Performance of Induced Trench Culverts in New Brunswick

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ABSTRACT

The induced trench method of culvert construction has been in use for over 80 years. In this construction, a compressible layer is placed directly above a rigid culvert to induce positive arching. The design is based on the research work done by Marston and Sprangler in the 1920's and 1930's. In spite of its long history, the induced trench method of design and construction is viewed with skepticism because of many simplifying assumptions used in the design method. The latest edition (2000) of the American Concrete Pipe Association Handbook has deleted this method reflecting the current reservations about this method of construction.

In response to some of these recent concerns, an inspection program was implemented by the New Brunswick Department of Transportation (NBDoT) in the summer of 2001 to assess the performance of induced trench installations. Each installation was visually inspected for signs of structural distress or any other signs of failure. In this paper, the results of this inspection and analysis of the resulting data are presented. It is concluded that induced trench construction results in a significant savings and the design methods and construction details used by NBDoT result in buried conduits which satisfy serviceability limit states.

INTRODUCTION

The concept of induced trench was introduced by Marston (1930) to reduce earth pressures on buried conduits located at the bottom of an embankment of significant height (heights > 10 m). A reduction in vertical pressure is achieved by inducing positive arching in the soils above the conduit. The basic idea of an induced trench design compared to positive projecting culverts is shown in Figure 1. As shown in this figure, the presence of compressible layer results in greater settlement of a soil column above the pipe in relation to the adjacent soil. The resulting differential settlements lead to positive arching which reduces the vertical loading on the pipe. In comparison to an induced trench design, a positive projecting conduit will result in negative arching leading to vertical stresses being greater than the overburden stresses at the crown of the pipe.

The following equation (ACPA 1988) is used to calculate the load per unit length of the pipe (W_i) for an induced trench culvert:

$$W_i = C_i \ \gamma \ B_c^{\ 2} \tag{1}$$

Where γ = unit weight of soil, B_c = outside diameter and C_i is given by either Eq. 2 or 3.

$$C_i = \frac{e^{-2k\mu\frac{H}{B_c}} - 1}{-2\ K\mu} \ where\ H \leq H_e \tag{2}$$

$$C_i = \frac{e^{-2\ K\mu\frac{H_c}{B_c}} - 1}{-2\ K\mu} + \left[\frac{H}{B_c} - \frac{H_e}{B_c}\right] e^{-2\ K\mu\frac{H_e}{B_c}} \ where\ H > H_e \tag{3}$$

Where H = height of the fill above top of pipe, H_e = height above top of pipe to plane of equal settlement, K = coefficient of active earth pressure and μ = coefficient of friction for backfill material. The plane of equal settlement is defined as a plane where the settlements of soil column above compressible layer are same as adjacent soil.

The relative settlement ratio, r_{sd} is defined as:

$$r_{sd} = \frac{s_g - (s_d + s_f + d_c)}{s_d} \tag{4}$$

Where s_g = settlement of the embankment at the top of compressible layer, s_f = settlement of foundation, s_d = settlement at top of compressible layer, and d_c = reduction in diameter.

The required pipe strength is then determined using the load per unit length and appropriate bedding factor.

The main advantage of induced trench design is its ability to use standard pipe sizes even when embankment heights exceed 10 m as a positive projecting type design in these instances would result in other more costly designs such as cast-in-place concrete or arch culverts. The savings by adopting induced trench design are estimated to be about 15% when compared to positive projecting pipe installations. Generally, cost savings offered by induced trench installations are greater for larger pipe diameters.

BACKGROUND FOR PRESENT STUDY

Even though induced trench design has been in vogue for almost 80 years, the design is viewed with skepticism because of many simplifying assumptions and in the development of it's theory. These are also additional concerns about quality control during the construction of an induced trench (Childs, 2003). As a consequence, the 2000 edition of the American Concrete Pipe Association Handbook has deleted induced trench method of design.

In order to address the concerns expressed by other transportation agencies about induced trench design, an inspection program was implemented by the New Brunswick Department of Transportation in 2001 to evaluate the performance of induced trench installations in the Province of New Brunswick.

FIELD WORK

The scope of field work consisted of inspection of 50 induced trench installations. The interior of each culvert was visually inspected for signs of structural distress. For smaller diameter conduits (less than 1.2 m) a remote controlled camera was used for inspection. A series of photographs were taken to establish bench marker conditions for future assessments. All the cracking on the interior at pipes, sagging or distortion of pipes or any other visible damage was recorded.

INSTALLATION DETAILS

The 50 installations inspected had embankment fill heights ranging from 9 m to 32.5 m. The inside pipe diameters ranged from 750 mm to 3000 mm. A single culvert was utilized at 49 out of 50 locations. There was only one case of twin culverts where two 1800 mm diameter pipes were utilized. The spacing between these twin pipes was 1.6 times the outside diameter and the embankment height was 13.5 m. The twin culverts were designed as two individual single induced trench culverts without accounting for any interaction between the two culverts.

The thickness of the compressible layer varied from 0.5 B_c to 1.5 B_c. The width of compressible layer was 1.0 B_c in all installations including twin culverts. The material used for the compressible zone mostly consisted of sawdust or wood chips.

The pipes were founded on a lightly compacted bedding layer, 0.3 B_c in width. A well graded granular material was placed around the pipe in accordance with the details shown in Figure 2. This is the standard detail which has been used in all installation.

Table 1 summarizes the design data pertaining to the culverts installed between 1991 and 1999. The outside diameters of the pipe varied from 950 mm to 3600 mm and the fill heights varied from 9 m to 32.5 m. The height to outside diameter ratios varied from 3 to 13 (Figure 3) and the period of service at the time of inspection varied from 10 years to 2 years (Figure 4). Twenty induced trench culverts were constructed in 1997 and the height to outside diameter ratio of 5 was noted for 13 out of 50 installations.

FIELD OBSERVATIONS

Radial cracking of the headwalls at the inlets and outlets of each culvert was the most common damage observed. Circumferential cracking near the pipe joints was also noted in few installations. The circumferential crack lengths at the joint locations ranged from hairline cracks (5-10 cm long), to cracks which almost extended along the entire inside circumference of the pipe (Figure 5). As this type of cracking was noted in the vicinity of joints, it was concluded that this damage most likely was caused due to overstressing of pipe joints during installations. Longitudinal cracking was observed at the springing level in only two pipe installations. In one instance the length of these longitudinal cracks varied from 1 to 3.3 m at four different locations approximately at the mid-sections of the longitudinal axis of the pipe (Figure 6). These cracks were classified as stage 1 cracks (Spangler, 1964). In the second case, similar cracking was observed near the end sections of the culvert where the height of embankment was less than the maximum height and the culvert was outside the influence of compressible layer.

The inspections revealed that the culverts which were installed under the two highest fill heights of 32.4 and 32.5 m did not have any circumferential or longitudinal cracking.

INDEPENDENT ANALYSIS

An independent analysis for each of the field installations was carried out to determine required class of pipe (Bourque, 2002; McLeod, 2003). The procedure recommended in the Concrete Pipe Handbook (ACPA, 1981) was used to determine class of pipe.

The results of independent analysis are presented in Table 2. For each and every installation without the use of an induced trench, conduits with pipe strengths greater than Class V (140-D) would have been required. As these class of pipes are not commercially available from pre-cast plants, either a cast-in-place pipe or a site specific pre-cast pipe would have been required resulting in increased costs. A comparison of independent analysis with the NBDOT designs indicates that at many locations a pipe of lesser strength than the field installed pipe could have been used. However, this difference in class of pipe did not exceed more than the next pipe class. The requirement of selecting pipes of a certain class with a specified strength exceeding the required strength results in conservative design.

CONCLUSIONS

A field inspection program of 50 induced trench culvert installations in the Province of New Brunswick indicates that all these structures have performed satisfactorily. The survey included culverts whose outside diameters varied from 900 mm to 3600 mm with fill heights above the crown varying from 9 m to 32.5 m. The field inspections program included culverts varying in ages from 2 years to 10 years. The results of this performance appraisal confirm the suitability of induced trench culvert installations for fill heights in excess of 9.0 m. To achieve similar results in future, the Marston-Spangler design approach combined with the bedding and other construction details used by the NBDoT should be followed.

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Table 1 NBDoT induced trench installations between 1991 and 1999.

Outside Pipe Diameter (B_c) (mm)	Pipe Class	Fill Height (m)	Thickness of Compressible Layer (mm)	Projection Ratio (p’)	Relative Settlement Ratio (r_{sd})
1000	III	12	1000	1	-0.7
1500	III	10.8	1500	1	-0.7
1450	IV	14.4	1450	1	-0.7
1830	IV	18.5	2745	1.5	-1
1500	IV	11.4	1500	1	-0.7
1500	IV	11.8	1500	1	-0.7
1800	IV	12.3	1800	1	-0.7
1500	IV	12	1500	1	-0.7
1500	IV	9.5	1500	1	-0.7
1800	IV	11	1800	1	-0.7
1830	III	9.5	915	0.5	-0.5
1830	III	10.9	915	0.5	-0.5
1850	IV	10.2	1850	1	-0.7
2222	V	22.8	2000	0.9	-0.66
2200	III	10	1100	0.5	-0.5
2200	IV	11.8	2200	1	-0.7
2200	V	13.5	2200	1	-0.7
1850	IV	13.6	925	0.5	-0.5
1850	IV	12.3	925	0.5	-0.5
1867	IV	21.2	2800	1.5	-1
950*	IV	11.9	475	0.5	-0.5
950	III	8.9	475	0.5	-0.5
1300	IV	10.4	650	0.5	-0.5
1300	III	11.8	650	o.5	-0.5
3000	IV	16.6	3000	1	-0.7
2400	V	32.4	1800	0.75	-0.6
1467	V	32.5	2200	1.5	-1
2500	IV	15.4	1250	0.5	-0.5
2500	IV	12.6	1250	0.5	-0.5
2200	III	11.8	2200	1	-0.7
1500	III	9	1500	1	-0.7
1300	III	10.1	1300	1	-0.7
1500	III	10.2	1500	1	-0.7
1300	III	11.2	1300	1	-0.7
2950	III	15.9	2950	1	-0.7
1300	III	12	1300	1	-0.7
1200	III	13.5	1200	1	-0.7
1200	IV	16.2	1200	1	-0.7
2600	V	22.45	2600	1	-0.7
1829	V	16.14	1500	0.82	-0.628
2500	65-D	9.5	2500	1	-0.7
1300	65-D	12.7	650	0.5	-0.5
1850	65-D	11.2	925	0.5	-0.5
3600	100-D	19.1	3600	1	-0.7
2600	100-D	15.1	2600	1	-0.7
2600	65-D	15.4	2600	1	-0.7
3600	100-D	13.5	1800	0.5	-0.5
2600	65-D	11.4	1300	0.5	-0.5
2600	100-D	13.5	2600	1	-0.7
3600	100-D	16.1	1800	0.5	-0.5

*Conduit experienced significant longitudinal cracking

Table 2 Summary of pipe classes

Outside Pipe Diameter (B_c) (mm)	Fill Height (m)	$D_{0.01}$ required in (N/m/mm)		Pipe Class		
		Positive Projection	Induced Trench	Installed Pipe	Induced Trench (required)	Positive Projection
1000	12	212.36	43.26	III	III	Exceeds V
1500	10.8	177.51	39.13	III	III	Exceeds V
1450	14.4	230.28	48.10	IV	III	Exceeds V
1830	18.5	327.06	43.88	IV	III	Exceeds V
1500	11.4	187.59	40.94	IV	III	Exceeds V
1500	11.8	194.32	42.14	IV	III	Exceeds V
1800	12.3	193.77	43.18	IV	III	Exceeds V
1500	12	197.68	42.74	IV	III	Exceeds V
1500	9.5	155.62	35.24	IV	III	Exceeds V
1800	11	172.80	39.45	IV	III	Exceeds V
1830	9.5	150.94	49.42	III	III	Exceeds V
1830	10.9	173.92	56.20	III	III	Exceeds V
1850	10.2	164.16	38.42	IV	III	Exceeds V
2222	22.8	368.96	83.30	V	IV	Exceeds V
2200	10	158.36	52.29	III	III	Exceeds V
2200	11.8	188.02	44.32	IV	III	Exceeds V
2200	13.5	216.00	49.27	V	III	Exceeds V
1850	13.6	220.61	71.02	IV	IV	Exceeds V
1850	12.3	199.05	64.35	IV	III	Exceeds V
1867	21.2	346.77	44.24	IV	III	Exceeds V
950*	11.9	200.21	63.41	IV*	III	Exceeds V
950	8.9	149.05	47.56	III	III	Exceeds V
1300	10.4	169.69	54.44	IV	III	Exceeds V
1300	11.8	193.04	61.66	III	III	Exceeds V
3000	16.6	270.74	63.33	IV	III	Exceeds V
2400	32.4	536.60	137.13	V	V	Exceeds V
1467	32.5	531.73	52.34	V	III	Exceeds V
2500	15.4	240.01	77.89	IV	IV	Exceeds V
2500	12.6	195.11	64.01	IV	III	Exceeds V
2200	11.8	188.02	44.32	III	III	Exceeds V
1500	9	147.18	33.74	III	III	Exceeds V
1300	10.1	164.70	35.79	III	III	Exceeds V
1500	10.2	167.38	37.34	III	III	Exceeds V
1300	11.2	183.02	39.07	III	III	Exceeds V
2950	15.9	254.80	60.00	III	III	Exceeds V
1300	12	196.40	41.47	III	III	Exceeds V
1200	13.5	238.69	49.02	III	III	Exceeds V
1200	16.2	287.10	57.73	IV	III	Exceeds V
2600	22.45	366.83	78.31	V	IV	Exceeds V
1829	16.14	259.97	63.72	V	III	Exceeds V
2500	9.5	145.36	39.24	65-D	65-D	Exceeds V
1300	12.7	208.03	66.31	65-D	100-D	Exceeds V
1850	11.2	180.75	58.70	65-D	65-D	Exceeds V
3600	19.1	298.66	70.62	100-D	100-D	Exceeds V
2600	15.1	244.34	56.46	100-D	65-D	Exceeds V
2600	15.4	249.33	57.34	65-D	65-D	Exceeds V
3600	13.5	208.07	69.75	100-D	100-D	Exceeds V
2600	11.4	182.60	60.46	65-D	65-D	Exceeds V
2600	13.5	217.63	51.76	100-D	65-D	Exceeds V
3600	16.1	250.15	82.71	100-D	100-D	Exceeds V

*Conduit experienced significant longitudinal cracking

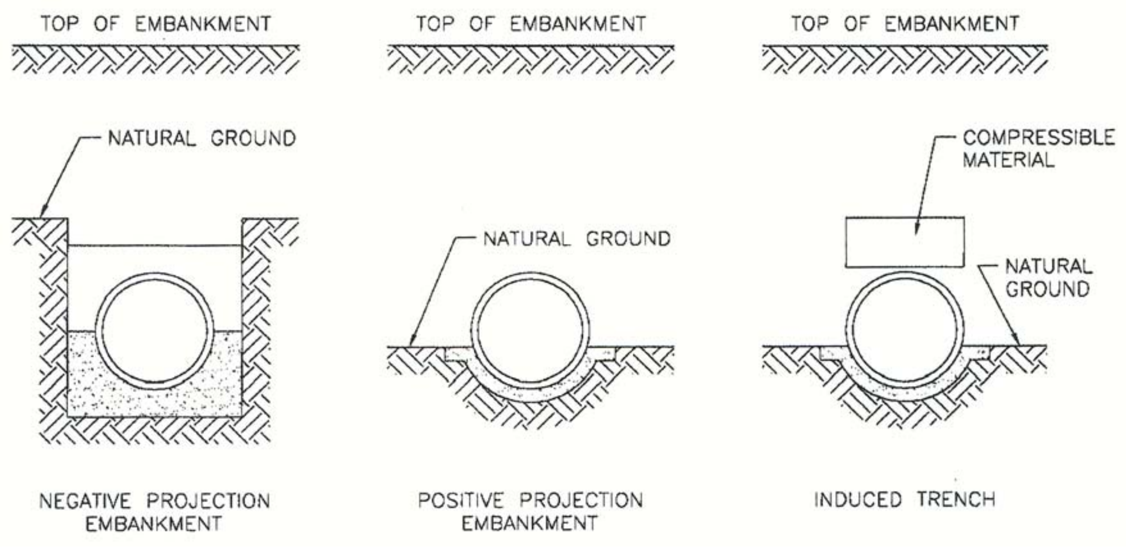

Figure 1 Features of negative projecting, positive projecting and induced trench embankment installations (after APCA, 1998).

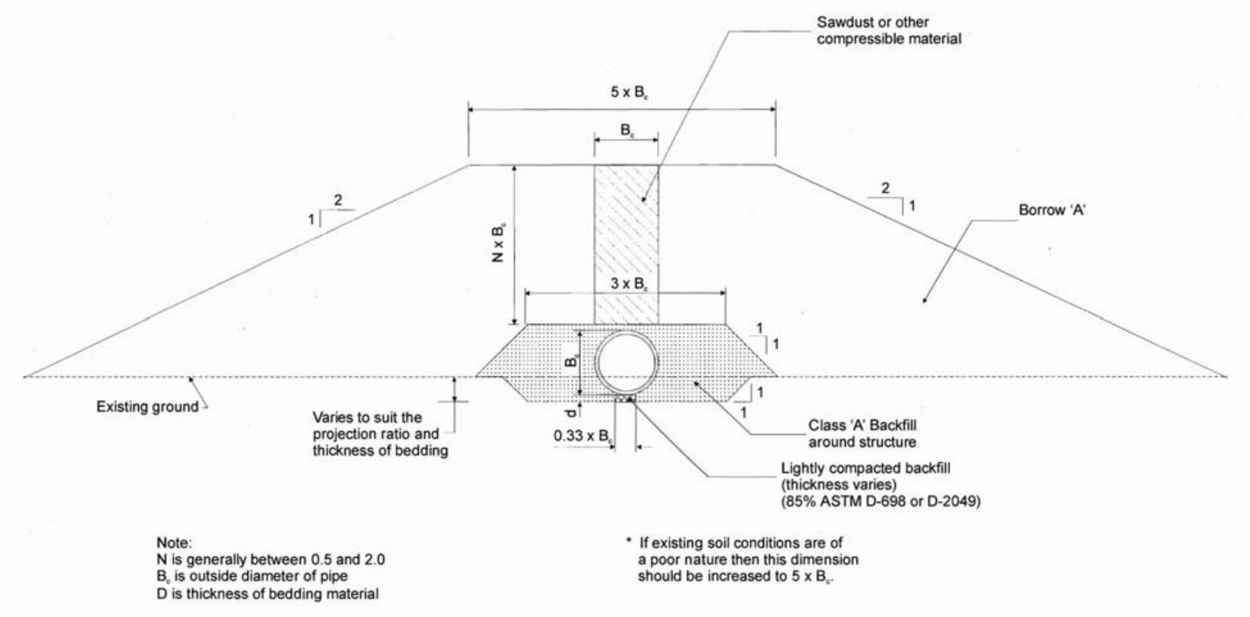

Figure 2 New Brunswick Department of Transportation typical induced trench installation.

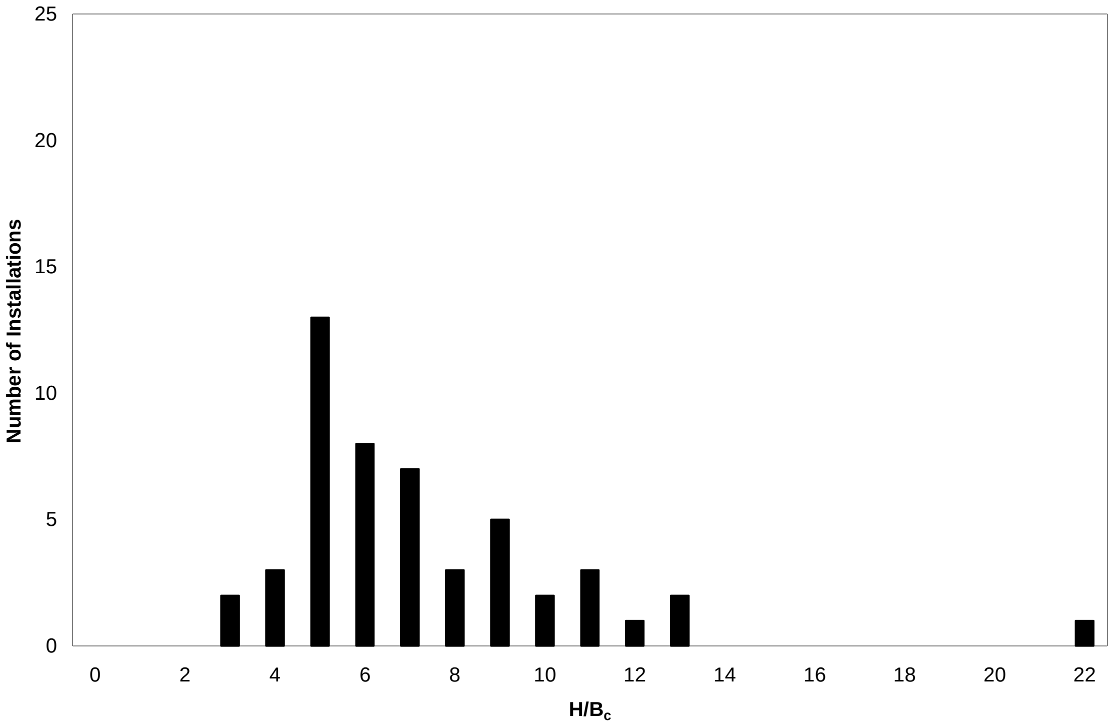

Figure 3 H/B_c variations in various installations.

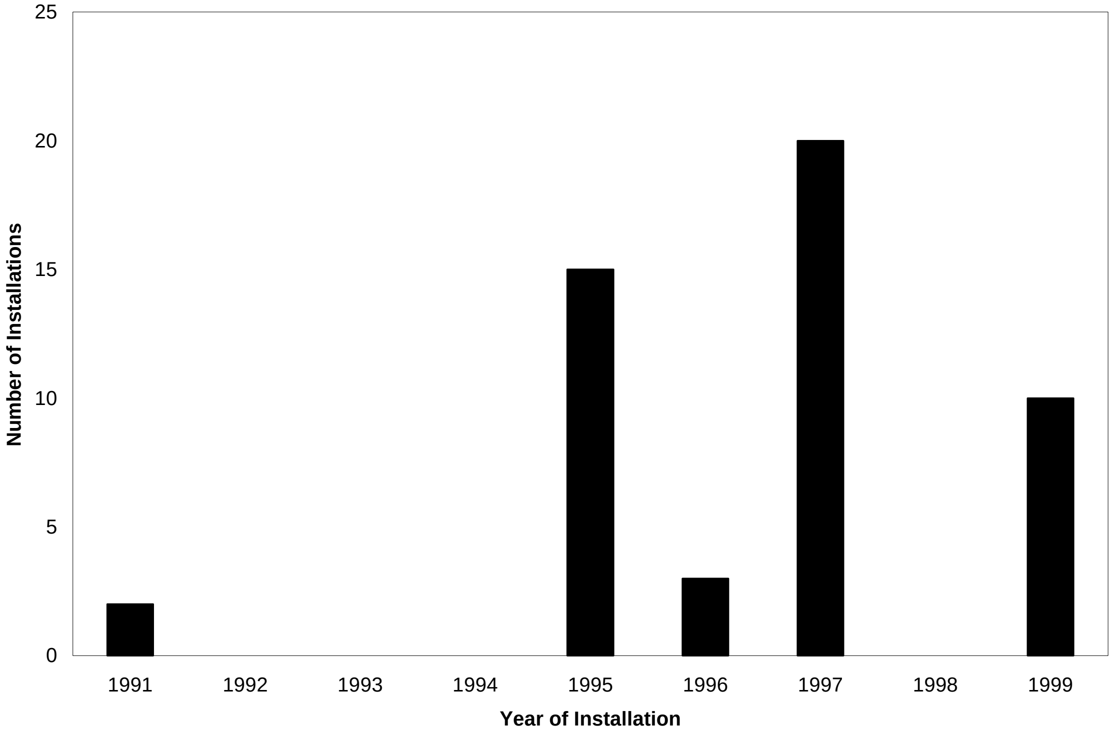

Figure 4 Period of service of various installations.

Figure 5 Typical circumferential cracking.

Figure 6 Longitudinal cracking observed in two installations out of 50.