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Challenging the Limits: Class D Pipe Bursting – Connecting Research and Practice

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1.0 ABSTRACT

In 2024, the City of Chilliwack, British Columbia, undertook a significant sanitary sewer upgrade, utilizing pipe bursting to increase capacity in the growing Sardis neighbourhood. The project involved upsizing 350m (1,150') of 300mm (12") ID PVC pipe to 500mm (20") OD HDPE, a quadruple upsize and increase of approximately 178% in cross-sectional area. The work was carried out in a high groundwater environment, adjacent to structures and a 750mm (30") concrete storm sewer, necessitating a trenchless approach to mitigate settlement risks.

The Chilliwack project is a recent example among several IPBA Class D "Developmental" pipe bursting projects, successfully completed by PW Trenchless Construction, a British Columbia based trenchless contractor. By presenting a history of 15 successfully completed Class D pipe bursting projects since 2017, and combining this with the findings of academic literature, the paper aims to challenge the expectations and limitations of pipe bursting. The paper questions if current pipe bursting classifications and feasibility criteria are too conservative, and highlights the anecdotal evidence which may suggest the need for revision.

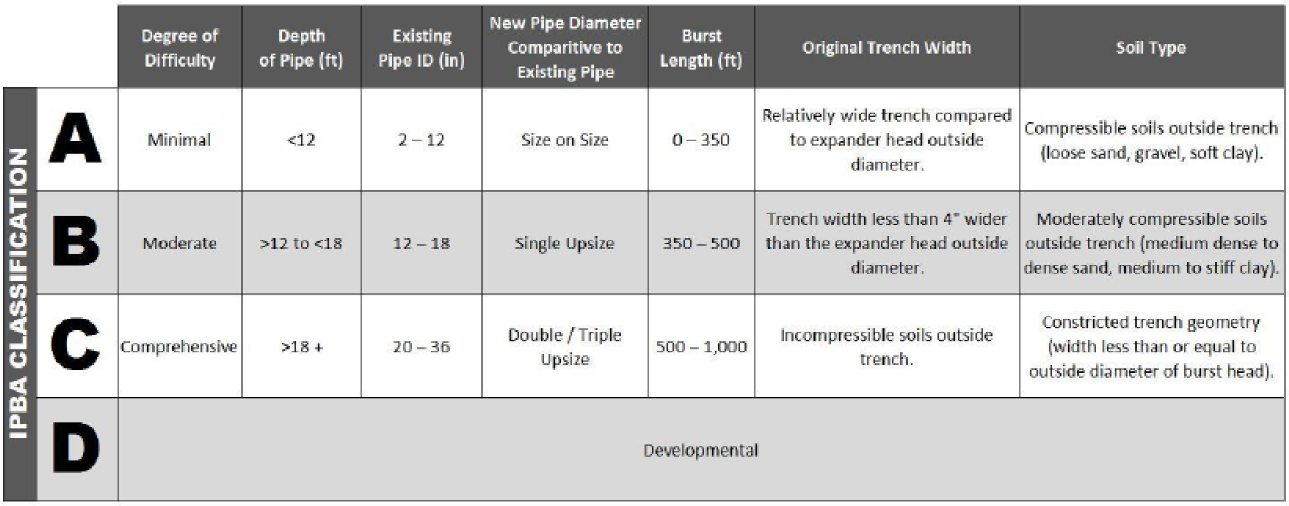
It is hoped that by presenting this anecdotal evidence in the form of contractor experience, alongside the findings of previous studies, this will trigger the final steps in research towards the development of scientifically proven pipe bursting feasibility and design guidelines. Moreover, by proposing systematic field monitoring, pre & post density testing and more collaboration between industry and academia, it is hoped that progress can been made towards developing evidence-based approaches to pipe bursting project design, with predictable outcomes.

2.0 INTRODUCTION

The City of Chilliwack project discussed in this paper is a recent example of a quadruple upsize pipe bursting project, classified as Class D "Developmental", according to the International Pipe Bursting Association (IPBA) pipe bursting classification table (IPBA, 2012). Forming part of a wider sewer upgrade project, the replacement of an approximately 350m long section of sanitary sewer pipe was proposed. This section of the alignment, between Knight Road and Topaz Drive, proved a significant challenge for an open cut approach, due to the proximity of nearby residential buildings, a 750mm concrete storm sewer, yards, and a multiuse trail at surface level. Due to the constraints and risks of an open cut approach, PW Trenchless were contracted to complete the replacement and upsize via pipe bursting. Pipe bursting significantly reduced the extent of the excavations required to complete the replacement and the project was completed successfully without any damage to the nearby residential buildings. The existing 300mm (12”) PVC sanitary pipe was located at a depth of 3 to 4m, and was replaced with a 500mm (20”) fused HDPE pipe.

Table 1 shows the IPBA pipe bursting classification criteria. Typically, Class B (Moderate) & Class C (Comprehensive), classifications involve 1 to 2 degrees of upsizing (DOU). Applying these criteria to the Chilliwack project classifies it as a Class D “Developmental” pipe burst, with upsize being from 300mm to 500mm, or 4 DOU. According to IPBA (2012), class D bursts required careful planning, however little detail is given. In the NASTT Good Practices guide, Ambler, Timberlake and Woodcock (2019) state that this type of installation requires a comprehensive level of planning and experience, but do not go into specific detail. A lack of published examples and research surrounding what are considered more challenging pipe bursting projects, may be a reason for the lack of guidance on planning, experience requirements and design considerations for future projects.

Table 1 IPBA Classification Table (IPBA, 2012)



IPBA CLASSIFICATION	Degree of Difficulty	Depth of Pipe (ft)	Existing Pipe ID (in)	New Pipe Diameter Comparitive to Existing Pipe	Burst Length (ft)	Original Trench Width	Soil Type
A	Minimal	<12	2 – 12	Size on Size	0 – 350	Relatively wide trench compared to expander head outside diameter.	Compressible soils outside trench (loose sand, gravel, soft clay).
B	Moderate	>12 to <18	12 – 18	Single Upsize	350 – 500	Trench width less than 4" wider than the expander head outside diameter.	Moderately compressible soils outside trench (medium dense to dense sand, medium to stiff clay).
C	Comprehensive	>18 +	20 – 36	Double / Triple Upsize	500 – 1,000	Incompressible soils outside trench.	Constricted trench geometry (width less than or equal to outside diameter of burst head).
D	Developmental						

A study of current pipe bursting trends by Ariartnam, Lueke and Michael (2012), which used a survey of 886 projects between 2007 & 2010, 70% of the projects surveyed were 150-200mm or 200-250mm. Contractors participating in the survey were asked about the largest upsize achieved, however only the largest reported upsize was presented. The data collected in this survey was used to develop a pipe bursting technical envelope, which differs from the IPBA classification system. It is categorized into four categories of difficulty: 1) Routine, 2) Cautionary, 3) Difficult, and 4) Outside Technical Envelope. While based on more recent data, the technical envelope is based heavily on contractor perception of difficulty, as opposed to scientific observations in the field. Additionally, it is suggested that the smaller host pipes and upsizes are reported most frequently, as there are more of these smaller diameter pipes in municipal networks. In apparent contrast to the technical envelope developed by Ariartnam, Lueke and Michael, the experience of PW Trenchless in the successful completion of large upsize pipe bursting projects since 2014 (including the recent, City of Chilliwack project), demonstrates some apparent discrepancies with the technical envelope. The completed projects are summarized in Table 2 in the below section, and have been plotted against the Ariaratnam, Lueke and Michael technical envelope, in Figure 1. It can be observed that that 4 projects are "outside the technical envelope", and 6 projects fall within the "Difficult" category. The frequency of completed projects falling within the upper categories of the technical envelope may suggest that these projects are more routine than the guidance suggests.

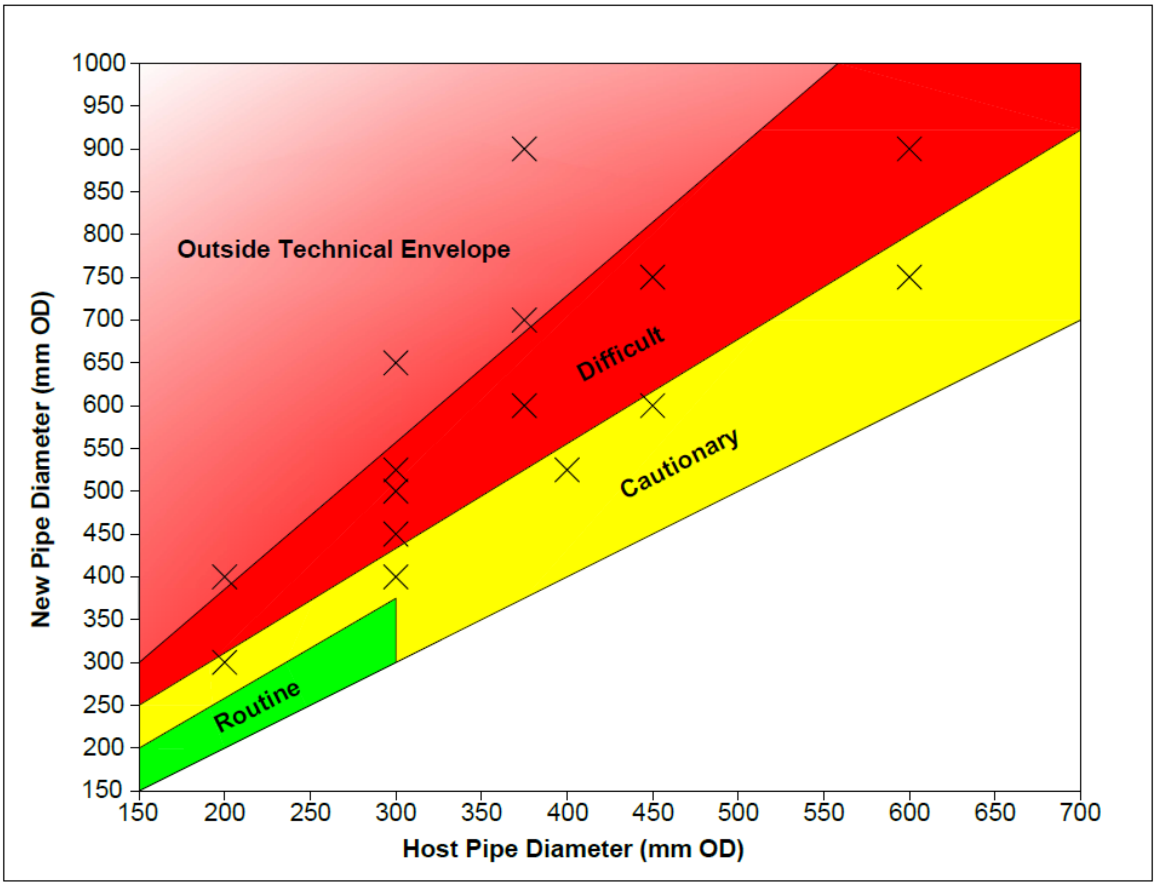


Figure 1. Upsizes achieved by PW Trenchless in successfully completed pipe bursting projects from 2014-2024, applied to the Ariaratnam, Lueke and Michael (2012) pipe bursting technical envelope.

3.0 DISCUSSION OF PAST WORK & RESEARCH

Table 2. Selected Pipe Bursting Projects by PW Trenchless from 2014-2024. IPBA classification criteria highlighted for each project.

Year	Project	Location	Host Pipe ID (mm)	Host Pipe Material	New Pipe OD (mm)	Degree of Upsize (nominal HDPE sizes)	Depth (m)	Soil Type	Total Pipe Bursting Project Length (m)	Longest Pull Length (m)	IPBA Classification
2015	SFU Sanitary	Burnaby	200	PVC	400	**4**	4	Till type and imported backfill	57.37	57.37	**D**
2016	Gloucester Estates	Langley	300	AC	500	**4**	1.5 to 2	Clay and imported backfill	504.51	175.51	**D**
2016	80th Ave	Surrey	200	PVC	300	2 & 3	**5 to 6**	Till type and imported backfill	1003.56	136.97	**D**
2017	River road, Phase I	Maple Ridge	375	PVC	900	**5**	**5 to 7**	Gravely silts	1070.43	120.8	**D**
2017	Robson Creek	Surrey	300	AC	500	**4**	2 to 4	Sand & Silt with trace gravel	216.65	150.07	**D**
2018	West Queens	North Vancouver	450	AC	750	**6**	2 to 4	Till	320.6	100	**D**
2019	River Road, Phase II	Maple Ridge	375	PVC	711	**6**	4 to 5	Gravely silts	535.2	118.2	**D**
2019	St Thomas St	Port Coquitlam	300	AC	525	**4**	2 to 3	till type and imported backfill	229.2	104.5	**D**
2020	Lefeuvre Road Culvert	Abbotsford	600	CSP	900	**6**	**7**	Road crossing pit run	41	41	**D**
2022	Indian River Drive	North Vancouver	>300	Wood	650	**7**	2	Road crossing pit run	13.91	13.91	**D**
2024	106 Ave	Surrey	200	PVC	400	**4**	3 to 4	Till type and imported backfill	128.62	84.48	**D**
2024	Topaz Drive	Chilliwack	300	PVC	500	**4**	3 to 4	Clay	365.29	108.34	**D**
2018	Chelsea Avenue	Port Coquitlam	375	Conc	600	**4 to 5**	1 to 2		483.95	120.68	**D**
2021	Ridgeview Dr	North Vancouver	700	CSP	900	**4**	2 to 3	Road crossing pit run	38.6	22	**D**
2021	16 Ave	Langley	450	Conc	750	**6**	4	Pit run	24.46	24.46	**D**
2014	Pemberton Ave	North Vancouver	**900**	CSP	1050	1	4	Sands/gravels/Some pollution	280	90	**C**
2015	Marine Dr @ Taylor Way	West Vancouver	300	Conc	400	**2**	3		96	53.5	**C**
2015	Marlborough Avenue	Burnaby	300	Conc	400	**2**	4		58.4	58.4	**C**
2016	Salton Road	Abbotsford	300	AC	400	**2**	4 to 5		227.9	87.4	**C**
2016	Millstone Creek	Nanaimo	**600**	AC	750	1	5	Gravels and Sands	478.47	146	**C**
2016	Hodgins Ave	Abbotsford	300	AC	450	**3**	3	sands/ silts	278.79	102.94	**C**
2017	Sullivan Area	Surrey	300	AC	450	**3**	4 to 5	Clays/silt	114.3	110.3	**C**
2018	Liverpool St	Port Coquitlam	300	AC	450	**3**	2 to 4	Till type and imported backfill	161	52	**C**
2018	Summers St	Port Coquitlam	450	Conc	600	**3**	2	till type and imported backfill	53.75	53.75	**C**
2024	Cade Barr St	Mission	400	Conc	525	**2**	2 to 3	Till	84.68	84.68	**C**
2018	48 Ave	Langley	200	AC	300	**2**	4 to 5	Clay	392.8	93.1	**C**
2019	203 St	Langley	200	AC	300	**2**	3 to 4	Clay	51.1	30.6	**C**
2021	188 St	Surrey	200	PVC	300	**2**	3 to 5	Till/ Clay	123.3	70.65	**C**

This excerpt from a doctoral thesis (Nkemitag, 2007) sums up the sentiments of these authors perfectly in describing the unknowns in pipe bursting:

> *"Use of these procedures and the design of pipe bursting projects are largely governed by experience and simple 'rules of thumb'. Issues of concern to contractors and the owners of the infrastructure being replaced and in the vicinity of the project, include ground movements that result during soil 'displacement' and the pulling forces that are needed to break and displace the old pipe, and pull the new pipe into place, [1]. Unfortunately, without calculation procedures and design tools that include rational consideration the of the soil-pipe interaction, it is difficult to obtain reliable estimates of ground movement and pulling force that consider the many different geometrical and material conditions encountered on these projects."*

In our opinion, this question, 18 years on, has still not been addressed, we believe it needs to be studied and resolved.

The summary of Class D and C pipe bursting projects completed by PW Trenchless between 2014 and 2024 is evidence that larger upsize pipe bursts are being completed successfully, on a regular basis. What we still do not know is exactly why these projects are successful, or how close these projects are to success or failure.

The question we would ultimately like to see resolved through science rather than the 'gut feeling' of an experienced contractor, is 'what information is required to burst a pipe of more than 2 DOU, or a pipe that is bigger than 300mm?'

This is a difficult question to answer. Reviewing existing studies is like comparing apples with pears. Close, but not close enough for direct comparison, and there little in the way of well documented, full scale field trials. The full-scale projects presented in Table 2 are compelling, unfortunately those results have not been incorporated into academic literature. Doing so would have advanced the research and allowed better design guidelines to be developed. To advance the science of pipe bursting from educated guesswork to evidence based – we invite academia to work with industry to improve upon the existing literature that is currently used by consulting engineers and contractors.

The academic studies we reviewed had been carried out in different materials with different trench walls at different depths so again, it is difficult to compare the results between studies. The common observations we have gleaned is that vertical displacements decreased with increased depths, which is intuitive.

It makes sense that the displacement measurements varied more at shallower depths and less with the deeper pipes. We know that when the pipes were placed, they were likely laid out on some kind of prepared base to protect the pipe, then covered in loose lifts of imported or native fill that were lightly compacted so as not to damage the new pipe, with either a light plate tamper, or even an excavator bucket.

From the time that utilities were being installed in North America up to WWII most excavations would been by hand and or by steam shovels leaving little or no options for backfill compaction except at the surface with steam rollers, see Figure 2. That being the case for these very old installations, the existing backfill may not be considered 'compacted', especially at any considerable depths.

Post WWII with the introduction of hydraulics there would have been some attempts at compaction. But that compaction would have consisted of a bucket "hitting" the backfill. It was not until the 70's or 80's that "hoe packing" and other compaction equipment became common and therefore achieving higher density backfill.

In rehabilitating these older pipes, the pipe bursting energy is being absorbed by densifying this relatively poorly compacted backfill material through a process called "Cavity Expansion".

Figure 2. 1923 Bucyrus Model 50 Steam Shovel

4.0 CURRENT STATE OF PRACTICE

What do we know from the current state of practice?

1. There are 3 variables to overcome when attempting to burst a pipe: the energy to break the existing pipe, the energy to displace the soil, and the energy to overcome the frictional force on the new pipe being installed.
2. Understanding these three forces are critical in the planning of the pipe bursting project.
3. The frictional resistance from the new pipe being installed becomes a relevant issue when the new pipe is 300mm or larger. This is easily managed by using lubrication or extra pulling force.
4. The energy required to break the existing pipe is not a major issue. Issues arise when unexpected changes in the existing pipe material or fittings are encountered. During the design phase, a CCTV inspection is critical. The results of these surveys can do much to identify issues, plan for them, and decrease the risk of unexpected obstacles.
5. It is soil "Cavity Expansion" that is the major component of the total pull force required, and the main topic of this paper.
6. The methods for calculating soil cavity expansion are still limited.

7. Although there has been much research into predicting the forces introduced by cavity expansion there is no user-friendly, research backed digital tool which invites the host to; enter the host and new pipe sizes and material, burial depths, soil classification(s) through the various layers of the original trench, soil density of the trench fill and the undisturbed surrounding material, water content(s) and water levels, and deliver the required pulling force, or definitively predict soil heave, or possible displacements at nearby utilities.

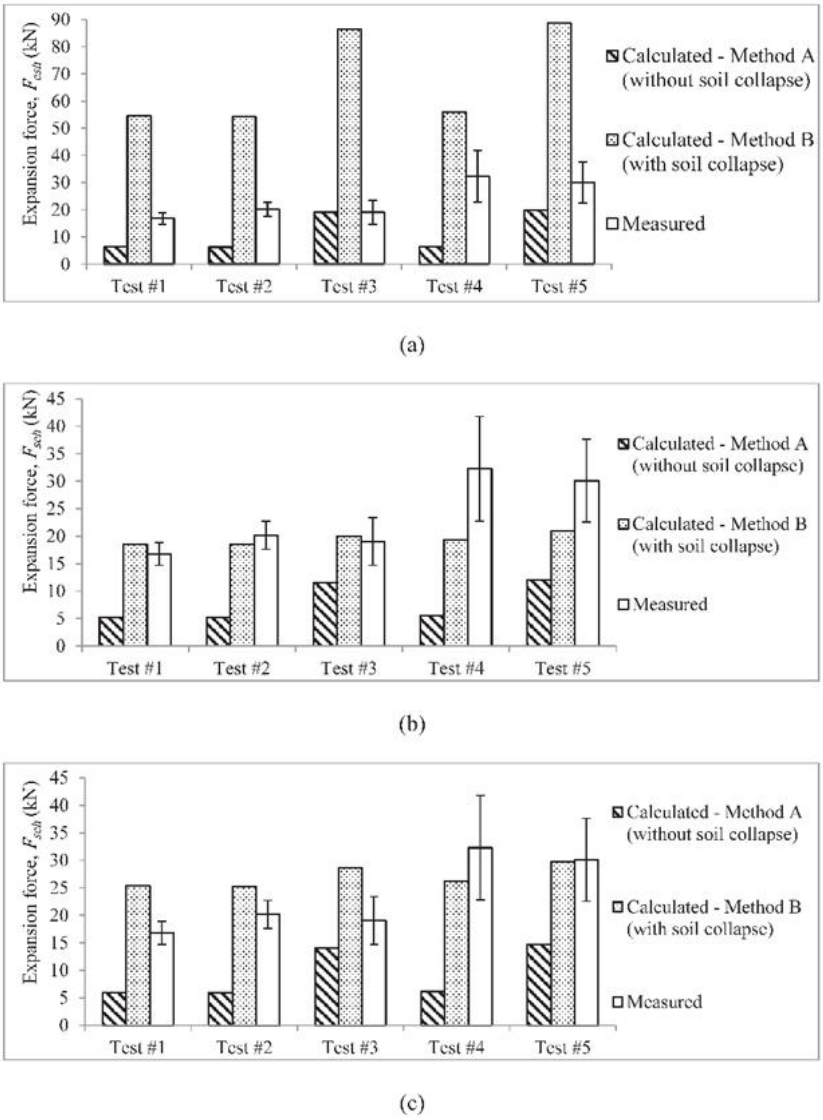


Fig. 3.7. Measured and calculated soil expansion forces based on: (a) Carter et al (1986); (b) Delft; (c) Yu and Houlsby (1991)

Figure 3 Measured Soil expansion forces from Ngan (2015)

The methods summarized by Ngan in 2015 examines cavity expansion solutions that include Carter et al (1986), the Delft solution, and Yu and Houlsby (1991). In his thesis Ngan uses these solutions to calculate the soil expansion forces during a pipe bursting installation and compares these figures to the measured results. He also used infinite element modelling software to calculate the soil expansion forces and compared them to measured results. Figure 4 shows that there is a consistent relationship between the calculated and measured results.

Without diving into elaborate descriptions of laboratory and field tests on soil response to pipe bursting, or the history, development and application of Cavity Expansion theory and solutions, Ngan concludes that the three cavity expansion solutions used to predict the expansion force for static bursting and installation were validated with the laboratory experiments, specifically:

"Results indicate that the calculation method based on Yu and Houlsby (1991) provides a reasonable estimation of soil expansion force required. Conversely, expansion forces calculated based on Carter et al. (1986) and Delft solution are conservative and underestimated, respectively. Due to the complexity of the pipe bursting process and the simplifications adopted in expansion force calculation method, more experimental and field measurements are required to validate and improve the calculation method."

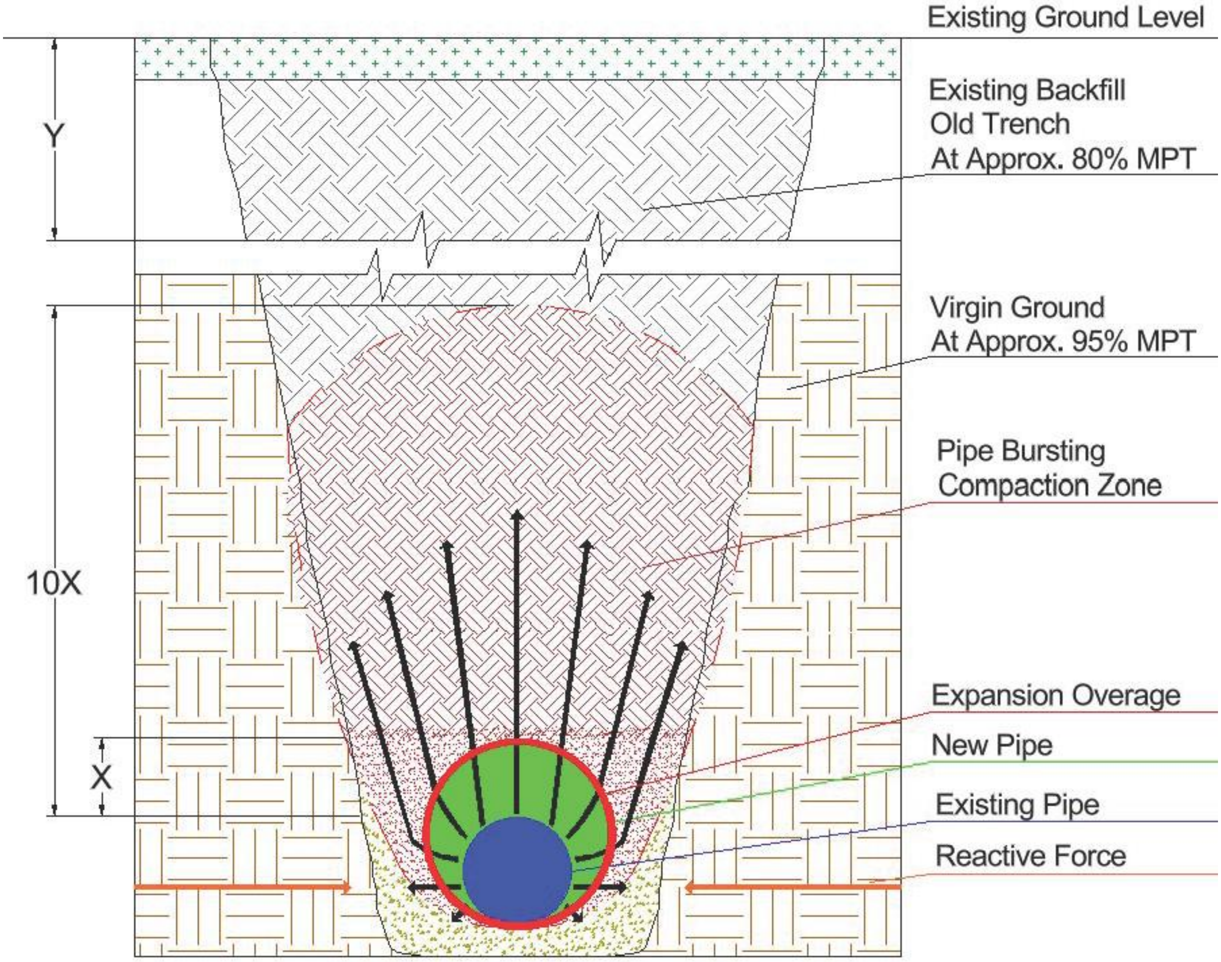
In his conclusions Ngan recommends that future work should include improving the many assumptions of the many variables and carrying out additional field testing, especially large-scale testing to “further validate and improve the proposed methods for the calculation of soil expansion force.”

5.0 PW TRENCHLESS THESIS

It is hypothesized that after 1.5m – 2m depth there is essentially no difference in the vertical displacements. We believe that the poorly compacted trench backfill is absorbing the expansion. This tends to be supported by the research we have been reviewing. Once we get deeper than about 2m there seems to be no vertical displacement.

Of course this will not always be the case, it may be that in very densely compacted trenches or stiff soils combined with a very significant upsize it is possible that the heave or vertical displacement may be expressed at the surface.

We are theorizing that the backfill over the host pipe, no matter how old it is, that is no matter how many years it has had traffic running over it, has never reached the maximum dry density. It was never compacted to and will never reach the maximum dry density and therefore there is room in that backfill for it to be compressed or densified during the pipe bursting process. Figure 5 shows PW Trenchless theory of why we believe several degrees of upsizing, or large pipe bursting projects have been successfully completed.



Where x = upsize, Y= Unaffected depth, 10x = zone of influence above the disturbance, MPT = Modified Proctor Test

Figure 4. PW Trenchless Thesis on ground movement during cavity expansion

As a suggested starting point, we believe collecting pre and post backfill density data to validate the thesis and provide design information for predicting the limits of cavity expansion would be useful.

6.0 PRACTICAL CONSIDERATIONS

One of the issues in our experience is that if the consultant or the client is not well informed about the pipe bursting process, limitations and the risks of pipe bursting, and only know about the theory, they will be completely reliant on the contractor. If the contractor is ‘good’ here, meaning experienced and honest, that should lead to a favorable result, but that is not a recommended approach to successful contract management. If the contractor has little track record in pipe bursting – especially upsizing by more than 2 DOU, or upsizing large pipes, well, that in combination with an ill-informed owner and owner’s engineer will have less chance of a successful result.

We know that in theory the pipe will burst in an eccentric or in an invert-to-invert manner, regardless of the degree of upsizing. In over 95% of PW Trenchless projects the inverts match up.

In most geotechnical endeavors we deal with materials that can be highly variable in both composition and condition, disturbed (backfill) and undisturbed (native). We as contractors rarely know the density of the material that the host pipe is backfilled with and yet this variable has a great influence on the approach and the results of pipe bursting.

We know for example that the nature of the backfill is not perfectly homogeneous and that as the expander progresses it is possible to have ‘bellies’ in the new pipe as there could be weaker soil underneath the host pipe than was originally assumed. The relative density above could be higher than below, directing the expansion energy downwards rather than up. In some cases, the new pipe invert could be lower than the host pipe invert and not meet up properly with other infrastructure, say another manhole. If we had more data before the start of the work or perhaps during earlier stages of the work such as design and layout, if there was compaction testing done at and beside the existing pipe we may reasonably predict whether the inverts will match up.

This is a manageable risk that can be easily dealt with in the contract documents as an extra with a unit rate. One way of dealing with this could be to recognize these variations in the contract in a way that takes the risk of the unknown into account and shares that risk or at least allocates it more fairly, or to the appropriate party. Do these costs get borne by the contractor or by the owner? Was the failure to proceed caused by the pipe bursting machine being too small, the contractors’ issue, or unforeseen ground conditions, the owners issue? What about changes in the condition of the host pipe, owners issue? Unexpected repair clamps, owners issue? A well-written contract can manage risks and lower costs.

Having said that – we remind the reader that it is not a catastrophe if; the inverts don’t match up due to softer than expected soils under the host pipe, or the bursting head gets stuck due to host pipe changes unless the work is being done under a watercourse or a building. In these cases, the risks must be managed differently, including the critical pre-CCTV survey discussed earlier.

We also ask the reader at this point to consider; unlike many other risk assessments in engineering where the risk of failure, or the risk of a specific weather event, or even a combination of weather events, or loading events is low, that the consequences are often high, maybe even catastrophic. In pipe bursting upsizing projects – the risks are unquantified, it could be high, it could be negligible. What we do know is that the consequences are rarely catastrophic and can be easily managed by a 911 rescue pit, and the project carries on with only a little time lost and some extra costs.

Since we are speaking about the compaction of materials and our lack of knowledge of the ability of different soils and different soil conditions to absorb the expansion of the cavity, we are left with little ability to accurately predict the effect on surrounding utilities. Semicevic and Sterling (2001) did speak about a 10:1 factor in a study in March 2001. To expand upon his theory, we propose a risk assessment be added to the Sterling recommendations, when dealing with high-risk utilities.

7.0 LOOKING AHEAD – RECOMMENDATIONS

Our goal today is to advocate for research that includes monitoring these in situ, real life projects to prove our thesis and to refine the classification tables published by IPBA and Ariatanam, Lueke and Michael. We believe that these tables are examples of what we do not yet understand. Let us refine these figures, create a new table of guidelines. The IPBA table in Figure 1, especially in Classifications C and D were written with a level of caution because of a lack of field information on cavity expansion. Let us all collaborate and refine this table. While the academic research is available, it has not yet been calibrated with field data.

These are the factors that we recommend moving forward to improve the success rate of significant upsizing in pipe bursting projects.

7.1 GEOTECHNICAL REQUIREMENTS

Correct soils information should be collected before the project starts, to judge viability. Based on the information above, at minimum it would be helpful to establish the density of the soil above and beside the host pipe trench.

To advance the science, collecting data during the pipe bursting process would greatly add to the library of knowledge. Applying instrumentation to real projects with runs longer than what can be reproduced in a laboratory, we believe would provide researchers with valuable data that could be used to estimate the probable cavity expansion, and act as a template for collecting data for future projects.

7.2 GENERAL CONSULTANT

The Consultant needs enough knowledge and experience to ask the contractor the right questions to verify that A) they are qualified, B) they are prepared for the project and C) they are prepared with contingency plans in the event of the unexpected. The IPBA guidelines *(IPBA, 2012)* identify a baseline set of minimum requirements for pre-qualifying contractors, which include verifying that the contractor is trained in the use of the pipe bursting equipment, pipe handling, joining and installation, and sets a minimum 50,000 linear feet accumulative length of completed installations of a similar pipe bursting class. While this provides a starting point, it is highlighted that standards of training can vary significantly between different equipment and material suppliers. Additionally, qualifying a contractor based on volume of completed work, as opposed to their experience in mitigating specific challenges may not comprehensively ensure that the contractor has the right type of experience.

This paper does not aim to comprehensively examine or propose changes to contractor qualification requirements, however it is highlighted that these standards may need to be examined for their effectiveness, particularly if pipe bursting classification criteria are modified following future studies.

Consultants (and potentially, other project stakeholders) who plan to work on pipe bursting projects, should possess a solid understanding of the specific challenges and risks involved, which can be gained through training and project experience. To align education among consultants, training could be delivered in a measurable format through courses by organizations such as North American Society of Sewer Service Companies (NASSCO) or NASTT, with a formal accreditation. A similar system is adopted for pipeline CCTV inspection and condition assessments by NASSCO in the form of the Pipeline Assessment Certification Program (PACP), whereby a certificate and registration number is provided upon successful completion of the course. This qualification must be kept current through subsequent refresher courses. Adopting a similar system may be a positive step in standardizing consultant knowledge and for owners to ensure project teams have suitable training in pipe bursting.

7.3 GENERAL CONSULTANT AND OWNER

Both parties need to understand the risks such as soft soils under the host, old repairs, nearby utilities or other unexpected issues that may arise. The contract should have mechanisms to address these unknowns. All these issues need to be discussed by the consultant with the owner when deciding where the risk is going to be allocated in the contract. But more importantly these risks need to be understood by all parties.

7.4 RESEARCH

Collect and corelate the considerable volume of academic work done in the papers from the 1990's to the present and prepare useful summaries to a state where it can be used by consulting engineers in a practical format.

8.0 CONCLUSION

With further research and field trials into cavity expansion theory and a true partnership between academia and industry, the future of pipe bursting will see many more successful outcomes as projects are planned based on scientific principles in addition to the instincts of experienced pipe bursting contractors.

This paper is a call to action, an invitation if you will between academia and industry. Come out to our sites and we will support your efforts to safely and accurately monitor real projects that are of significant length or upsizing.

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