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Comparative study for designing the horizontal thrust blocks in pipelines for water and sewage networks

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ABSTRACT

The thrust block is one of the most widely recognized methods of resisting thrust forces. This type of infrastructure should be installed in bends, dead ends, tees and wyes. Thrust blocks perform the function of transferring thrust force to the ground safely. Thrust block dimensions are designed based on hydrostatic pressures, bend angles, and soil properties in the surrounding area. Several codes exist for designing thrust blocks, but we focus on Egyptian code for design and implementation of pipelines for drinking water and sewage networks (ECDIPWSN) and the American Water Works Association (AWWA). In this methodology, the steps of thrust block design by the codes are demonstrated and applied individually to one of the published papers. The goal of the study was to find the optimum percentages between the dimensions of the block in the two codes and to compare the quantity of concrete after the block was designed by each code. Based on the research, it was found that the concrete amount of the block designed by AWWA was smaller than that designed by ECDIPWSN.

Key words: AWWA, ECDIPWSN, thrust block, thrust force

HIGHLIGHT

- Results of the study discovered the volume of the thrust block created by the AWWA method was smaller than the volume created by the ECDIPWSN method when excavation depth was low but was larger when excavation depth was large.

NOTATION

A	Area of pipe
A_b	Bearing area required (ft^2)
b	Width of the block calculated block width (ft)
d	Internal pipe diameter
e	Soil pressure at the bottom of the block
e'	Soil pressure at section x
Fe	Pressure force at the bottom of the block
Fe'	Pressure force at section x
h	Height of the block
I	The second moment of area about the neutral axis z
Kp	Passive pressure
M(x-x)	Moment about section x
P	Hydrostatic test pressure
Sb	Bearing strength (lb/ft$_2$)
Sf	Safety factor
T	Thrust force (lbf)
y	The perpendicular distance to the neutral axis
σ	Normal stress
θ	Degree of bent pipe
γc	Concrete density
γ	Soil density
φ	Friction angle

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INTRODUCTION

Pipelines are a traditional way of transferring the water between the zones on the city plan. A layout has crossing lines, a change in direction produces an unbalanced thrust force. Thrust forces could cause the elbows to separate from the pipe or cause damage to the soil around them. A thrust block is typically used to provide resistance for thrust forces by transferring them to the soil in such a way that the resultant stress is less than the soil's bearing strength. In ECDIPWSN, the thrust blocks are in the form of L sections, while in AWWA the thrust blocks are truncated pyramids. According to EPCOR (2021), prior to any acceptance of testing activities for concrete thrust blocks, the concrete must be cured for a minimum of 3 days in the case of high early strength concrete or 7 days in the case of normal/sulphate-resistant concrete. Based on the WSSC (2019), 1 ft is the minimum depth of filling over the thrust block Dipra (2016) stated that a standard Proctor density of at least 90% must be achieved between the bearing surface and the undisturbed soil.

For all materials and applications of pipes, Jeyapalan & Rajah (2007) presented their thrust block design based on the fundamental principles of fluid mechanics and geotechnical engineering. The researchers concluded that, when calculating the length of the pipe with joints restrained on each end, the type of pipe material does not matter. According to the Abu Ghdaib *et al.* (2011) investigation, an anchor block for a pipeline crossing state lines can be reduced significantly in size. Using analysis of a large-diameter hydrocarbon pipeline and an anchor block at a remote launching/receiving station, the team monitored the pipeline in the field. As a result of field monitoring, the researchers concluded that the pipe anchor block system's size could be reduced. Genetic algorithms were used to optimize the bearing area of thrust blocks by Anwar *et al.* (2012). The design equation was used to calculate the bearing area, which then distributed among the width and height. Based on their findings, the height of the blocks must vary between one and two times the width of the blocks for any soil, and vice versa for hard clay. To estimate the performance of a traditional approach in ensuring economic design for Nigerian applications, a genetic algorithm was used to simulate the design of a thrust block on some Nigerian soils by Anwar *et al.* (2013). They concluded that a block's width should be between one and two times its height for optimum efficiency.

A thrust block was manually designed by Gupta & Hussain (2018) for the proposed palatable water supply line-1 in the state of Uttarakhand for the town of Berinag, part of Pithoragarh district, located in India. Anchor blocks and penstock pipes were designed by Moni *et al.* (2018) for several locations at different heads, and analyzed according to water hammer impacts. Model experiments were carried out on a buried pipe model in a model ground by Araki & Hirakawa (2019) with a constant load simulated thrust applied laterally with an increase in hydraulic gradient step by step decreasing the internal effective stress. On the ground, gabion models were arranged at different widths according to the thrust direction. Researchers found that the gabions stabilized the pipe even when the effective pressure of the surrounding ground decreased significantly, and that the width of the gabions affected their behavior in the ground. The study of thrust blocks installed in Bidhnoo Block, Kanpur District, India, was conducted on six types of poorly graded soil by Mishra & Kumar (2019). The goal of the research was to find the optimum area of a thrust block.

RESEARCH SIGNIFICANCES

This research has more than one aim. The first aim was specific to AWWA, to find the proportion between height and width of the soil contact area. Another aim for ECDIPWSN, was based on determining the proportions among the six dimensions that make up the thrust block. The third aim was to compare the two codes regarding concrete quantities and analyze how the pipe level affects concrete quantities.

ANALYSIS SECTION

In this study, two methods for designing a thrust block were considered. Figure 1 shows AWWA, while Figure 3 shows ECDIPWSN. Equations are given below that can be used to calculate AWWA's required block area:

$$A_b = h * b = S_f * T/S_b \tag{1}$$

$$T = 2PA\,\sin\left(\frac{\theta}{2}\right) \tag{2}$$

$$b = S_f * 2P * A * \sin\left(\frac{\theta}{2}\right)/(h * S_{b)} \tag{3}$$

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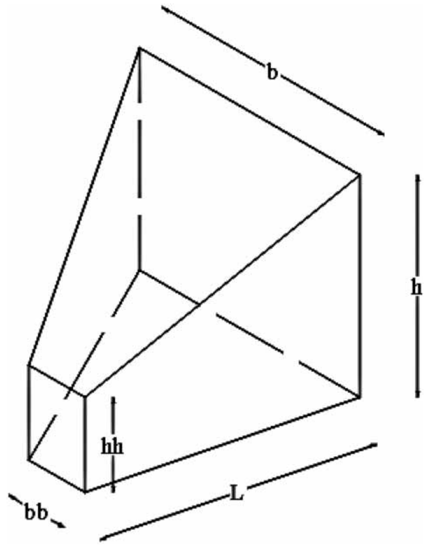

Figure 1 | Thrust block of a horizontal bend for AAWA (American Water Works Association 1999, 2004, 2008, 2009).

Mishra & Kumar (2019) presented a design of a thrust block located in sandy silt soil, with a bearing capacity of 143.6 kN/m^2, the results of this study are shown in Table 1.

By solving the design equations, one can calculate the minimum bearing area, but the issue is how to divide the area into width and height (b and h). The bearing area dimensions can be varied and give the same bearing area (Ab) but different volumes. For the optimal design, the block width should differ between one and two times the height and vice versa according to Anwar *et al.* (2013). As shown in Figure 2, we put the proportion of the (h/b) from half to two to attain the optimum volume. According to Figure 2, the optimum thrust block volume is at $h = 2b$.

Table 1 | Dimensions of the thrust block for sandy silt with bearing capacity = 143.64 kN/m^2 (Mishra & Kumar 2019)

S. no.	Diameter of pipe (m)	Thrust force (kN)	Block area (m^2)	Width (b) (m)	Height (h) (m)
1	0.40	125.6	1.31	0.85	1.535
2	0.50	196.25	2.049	1.066	1.92
3	0.60	282.6	2.95	1.28	2.304
4	0.70	384.65	4.0168	1.493	2.688
5	0.80	502.4	5.246	1.707	3.07
6	1.00	785	8.197	2.133	3.84

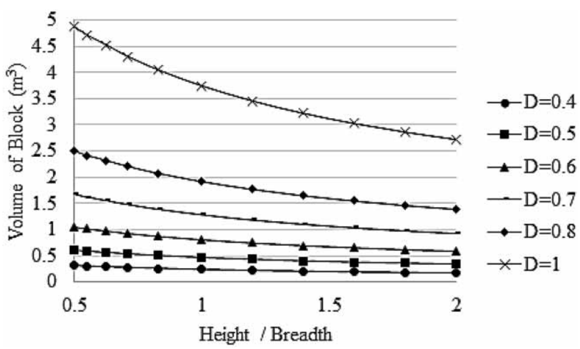

Figure 2 | Optimum volume of a thrust block.

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As shown in Table 2, there are two types of columns. The first category contains the first three columns (diameter of pipe, thrust force and block area) obtained from Mishra & Kumar (2019). Within the second category, you will find columns four and five (optimal width and height) which are based upon the proportion (h/b) in Figure 2, and the last column presents the optimal volume:

$$T = 2P*\left(\pi*\frac{d^2}{4}\right)*\sin\left(\frac{\theta}{2}\right) \tag{4}$$

$$W_1 = \left[h1*b1*\frac{C1+C3}{2}\right]*\gamma_C \tag{5}$$

$$W_2 = \left[h2*(b1+b2)*\frac{C1+C2}{2}\right]*\gamma_C \tag{6}$$

$$K_p = \ tan^2\left(45+\frac{\varphi}{2}\right) \tag{7}$$

$$e = \gamma*(h1+h2)*K_P \tag{8}$$

$$F_e = 0.5*e*(h1+h2)*C1 \tag{9}$$

$$Sf_{Overturning} = \left(\frac{Equilibrium\ Moment}{Overturning\ Moment}\right) > 1.2 \tag{10}$$

$$Sf_{Sliding} = \left(\frac{Stability\ Forces}{Sliding\ Forces}\right) > 1.2 \tag{11}$$

$$e' = \ \gamma*h1*K_p \tag{12}$$

$$F\ e' = 0.5*e'*h1 \tag{13}$$

$$M(x-x) = \left(T*\frac{d}{2}\right) - \left(Fe'*\left(\frac{h1}{3}\right)\right) \tag{14}$$

$$\sigma = M(x-x)*\frac{y}{I} \tag{15}$$

$$Sf_{Bearing\ Stress} = \left(\frac{Concrete\ stress\ in\ tension}{T}\right) > 1 \tag{16}$$

The thrust block in Figure 3 had six dimensions (b1, b2, c1, c2, h1 and h2), and the minimum dimensions of h1 and b2 was the same pipe diameter. Three main factors determine the optimum dimensions (safety factor against sliding, overturning, and minimum volume). We made two assumptions in order to determine the optimal dimensions. The first assumption is that the minimum dimension equals the diameter of the pipe. The second assumption is to change one dimension without changing the others.

Table 2 | Optimum volume of a thrust block for sandy silt with bearing capacity = 143.64 kN/m² (Mishra & Kumar 2019)

S. no.	Diameter of pipe (m)	Thrust force (kN)	Block area (m^2)	Optimum width (m)	Optimum height (m)	Optimum volume (m^3)
1	0.4	125.6	1.31	0.81	1.62	0.16
2	0.5	196.25	2.049	1.01	2.02	0.30
3	0.6	282.6	2.95	1.21	2.43	0.52
4	0.7	384.65	4.0168	1.42	2.83	0.83
5	0.8	502.4	5.246	1.62	3.24	1.24
6	1.0	785	8.197	2.02	4.05	2.43

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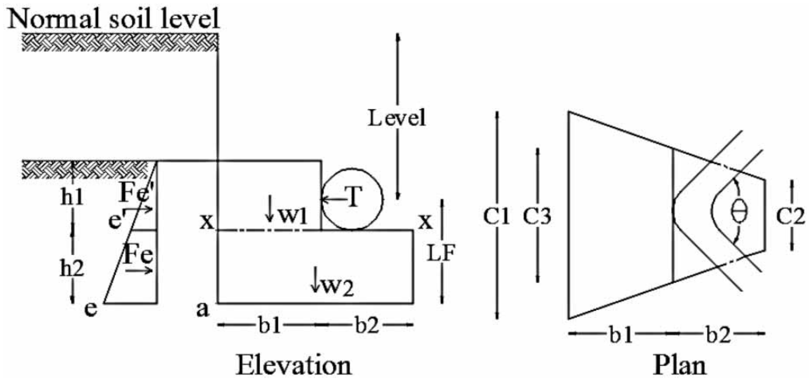

Figure 3 | Thrust block of a horizontal bend for (ECDIPWSN).

Figure 4(a) shows the impact of thrust block dimensions on the safety factor against sliding. Dimensions (b1, b2, and c2) have a small effect and can be neglected, dimension (c1) has a moderate effect, whereas dimensions (h1 and h2) have a large effect. By increasing dimension value, the gap between the effects of (b1, b2, and c2) and the effects of (h1 and h2) widened.

Figure 4(b) illustrates how thrust block dimensions affect the safety factor against overturning. Compared to dimensions (b1, b2, c1, and h2), dimension (c2) had an insignificant effect, and dimension (h1) was the most crucial in terms of determining the safety factor against overturning. The gap between the effect of (h1) and the other dimensions widened as the dimension value increased.

Figure 5 shows the effect of thrust block dimensions and their volume. Based on these measurements, dimensions (h1 and b2) provide the smallest volume, dimensions (b1 and h2) give the largest volume, while dimensions (c1 and c2) have the most average volume. In light of the data in Figures 4 and 5, it can be assumed the ratio of the dimensions is as follows:

$$h1:h2:c1:c2:b1:b2 \text{ as } 0.89:0.89:1.0:0.43:0.43:0.43$$

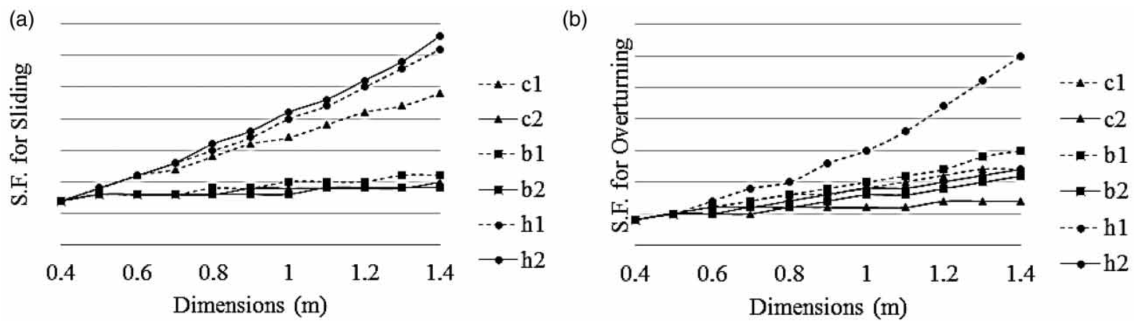

Figure 4 | Effect of dimensions on the safety factor against (a) sliding; (b) overturning.

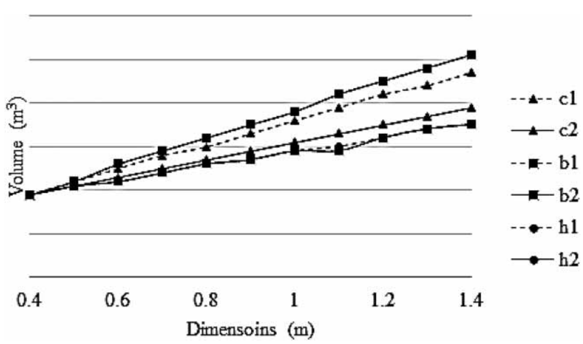

Figure 5 | Relation between thrust block dimensions and its volume.

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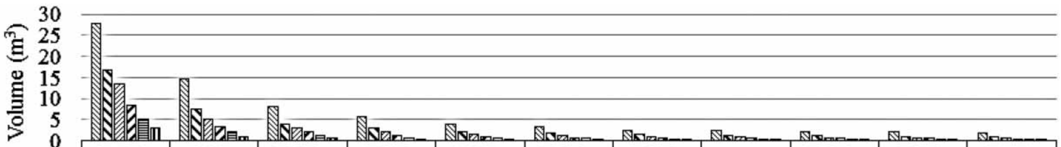

	ECD. -1m	ECD. -2m	ECD. -3m	ECD. -4m	ECD. -5m	ECD. -6m	ECD. -7m	AWWA	ECD. -8m	ECD. -9m	ECD. -10m
D=1m	27.72	14.55	8.06	5.64	3.86	3.43	2.43	2.43	2.18	2.12	1.88
D=0.8m	16.62	7.49	3.86	3.03	2.12	1.88	1.45	1.24	1.23	1.07	1.03
D=0.7m	13.4	5.09	3.03	2.12	1.45	1.23	1.03	0.83	0.75	0.75	0.61
D=0.6m	8.35	3.43	2.12	1.23	1.03	0.75	0.61	0.52	0.61	0.51	0.48
D=0.5m	5.2	2.12	1.23	0.75	0.61	0.51	0.48	0.3	0.27	0.26	0.26
D=0.4m	2.94	1.07	0.61	0.48	0.27	0.26	0.26	0.16	0.19	0.1	0.1

Level of pipe (m)

D=1m D=0.8m D=0.7m D=0.6m D=0.5m D=0.4m

Figure 6 | Relation between volume of thrust block and diameter of pipe at different levels.

We proceeded to the second step of the paper, which is the comparison between the two methods after which we determined the optimal ratio of the dimension to the other dimensions. According to the ECDIPWSN, the same data (diameter of pipe and thrust force) are analyzed in Table 2. The ECDIPWSN method takes into account the pipe level, so we examined 10 levels of pipe between -1 m and -10 m.

In Figure 6, the thrust block volume decreased as the diameter of the pipe decreased, as well as when the digging depth increased, because the soil pressure is linearly proportional to the digging depth. Additionally, the volume of the thrust block created by the AWWA method is smaller than that created by the ECDIPWSN method when the excavation depth ranged from 1 to 6 m, and they were similar at between 7 and 8 m, but larger at more than 8 m.

SUMMARY AND CONCLUSIONS

Thrust blocks are among the most essential underground structures. Any pipe network project should include thrust blocks, especially at bends, whether horizontal or vertical. Thrust blocks are designed to resist thrust forces. Many codes refer to the thrust block as AWWA and ECDIPWSN. In this study, we aimed to find the minimum cost of the thrust block by finding the minimum volume of it.

Our research had three objectives; the first was to determine the ratio between area dimensions of a thrust block designed using the (AWWA) method, which revealed that $h = 2b$. The second objective was to obtain the ratios among the dimensions of the thrust block designed by the ECDIPWSN method, which concluded that h1: h2: c1: c2: b1: b2 as 0.89:0.89:1.0:0.43:0.43:0.43. From a point of view of optimal volume, a comparison between the two methods is the third objective. Results of the study discovered the volume of the thrust block created by the AWWA method was smaller than the volume created by the ECDIPWSN method when excavation depth was low but was larger when excavation depth was large.

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DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

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