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TRENCH BREAKER IN DESIGN, CONSTRUCTION AND PIPELINE INTEGRITY – STATE OF ART

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ABSTRACT

Trench breakers play a critical role not only during pipeline construction but also throughout the operational life of the pipeline by helping to maintain its integrity. These structures are installed to support and stabilize backfill material within the trench, particularly in steep slope areas, where they also serve to protect the pipeline from geotechnical hazards. The stability of sloped terrain is closely tied to both the presence of such hazards and the ongoing integrity of the pipeline.

Various trench breaker techniques exist, each with its own advantages, limitations, and unique features. The proper selection, design, sizing, and construction of trench breakers are essential to preventing failures—whether during construction or later in service.

This paper provides a summary of current trench breaker techniques and outlines key considerations for their design and construction in pipeline projects. It also examines common root causes of failure and discusses the potential impact on pipeline integrity from a threat management perspective. A case study is included to emphasize the importance of proper design and construction practices.

There is a clear need to update existing standards and develop more accurate theoretical models to reduce dependence on empirical approaches. This paper identifies areas for future research and suggests pathways for developing improved trench breaker technologies.

NOMENCLATURE

a	slope inclination
b	angle of backfill
d’	internal angle of friction between fill and wall
Θ	angle of back face of wall
F’	angle of failure plane
K	earth pressure

1. INTRODUCTION

Trench breakers are structural elements used in pipeline construction to prevent the migration of backfill material and to control water flow within the trench. These structures are particularly vital on sloped terrain, where gravitational forces can trigger soil displacement, erosion, or pipeline exposure. Despite their importance, trench breakers are often designed using highly empirical methods that may not fully account for site-specific conditions.

A trench breaker functions as a retaining wall within the trench, designed to stabilize backfill soil after pipeline installation. Its primary purpose is to minimize and control erosion along the trench slope. When a pipeline is installed on a hill, gravity and water movement tend to displace the uncompacted backfill material downhill, affecting the pipeline's stability. The trench breaker acts as a physical barrier that retains soil and filters water. Typical trench breaker configurations are shown in Figures 1 and 2.

The design and construction of trench breakers present several challenges. Empirical methods often cannot be standardized due to the unique conditions of each installation site. Effective trench breaker design should consider appropriate engineering theories, soil properties, and water management conditions to minimize the risk of failure.

In addition to design challenges, construction techniques and procedures play a critical role in the long-term functionality of trench breakers. These structures also contribute to pipeline integrity, as soil and weather conditions can impact their performance, as well as the stability of the right-of-way and the surrounding slope where the pipeline is located.

2. TRENCH BREAKERS GENERAL CONSIDERATIONS

2.1 Functionality

The main function of a trench breaker is to reduce the water velocity, filtering fine material, and stabilizing the backfill material in place.

The configuration of the trench breaker will depend on the size and configuration of the trench where the pipeline will be placed. The trench breaker should be installed surrounding the pipeline and sealing the trench. A typical trench cross section with a pipeline and trench breaker installed is presented in Figure 1.

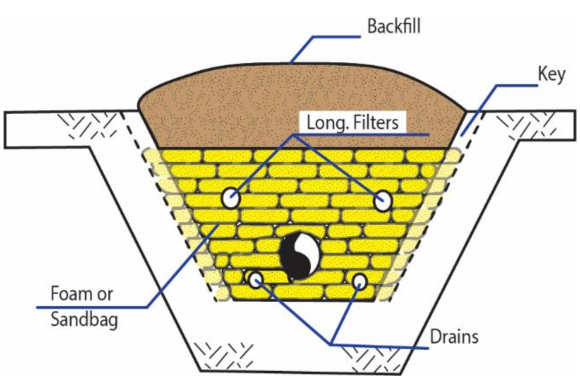

FIGURE 1: TYPICAL TRENCH CROSS SECTION WITH PIPELINE AND TRENCH BREAKER INSTALLATION. KEYS ON THE TRENCH'S WALL HELP TO LOCK THE TRENCH BREAKER.

2.2 Configuration

The trench breaker needs to cover across the trench and completely seals its section to prevent washout backfill material through it. The trench breaker must work as an internal retaining wall with the capacity to support the loads produced by the backfill material, water and other loads imposed by other variables acting against the wall that are specific for each site.

The forces applied to trench breakers have to be considered as a retaining wall structure. In general, they have a typical pyramidal cross section (the wider part is on the base or heal) shown in Figure 2. The base dimension will depend on the trench height. Depending on the slope inclination, trench breakers can be directly erected on the trench bottom for low slopes; for medium and high slopes the bottom of the trench should be level using an embankment or soil berm (Fig. 2); and for high slopes a foundation structure should be used.

2.3 Water management

To avoid water accumulation within the trench, some designs use permeable materials that allow the passage of water. In some other cases when the material does not allow so, or the amount of water is higher, drainpipes are installed within the breaker (Fig. 1). Finally, when the amount of water to evacuate out the trench is quite high, longitudinal filters along the slope are installed, passing through the trench breakers.

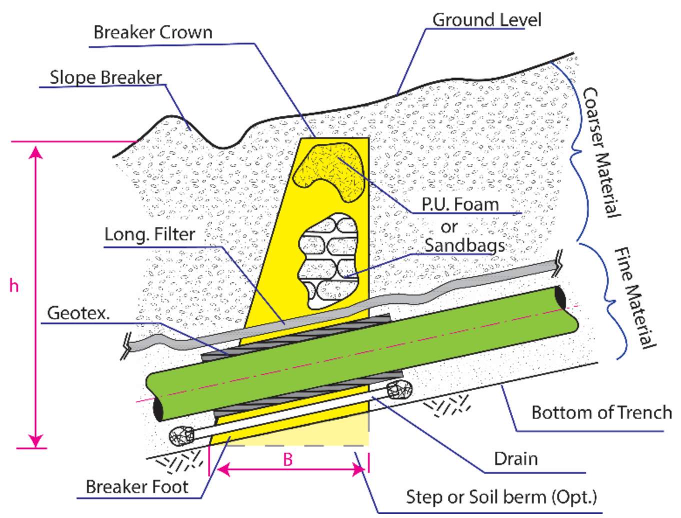

FIGURE 2: TYPICAL TRENCH BREAKER CONFIGURATION – LATERAL VIEW. FOR HIGH INCLINATION, THE BOTTOM OF THE TRENCH IS LEVEL, FORMING A SOIL BERM (DOT LINE).

2.4 Shape/Geometry

In general, trench breakers have different geometric configurations, which depend on trench size, soil, loads and other design and construction considerations. The following shapes are commonly used for pipeline construction:

- **Arch Form :** sometimes an arch form facing the upslope direction is used, this geometry offers a better redistribution of the stresses over the structure. Thus, the breaker can work in a more efficient way (mechanic wise), transferring most of the load on the trench wall. This configuration is shown in Figure 3

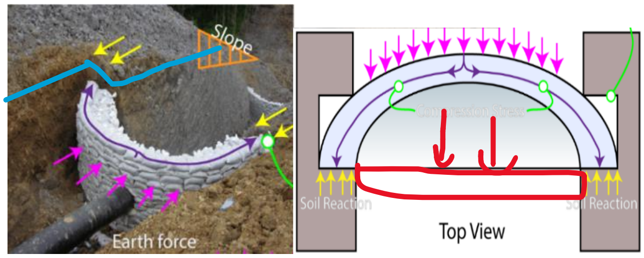

FIGURE 3: ARCH FORM. LATERAL FORCE IS TRANSFERRED TO TRENCH'S WALL.

- **Trench wall Key:** The key is a notch with reticular cross section that is made on the trench wall. The breaker corners lay on the keys, helping to transfer the load to the ground. (Fig. 3).

- **Pyramidal shape:** The load applied on the breaker varies with the depth, being minimum on the surface and maximum on the breaker heal. As a result, the breaker cross section varies too, being thicker on the base and thinner on the top.

2.5 Trench Breaker Materials

There are different materials and techniques to build breakers; the most extensively used ones are: foam polyurethane, sandbags or soil berm, stone gabions, and reinforced concrete or grout – based breakers.

2.5.1 Foam

A reactive chemical (polyurethane) is sprayed over the pipe to form a transversal wall. When applied, the product forms a flexible foam that copies the pipe and trench from. When the polymer cures, it increases hardness, forming a monolithic wall. Its application is limited to low inclination slopes. It is associated with the negative impact on pipe cathodic protection [1].

2.5.2 Sandbags

Sandbags are typically filled with sand and stacked in a staggered or interlocking pattern, creating a dense, stable wall**.** The material of the sandbags can also filter out some of the sediment and debris carried by water. Sandbags are often used within the trench to stabilize areas prone to erosion. Properly placed sandbags can help maintain the roundness of the pipeline and prevent ovality, especially in thinner-walled pipes. Its mechanical resistance is based on the friction among sandbags; thus it is usually higher than that of foam trench breakers.

2.5.3 Gabions

Gabion walls within the trench are installed as a retaining wall, erosion control and slope stabilization, when the pipeline is installed in steep slope and /or when the soil material is rock. The gabion wall is permeable, flexible and adaptable to different terrains. This structure requires proper water management. They present good mechanical resistance, but construction time is higher with respect to sandbags or foam.

2.5.4 Concrete arch

Steel reinforced concrete structure is used in extreme cases, in which high loads are expected.

They have excellent mechanical resistance, but they are associated with long construction time and complex logistic.

FIGURE 4: TRENCH BREAKER MATERIALS. FOAM (a), SANDBAG (b), AND GABIONS (c).

3. DESIGN CONSIDERATIONS

Most of the pipeline construction projects establish construction specifications for trench breakers installation, but standard design methodologies do not exist nowadays to design these structures. As trench breakers work as a retaining wall within the trench, the theory of earth pressure provides the closest method for calculating and assessing the mechanical behavior of these structures.

There are many theories and methods to calculate a retaining wall. However, it is not the objective of the present paper to address the state of the art in terms of retaining wall calculations. A summary of the theories and methodologies applicable to this matter have been extensively presented by other authors such as Pantelidis [2], and Trujillo [3]. Although each theory or method has its own approach, it can be established certain assumptions and conditions common to most of them.

Additionally, project engineering design relies on existing best practices, rules of thumb or supplier specific design guidelines. These well-known methodologies were assessed as part of the preparation of this paper and the main findings will be summarized in the following sections.

3.1 Earth Pressure

The analysis of retaining walls started centuries ago. Cuolomb in 1776 [4] and lately Rankine in 1857 [5] have

addressed the case with such a simple solution that nowadays those theories are still in use.
The Coulomb theory for lateral earth pressure is expressed as follow.

$$K_a = \frac{cos^2(\emptyset' - \theta)}{cos^2\theta \cdot \cos(\delta' + \theta) \cdot \left[1 + \sqrt{\frac{\sin(\delta' + \emptyset') \cdot \sin(\emptyset' - \alpha)}{\cos(\delta' + \theta) \cdot \cos(\theta - \alpha)}}\right]^2} \quad (1)$$

It assumes that there is a failure plane from where soil is going to start moving (Fig. 5). This plane is at a certain angle (ø´). The wall induces a reaction force (Pa) required for equilibrium. This reaction force is an angle d. Coulomb theory assumptions

1. Soil is isotropic and homogeneous and has internal friction (c = 0).
2. The rupture surface is a plane surface. The backfill surface is planar (it may slope but it is not irregularly shaped).
3. The friction resistance is distributed uniformly along the rupture surface and the soil-to soil friction coefficient τ= tan F.
4. The failure wedge is a rigid body undergoing translation.
5. There is wall friction, i.e., as the failure wedge moves with respect to the back face of the wall a friction force develops between soil and wall. This friction angle is usually termed δ.
6. Failure is a plane strain problem—that is, consider a unit interior slice from an infinitely long wall.

This theory from the 18th century has evolved along the years, increasing the precision and complexity, however the essential assumptions remain.

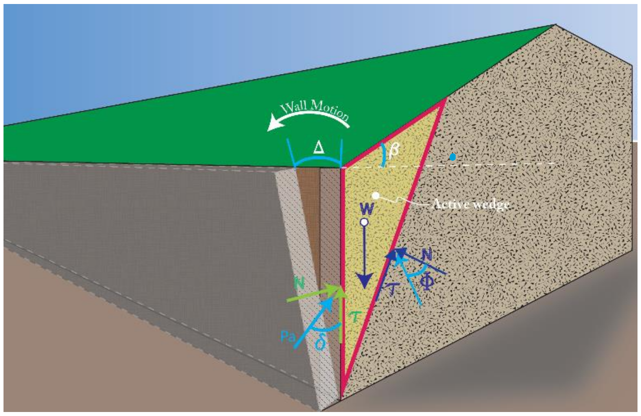

FIGURE 5: COULOMB EARTH PRESSURE METHOD. A FAILURE PLAN LAYS ON AN ANGLE F. THE SOIL OVER THE FAILURE PLANE MOVES TOWARD THE WALL.

Many current specifications and codes (i.e. Wisconsin DOT bridge code [6]) still refer to Coulomb Method as the main methodologies to design retaining walls. Most of these theories are based on the following assumptions: 1). The retaining wall is an infinitive plane; 2). the whole arrangement is in flat position, and 3). Consider surrounding soil as dry material.

For pipeline construction on steep slopes, where the trench breakers are mostly required, these assumptions vary significantly in the following main aspects: 1). Trench breakers are not installed in a flat position; 2). Trench breakers have a certain width given by the trench geometry to properly work; 3). Sometimes trench breakers rest on keys made on each trench side; 4). the backfill material is usually not compacted and 5). Any breaker must be designed and installed to work in conjunction with a drainage system designed to manage superficial and internal water streams; then, in this case saturation conditions are not always dry.

3.2 Slope

In a slope, the thrust that uncompacted soil produces over the wall is a function of the slope inclination. The steeper the hill is, the major the thrust will be. The inclination is usually measured in degrees. It can also be expressed as the vertical-horizontal component ratio. Thus, for slopes greater than 30° (86%), high resistance trench breakers such as reinforced concrete, gabions (or a combination of them) are used. Intermediate slopes (15°≤ a < 30°) allow for the use of sandbags, while low inclination hills can use either sandbags or polyurethane.

3.3 Dimensions

Some trench breaker types are internal, so they are not exposed. This is the case for trench breakers installed in low and intermediate slopes. In this case, the breakers are erected up to 12 inches below ground level (approx.). Then, they are hidden by the backfill material. However, when the slope is steeper the size/weight of the breaker increases. Consequently, the top part of the trench breaker rises out of ground level. In extreme cases, the backfill material is almost replaced completely by breakers (gabions). Thus, the section becomes almost a step pyramid.
In the case of embedded breakers, the depth of the breaker base (heal) is related to its height. Typically, the heal should be 50% of the breaker height (approx.) and the depth of the top part should be 20% of the height, forming a pyramidal shape between the base and the top part.

Maximum height and width of a trench breaker are limited by its own resistance. Typically, spray polyurethane foam trench breakers are limited to 3-3.5 meters in height and 4 meters wide. Sandbags breakers can typically reach up to 4-4.5 meters in height and 5 meters wide. Beyond those dimensions, gabions or steel reinforced concrete arches are used instead.

3.4 Foundation

In the trench cross section, the breaker must be placed below the pipe in such a way that the whole trench cross section (including the pipe) is sealed by the breaker heal.
Usually, the place where the breaker is going to be erected must be rectified and leveled (Fig. 2). In this way, the ground reaction

force is vertical. This is essential for trench breakers that rely on friction (i.e sandbags) and mass inertial (i.e reinforced concrete). That helps increase the trench breaker resistance.
Trench breakers must be installed on stable terrain capable to stand weight and lateral force. If by chance, that is not the case, then steel reinforced concrete foundations must be installed to assure trench breaker stability. In some particular cases, the ground must be rectified with positive angle (Fig. 6). When soil does not stand the load, strong foundations must be used, and in unstable terrain or when earth pressure is very high, pilots are used.

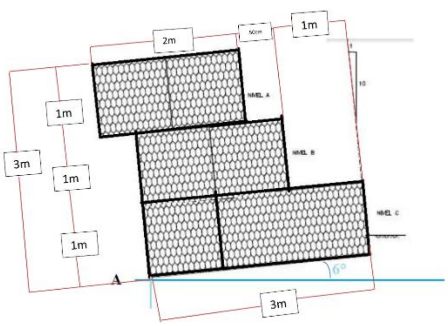

FIGURE 6: LARGE TRENCH BREAKER. FOUNDATION WITH POSITIVE ANGLE.

3.5 Trench breakers distance calculation

The theory can help verify if a given trench breaker can stand the earth pressure, but it does not tell us about the distance between breakers. A literature review has been carried out of the main information sources such as INGAA[AI1], the association of geotechnical engineers, but no work addressing this matter was found.
Following, the most widely used empirical rules to calculate distance between breakers are presented. They bring to certain slope inclination (usually used for polyurethane breakers).

The spacing between trench breakers is empirical and little technical background can be found. For example, one rule used to determine the spacing states that the top of the down slope trench breaker must be aligned with the foot of the neighbors one (Fig. 7 horizontal red dot line).
There is no standard or recognized methodology to apply. Pipeline construction codes and related standards address trench breaker spacing calculation based on workmanship. Different operator's standards or recommended practice have different spacing, but what is common to all the spacing is related to slope inclination only [7,8,9,10,11,12]. There is no relationship with important variables such soil type, rain level, etc.

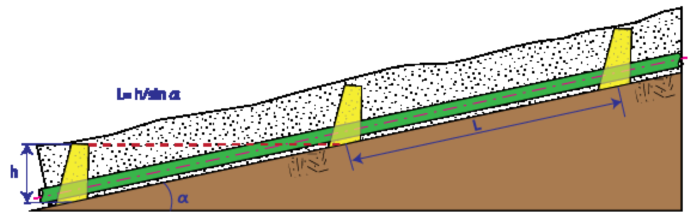

FIGURE 7: TRENCH BREAKER SPACING. TOP PART IS AT THE SAME LEVEL OF THE NEIGHBOR'S BASE (RED DOT LINE).

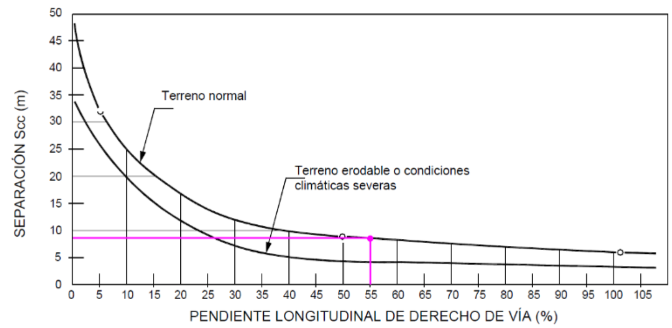

FIGURE 8: TRENCH BREAKER SPACING VS. SLOPE % CHART [8].

4. Pipeline Construction Considerations

Typical pipeline construction procedure includes:

- Open the trench
- Prepare the pipe bed
- Installing the pipe in the trench
- Back fill the trench with uncompacted material.
- Restoration of the Right of way

The backfilling of the trench uses in general native material obtained during trenching, the backfill is placed mechanically without any compaction. Through this process, native soil loses compaction and cohesion. Consequently, once the material is placed back in the trench it tends to move downhill due to gravity.

Additionally, this effect is increased by the presence of water. Rain introduces water inside the trench causing two main effects: 1) increasing soil density and adding weight/load and 2) moving fine material downhill; causing erosion within the trench.

The backfill material is usually not compacted and deposited in the trench which is inclined position (Figure 3). This non-consolidated material is surrounded by consolidated native material. Consequently, gravity plays a different role in this case. There will be a driving force pushing the backfill material against the wall (trench breaker). Depending on the slope inclination, these forces will become more important.

In theory, any trench breaker must be designed and installed to work in conjunction with a drainage system designed to manage superficial and internal water streams. The main objective of the drainage system is to control water erosion and avoid water accumulation in the trench. However, in many cases for omission, undersized engineering, or simply bad practice, water is not completely evacuated out the trench and the wall neighbor areas, (in contact with the trench breaker). Thus, the terrain becomes saturated. [AI3]

Normal practice during back filling is to use fine material for the first layer of backfilling. This layer usually extends up to covering the whole pipe. The fine material is usually obtained by screening the native material removed previously during trenching. In some cases, such in rocky terrain, when fine material does not abound, foreigner material is used instead. In the following layer much coarser material is used (sometimes with rocks). This fact definitely gives different characteristics to each layer (Figure 10).

Finally, the presence of the pipe in the cross section of the backfill material is a singularity itself. Pipe diameter and weight might influence variables such as compaction, water drainage and other factors.

5. ROLE OF TRENCHBREAKERS IN PIPE INTEGRITY

Trench breakers contribute to pipeline integrity by:

- Stabilizing soil within the trench.
- Preventing erosion of backfill material.
- Controlling water accumulation and hydrostatic pressure.

Trench breakers design and performance are particularly critical in sloped areas where improper construction can lead to significant safety and operational risks.

Erosion within the trench is a trigger for landslide occurrence, when erosion is present in the terrain it can create unstable slopes increasing the risk of landslides

Poor drainage within the trench can lead to water accumulation, increasing the load over the trench breakers and imposing an overload on the pipeline.

During maintenance and execution of integrity programs for pipelines, it is normal to evaluate conditions of the right of way frequently. Main indicators to identify during patrol activities are the signs of erosion in the right of way and subsidence of the soil within the right of way, which are clear indicators of trench instability that can impact the integrity of the pipeline.

In the following sections some examples of trench breakers failures are presented.

FIGURE 9: TRENCH BREAKERS DAMAGED BY WINTER ROCK FALLS (PIPELINE PRACTICE GUIDE, http://huckbody.com).

6. COMMON FAILURES

Trench breaker failures can typically be attributed to:

- Incorrect spacing between breakers, leading to soil movement.
- Inadequate drainage mechanisms, causing water accumulation and pressure buildup.
- Poor construction techniques, including improper compaction and material selection.

These failures often stem from outdated or overly simplistic design methodologies.

7. CASE STUDY

This construction project takes place in a rainforest mountain area; the site is characterized for +30 degrees steep slope 100m long. Engineering design considered the construction of trench breakers using gabions wall. Due to the steep slope, gabion wall should be erected from the bottom of the trench up to above ground level to control erosion on the right of way.

Due to extreme rain conditions and project progress, it was decided in the field to change the material and use foam trench breakers. The decision was taken only for time and budget consideration and no engineering evaluations were considered at that moment.

The change in the trench breakers design was not only in the material but also in the separation between the structures, decreasing the original distance with the argument of increasing resistance.

Foam trench breakers installation usually starts from the base of the slope upwards while gabion trench breakers are usually on the top hill. The foam trench breakers were installed without a key and flat, to speed up installation. Pipe longitudinal drainage was not properly installed, and then Built-in filters were installed without the use of geotextile as filter.

FIGURE 9: STUDY CASE. WASHOUT AND TRENCH BREAKER COLLAPSE DUE TO POOR DESIGN.

No temporary superficial water management was installed at the time of the project when suddenly the rainy season started; and jobs on the slope were stopped for safety reasons. After a couple of days of heavy rain, the installation collapsed as shown in Fig. 9. Foam breakers did not resist earth pressure. A large amount of water was accumulated in the trench, increasing the stress over the trench breakers. After collapse, backfilling material washout; exposing the pipe, which resulted in pipe damage.
An engineering assessment was carried out, pointing to insufficient wall resistance, and inadequate spacing between foam trench breakers as main failure factors. Then, after clean-up foam breakers were replaced by gabions to ensure backfill material stability and pipe integrity and proper water management techniques were used.
The main lessons learnt were the following:

- Design of trench breakers and changes should be evaluated and validated by geotechnical engineers
- Decision making process should consider feasibility studies, alternative assessment, risk assessment, and any other considerations to properly decide best methodology used in field
  - Design of trench breakers should consider the entire life cycle of the asset, especially during operation to maintain stability of right of way and integrity of pipeline
- Underestimation of Geotechnical works during bidding can lead to delays and over costs.
- Water management in the trench and out of the trench is key.
- The insufficient capacity to drain water out of the trench, plus the absence of temporary installations for superficial water management boosts earth pressure on the breakers.
- Flat shape instead of arch shape in PU breakers, plus the lack of key on the trench wall, contributes to breaker collapse.
- Production rate in Geotechnical works is not necessarily proportional to the number of resources. Limited space and highly manual work produce that more resources in the site just interfere with each other rather than increase productivity.

8. RESULTS AND DISCUSSION[GG4]

The main finding of this investigation is that there are many opportunities to refine, and adequate current methodologies used for calculating trench breakers in pipeline. Following, the most important points are highlighted.

Earth Pressure Calculation

- Need to adapt current models including the trench breaker border conditions.
- Include all forces involved: passive and active
- Run FEA and real scale models

As detailed in sec. 3.1 of this paper, the assumptions for the current models and theories used for retaining walls are different from those for trench breakers. Assumption, border conditions, and other details shall be more realistic. In particular, finite wall width, saturated soil, and uncompacted back fill material should be considered.
All forces involved in a typical trench breaker configuration should be considered in the new models. Computational and full-scale models should be used to corroborate the new models.

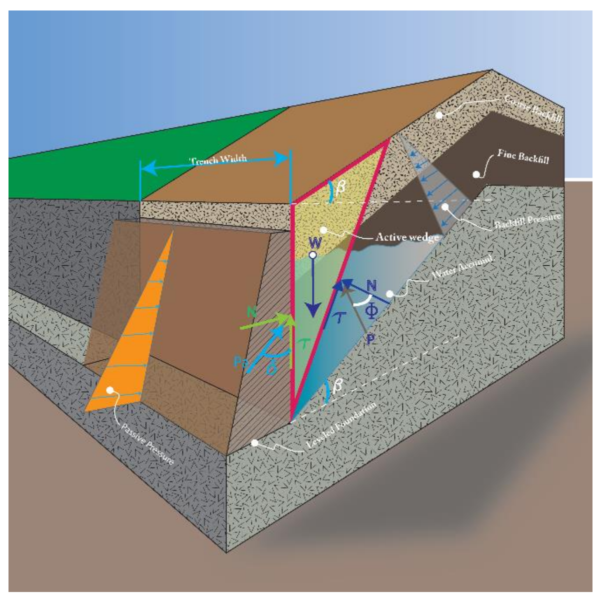

Figure 10: FORCE DIAGRAM FOR TRENCH BREAKER. MAIN FEATURES: FINITE WIDTH. BACKFILL MATERIAL IS OVER AN INCLINED CONSOLIDATED NATIVE SOIL. BACKFILL MATERIAL AT FRONT SIDE PUSHES BACK (PASSIVE PRESSURE). BACKFILL MATERIAL IS HETEROGENOUS (AT LEAST TWO DIFFERENT MATERIALS). WATER ACCUMULATION PRODUCES EXTRA PRESSURE.

Structural resistance of trench breakers

Structural resistance of trench breakers should be studied in more detail. The nature of each construction material should be considered. For example, sandbags trench breakers should not be considered as monolithic wall. Its fiction-based nature should be considered instead. Current sandbags structural analysis [13,14,15,16] should be adapted to actual trench breaker conditions.

Distance between breakers

Once precise models developed specifically for trench breakers are established, distance between trench breakers could be calculated based on them. New methodologies should corroborate (and eventually replace) current empirical methods, focusing on maximizing each field design.

Design and Selection Standardization

New models should help to evaluate design and construction details such as trench size, arch form, keys, etc. New guidelines and standards could be established after evaluating the impact of each main variable on the trench breaker behavior.

Backfill material compaction

One important variable to evaluate will be the need for backfill compaction. Some pipeline operators require that backfill material shall be compacted in steep slopes. This requirement slowdown construction peace and it is challenging to check during construction. Its use in conjunction with trench breakers and other techniques might be unnecessary.

Water management

~~8.1~~

FEA modeling a real scale model could also help to engineer in-trench water management resources such as built-in and longitudinal filters, maximizing each field design.

Superficial water management techniques should be considered in the analysis too.

Failure analysis and new models could help to classify failure modes, helping to the analysis and remediation assessment.

9. CONCLUSION

Trench breakers play a crucial role in pipeline construction and pipeline integrity during operation.

There is no standardization in terms of calculation, design, construction and maintenance.

Current methods, models, and calculations shall be adapted to this application, considering actual borders conditions for trench breakers.

Standards and guidelines should be established.

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