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Comparative Study between the Behavior of the Concrete Thrust Block and the Restraint Joint in a Water Distribution System; Review

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ABSTRACT

Thrust blocks and restraint joints are the two most popular methods of counteracting the thrust force that generated at pipe fittings (bends, Tee, wye, reducers, dead ends, etc...). Both systems perform the same function, which is to prevent the joints from separating from the pipes. The aim of the study is to review previous studies and scientific theories related to the study and design of thrust blocks and restraint joints to study the behavior of both systems under thrust force and to study the factors and variables that affect the behavior of these systems. The behavior of both systems must be studied because they cannot be abandoned, as each system has conditions whose use is more feasible, scientific, and economical. The use of thrust blocks is usually more economical. Still, in many cases, its use is not appropriate, as it is required to wait for the result of the compressive strength test of the concrete. It is required to close the pipe trench as soon as possible; thus, this affects the safety of workers. Or there are future excavation works that may harm the stability of the block, and when the pipe diameter is large, we need a large amount of concrete which affects the economic aspect of the work. For this, the alternative system (restraint joint) must be studied. The main result of the research is that each system provides the opposite force against thrust force with a different mechanism from the other depending on the properties of the soil.

Keywords: thrust force, pipe fitting, thrust block, restraint joints, water distribution system.

دراسة مقارنة بين سلوك كتلة الدفع الخرسانية ومفاصل التقييد في نظام توزيع المياه ; عرض

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الخلاصة

تعد كتل الدفع ومفاصل التقييد أكثر الطريقتين شيوعاً لمواجهة قوة الدفع الناتجة عند تراكيب الأنابيب (الانحناءات، Tee، wye، المخفضات، النهاية، إلخ...). يؤدي كلا النظامين نفس الوظيفة، وهي منع المفاصل من الانفصال عن الأنابيب. الهدف من

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الدراسة هو مراجعة الدراسات السابقة، والنظريات العلمية المتعلقة بدراسة وتصميم كتل الدفع والمفاصل المقيدة، لدراسة سلوك كلا النظامين تحت قوة الدفع، ودراسة العوامل والمتغيرات التي تؤثر على سلوك هذه الأنظمة. يجب دراسة سلوك كلا النظامين لأنه لا يمكن التخلي عنهما، حيث أن لكل نظام ظروف يكون استخدامها أكثر جدوى وعلمية واقتصادية. عادة ما يكون استخدام كتل الدفع أكثر اقتصادا، ولكن في كثير من الحالات لا يكون استخدامها مناسباً، حيث يلزم انتظار نتيجة اختبار مقاومة الانضغاط للخرسانة، ويلزم إغلاق خندق الأنابيب بأسرع ما يمكن وبالتالي هذا يؤثر على سلامة العمل، وكذلك عندما تكون هنالك أعمال حفر مستقبلية قد تؤثر على استقرار كتل الدفع، وعندما يكون قطر الأنابيب كبيراً، نحتاج إلى كمية كبيرة من الخرسانة التي تؤثر على الجانب الاقتصادي من العمل لهذا يجب دراسة النظام البديل (مفاصل التقييد). النتيجة الأساسية للبحث هي ان كل نظام يوفر القوة المعاكسة لقوة الدفع باليه مختلفه عن الاخر اعتمادا على خواص التربه.

الكلمات الرئيسية: قوة الدفع، تراكيب الانابيب، كتلة الدفع، مفاصل التقييد، شبكة توزيع المياه

1. INTRODUCTION

Pipes are the most common way to transfer fluids between different areas. In many cases and according to the planning of the water distribution network, which needs to change the path of the pipes or add new branches or change the diameters, this change will produce an unbalanced force, so the thrust force that is concentrated in the zone of the configurations of pipe and causes damage them that may lead to the separation of the configurations from the pipes (DIPRA, 2006). The two support systems (thrust block system and joint restraint system) are designed to provide an opposite force capable of reversing the thrust force. The main goal in the design of the block is to find the bearing area with the soil, but there are infinite values of width and height that give the same bearing area. Finding the best dimensions that provide the most economical design needs a tool to simulate blocks design (Anwar et al., 2012).

(Anwar et al., 2012) used a genetic algorithm and concluded that a block's width/height ratio that gives the minimum volume of concrete, which the design of the concrete thrust blocks does not depend on the pipe wall material or pipe application, but depends on the principles of fluid and soil mechanics (Jeyapalan and Rajah, 2007). Washington Suburban Sanitary Commission (WSSC, 2008) stated that the concrete could be unreinforced if the movement of the joint is in a direct direction on the block so that the thrust block is under a pure compression force. In the case of vertical bends only, the thrust block must place under the joint and be attached to the joint with a steel tie to resist the thrust force (Halifax Regional Water Commission, 2010).

According to (EPCOR, 2021), the first step after pouring the concrete and before any other test of the block, the concrete must be cured for a period of three days after pouring in the case of high-strength concrete, or seven days in ordinary concrete. The problem with the design of restraint joints is basically to find the length of pipe to be restrained on both sides of the joint and which provides the force opposite thrust force (Jeyapalan and Rajah, 2007). The joint restraint system can be of many forms, such as push-on or mechanical joint (DIPRA, 2016). Apart from these two types, there is another type, which is the one that grips or locks the joint together to prevent axial movement (United States Pipe and Foundry Company U.S.P.I.P.E, 2006). When this restraint system is used without the use of supporting thrust blocks, it is necessary to restrict both sides of the joint of the pipe. The number of connections and the length of the pipe to be restricted on both sides of the joint is calculated based on several variables (Shah Rahman and Michele Diamond, 2006).

2. HYDRAULIC ANALYSIS



2.1 Water Flow

The first aspect of this research precedes the process of selecting a pipe joint supporting system, which is the analysis of the water flow in the pipe and the calculation of the maximum force that will exert on the pipe configurations. There are several ways to describe the flow of liquid in the pipe. The first method is the differential method, which depends on differential quantities of fluid in the calculations. Still, the solution of the differential equations resulting from this method requires numerical methods or computer software. (Patankar et al., 2000) presented Eulerian-Lagrangian numerical simulation (LNS) scheme to simulate the particulate flows. While the other method is the practical and realistic tests that can be economically costly. (Davies and White, 1928) made an experimental study of the flow of water inside a rectangular pipe. Another experimental study conducted by (V.Bagarello et al., 1995) showed the resistance to flow inside a small plastic pipe. When the fluid reaches the joint area, momentum forces are formed. The momentum equation is used in order to calculate the resultant thrust force on the joint (Bansal, 1983). Sections 1, 2 before and after pipe bend as shown in Fig.1.

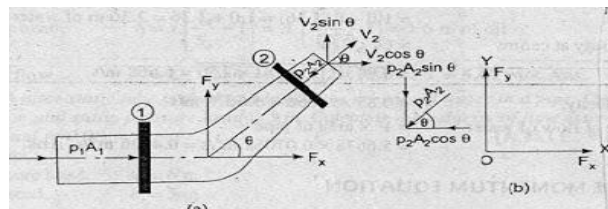


Figure1. Forces on pipe bend (Dr.R.K Bansal, 1983).

Where:

v1, v2: velocities of water flow at sections 1, 2

p1, p2: pressures intensity at sections 1, 2

A1, A2: cross-section areas of pipe at sections 1, 2

Fx, Fy: Components of the forces on the bend in x- and y- directions due to the flowing of water.

2.2 Water Hammering

It is the phenomenon of an increase in the internal pressure of the fluid inside the pipe as a result of the sudden or slow closure of the fluid source. This phenomenon must be considered in water distribution networks because it causes an increase in pressure and momentum forces at the fitting. (Azoury et al., 1986) made a study on the effect of valve closing schedule using the computerized method. This phenomenon is affected by the properties of the pipe material, such as the modulus of elasticity, Poisson's ratio, and others where (Kandil et al., 2020) conducted a study by the MATLAB program to study these variables. A study was conducted for completely restricted joints, but this phenomenon was taken into account, and it was noted that there was a slight movement in the joint as a result of the increase in pressure (Wood and Chao, 1971).

3. SOIL CHARACTERISTICS



As known, the thrust block transfers the thrust force to the surrounding soil (**Shah Rahman and Michele Diamond, 2006**). The soil behind and under the thrust block must be capable of facing the thrust force as well as the self-weight of the block and soil above it, respectively (**Thorley and Atkinson, 1994**). The Soil resistance components on a concrete thrust block are shown in **Fig.2**

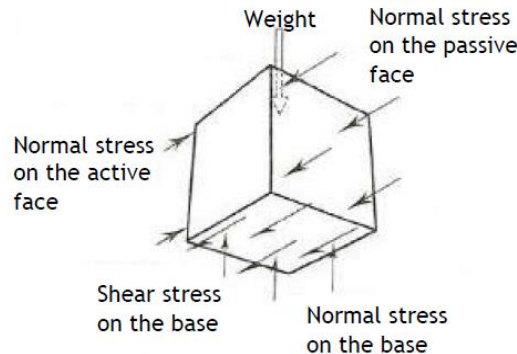


Figure 2. Soil resistance components on a concrete thrust block (**Thorley and Atkinson, 1994**).

Since the governing factor in determining the size of the block is the bearing area between the block and the soil, the passive soil lateral pressure is the most important property in the soil that enters into the design of the thrust blocks. (**Rankin, 1857**) was the first to develop a theory for calculating lateral pressure based on vertical pressure by Eq. (1) and (2):

$$P_a: k_a \cdot W \tag{1}$$

$$P_p: K_p \cdot W \tag{2}$$

Where:

P_a : Lateral active earth pressure.

K_a : Rankin's active earth pressure coefficient

P_p : Lateral passive earth pressure.

K_p : Rankin's passive earth pressure coefficient

W : vertical pressure

$$K_a = \frac{1 - \sin\phi}{1 + \sin\phi}, \quad k_p = \frac{1 + \sin\phi}{1 - \sin\phi}$$

where:

ϕ : angle of internal friction of soil

But Rankin did not deal with soils with cohesion (**Bell, 1915**) developed his analysis theory to calculate the role of cohesion at passive pressure because most soils have internal cohesion, even if it is slight. Bell relations are as follows in Eq. (3) and (4):

$$P_a: k_a \cdot W - 2c\sqrt{K_a} \tag{3}$$

$$P_p: K_p \cdot W + 2c\sqrt{K_p} \tag{4}$$

Where:

c : soil cohesion

Another factor affecting the behavior of restraint systems, especially the restraint joint system, is the condition of the trench, especially the trench bed. It is difficult to understand and know the

effect of the type of bottom of the trench on the support of the pipe joints, 240 separate real tests were conducted in order to clearly know the effect of the bedding factor (**WATER INDUSTRY INFORMATION and GUIDANCE NOTE, 1988**). Each organization or specification deals with the interaction between the pipe and trench bed separately from the other. Some of them enter it explicitly, such as the (**British Code**) and some do not explicitly, such as (**Dipra, 2016**). (**American Water Work Association ANSI/AWWA C151/A21.51-09**) identify five types of pipe bedding as shown below in **Fig.3**:

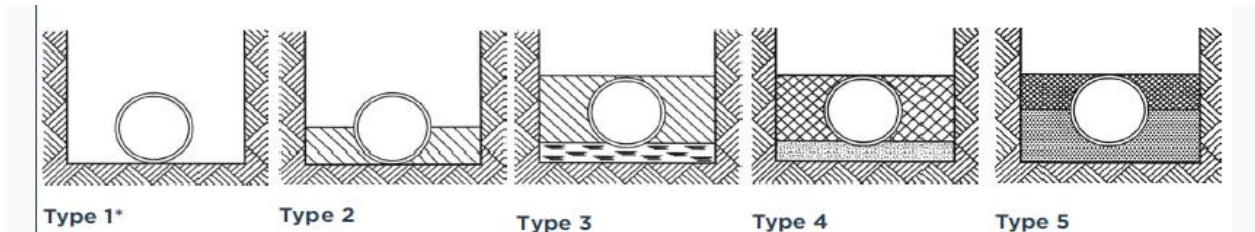


Figure3. Laying condition (**ANSI/AWWA C151/A21.51-09**).

Details of the above types can be reviewed in the specification.

The addition of pipe bedding to pipe strength ranges from 10% to 120%, depending on the type of bedding (**British Code**). (**Chapman et al., 2017**) conducted a study to find out the effect of bedding type on the resistance of pipes and compared the results with the British Standard and found that the British bedding factors are very conservative and uneconomical. Another important factor in designing restraint systems is the vertical load above the pipe, and because the pipe is circular, calculating the load affecting it is not easy.

(**Marston and Anderson, 1913**) were first to present a theory for calculating the vertical load above the pipe. (**Marston and Anderson, 1913**) stated that the vertical load on pipe given by Eq. (5):

$$W_e = C_c \gamma D^2 \tag{5}$$

Where:

W_e : vertical earth load

C_c : Load factor

γ : Density of the

D : the outer diameter of the pipe

Marston differs from other researchers in the value of C_c; in the “GB50332-2002, structural design code for pipelines of water supply and wastewater engineering,” the C_c value is given by Eq. (6) (**Liu and Yang, 2001**).

$$C_c: 1.4 \frac{H}{D} \tag{6}$$

Where:

H: vertical distance from the top of the pipe to the ground surface

While in “USAS A21.1, USA Standard for Thickness Design of Cast Iron Pipe, Thickness Determination for Pipe on Piers or Piling Above Ground or Underground,” C_c is given by Eq. (7) (**Matyas and Davis, 1983**).

$$C_c = 1.961 \frac{H}{D} - 0.934 \tag{7}$$

(Spangular, 1941) Suppose another model is similar to the Marston model, where it is assumed that the vertical load is uniform over the width of the pipe. Still, the lateral bearing resistance is in the shape of a parabola with a range equal to 100 degrees (Tian et al., 2014). Spangular model shown in Fig.4 below:

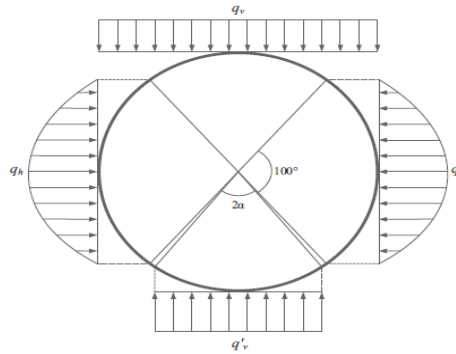


Figure 4. Spangular Model (Young Tian et al., 2014).

Countries' standards differ in calculating the value of the vertical load on the pipe, but in general, most countries depend on Marston and Spangular theory (Tian, 1989).

4. STRUCTURAL DESIGN

4.1 Thrust Block System

As mentioned, the main objective of the thrust block design is to find the bearing area between the soil and the block to transfer the thrust load to the surrounding soil safely. The thrust blocks are divided according to their structural behavior into two types; bearing thrust blocks and gravity thrust blocks (DIPRA, 2016). The thrust blocks that transfer the load to the lateral soil are classified as bearing thrust blocks, while those that support vertical bends are classified as gravity blocks (Jeyapalan and Rajah, 2007). In the bearing blocks, the goal is to find the best ratio between width and height that provides the least volume of concrete. Therefore, most specifications specify the best shape of blocks. For example, the shape of the design of the thrust blocks differs from one code to another, as in ECDIPWSN, the block is an L shape, while in AWWA, the shape is hierarchical (Osama S. Hussien, 2021). According to (Dipra, 2016), block width should equal one to two times the height. (Boston Water and Sewer Commission, 2012) states that, the height of the area that contact with a pipe is usually equal to the outer diameter of the pipe, while its width follows the diameter of the pipe and the type and angle of fitting. For the gravity block, the main goal is to find the volume of concrete capable of providing a force that can counter the vertical component of the thrust force (Jeyapalan and Rajah, 2007) according to Eq.(8) :

$$V = \frac{Sf T}{\gamma} \tag{8}$$

V: Volume of concrete

Sf: Safety factor

T: Thrust force

γ : Density of concrete

while the horizontal component must be resisted by the lateral soil (Dipra, 2016).

There are recommendations for using tie rods for vertical bends (Halifax Regional Water Commission, 2010). The minimum compressive strength at the age of 28 days for the thrust blocks is 20 Mpa (ABDULKADIR, 2013).

4.2 Restraint Joint System

As mentioned, the main factor in the design of thrust blocks is to find the contact area between the soil and the block; similarly, the problem of designing the joint restraint system is to provide a force near the pipe joint that is generated between the soil and the pipe against the thrust force. The main objective in designing this restraint system is to find the minimum length of pipe capable with the soil to provide a force opposite the thrust force without exceeding the soil capacity (U.S, Pipe, 2006).

This opposite force comes from two sources, the first source is the friction force between the soil and the pipe, and the second is the passive bearing between the soil and the pipe (Ebaa Iron Connection, 1995).

The interaction between soil and pipe is illustrated in Fig.5 below:

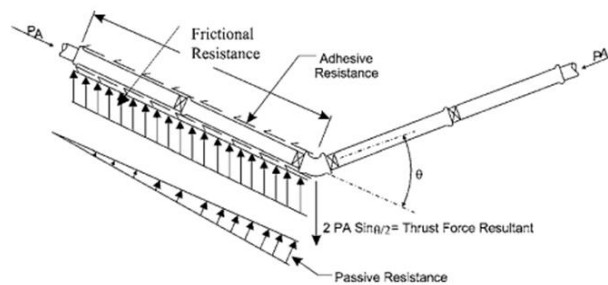


Figure 5. Pipe soil interaction (Jeyapalan et al., 2007).

The passive bearing resistance is noted to be the highest possible in the joint and decreases a movement away. This theory follows the fact that the highest reaction of the soil is at the point where the highest deformation occurs (at the joint) and decreases as the deformation decreases until it reaches a value of zero at a distance equal to the length of restriction where the thrust force has no effect (DIPRA, 2016). By equilibrium, we can get the length that must be restricted since the sum of the forces in the direction of the **y axis** is equal to the thrust force.

Since this interaction between the soil and the pipe is complex, several studies have been conducted to simulate this interaction, such as the Experimental and Numerical Analysis of Soil–Pipe interaction conducted by (Calveti et al., 2004). So, the use of this system depends on the properties of the soil and on the internal forces of the soil, this system cannot be used for pipes above the surface of the ground, and other means of support must be provided (PHCP PROS, 2018).

5. DISCUSSION

The two systems perform the same function, but each has its own mechanism to confront a thrust force. Each of the two systems is effective, appropriate, and practical under certain conditions, so a feasibility study must be carefully studied to choose the appropriate restriction system. The variables that enter into the design of both systems must also be studied, as they constitute the main factor in the design.



The relationship between fluid mechanics (formation of the thrust force and its effect on the configurations), soil mechanics (knowledge of the type of soil in which the pipe is buried), and structural design (designing the selected restraint system) represents an intertwined and complex process that depends on each other. Therefore, several tools are employed to study this interrelationship between the three aspects Such as the finite element method, MATLAB, and others.

6. CONCLUSIONS

The most important points deduced from the study of previous studies and theories can be summarized as follows:

1. Water networks should not be designed based on the nominal pressure only, but other phenomena such as water hammering should be taken into consideration because of their great influence on the selection of the type of restriction system.
2. Both systems are highly dependent on soil type, but the self-anchoring system depends more on most soil properties because the resistive force to the thrust force is mainly caused by the interaction between the soil and the pipe.
3. The trench bed represents a key factor in the amount of bearing strength in the joint restraint system, so it is more effective in this system than in the thrust block system.
4. As a structural behavior, the main force in the thrust block system results from the passive lateral resistance of the soil, while in the joint restraint system, it results from the friction between the soil and the pipe and the normal passive resistance of the soil.
5. Since the main factor in the design of the thrust blocks is to use the minimum amount of concrete as possible, the best ratio between the height and width of the block must be chosen in order to reduce the size to the least possible.
6. The thrust block system is not suitable in weak soils where it needs a large contact area between the soil and the concrete, so it is better to rely on the joint restraint system.

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