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SIDD pipe bedding and Ontario Provincial Standards

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ABSTRACT: The current OPSS and OPSD that provide specifications for drainage pipes in Ontario, are shown to be a simplified and more conservative version of the traditional Marston-Spangler method. The SIDD method was developed through extensive finite element analyses. It improves the pipe installation practice by lessening the requirements in bedding and compaction, and allowing the use of native backfill materials. There is potential cost-savings in using the SIDD method. The SIDD standard adopted by ASCE/ANSI, however, seems to have missed a few important pieces of design information and is inconsistent with the original SIDD research publication in the definition of soil types. The paper shows that an improved version of the SIDD method should be considered for adoption as an alternative in the OPSS, while the traditional Marston-Spangler method is maintained in the standards.

1 INTRODUCTION

Designs and installations of drainage pipes in Ontario are provided in various Ontario Provincial Standards Specifications (OPSS) and Drawings (OPSD). Specifications for rigid circular concrete pipes are given in OPSS 410, 421, 501, 514 and 1820; OPSD 802.030 to 802.034; OPSD 807.01, 807.03 and 807.04. These specifications (herein referred to as “the OPSS”) represent the best practice and have been widely and successfully used in Ontario, Canada.

The OPSS on rigid pipes are based on the traditional indirect method. In this method, designs of rigid pipe rely on the Marston-Spangler theory for earth loads in trench and embankment installations (ACPA 1992; OCPA 1986). Recently, analyses of pipe-soil interactions using the finite element method have resulted in the development of a direct design method. This method, commonly referred to as the Standard Installation Direct Design (SIDD) standard (ASCE/ANSI 1993), provides a different earth pressure distribution around the pipe for each of the four standard installation types. Because of the due consideration of lateral earth support and reduced reaction at the pipe invert, the SIDD method can provide significant savings in the pipe design and its installation. The SIDD method is not currently included in the OPSS.

This paper presents comparisons between the OPSS and SIDD method in terms of technical development, construction specifications and costs.

The results of a short survey on the SIDD method are also discussed.

2 DEVELOPMENT OF ONTARIO PROVINCIAL STANDARDS

The traditional Marston-Spangler method is referred to as the “indirect method” (ACPA 1992; OCPA 1986) because the strength of a pipe is determined by 3-edge bearing tests, and then related to the field strength by bedding factors (Marston and Anderson 1913; Heger et al. 1985; McGrath 1993). Based on this method, four types of bedding for concrete pipe have been developed: types ‘A’, ‘B’, ‘C’ and ‘D’ (ACPA 1992).

In the early 1900’s, Marston and his co-workers developed the formulas for soil loads and superimposed loads on buried rigid pipe installed in both trench and embankment conditions (Marston and Anderson 1913; Marston 1930). This work was based on the silo theory for grain loads on silo walls and floors developed by Janssen in 1895 (Kellogg 1993; Jeyapalan and Hamida 1988). Marston’s trench theory was further expanded by Spangler and his co-workers (Spangler and Handy 1973). Therefore, the trench theory is commonly referred to as the Marston-Spangler method (Selig and Packard 1986).

2.1 Loads on buried pipe

Design loads for rigid pipe have traditionally been determined using the Marston load theory (Marston 1930):

$$W = C\gamma B^2 \quad (1)$$

where W = backfill load per unit length; C = load factor; γ = unit weight of backfill material; and B = trench width, B_d , at top of pipe for trench condition or pipe outside width, B_c , for embankment condition. The formulas for calculating load factor, C , vary for different types of installation (Marston 1930).

2.2 Bedding factors

In the Marston-Spangler method, bedding factors are used to relate the calculated external loads to the 3-edge-bearing strength of pipe:

$$S_{eb} = \frac{W}{B_f} \quad (2)$$

where S_{eb} = 3-edge bearing strength; W = calculated external load; and B_f = bedding factor.

Bedding factor, B_f , is dependent on bedding angle, quality of contact between the bedding and the pipe, the supporting lateral pressure on the pipe, and the area over which this lateral pressure acts (Selig and Packard 1986). The higher the bedding factor, the better the quality of the bedding. In general, there are four classes of bedding as shown in Table 1 for trench conditions and in Table 2 for embankment conditions (ACPA 1988; Spangler and Handy 1973). Shaped bedding is one of the options for classes B and C for both trench and embankment conditions. Values of corresponding bedding factors given by the OPSS are included in the tables for comparison.

Table 1. Bedding classes and bedding factors, trench condition

Bedding class†	Bedding factor, B_f	
	ACPA (1988)	OPSD 807.01
A	2.8 to 4.8 (depends on reinf. ratio)	2.8
B	1.9	1.9
C	1.5	1.5
D	1.1	not available

† bedding class A= either a concrete cradle or arch, reinforced or plain; B = either a shaped subgrade with granular foundation, or a granular foundation to springline; C = either a shaped subgrade, or a granular foundation to 1/6 of outside diameter; and D = Flat subgrade.

For trench conditions, the OPSS bedding factors are the same as the industry standards for classes B and C. For class A, the low value that corresponds to plain concrete cradle or arch is used by the OPSS, which yields more conservative designs with this class.

Table 2. Bedding classes and bedding factors, embankment condition

Bedding class	Bedding factor, B_f		
	ACPA (1988)	OPSD 807.03†	
		Positive projection	Zero projection
A	B_f (Equations 3 and 4)	2.8	2.83
B		1.9	2.02
C		1.5	1.70
D		not available	not available

† $k\mu = 0.19$, $r_{sd} = 0.7$ and $p = 0.7$

For embankment conditions, the OPSS use the conservative but easy-to-use values. The ACPA manual gives a general semi-empirical equation for positive projection embankment condition:

$$B_f = \frac{A}{N - xq} \quad (3)$$

$$q = \frac{mk}{C_c} \left(\frac{H}{B_c} + \frac{m}{2} \right) \quad (4)$$

where A = a constant corresponding to pipe shape and for circular pipe $A = 1.431$; N = a parameter which is a function of the distribution of the vertical load and horizontal reaction; x = a parameter which is a function of the area of the vertical projection of the pipe over which active lateral pressure is effective; q = the ratio of the total lateral pressure to the total vertical load; k = the ratio of the unit lateral soil pressure to unit vertical soil pressure (Rankine's coefficient of active earth pressure and $k = 0.33$ will usually be sufficiently accurate); C_c = the load coefficient for positive projection pipe; H = cover depth; and B_c = pipe outside diameter.

As shown in Equations 3 and 4, bedding factors for embankment conditions are not readily available since they not only depend on bedding class, but also depend on the ratio of cover depth to pipe outside diameter, embankment type and the effective pipe area for active lateral pressure. Using the same conditions as the positive projection case of the OPSS, the bedding factors are calculated using Equations 3 and 4, and are plotted in Figure 1 as a function of the ratio of cover depth to pipe outside diameter.

Figure 1. Variation of bedding factor with ratio of cover to pipe outside diameter

In general, bedding factors for all four cases decrease as the ratio of cover to pipe outside diameter (H/B_c) increases until it reaches about 20. For H/B_c higher than 20, the bedding factors remain constant. These constant bedding factors for positive projection conditions are the same as for zero projection conditions where lateral earth supports are neglected. Table 2 and Figure 1 show that the bedding factors for zero projection conditions in the OPSS agree with those given by the equations. The values of the bedding factors for the positive projection in the OPSS, however, are less than those constant values shown in Figure 1. Nevertheless, those OPSS bedding factors are quite conservative because the ratio of H/B_c seldom exceeds 20 for most applications.

2.3 Discussions of Ontario Provincial Standards

Values of bedding factors given in the OPSS are the same as those given in Spangler and Handy (1973) and the ACPA manual (1988). However, the OPSS have the following distinctive features:

- Bedding class 'D' is not included, indicating its use is discouraged.
- Soil types are defined in the Occupational Health and Safety Act (OHSA 1978), which classifies soils into four types, mainly for shoring purposes (health and safety concern).
- Trench definition is also as per OHSA (1978).
- Compaction effort is more precisely defined than ACPA (1992). It is defined in terms of maximum dry density.
- Bedding factors are simpler and readily available for embankment conditions.
- Backfill materials are classified into five granular types, namely OPSS granular 'A', granular 'B' type I, granular 'B' type II, granular 'M' and selected subgrade material. Engineering properties and gradations of these granular materials are defined.

- Use of unshrinkable fill as backfill is allowed (OPSS 1359 1993).

As most other pipe standards and specifications, the OPSS currently do not include the SIDD "direct design" method that is based on the findings of recent research on interaction between rigid pipe and its embedment. There is a pressing need to update the OPSS so that they continue to represent best practice.

Lateral earth pressure is neglected for trench conditions, but is considered for embankment conditions. ACPA (1988) has modified this conservative approach by introducing the concept of variable trench bedding factors.

While most of the unique features listed above are improvements over the industrial standards such as ACPA (1988), others require modifications to reflect the state-of-the-art technologies. For instance, the OPSS refer to the OHSA trench and soil classifications, which are meant for preventing occupational hazards during constructions and protecting individuals working in and around the trenches. They are not meant for pipe design purposes.

It is worthwhile to note that the inherent difference between rigid and flexible pipe is not reflected in the OPSS – they are treated in a similar way, although OPSS 421 provides definitions for rigid and flexible pipe in terms of pipe behavior. Recognizing the different load-carrying mechanisms of rigid and flexible pipe and identifying the means to achieve optimal design will result in cost-effective and durable installations.

The above review shows that the OPSS are indeed based on the Marston-Spangler indirect method, but with simplifications. Furthermore, trenches and in-situ soil types are not defined in terms of the current engineering practice although backfill materials are well defined.

3 DEVELOPMENT OF STANDARD INSTALLATION DIRECT DESIGN

The SIDD method was introduced by the American Concrete Pipe Association (ACPA 1993) and was adopted as an ASCE Standard (ASCE/ANSI 1993). In this method, soil pressure distributions around a pipe are defined according to four standard types of installation. Vertical and horizontal arching factors are introduced to determine total vertical and horizontal loads. No bedding factors are used; instead, pipe wall design is based on the moments, thrusts and shears in the pipe wall due to the external and internal loads. This approach is referred to as the "direct design" method. The development of this method is reviewed in this section to provide background information for comparing it with the indirect method reviewed in the previous section.

3.1 Analysis of pipe-soil interaction

In order to understand fully the interaction between the buried concrete pipe and its surrounding soils, the American Concrete Pipe Association sponsored an extensive multi-year research project carried out by Simpson Gumpertz & Heger Inc. (Heger et al. 1985). As a result, a Soil-Pipe Interaction Design and Analysis program (SPIDA) was developed. The analysis part of the software uses the finite element method (FEM) and treats the pipe-soil system as a two-dimensional plane strain problem. The design part of the software is based on a strength and crack control design procedure that was specifically developed for circular reinforced concrete pipe (Heger 1982; ACPA 1993). Using SPIDA, a wide range of soil types and densities were studied and the results were used to develop the SIDD bedding standards (McGrath 1993).

Assuming symmetry about the vertical plane and uniform condition along the pipeline, SPIDA uses one half of the installation in the FEM model and takes a unit slice of the installation that is in a state of plane strain. This numerical representation of the pipe installation is a common approach in studying the behaviour of the pipe-soil system. The features and limitations of SPIDA are summarized by Heger et al. (1985).

3.2 Standard installation direct design method

Based on a large number of SPIDA simulation results covering a wide variety of conditions, four standard types of standard installations, each with a unique pressure distribution, were introduced by ACPA (1993) and adopted by ASCE (ASCE/ANSI 1993) and by AASHTO (1996). It seems, however, to be a step backward because the design practice has gone from a four-class bedding approach to FEM, and now back to another four-type installation approach. In this regard, Kellogg (1993) states:

“With the popularity of numerical methods of analysis, classical approaches to these problems have been waning. However, in the everyday practice of engineering, even in the computer age, closed-form solutions based upon classical mechanics and solutions to boundary-value differential equations are still needed. The time and cost to prepare sophisticated numerical models for analysis simply cannot be justified in the marketplace, except for the most complex and critical civil engineering structures.”

Trench and embankment conditions and the terms used in the SIDD standard installations are shown in Figures 2 and 3.

Figure 2. Trench configurations used in SIDD installations (ACPA 1993).

Figure 3. Embankment configurations used in SIDD installations (ACPA 1993).

Table 3 shows the four standard types of SIDD standard installation (ASCE/ANSI 1993) and soil types as defined in ASTM D 2487 (1993). Degree of compaction is in terms of Standard Proctor Density.

Table 3. SIDD Standard installation types[†] (ASCE/ANSI 1993)

Installation type	Bedding thickness (t_b)	Degree of compaction	
		Haunch and outer bedding	Lower side bedding
1	$t_b \geq D_o/24$, and $t_b \geq 75$ mm. For rock foundation: $t_b \geq D_o/12$, and $t_b \geq 150$ mm	95% SW	90% SW, 95% ML or 100% CL
2	$t_b \geq D_o/24$, and $t_b \geq 75$ mm. For rock foundation: $t_b \geq D_o/12$, and $t_b \geq 150$ mm	90% SW or 95% ML	85% SW, 90% ML or 95% CL
3	$t_b \geq D_o/24$, and $t_b \geq 75$ mm. For rock foundation: $t_b \geq D_o/12$, and $t_b \geq 150$ mm	85% SW, 90% ML or 95% CL	85% SW, 90% ML or 95% CL
4	No bedding required, For rock foundation: $t_b \geq D_o/12$, and $t_b \geq 150$ mm	No compaction required, except if CL, use 85% CL	No compaction required, except if CL, use 85% CL

[†] D_o = outside diameter of the pipe. Soil symbols as per Unified Soil Classification System (USCS) (ASTM D 2487 1993).

Of the four standard installation types, type 4 is of the lowest quality that requires no compaction (except for CL backfill soils), whereas type 1 is of the highest quality that requires well graded materials compacted to a minimum of 95% of the Maximum Standard Proctor density. Special care is required for the middle bedding (directly beneath pipe invert) where the soil needs to be kept loose in order to transfer the loads to the haunch area, thereby reducing stress concentration at the invert of the pipe (ASCE/ANSI 1993; Meyer et al. 1993). Excessive compaction of the middle bedding, and insufficient compaction of the haunch area can result in pipe cracking (Wilson 1985).

The ASCE/ANSI Standard (1993) provides the pressure distribution diagram, which is called Heger pressure distribution, and its coefficients (Figure 4); however, it falls short by not providing formulas and coefficients to determine maximum thrusts, bending moments and shears for each of the four standard installations (ASCE/ANSI 1993). These formulas and coefficients are provided in ACPA (1993) so that designers can use them to calculate design forces. Simpson Gumpertz & Heger Inc. provides SPIDA analysis service at a cost of US\$15 to US\$75 per design (Heger et al. 1985).

Installation Type	VAF	HAF	A1	A2	A3	A4	A5	A6	a	b	c	e	f	u	v
1	1.35	0.45	0.62	0.73	1.35	0.19	0.08	0.18	1.40	0.40	0.18	0.08	0.05	0.80	0.80
2	1.40	0.40	0.85	0.55	1.40	0.15	0.08	0.17	1.45	0.40	0.19	0.10	0.05	0.82	0.70
3	1.40	0.37	1.05	0.35	1.40	0.10	0.10	0.17	1.45	0.36	0.20	0.12	0.05	0.85	0.60
4	1.45	0.30	1.45	0.00	1.45	0.00	0.11	0.19	1.45	0.30	0.25	0.00	-	0.90	-

Figure 4. Heger pressure distribution diagram and coefficients (ACPA 1993).

3.3 Field performance verification

Sargand et al. (1994) independently instrumented a 600 mm diameter concrete pipe installed using the SIDD Type 3 installation in laboratory. They pointed out that to that date only a few installations had been instrumented and monitored for performance verification of pipe-soil systems that were laid according to the SIDD standards. Their monitored results showed that the SIDD method is good at predicting moments before the formation of cracks, but not so good after the formation of cracks in concrete pipe. Furthermore, measured thrusts were consistent with the predictions of the SIDD only for low surface pressures. Two reasons were given for the mismatch between the experimental and theoretical results:

- The SIDD FEM model is not capable of simulating the behavior of a cracked pipe section adequately. Although Heger et al. (1985) state that SPIDA can model uncracked and cracked pipe section by using different stiffnesses for the beam elements that represent the pipe section, the work by Sargand et al. (1994) showed that SPIDA needs improvement in modeling the pipe section so that formation of cracks can be adequately accounted for.
- SIDD assumes symmetry in geometry and loading, which is a common assumption in order to

reduce the three-dimensional pipe-soil interaction problem to a two-dimensional one.

In the laboratory tests by Sargand et al. (1994), however, four pressure cells were placed only at the invert, top and springlines where the pressure is maximum in the Heger pressure distributions (Figure 3). There were no pressure cells at locations where the pressures are minimum.

Simpson Gumpertz & Heger Inc. (1999) instrumented a 2400 mm diameter concrete pipe that was installed with 5 m cover. A total of three pipe sections were installed with 4 earth pressure cells on each: one at invert, one at crown and two at springlines. No strain gauges were used to measure strains in the pipe wall. Type 1 installation was achieved, although type 4 was intended. The pipe-soil system was monitored for 6 months, and the measured pressure distribution was reported to agree well with the prediction of SPIDA. However, no pressure cells were installed at locations where the pressures are minimum on the Heger pressure distributions.

4 COMPARISONS BETWEEN ONTARIO PROVINCIAL STANDARDS AND STANDARD INSTALLATION DIRECT DESIGN

4.1 *Design approach*

The OPSS design method is the Marston-Spangler indirect method that uses bedding factors to relate the required field strength to the 3-edge bearing strength. Inherent to this method is the omission of soil lateral support in trench conditions. The design of reinforcement is carried out using the working stress design approach.

The SIDD method uses the Heger pressure distributions for external loads and emphasizes the importance of compaction of material under the haunches. This compaction increases the size of the pressure bulbs under the haunches and decreases the concentrated pressure at the invert, which is the source of many problems with buried pipe installations. The SIDD method is a direct design method that is based on FEM modeling. It considers soil lateral support for all cases, and does not use bedding factors. The design of reinforcement is carried out based on the thrust, moment and shear in the pipe wall, and in accordance with the more rationale limit states design approach.

Conventional bedding classes B and C include an option of shaped subgrade and an option of flat subgrade with granular bedding materials. The OPSS further require that pipe bed be shaped to receive the bottom of the pipe, in either option (OPSD 802.030 to OPSD 802.024 1996). According to McGrath

(1993), the installation types in the SIDD bedding standard are similar to the old bedding types as:

- SIDD installation type 2 □ conventional bedding class B (flat subgrade with granular materials)
- SIDD installation type 3 □ conventional bedding class C (flat subgrade with granular materials)
- SIDD installation type 4 □ conventional bedding class D

SIDD installation type 1 is completely different from conventional bedding class A because latter has either a concrete cradle or arch.

4.2 *Backfill materials*

One of the advantages of the SIDD method is its adoption of the soil types according to the widely accepted Unified Soil Classification System (USCS) (ASTM D 2487 1993). The USCS classification minimizes the ambiguity of the term “granular material” since it defines soil types vigorously. In this regard, the current OPSS are sufficient because they also clearly define the granular aggregate materials. However, the OPSS refers to OHSA for trench definitions and classifications of native soils other than granular materials. The OHSA’s definitions and classifications, based on health and safety concerns, are not consistent with the current engineering practice, such as the SIDD method.

The other advantage of the SIDD method is that it allows the use of virtually all types of in-situ soils for backfilling, whereas the OPSS require the backfill materials from the springline up to be cover materials as specified (OPSS 514 1999). The OPSS further specify that cover materials requiring compaction shall be placed in layers and compacted to 95% of the maximum dry density. For all installations under roads, only granular materials are allowed as cover materials. No doubt, this difference will have a significant impact on installation cost.

Figure 5 shows the gradation curves for the OPSS granular A, B, M and select subgrade materials (OPSS 1010 1993). These types are then compared to the USCS classifications in Table 4. The comparison shows that the upper and lower bounds of the range of an OPSS granular material fall into different soil types of the USCS classification. However, all the OPSS granular materials are GP, SP or SW, all of which are considered as “Category I” soil in *Standard Installations and Bedding Factors for the Indirect Design Method, Design Data 40* (ACPA 1996). This category is somehow labeled as “SW” in the ASCE standard (ASCE/ANSI 1993).

Table 5 shows the OHSA soil classes to illustrate that it is not meant for pipe design purposes.

The SIDD method does not provide any information on the use of controlled low strength material (CLSM, also called unshrinkable fill), whereas the OPSS permits its use.

Figure 5. Gradation curves of OPSS granular aggregates.

Table 4. OPSS granular materials compared with SIDD soil types

OPSS granular materials				USCS	SIDD
Type	Range limit	C_c †	C_u †	soil type	soil category
Granular "A"	low	0.69	76.3	GP	I
	upper	1.76	17.2	SW	I
Granular "B"	low	0.75	3.25	GP	I
Type I	upper	2.67	6.3	SW	I
Granular "B"	low	0.66	68.8	SP	I
Type II	upper	2.67	6.3	SW	I
Granular "M"	low	0.58	58.0	GP	I
	upper	0.76	17.2	SP	I
Select	low	0.9	2.0	GP	I
subgrade material	upper	4.6	11.5	SP	I

† C_c : coefficient of curvature; and C_u : coefficient of uniformity.

4.3 Compaction requirements

Both the OPSS and SIDD methods specify compaction levels in percentages of standard or modified maximum Proctor densities. The difference, however, lies in the zones around the pipe. For the SIDD method, the central 1/3 of the bedding is left uncompacted, whereas the OPSS call for uniform compaction of at least 95% everywhere (bedding, haunch, cover and top backfill). The reduced compaction by the SIDD method will likely result in savings in construction labor cost.

The SIDD method, on the other hand, would require a more detailed specification. For the first time users, a higher degree of quality control, construction inspection and testing may be required to ensure that the right type of backfill is used, and appropriate levels of compaction are achieved in different zones.

Table 5. OHSA (1978) soil classes

OHSA soil classes	Description
Type 1	is hard, only able to be penetrated by a small sharp object with difficulty; can only be excavated by mechanical equipment; shows no sign of visible cracks after excavation; exhibits a dry, shiny appearance after excavation; and possesses a low moisture content and a high degree of internal strength.
Type 2	can be penetrated by small sharp objects easily; can be excavated with hand tools with moderate difficulty; exhibits signs of visible surface cracking; exhibits a damp appearance after excavation; and possesses a low to medium moisture content and a medium degree of internal strength.
Type 3	is loose, soft, sandy or previously excavated; can be excavated with hand tools easily; will run easily into a well-defined conical pipe if dry; will flow or shift unless supported if wet; and possesses a low degree of internal strength.
Type 4	is wet or muddy; will run easily or flow unless completely supported immediately after excavation; exerts substantial fluid pressure upon its supporting system; and possesses almost no internal strength

4.4 Factor of safety comparison

In recent times, the engineering profession has recognized that the use of a single factor of safety fails to provide uniform reliability and hence economy. As a result, structural design codes have moved towards the partial factor of safety approach, also known as limit states design, whereby loads, materials and performance are considered separately by means of statistically determined load and resistance factors (Allen 1975). The limit states design approach provides a more consistent degree of safety for structures than the single factor of safety approach and has formed the basis for a number of Canadian and American design codes, including the SIDD standards (ASCE/ANSI 1993; NBCC 1994; OHBD 1991; CSA A23.3-94; ACI 318 1989; UBC 1994).

The OPSS method uses the single factor of safety approach of the working stress design method.

4.5 Cost comparison

Design is a process of achieving the optimal balance between cost and performance. Costs of a structure include initial and subsequent maintenance and replacement costs. However, in this paper, the cost considered is limited to the initial cost. The long-term viability of concrete pipe is not expected to change with the use of alternative bedding standards.

There are a number of factors that may render the SIDD method more cost-effective than the OPSS method. These factors are:

- cost of pipe manufacture;
- cost of backfill material; and
- labour cost.

The cost of pipe manufacture consists of both concrete and reinforcement. According to Heger et al. (1985), the SIDD method provides the appropriate amount of reinforcement whereas the indirect method yields over-designs. Therefore, savings in reinforcing steel is expected when the SIDD method is used. Kurdziel (1999) reports a case study conducted by Wright State University in Ohio. A 2440 mm diameter concrete pipe was installed with a 6.1 m cover. The reduction of reinforcing steel was in the range of 17% to 32% compared to an equivalent indirect design. Schmidtler (1999) reports a case study in Calgary where a trunk sewer of 900 mm diameter was constructed using precast concrete pipe and the SIDD installation. Savings in reinforcing steel was about 7%.

Savings in the cost of backfill materials in SIDD installations is expected because not only granular materials, but also non-granular native materials like clay are allowed. Although the OPSS method does not always require granular materials for backfilling above the springline, granular materials are indicated. Savings in terms of compaction effort is also expected in SIDD installations because no compaction is required in the middle third of the bedding. The degree of compaction decreases as the installation type goes from type 1 to type 4.

However, these savings are not easily separated for a construction job. Schmidtler (1999) reports savings of about 4% in a SIDD installation for everything after the reinforcing steel was accounted for separately. Kurdziel (1999) reports total savings of 30% for type 2 and 27% for type 3 installations (including reinforcing steel). Smith and Schmidtler (2000) report substantial savings by using the SIDD method in two separate installations.

5 SURVEY AND RESULTS

A short questionnaire was sent to nine municipalities or departments of transportation (DOT) in Canada and in the United States that were identified as having accepted or partially accepted the SIDD method. Seven the municipalities/DOTs responded.

The survey results reveal, to a certain degree, the current acceptance and perceptions of the SIDD method by those municipalities and DOTs. Although some respondents indicated that they use the AASHTO standard (1996) that has adopted the SIDD, they do not necessarily accept all four standard SIDD installation types. The fact that type 1 SIDD installation is the most accepted indicates that

majority of the engineering practitioners prefer granular bedding and backfill materials with a relative high degree of compaction. This preference is expected because of the requirements of the road under which the pipe is often laid. Allowing only one soil category also simplifies the contract specifications and reduces the requirement of on-site supervision. More conservative designs such as given by the Marston-Spangler method seem to provide more comfort margin for engineers over unforeseeable future condition changes.

The SIDD method is not perceived to be easier to use than the traditional method. This may be due to the fact that the Marston-Spangler method is well understood and widely used, whereas the SIDD method is a relatively new concept.

No conclusive observations can be made in terms of cost-effectiveness because only three respondents indicated previous use of the SIDD method in their projects.

6 FIELD PERFORMANCE VERIFICATION

As part of the overall project, type 2 and type 3 SIDD installations were included in the construction of a 1,370 mm diameter precast concrete culvert in the summer of 2000. Two of the pipe sections were cast with embedded strain gauges for measuring the strains in the pipe wall. These instrumented pipes were placed one on each side of the road centreline, separated by a regular pipe section (Fig. 5). Although granular 'A' material was used for bedding and backfill up to the springline for the entire culvert, the degree of compaction was carried out according to type 2 SIDD installation on one side and type 3 on the other. The trench above the springline was backfilled with the excavated native soil.

Figure 5. Installation of a culvert with monitoring sensors.

Earth pressure cells were installed on the pipe surface and in the backfill soil to measure soil pressure distributions not only at expected maximum but also minimum pressure locations around the pipe circumference. Soil temperatures were measured at the pipe centreline and at the edge of the trench by thermocouples. On the finished road pavement, rows of survey pins were installed to facilitate periodical survey in order to determine road settlements. All the installed sensors are connected to and controlled by two on-site dataloggers. Remote communication with the monitoring system is established via a modem.

The intended monitoring period is three years starting in August 2000 and surface settlement survey is scheduled four times a year. The data obtained for the first few months indicated that the system is working properly. The results of this in-situ performance monitoring will be reported in the future.

7 SUMMARY AND CONCLUSIONS

Specifications for the designs and installations of drainage pipes in Ontario are provided in various Ontario Provincial Standards Specifications and Drawings. These specifications and drawings represent the best practice and have been widely and successfully used in Ontario. However, like most other existing specifications on buried pipes, the OPSS are based on the traditional Marston-Spangler method for determining earth loads and the required pipe strength by means of bedding factors. This research revealed that the current OPSS on concrete pipe have lagged behind the pipe industry. Furthermore, the OPSS need to have more appropriate definitions of trenches and soil classifications while maintaining the cross-reference to the OHSA.

The SIDD method was developed through extensive finite element analyses of a wide range of soil types and installation configurations. The SIDD method improves the pipe installation practice by lessening the requirements in bedding and compaction and allowing the use of native backfill materials. It uses the commonly-used USCS soil classifications and specifies compaction effort in the Proctor density terms. This research has identified the potentials in cost-savings in using the SIDD method. The SIDD standard of ASCE/ANSI (1993), however, seems to have missed a few important pieces of design information. In addition, the soil types used in the ASCE/ANSI standard are not as clearly defined as in the ACPA publication (1996).

The OPSS specify granular backfills and degree of compaction similarly as the SIDD method, which makes it easier to adopt the SIDD method in the OPSS. The OPSS allow the use of unshrinkable fill

as trench backfills, which is not considered in the SIDD method.

The results from a short questionnaire indicated the current acceptance and perceptions of the SIDD method by municipalities and DOTs. The fact that type 1 SIDD installation is the most accepted type indicates that majority of the engineers prefer granular bedding and backfill materials with a relative high degree of compaction. There is a concern over potential change in the Heger loading distribution of the SIDD method due to future lateral sewer connections.

An improved version of the SIDD method should be considered for adoption as an alternative in the OPSS, while the traditional Marston-Spangler method is maintained. Traditional methods are still valid and viable in situations where in-situ soil conditions do not warrant the use of the SIDD method.

A field test SIDD installation has been realized on a concrete culvert that crosses one of the regional roads in the outskirts of Ottawa, ON. The monitored performance will be compared to the performance predicted by the SIDD method. The results of this full-scale field monitoring will be reported in future publications.

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