performance. In turn, this means that the shape of the bench remote to the load - reaction path has little to do with the structural behavior or the eventual failure response. As noted above, this fact underlies the bench shape considered for this discussion. It too suggests difficulty implementing a design criteria to achieve failure "when the additional cumulative loading produced by complete backfill and hydrostatic testing is applied" as in the KNI claim[1].

Because the contact stresses are very high, compressive failure for a foam with uniform properties will occur almost immediately in areas where contact occurs with the pipe and trench bottom, but areas remote to these will exist at stress levels far from failure if they develop as shown in Figure E4. Given the tendency for steep stress gradients associated with the contact loads, and lower stresses elsewhere, bench design "to fail when the additional cumulative loading produced by complete backfill and hydrostatic testing is applied" as in the KNI claim

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[1] Given rock can be present along the ditch bottom, it is unclear that designs that lead to "failure of the bench" are practically viable – as such failure would transfer load uniformly to along the length of the pipeline. Absent sag-bends and over-bends, it is conceivable although uncertain that adequate bedding and bench clearance could limit pipe contact with a rocky ditch bottom. However, the concentrated loading that would develop at all vertical bends opens the door to such contact, thereby defeating the purpose of pipe bedding. It appears a better scheme is one where the bench deforms enough to transfer some load to the bedding, to compact this material and share the support load for the pipeline, in contrast to one where the bench fails allowing the pipe's loading to transfer uniformly along the ditched bottom. But given the variability that develops in trenching and in the profile of the as-strung pipe in contrast to dimensions the order of 0.01 to 0.5 inch, design criteria that lie within this uncertainty are practically irrelevant. Tried and proven methods are both practical and appropriate in such settings, with the flexibility of systems like sprayed-in-situ foam providing a viable alternative based on the results of this project.

will be difficult. Such requires that the bench width, which controls the load per unit bench thickness and the related local contact stress, be selected along with the viscoelastic compliance and time constant for the foam-mix, to create uniform stresses in the bench just marginally below the collapse stress, thereby smoothing the gradients evident in Figure E4.

As pointed out in the report in reference to the use of foam benches in Canada now for decades, results like that presented above indicate viscoelastic supports have the virtue of settlement of the pipe-string onto its bedding. None of the results imply foam benches are inappropriate for use as pipeline supports. Rather, they simply indicate the concept of bench design "to fail when the additional cumulative loading produced by complete backfill and hydrostatic testing is applied" might be difficult to implement under practical field conditions.

The Theory of Vicsoelasticity[46] and test data that calibrate the rate of compression deformation to the applied stress can be used to estimate the rate at which pipe supports would transfer load to the soil. In simplest idealization, the rate of loading is considered much shorter than the time for settlement and eventual soil compaction. On this basis, a first order estimate of the deformation of a bench can be estimated from the creep compliance, C(t), of the response in the form shown in Equation E1[2].

$$\varepsilon(t) = \int_0^t C(t-\tau)\frac{d\sigma(\tau)}{d\tau}d\tau \quad , \qquad \text{(E1)}$$

where $\varepsilon(t)$ is the strain, $\sigma(t)$ is the stress, C(t) is the creep compliance expressed for a standard linear solid expressed in the form:

$$C(t) = C_g + (C_r - G_g)(1 - e^{-t/t_c})$$

where C_g, C_r, and G_g are material constants.

The creep compliance can be derived from tests and is likely to be a strong function of temperature. More generally, the compression load on a bench will reflect a soil-structure interaction as load is transferred to the soil, and also show complexity associated with the soil's time-dependent mechanical properties. Soil-structure interaction requires models much more complex than that represented in the form of Equation E1.

---

[2] Lakes, R.S. and Vanderby, R. "Interrelation of Creep and Relaxation: a Modeling Approach for Ligaments", J Biomech. Engineering, 121, 612-615, December 1999: see also Roylance, D., "Engineering Viscoelasticity", Department of Materials Science and Engineering, Massachusetts Institute of Technology, Cambridge, MA 02139, October 2001.