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Review Of Risk Identification Of Buried Pipeline Under Railroad Tracks

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ABSTRAK

Keberadaan pipa di bawah jalur kereta api menimbulkan potensi risiko dan bahaya bagi operasional kereta api. Diperlukan identifikasi risiko yang timbul dari pipa yang terletak di bawah jalur kereta api untuk evaluasi dan penyusunan langkah-langkah strategis dalam mengurangi tingkat risiko tersebut. Fokus utama dari artikel ini adalah identifikasi risiko terkait dengan pipa yang berpotongan dengan jalur kereta api. Risiko yang perlu diperhatikan meliputi deformasi pipa, korosi, kesalahan desain dan instalasi, serta kesalahan dalam pengoperasian. Untuk memastikan keamanan, pemantauan dan inspeksi pipa harus dilakukan secara rutin. Identifikasi risiko tersebut bertujuan untuk memahami potensi – potensi risiko yang dapat mempengaruhi keamanan, keandalan, dan operasional, baik terhadap jaringan pipa maupun perjalanan kereta api itu sendiri. Artikel ini meninjau beberapa studi dan standar terkait keselamatan pipa di bawah jalur kereta api, serta merangkum potensi kegagalan pipa yang berada di bawah jalur kereta api, aspek – aspek keselamatan pipa dan kereta api, serta standar – standar yang dapat dijadikan acuan dalam merancang pipa yang terkubur di bawah jalur kereta api. Berdasarkan dari reviu artikel ini, selain memperhatikan dari kekuatan pipa yang terkubur di bawah jalur kereta api, perlu juga untuk memperhatikan unsur geoteknikal guna memastikan struktur jalur kereta api tetap berfungsi dengan baik dan aman.

Kata kunci : Identifikasi risiko, kereta api, pipa di bawah jalur kereta api, pipa terkubur

ABSTRACT

The presence of pipes beneath railway lines poses potential risks and hazards to railway operations. Identification of the risks arising from pipes located under railway lines is necessary for evaluation and preparation of strategic measures to reduce the level of risk. The main focus of this article is to identification of risks related to pipeline crossing the railway tracks. Risks to be considered include pipe deformation, corrosion, design and installation errors, and operating errors. To ensure safety, pipe monitoring and inspection must be conducted regularly. The aims of these risks identification is to understand the potential risks that can affect the safety, reliability, and operations of both the pipeline network and railway transportation itself. This article reviews several published studies and standards related to the safety of pipelines under the railways and summarizes the potential failures of pipelines located beneath railway tracks, various aspect of pipelines and railway safety, and the standards that can be used as references in designing pipelines buried beneath railway tracks. Based on the review of this article, in addition to considering the strength of pipelines, it is also important to pay attention to geotechnical elements to ensure the railway track structure remains functional and secure.

Keywords: Risk identification, trains, pipeline under railway, buried pipeline

1. INTRODUCTION

In recent decades, trains have become one of the preferred modes of transportation in every country due to their advantages, including high carrying capacity, relatively high speed, and the ability to reach city centers in every region. With the increasing interest in rail transport, the frequency of trips has also increased. The next 20 – 30 years will see an unprecedented demand for growth in rail transport in terms of the axial load and the number of trains in service [1]. On the other hand, from a different perspective, energy sources such as gas and fossil fuels are mostly found in sparsely inhabited regions, making it necessary to transport these resources over great distances to reach customers [2]. In order to transport large quantities of these resources, routes or pipelines must be created. With increasing urbanization and demand for both railways and pipelines to connect to towns and cities, there are often points where the pipelines cross the railways, and in some cases, they must be constructed underneath the railways.

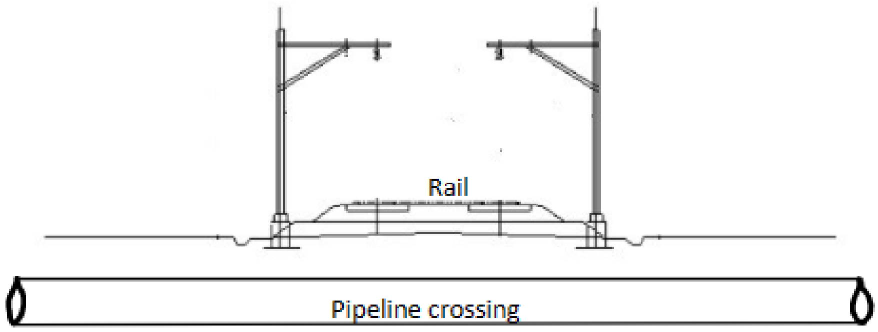

Figure 1. Illustration of Pipeline Crossing under railway tracks

Despite playing an important role in supplying the needs of society, pipeline networks are often considered as small structures and their maintenance is often neglected. This has the potential to cause pipeline failures and disrupt infrastructure, including railways[1]. Another issue is that most of the installed pipelines have been in place for decades, and there is currently no information provided by pipeline owners to indicate the remaining lifespan and quality of the pipes installed under railway tracks for evaluation, prediction of failure, facilitation of maintenance decisions, and so on [1].

The placement of pipelines beneath railway tracks can result in significant consequences, as concluded by the analysis conducted by Gamabaki et al [1]. Among the potential failure modes at pipeline-railway crossings, pipe deformation has the greatest impact, followed by pipe rupture. Causes of pipeline failure such as ageing and external loads are considered more critical than other factors. In terms of consequences, disruption of deliveries is considered to have the most significant impact, followed by the deterioration of roads in proximity to the pipeline failures. The installation of pipelines under railway tracks may also increase the complexity and cost of maintaining both the pipelines and the tracks, leading to extended periods of downtime for both. Additionally, conflicts may arise between pipeline and railway operators if there are disagreements over the best way to manage shared resources and infrastructure.

Figure 2. The Preparation of placement pipelines beneath railway tracks

Figure 3. Excavation Process Of Placement Pipelines beneath Railway Tracks

Aside from the aforementioned factors, poor installation and maintenance of pipes can also cause disruptions in the operational performance of railways [3]. It is possible for the presence of pipelines under railway tracks to result in soil settlement in the surrounding areas, which may eventually damage and interfere with the railway track structure. The impact of buried pipelines on railway tracks ultimately depends on several factors, such as the exact location, age, and condition of the pipelines, as well as the frequency and volume of railway traffic. The aims of this review paper is to provide a summary of risk identification for pipeline installation beneath railway tracks and the risk reduction strategies based on previous research and applicable standards. The focus of this article is on the natural risks that arise, such as pipeline deformation, corrosion, design and installation errors, and operational errors. Meanwhile, risks caused by criminal activities such as sabotage, theft, and others are not included in the scope of this article.

2. METHOD

The article is based on a literature review from sources that discuss the risks of failure of pipelines buried under railway tracks and their impact on the railway infrastructure. The methodology for writing this article is shown in Figure 4.

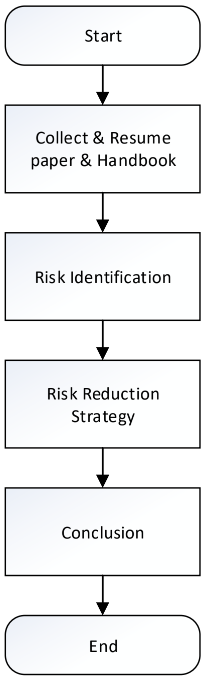

Figure 4. Methodology

The initial step in developing this article involved gathering information from papers, literature books, and international standards. The gathered information was then classified into two main categories: risk identification and risk reduction strategies for pipes buried beneath railway tracks. The final step of this article is summarizing the identification risks and strategies to minimized the risks associated with a pipeline under the railway tracks.

3. RISK IDENTIFICATION FOR PIPELINES UNDER RAILWAY TRACKS

Risk is defined as the combination of the probability of occurrence of a hazard and the magnitude of the consequences of the failure. By the definition, risk has increased when either the probability of the event increases and or when the magnitude of the potential loss increases[4]. Risks can be reduced by combining preventive steps that can reduce the frequency of occurrence that may cause losses and reduce the severity level of each event.

The initial goal of any activity of risk management is to determine whether hazards can be avoided. However, if that is not possible, the next consideration is whether the frequency of hazards can be reduced to an acceptable level. If this level cannot be achieved, the next goal is to ensure that the frequency of hazards that could lead to accidents is kept as low as possible. If this is still inadequate, the final step is to minimize the severity level of the resulting accidents as much as possible [5][6]. One of the objectives of risk management for pipelines under railway tracks is to identify, analyze, and evaluate the potential risks of pipeline failure, and to reduce or even eliminate any possible consequences of such failure, especially to ensure the safety of railway operation above the pipelines.

In this stage, all possible risks related to the construction, operation, and maintenance of the pipeline crossing under the railway track are identified. Based on Pipeline Risk Management [4], railway tracks above the pipelines include the potential risk causes of Third Party Damage. The examples of risks that may occur are include damage to the pipeline due to the weight of the railway train, erosion or settlement of the soil, and corrosion of the pipeline [1] . Initially, hazard identification can be conducted to identify potential hazardous events, and then move on to the hazard group level and eventually to the system level. The information gathered from the hazard identification process can then be used to create a risk tree [7],[8] . A risk tree for Pipeline buried under railroad tracks as shown in Figure 5.

3.1 Hazardous Event

3.1.1 Pipeline Deformation

The minimum thickness of each pipe is determined based on the stress that the pipe must withstand. Design of the pipe is determined by considering all the load that the pipe will experience, including earth loads, live loads, and internal loads [4] [9] [10]. For each of these loadings, failure is often defined as permanent deformation of the pipe. After permanent deformation, the pipe may no longer be suitable for its service and function.

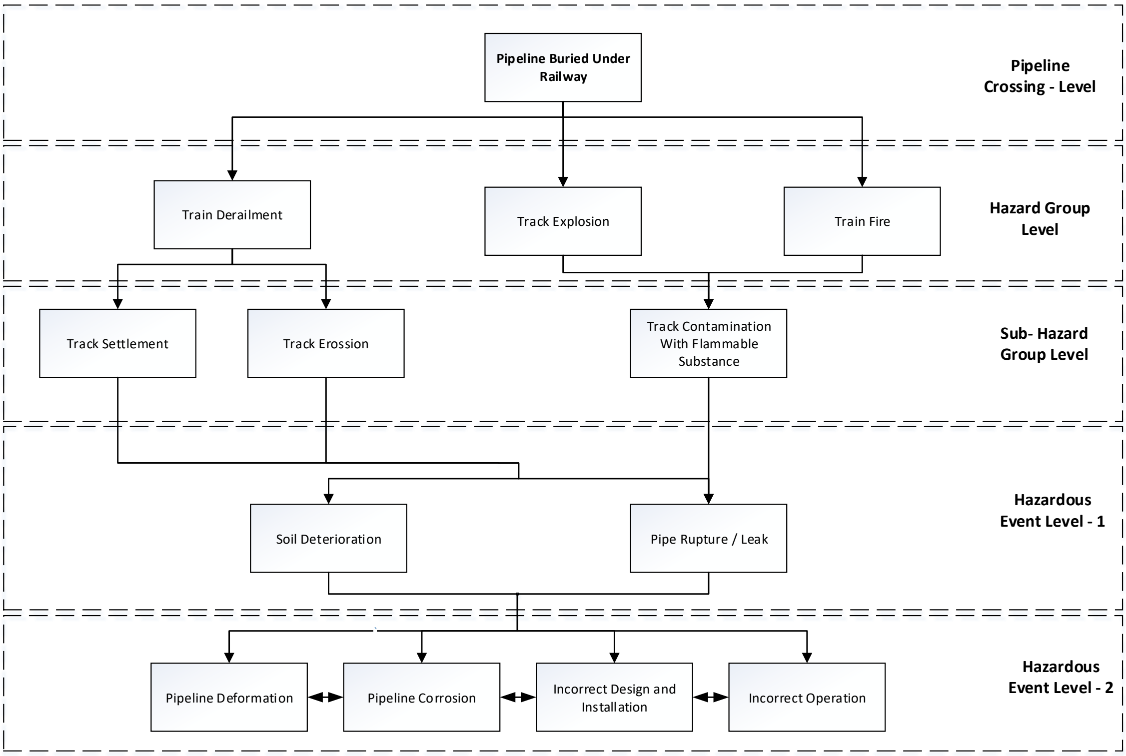

Figure 5. Risk Identification at different levels
for Pipeline buried under railroad tracks (redrawn from [7])

Pipeline deformation is one of the most significant risk associated with pipeline buried under railway tracks due to weight and vibration of passing trains [1]. When a train passes over a pipeline buried beneath the railway tracks, the pipeline can experience significant stress and strain due to the weight of the train and the dynamic loading caused by the vibration of the train. This stress and strain can cause the pipeline to deform, resulting in stress concentrations that can lead to pipeline failure. In particular, the bending stress induced by the deformation can cause fatigue and cracking in the pipeline, which can ultimately lead to a rupture or leak. Furthermore, the deformation of the pipeline can cause to position shift relative to its original installation, which can increase the risk of damage from other external factors, such as nearby construction or excavation work.

The construction of boreholes for crossings between pipelines and railway lines also has the potential to cause damage to the pipelines, especially in constructions located under sandy, rocky, and gravel layers that may compromise the pipeline integrity[11][12]. This is initiated by the occurrence of local dents due to the presence of rocks and gravel in the borehole. Local dents not only damage the wall coating but also cause cracks in the pipeline. These cracks can widen under internal pressure and external loads, which can lead to pipeline failure. To reduce the probability of failure and improve the pipeline's service life, a protective device is needed to prevent damage. Therefore, the pipeline casing can also be useful in reducing the potential deformation caused by imperfections in the borehole due to unfavorable geological conditions[11].

3.1.2 Pipeline Corrosion

One of the most common risks associated with steel pipelines is the possibility of failure due to corrosion [4],[13]. Pipeline corrosion is a common cause of pipeline failure, accounting for 22% of hazardous liquid and gas transmission and distribution incidents [14]. In general, corrosion in metal materials occurs due to the presence of four elements, namely anode, cathode, electrical connection between them, and electrolyte. If one of these elements is removed, the corrosion process will stop. Corrosion prevention measures are designed to eliminate one or more of these elements in order to stop corrosion [4]. In the oil and gas industry, the susceptibility to corrosion is typically mitigated by coating all buried pipelines and utilizing a cathodic Protection (CP) system [14]. Corrosion is a matter of concern as it inevitably leads to a decrease in the thickness of the pipe wall, resulting in a compromised structural integrity, and therefore, an increase in risk of failure [4].

Two factors that must be considered in the threat of corrosion are the material type and environmental conditions, especially those that will affect the pipe wall. Selecting the wrong material for an environment can create potential failure. Placing a pipe material that is not suitable for the environment can initiate or accelerate corrosion . There are two general categories of potential corrosion that can occur to buried pipelines underneath railway tracks: internal corrosion and external (subsurface) corrosion [4], [14], [15].

a. Internal corrosion

Internal corrosion is related to corrosion that occurs inside a pipe. It occurs when the pipe material is oxidized due to the chemical reaction of the fluid transported inside it. This can happen when the fluid transported inside the pipe contains corrosive materials, or when the humidity inside the pipe reaches a high level. Internal corrosion can reduce the thickness of the pipe wall, thereby reducing the pipe's ability to withstand pressure, increasing the risk of leakage and pipe failure.

b. **External (subsurface) corrosion**

Most corrosion failures are caused by external corrosion, which reflects the complexity of the corrosion mechanisms involved in this type of corrosion. External general corrosion is often found at the bottom of the pipe and can result from inadequate coating or cathodic protection or both of combination [14]. The potential for external corrosion can be caused by several factors, such as poor pipe coating, inadequate cathodic protection installation, soil corrosivity, contact with buried metals, stray currents, and potential stress corrosion cracking. External corrosion can also result in a reduction of pipe wall thickness from the outside, reducing the ability of the pipe to withstand pressure and can lead to rupture, leaks, and other failures [4], [14],

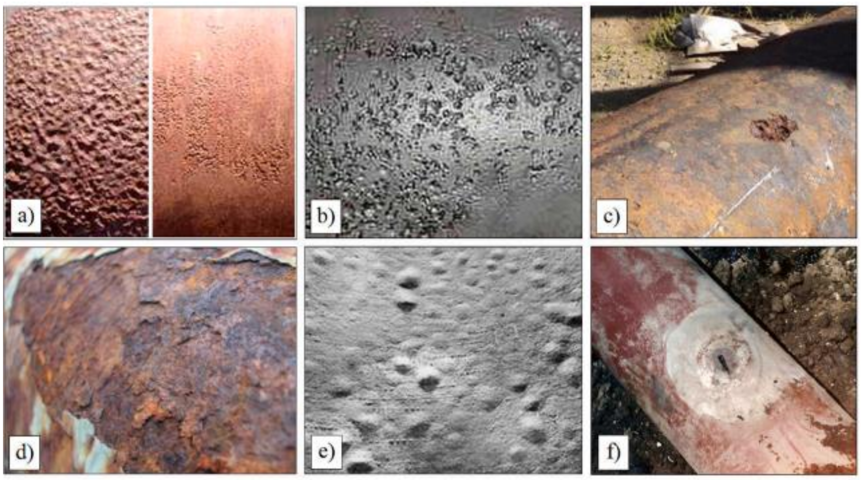

Figure 6. The type of Pipeline corrosion : a) Uniform corrosion ; b) Pitting corrosion; c) Crevice corrosion ; d) Under-deposit corrosion; e) Delamination-bulging, hydrogen blister; f) Coating damage [15]

3.2 Incorrect Design and Installation

The design stage is the initial phase in planning the construction/installation of pipelines beneath railway tracks. The main objective of this stage is to ensure that the pipeline buried beneath the railway track, in terms of design and material, not only has a strong structure but also minimizes other potential failures [4]. An essential element in the pipeline design risk assessment is how the pipeline is initially designed and how its safety margin can cope with uncertainties during operation [4].

The following are some pipeline failures caused by design errors:

a. Inappropriate pipe thickness. The pipe thickness must be designed to withstand the internal and external pressures that occur during operation. If the pipe is too thin, it may cause deformation and lead to leakage or rupture.
b. Poor-quality pipe materials. The pipe must be made of strong and corrosion-resistant materials to ensure its longevity. If the pipe is made of poor-quality materials, it may corrode and reduce the pipe's thickness.
c. Poor corrosion protection system. The pipe should be protected as much as possible from corrosion with a corrosion protection system such as coating and cathodic protection. If the protection system fails, the pipe may be subject to corrosion, reducing its thickness.
d. Welding failure. Poor welding can cause damage to the pipe.

The installation phase is one of the stages that has a high failure rate, as reflected in the bathtub curve, which explains that the pipe installation phase is included in the infant mortality phase, as illustrated in the figure 6. The installation of utilities such as pipes can cause soil shifting or settlement, which can lead to faster track settlement. The risk of settling can be even higher and deeper during utility installation works. For example, the risk of horizontal directional drilling (HDD) can cause a domino effect, especially in sandy and gravelly soil conditions. Soil structures around the borehole area can be damaged by groundwater flow, causing large cavities in the soil. If these cavities are not refilled, they can become new groundwater channels that enlarge over time and cause instability and soil surface collapse, which poses a fatal threat to train operations[16]

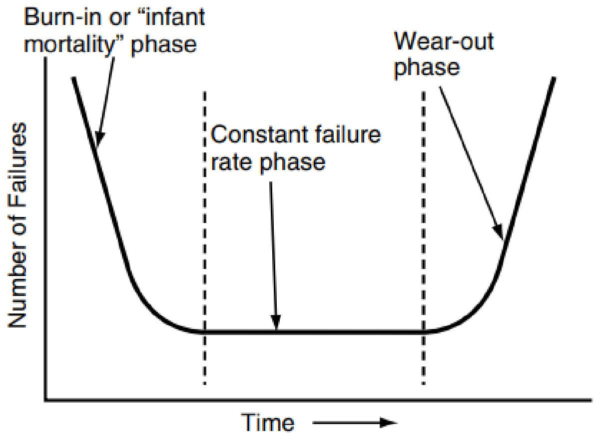

Figure 7. Common failure rate (bathtub curve) [4]

3.3 Incorrect Operation

Based on historical data, it is known that 80% of all accidents caused by pipelines are due to human failibility [4]. This can occur because most of the other potential risks are determined by various calculations and considerations made by humans. Potential failures due to human failibility can arise from the following factors [4]:

a. Errors during the design considerations stage. At this stage, engineers may provide incorrect recommendations regarding hazard identification, make mistakes in calculating the Maximum Allowable Operating Pressure (MAOP), design pipeline safety systems, determine the appropriate materials, and create checklists for design inspection procedures.
b. Errors made during the construction phase. At this stage, engineers may make mistakes in construction considerations, such as errors in the process of considering soil conditions and the surrounding environment, errors in determining the depth of pipe installation, errors in the process of providing corrosion protection for the pipe (coating and cathodic protection), errors in selecting construction methods, and errors during backfilling.
c. Errors made during the operational phase. At this stage, engineers may make mistakes in carrying out pipeline operational activities, such as not following procedures properly, not having a good safety program, not providing proper training to their employees, and not being careful in

anticipating potential operational/mechanical errors.

d. Errors made during the maintenance phase. At this stage, engineers may make mistakes and be careless in performing maintenance activities, such as being careless in determining and performing maintenance, being careless in following maintenance procedures, and being careless in documenting the maintenance processes and history.

3.4 Hazard Group

3.4.1 Track Settlement

Under the weight of a train and the additional high-frequency load variations, the ballast and sub-ground of a track can undergo non-elastic deformations [3]. Even when the train has passed, the track will not return to its exact original position but to a position very close to it. After many train passages, these small non-elastic deformations will accumulate and result in a new track position that varies in different parts of the track. This process is known as differential track settlement, and it causes changes in the track alignment and level over time. The wavelength of these track irregularities will depend on the sub-ground, and can range from a few meters to several hundred meters.

Railway tracks are prone to settling or changing their position due to the permanent deformation of the ballast and the underlying soil. The extent of settlement depends on the quality and behavior of the ballast, sub-ballast, and subgrade, as well as the frequency of traffic loading. Track settlement occurs in two main phases. The first phase occurs immediately after tamping, where the track is adjusted to a straight and level position. During this phase, settlement occurs relatively quickly until the gaps between the ballast particles are reduced and the ballast is consolidated. The second phase of settlement is caused by various mechanisms of ballast and subgrade behavior.

The second phase of track settlement is caused by various fundamental mechanisms of ballast and subgrade behavior. These mechanisms include continued volume reduction or densification of the ballast and sub-ground, resulting from particle rearrangement due to repeated train loading. Sub-ballast and subgrade penetration into ballast voids can also cause the ballast to sink and change the track level. Additionally, volume reduction can occur due to particle breakdown from train loading or environmental factors, while abrasive wear can cause particles to diminish in volume. Inelastic recovery on unloading can also lead to permanent deformation, as not all deformations will be fully recovered upon unloading the track. Movement of ballast and subgrade particles away from under the sleepers and lateral or longitudinal movement of sleepers can also cause sinking of the sleepers into the ballast.

The track damage is initially manifested by the loss of line and geometry of the track [17]. Initially, this is possible due to repeated loads from trains causing the track to move laterally and vertically. The loss of line and track level geometry also caused by the loss of the effectiveness of the ballast and sub-ballast function, or problems caused by the subgrade. The problem with the subgrade mostly occurs due to excessive deformation caused by repeated loads on soil with high water content. Typically, over a maintenance cycle lasting 1 to 2 years, track settles around 25 mm from its highest level [18], however, In fact, this is quite easy to restore, especially with the track maintenance process.

If a pipeline buried under a railway track fails, it could potentially pose a danger to the railway's operation. For example, if there is a leak in the pipeline, the liquid or gas inside the pipeline will flow and enter the ground surface, causing erosion or soil instability under the railway track. This will initiate a decrease or the occurrence of voids in the structure of the railway track, which could potentially result in the derailment of the train.

3.4.2 Track Explosion and Train Fire

The threat posed by pipeline failures is the potential security disturbance caused by the pipeline. The most serious impact is the leakage of flammable fluids or gas, which not only disrupts the operation of the railway and the pipeline itself, but also damages the environment and potentially leads to explosions, fires, or other accidents, which threaten the safety and economic losses[19].

Figure 8 . The leakage of pipes leads to the contamination of the environment and poses a potential risk of fire as it involves the release of oil from the pipes [20]

4. RISK REDUCTION STRATEGY

1.1 Design & Cover

The Design & Cover stage is the initial phase in planning the construction/installation of pipes under railway tracks. The main goal of this stage is to ensure that the design and material of the buried pipe under the railway track can minimize the potential for failure. One of the factors to consider in determining the design is the consideration of the loads and stresses that will be imposed on the pipe under the railway tracks. There are two categories of stresses experienced by the pipe, stresses due to external load and stresses due to internal load [9].

External loads caused by earth loads and live loads. Earth loads refer to the external load exerted by the soil material covering the pipe buried beneath the railway track. This load can vary depending on the type of soil, depth of pipe burial, and lateral pressure from the surrounding soil. Live loads, on the other hand, are external loads generated by activities or movements that occur on the railway track. Live loads include the weight of the trains, the motion or vibrations generated by passing trains, as well as loads resulting from activities such as construction or track maintenance[9].

Internal load refers to the forces or loads generated by fluids or gases flowing within the pipe. When fluids or gases flow through the pipe, they exert pressure on the pipe walls. From the combination of external load and internal load, various types of stress are produced, including circumferential stress, longitudinal stress, and radial stress. [9], [21].

There are two standards being reviewed :API 1102 – Steel Pipelines Crossing Railroads and Highways, and American Railway Engineering and Maintenance of Way Association (AREMA). API 1102 is a standard developed by the American Petroleum Institute (API) that provides guidelines for the design, construction, and maintenance of steel pipelines that cross under railroads or highways. Furthermore, the American Railway Engineering and Maintenance of Way Association (AREMA) has manual guidelines for pipeline installation. In this manual, there are three main discussion regarding underground pipelines, subject to pipelines conveying flammable substances, uncased gas pipelines within the railway Right Of Way (ROW), and pipelines conveying non - flammable substances [22][23]. The comparison method of cover and design procedure between API 1102 and AREMA as shown in Figure 9.

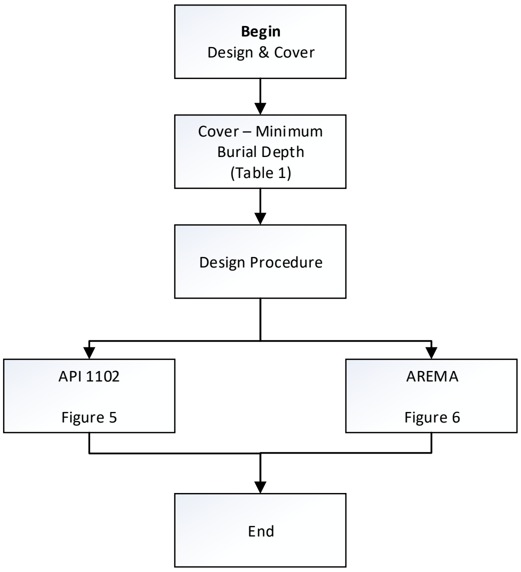

Figure 9. Comparison Method of Cover and Design Procedure API 1102 and AREMA

Table 1. Comparison of the minimum burial depth for API 1102 railroad crossing design and AREMA's crossing design [9], [22]

	API 1102's guidelines for minimum burial depth (m)		AREMA's guidelines for minimum burial depth (m)	
	Mainlines	Other tracks	Mainlines	Other tracks
Cased	1.7 m	1.4 m	1.7 m	-*
Uncased	1.8 m	-	3.0 m	-*

In general, both standards have the same goal, which is to ensure that the pipeline buried beneath the railway track has the ability to withstand the loads generated from earth loads, live loads, and external loads. A comparison of the minimum cover requirements for pipelines beneath railway tracks between API 1102 and AREMA can be seen in Table 1.

API 1102 provides quantitative guidelines for the installation and operation of pipes under railway lines. API 1102 provides guidelines for measuring pipe stresses in the circumferential, longitudinal, and radial directions, calculated on their respective load sources. This allows for the prediction of potential fatigue issues that may impact pipe performance. On other hand, AREMA provides guidelines as well as recommendations for selecting materials according to the carrier inside the pipe. The design procedures in API 1102 and AREMA can be seen in Figure 10 and Figure 11, respectively.

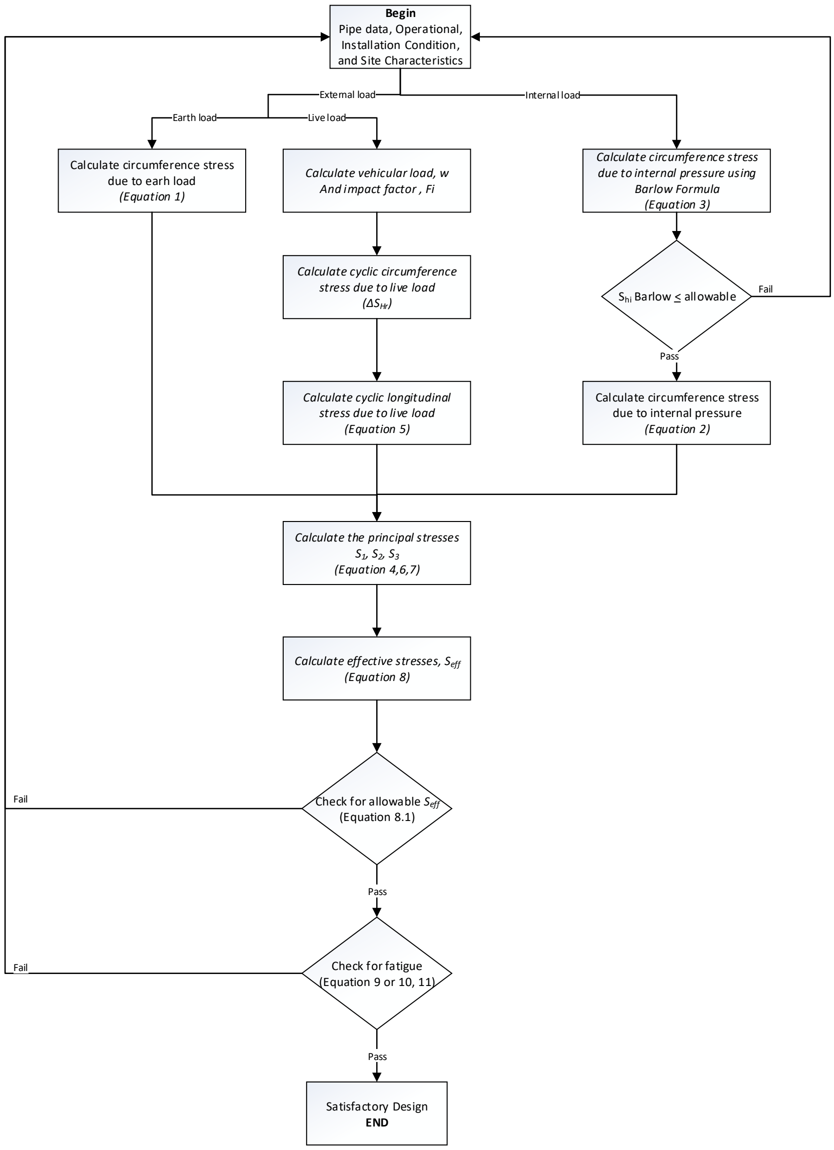

Figure 10. API 1102’s Pipeline Crossing of Railroad Design Procedure [9] [21] [24]

a. Circumferential Stress

Circumferential stress due to earth load

$$S_{HE} = K_{HE} B_E E_E \gamma D \quad (1)$$

Where,
S_{HE} = Circumferential stress due to earth load
K_{HE} = Stiffness factor for circumferential stress from earth load
B_E = Burial factor for earth load circumferential stress
E_E = Excavation factor for earth load
γ = Soil unit weight
D = Pipe outside diameter

Circumferential stress due to internal pressure

$$S_{Hi} = \frac{p(D-t_w)}{2t_w} \quad (2)$$

Barlow Formula :

$$S_{Hi}(Barlow) = \frac{pD}{2t_w} \le F \times E \times T \times SMYS \quad (3$$

Where,
p = internal pressure
D = pipe outside diameter
t_w = wall thickness
F = Design Factor
E = Longitudinal joint factor
T = Temperature derating factor
$SMYS$ = Speccified minimum yield strength

Maximum circumferential stress

$$S_1 = S_{HE} + \Delta S_{Hr} + S_{Hi} \quad (4)$$

Where,
ΔS_{Hr} = cyclic circumferential stress due to rail road ($K_{Hr} G_{Hr} N_H F_i w$)
K_{Hr} = Railroad stiffness factor for cyclic circumferential stress
G_{Hr} = Railroad geometry factor for cyclic circumferential stress
N_H = Railroad single or double track factor
F_i = Impact Factor
w = applied design surface pressure

b. Longitudinal stress

c. Cyclic longitudinal stress due to railroad

$$\Delta S_{Lr} = K_{Lr} G_{Lr} N_L F_i w \quad (5)$$

Where,
K_{Lr} = Railroad stiffness factor for cyclic longitudinal stress
G_{Lr} = Railroad geometry factor for cyclic longitudinal stress
N_L = Railroad single or double track factor
F_i = Impact Factor
w = applied design surface pressure

d. Maximum longitudinal stress

$$S_2 = \Delta S_{Lr} - E_s \alpha_T (T_2 - T_1) + V_s(S_{He} + S_{Hi}) \quad (6)$$

Where
ΔS_{Lr} = Cyclic longitudinal stress due to railroad
E_s = Young's modulus of steel
α_T = Coefficient of thermal expansion of steel
T_1 = Temperature at time of installation
T_2 = Maximum or minimum operating temperature
v_s = Poisson's ratio of steel

c. Radial stress

$$S_3 = -P \quad (7)$$

Where,
S_3 = Radial stress
P = MOP (Maximum Operating Pressure)

d. Vehicular load

Recommended that loading of w = 13.9 psi (96kPa)

e. Total Effective stress

$$S_{eff} = \sqrt{\frac{1}{2}[(S_1 - S_2)^2 + (S_2 - S_3)^2 + (S_3 - S_1)^2]} \quad (8)$$

$$S_{eff} \le SMYS \times F \quad (9)$$

f. Fatigue Check

Girth Weld

If a grith weld is located less than 1.5 m from centerline of the track, then :

$$\frac{\Delta S_{Lr}}{N_L} \le S_{FG} \times F \quad (10)$$

If the grith weld is located greater than or equal to 1.5 m but less than 3 m:

$$\frac{R_F \Delta S_{Lr}}{N_L} \le S_{FG} \times F \quad (11)$$

Where
ΔS_{Lr} = cyclic longitudinal stress
N_L = single or double track factor
S_{FG} = fatigue endurance limit of grith weld (12,000 psi (82,740 kPa)
F = design factor
R_f = longitudinal stress reduction

Longitudinal Weld

$$\frac{\Delta S_{Hr}}{N_H} \le S_{FL} \times F \quad (12)$$

Where
ΔS_{Hr} = cyclic circumferential stress
N_H = Single or double track factor
S_{FL} = Fatigue endurance limit of longitudinal weld
F = design factor

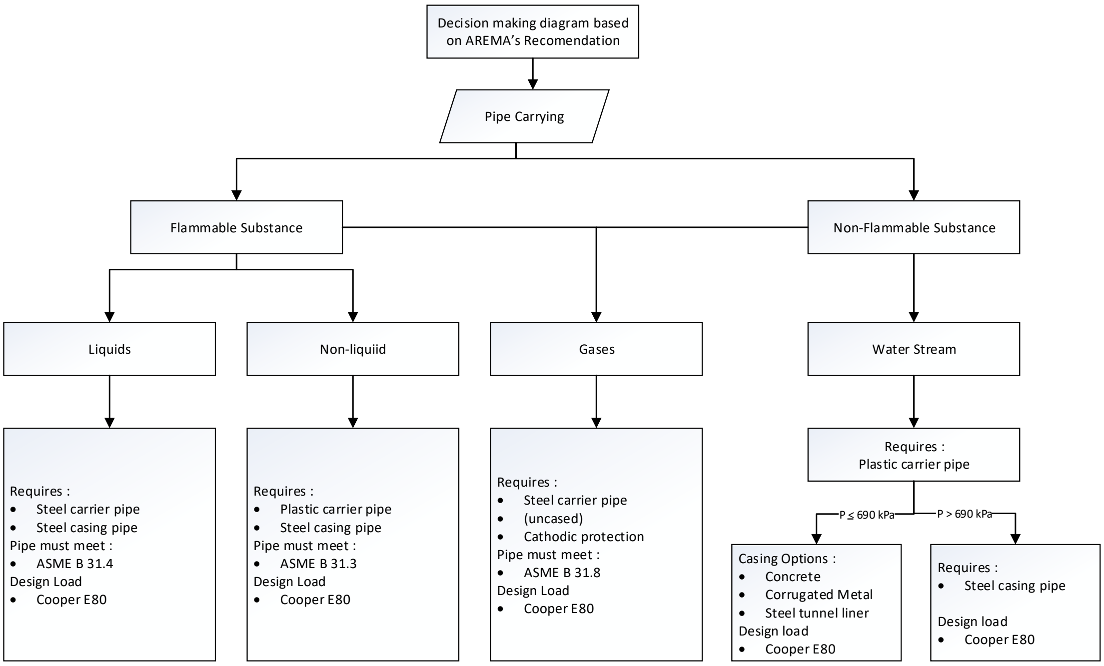

Figure 11. Decision Making Diagram Based on Arema's Recommendation [22]

According to AREMA's or API 1102 general requirements for installing pipes under railways, the pipe should be installed as near to 90 degrees as practicable. However, if that is not feasible, an angle should be less than 30 – 45 degrees with respect to the railway, preferably at the right angle. The burial depth of the pipe varies depending on whether the pipe is cased or uncased. If the pipe is cased, it should be installed at a minimum of 1.7 meters from the base of the rail to the top of the pipe. For uncased pipes, the burial depth should be at least 3 meters below the base of the rail.

AREMA's general requirements are divided into three categories based on the carrier material of the pipe: flammable substances, gases, and non-flammable substances [22][23]. For the flammable substances category, it is required that the pipe be provided with casing and the design load of the pipe must have a minimum equivalent to Cooper E80. Cooper E80 has a live load specification of 117 kN/m. For the category of pipes carrying gas, it is required that the pipe be made of steel material, but the pipe can be buried without using casing, provided that it meets criteria such as having a pipe thickness that can withstand the maximum allowable hoop stress due to internal pressure, the maximum combined multi-axial stress due to external and internal loads, fatigue in girth welds due to external live loads, and fatigue in longitudinal welds due to external live loads. For pipes carrying non-flammable substances, plastic pipes can be used and must be provided with casing. The required casing must be made of iron or steel material that has properties equivalent to Cooper E80.

1.2 Installation

1.2.1 Cased vs Uncased Pipeline

Pipes that are buried without casing have a higher probability of corrosion due to the possibility of localized corrosion cells compared to other areas of the pipe. Additionally, pipes without casing always have the risk of failure due to soil and traffic loads above the pipe. The basic purpose of providing casing for pipes is to protect the carrier pipe from external loads, provide space and a path for fluids in case of leakage, and allow for replacement of the leaking pipe[4], [9].

Pipes installed inside casing must maintain a distance from the casing pipe itself, so that no external load is transmitted to the carrier pipe, and to avoid contact between the carrier pipe and casing pipe, which can potentially cause stress concentrations [8][16]. The illustration of pipes located under railway, with and without casing, as seen in figure 12 and 13.

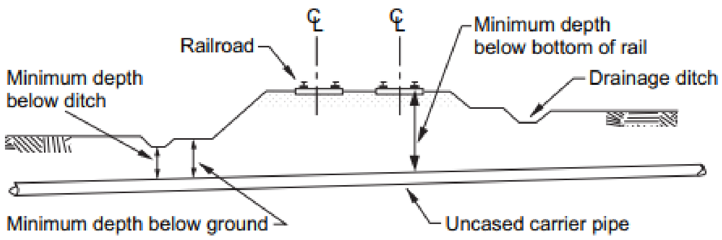

Figure 12. Buried Pipeline Under Railroads without Casing [9]

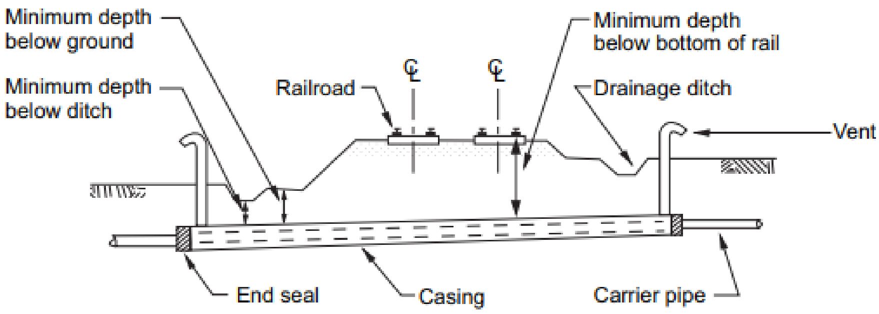

Figure 13. Buried Pipeline under Railroads with Casing [9]

Insulators are also needed to isolate the casing pipe and protect the carrier pipe from electrical networks. However, over time, the insulation properties of the insulators tend to decrease. In addition, the seal end of the casing pipe often suffers damage, leading to water and soil entering the casing pipe [25]. Therefore, to ensure the safety and long service life of the carrier pipe, the following recommendations are suggested [4]:

a. The carrier pipe that runs through must have a higher thickness than the standard specified as a corrosion allowance.
b. In addition to the requirements as specified in AREMA's standard [13], casing pipe is needed to provide a higher level of safety and reduce the probability of corrosion on the carrier pipe. However, periodic maintenance and monitoring, particularly for electrical isolation of the pipe, are essential.
c. The casing pipe should also have good coating quality.

1.2.2 Construction Methods

When rehabilitating or installing pipelines, traditional cut and cover methods, such as open-trenching, are typically used. However, in cases where underground utilities cross under railroads, interrupting railway operations can result in significant economic losses, making open-trench installation impractical. In these instances, trenchless technologies are a viable option for crossing pipeline construction under railway tracks, allowing pipelines to be installed beneath the track without the need for open trenching [22][23] .

In general, railroad owners provide design specifications and guidelines for trenchless technology crossing in railroad installations. In the United States, the American Railway Engineering and Maintenance of Way Association (AREMA) manual provides guidelines for pipeline installation, recommending jack and bore as the preferred trenchless technology to cross under railroads [22]. Jack and bore methods involve installing casing pipes as load-bearing members to reduce the risk of ground surface settlement or subsidence and provide leakage protection. Although other technologies like Horizontal Directional Drilling (HDD), pipe ramming, micro-tunneling, and direct pipe have been utilized by pipeline installation contractors, they are not explicitly detailed in the manual[22][23].

In the trenchless process, the placement and compaction of soil around the installed pipe must be carried out carefully to reduce the potential for settlement. The engineer must evaluate the risk of a void creation during the construction process. Good backfilling practices include filling the voids around the soil and pipe with soil or sand or another suitable methods to support the pipe securely under the railway tracks. Support materials that are susceptible to biological attack, such as wood, are not recommended because they can decompose and increase the potential corrosion on the pipelines [9], [22],[23].

1.2.3 Geotechnical Consideration

In addition to considering the strength and potential risks posed by pipes buried under railway tracks, it is also important to pay attention to the soil structure around the location where the pipes are planted. This is necessary because there is a risk of ground surface subsidence due to the installation or maintenance process of the pipes. As previously explained, the installation or repair of utilities such as pipes can cause soil shifting or settlement, which can lead to faster track settlement. The risk of settling can be even higher and deeper during utility installation works [16].

In railway institutions such as the Canadian National Railway (CN) and the Canadian Pacific Railway (CPR), geotechnical requirements must be met in placing pipes under railway tracks. The main principle of these requirements is to protect the railway track structure. The geotechnical requirements and guarantees that must be met include the following [26]:

a. Providing assurance of safe track conditions during and after installation;
b. Establishing specifications and procedures to reduce problems during pipe crossing installation with the rails;
c. Determining minimum engineering standards;
d. Ensuring that adequate geotechnical investigations and engineering reviews have been completed before work is carried out;
e. Ensuring that pipe crossing work under railway tracks can be completed on time.

These requirements specifically apply to pipes with a diameter more than equal 250 mm, while pipes with a diameter less than 250 mm can disregard these geotechnical requirements. Both CN and CPR require geotechnical engineer approval for pipeline crossing installation and compliance with the following:

a. Geotechnical study details, which must consist of geotechnical and geophysical field investigations.
b. Settlement monitoring plan, including monitoring point types, locations, and survey frequency and duration.
c. A statement from the Geotechnical Engineer declaring that the pipeline work has been deemed safe and there is no potential for soil stability issues.

1.3 Operations

Pipelines that transport hazardous materials typically have redundant safety systems and are designed with very strict safety factors.Therefore, an event that is impossible to occur is needed to cause a failure in the pipeline. However, history has shown that unlikely series of events occur more often than ever expected [4]. To minimize risks during pipeline operation, some of the things to consider are :

a. Maintain the stability and strength of the soil structure around the pipeline through regular observation and maintenance.
b. Maintain the quality and safety of the pipeline itself through regular observation and maintenance.
c. Have a monitoring system for the pipeline and its environment, such as using leak detection, pressure, and temperature monitoring tools.
d. Prepare emergency protocols to deal with emergency situations such as pipeline leaks or damage.
e. Provide appropriate geotechnical assurance in accordance with the railway line specifications.
f. Provide clear pipeline route markers that can be seen from all angles.

In addition, the frequency of pipeline patrol by personnel is also crucial to provide up-to-date condition reports on the pipeline under the railway track [4]. Patrols can also be used to detect pipeline leaks and threats to both the pipeline and railway infrastructure, such as construction activities, maintenance carried out by railway operators, or ground subsidence conditions on the railway track. In terms of reactiveness, patrols also aim to detect signs of leaks such as vapor and dead vegetation around the pipeline [4].

1.4 Pipelines Maintenance

Maintenance and inspection of pipelines buried under railway tracks are crucial to ensure the safety and reliability of the pipeline system while minimizing the risk of disrupting railway infrastructure. Some steps that can be taken to perform maintenance and inspection on pipelines buried under railway tracks are as follows [4][22]:

a. Corrosion monitoring.
   Corrosion is the major problem for pipelines buried under railway tracks. Therefore, corrosion monitoring must be carried out regularly and routinely to estimate the remaining life of the pipeline.
b. Cleaning and pipeline maintenance.
   Pipelines must be cleaned regularly to remove dirt, deposits, and other materials that can damage the pipeline. This is to prevent leakage or other serious damage.
c. Inspection.
   Inspection is carried out to check the condition of the pipeline and detect signs of damage such as

cracks or corrosion. Inspection can be done visually or using other non-destructive testing technologies.

d. Environmental monitoring.
Environmental monitoring such as humidity, temperature, and soil quality is also crucial to ensure stable environmental conditions that will not potentially damage the pipeline.

e. Emergency handling.
The pipeline system must be equipped with clear emergency procedures to address leaks or other damage. Therefore, pipeline operators must always ensure that the emergency system is functioning effectively.

5. CONCLUSION

The identification of risks and implementation of risk reduction strategies for buried pipes under railway tracks are crucial for ensuring the safety, reliability, and operational of the pipeline system while minimizing disruption to railway infrastructure. Risks such as pipeline deformation, corrosion, design and installation errors, and operational mistakes should be closely monitored through regular inspections. Environmental factors, including humidity, temperature, and soil quality must also be considered. Adhering to geotechnical requirements is essential to safeguard the integrity of the track structure. Two primary standards, API 1102 and AREMA, provide guidance for designing pipelines under railway tracks, each with their own advantages and considerations. Additionally, the effective management of risks associated with buried pipelines can enhance the performance of the railway track and reduce the likelihood of operational disruptions. Ongoing monitoring and inspection should encompass both the pipeline and geotechnical aspects to ensure the continued safety and functionality of the railway infrastructure.

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