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Basic Study of Forces Acting on Underground Water Pipeline

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ABSTRACT

The aim of this project is investigating parameters that affect response of buried pipelines due to high-frequency seismic excitations. The main focus of the study is on reinforced concrete pipelines. Steel pipelines are also studied for comparison purposes. Two-dimensional finite element models are developed for dynamic analysis of pipelines loaded by seismic waves that propagate from the bedrock through the soil. The models describe both longitudinal and transverse cross-sections of pipelines. The interaction between pipelines and surrounding soils is accounted for, including a nonlinear behavior. The pipelines studied are assumed to be surrounded by frictional soils with dense, medium and loose stiffness. The effects of water mass, burial depth, soil layer thickness and non-uniform ground thickness caused by inclined bedrock are studied. It is demonstrated how two-dimensional plane strain models can be used for seismic analysis of pipelines with circular cross-sections.

Introduction

Pipelines are long tubular structures that are used to transport significant amounts of liquids or gases over long distance. Materials transported by pipelines can be categorized into four groups; oil and gas, potable water and waste water, industrial materials (e.g., ammonia) and materials that are transported in small scale such as biofuels. Pipelines are often buried in the ground, for protection against e.g. severe climate, accidents and sabotage. However, this leads to difficulties in monitoring, maintenance and repair which leads to that a high degree of safety often is associated with pipelines that are important parts of the infrastructure.

Aim

The aim of this dissertation is to basic study of forces acting on underground water pipeline.

Objective

1)To Study different forces acting on pipeline.
2)To study the behavior of soil around the water pipeline and hoop stresses.
3)To study different way to failure.
4)To study of analysis of seismic forces on pipeline.
5)Different material specification and damage control in pipe.
6)Importance of water pipeline.

Need

Pipeline is the transportation of goods or material through a pipe. Water is essential factor in life. Earthquakes can cause extensive damage to buried water supply pipelines, resulting in major financial losses for water utility operators and lengthy disruption of an essential service for whole communities. Water is important factor of society, industries, and agricultural use etc. if water pipeline damaged then this is not good for above factor.

The purpose of this project is investigating parameters that affect response of buried pipelines due to high-frequency seismic excitations. The main focus of the study is on reinforced concrete pipelines. Water distribution systems are one of six broad categories of infrastructure grouped under the heading 'lifelines'. Together with electric power, gas and liquid fuels, telecommunications, transportation and wastewater facilities, they provide the basic services and resources upon which modern communities have come to rely, particularly in the urban context. Disruption of these lifelines through earthquake damage can therefore have a devastating impact, threatening life in the short term and a region's economic and social stability in the long term.

Methodology

A brief overview of steps needed for the completion of this dissertation is given below.

a) PART – I

1) Introduction

A general idea about the topic along with need and scope is stated.

2) Literature review

Literatures of various work done previously are reviewed.

3) Methodology

b) PART – II

1) Detailed study

Various types of water pipeline, loading cases, seismic considerations in IS

2) Analysis for various case consideration

Seismic analysis of underground pipeline, strong ground motion parameters

c) PART – III

1) Observations

Comparison between observations obtained from the various analyses is done.

2) Conclusion & limitation

3) References

Various literatures reviewed are entitled.

Detailed Study

Underground water pipeline systems

Piping materials are generally divided into two groups; rigid and flexible. Concrete and steel pipelines are examples of rigid and flexible piping materials, respectively. Compared with steel concrete is an economical and durable material,

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widely used in water and wastewater networks. In this chapter first damage patterns of pipelines with respect to piping material and joints are described. Typical concrete and steel pipelines which are commonly used in water and waste water networks are described thereafter.

Different types of pipeline

- Cast iron (CI) pipes
- Steel pipes
- Concrete pipes
- Copper pipes
- Galvanized iron (GI) pipes
- Plastic or polythene or PVC pipes
- Asbestos pipes
- Polypropylenes (PRP) pipes

Concrete pipeline application

Steel reinforcement concrete pipeline (SRCP) has a product life at of 100 years or more .one of the best service lives of any pipe products. It is the low risk choice for the specific with a long history of reliability, no limits to weather exposure prior to installation and increasing strength over time. It is easy to join and install, self-heals and performs soundly above or below the water table.

Application

- Transverse culvert
- Storm water drainage
- Pressure and irrigation
- Pipe jacking and micro-tunneling

Different loads on pipeline and Load consideration

Stresses due to pressure generated by the flow (internal pressure).

External pressure by the fluid if the pipe is submerged under water.

External pressure generated by the weight of the earth and live loads on buried pipes.

Loads due to thermal expansion, earthquakes

- Static load
- Live load
- Thermal load
- Bouncy forces
- Seismic forces
- Hoop stresses

Table No. 1. Structural aspects on the seismic behaviour of pipelines

Pipeline	Materials	Joints	Damage pattern
Continuous (CP)	Steel; polyethylene Polyvinyl chloride; glass fiber, Reinforced polymer	Butt welded, Chemical weld; Mechanical Joints; Special Joints	Tension cracks; Local Buckling, Beam buckling
Segmented (SP)	Asbestos Cement; Precast Reinforced Concrete/Reinforced Concrete; Polyvinylchloride; Vitrified Clay; Cast Iron; Ductile Iron.	Caulked Joints; Bell End and Spigot Joints; Seismic Joints	Axial Pull-out; Crushing of Bell end and Spigot Joints; Circumferential Flexural Failure and Joint Rotation

Concrete pipelines

Concrete pipelines are designed for pressure flow systems and gravity flow systems. Pressure flow concrete pipe are used to transport and distribute potable water. A sewage system is mostly separated in two parts; sanitary sewers and storm sewers. Gravity-flow concrete pipelines are widely used in sewer systems but some sanitary sewers use pressurized lines since they usually are deeply buried

Gravity-flow concrete pipelines

Reinforced and non-reinforced concrete pipelines are used for gravity systems. The non-reinforced concrete pipelines are typically in sizes ranging from 100 to 1000 mm diameter. Reinforced concrete pipelines consist of one or more cages of steel reinforcement placed in a concrete wall to withstand substantial live and dead loads. Non pressure flow concrete pipelines have concrete joint in bell and spigot shape that are sealed with mastic or rubber gasket. The diameter range for them is almost from 1000 through 4000 mm for pressure range up to 90 kpa. In Sweden, two typical concrete pipelines are used in sanitary and storm sewers system.

Pressure-flow concrete pipelines

Concrete pressure pipelines include various types of wall constructions. These are pre-stressed cylinder pipelines, reinforced cylinder pipelines, pre-stressed non-cylinder pipelines, reinforced non-cylinder pipelines, and bar-wrapped cylinder pipelines. The general description of these pipelines is based on whether or not the pipe has a full-length steel cylinder and whether it is conventionally reinforced with deformed bars, wire, or smooth bars, or pre-stressed with high-strength wire. Pre-stressed cylinder/non-cylinder pipelines are typically in sizes ranging from 500 mm to 4000 mm diameter. Reinforced cylinder pipelines are in sizes ranging from 250 mm to 4000 mm. Bar-wrapped cylinder pipelines are in sizes ranging from 250 mm to 1850 mm.

Steel pipelines

Steel pipelines have a variety of applications such as transport of water, wastewater, oil and gas but also for structural piling and supports [46]. The steel pipelines are generally made in two types; welded steel pipelines or seamless steel pipelines. The seamless type is commonly used for high pressure applications such as gas transmission lines [34]. Herein, welded water steel pipelines will be described. Steel water pipelines are typically manufactured in the size range from 100 mm to more than 3660 mm in diameter. There are commonly two methods for manufacturing water steel pipelines, as spiral seam pipelines and straight seam pipelines. Spiral seam pipelines are produced from coiled strips of steel through a continuous process.

Straight seam pipelines are manufactured from plates or sheets with parallel edges. Common types of joints for steel pipelines are butt welded joints, welded spigot and socket (sleeve) joints.

Advantages and Disadvantages of Concrete Pipeline

Advantages

- Suitable for conveying all types of water
- Easy to install and flexible joints
- Can withstand backfill pressure, as well as vehicles traffic loads taking place above it
- Because of smooth inner surface, there are small friction losses
- They are available in different diameter
- They are water tight and durable even with cracks in the inner and outer coating layers.

Disadvantages

- It is necessary to conduct detailed studies regarding the pipe fitting, based on the specific project requirements.
- They are heavy with this feature being reflected in their transportation and installation costs
- It is difficult to reestablish the inner and outer coating if it is damaged during repair works.

- They may require grounding measures in some cases.

Internal water Pressure or Static Pressure

The weight of water in a pipe running full generates an additional load; the equivalent external load on the pipe can be calculated from the following equation:

$$\mathbf{P_s = 9.81\left(\frac{3\pi}{4}\right)\left(\frac{d^4}{4}\right)}$$

Where, $\mathbf{W_w}$ = equivalent water load in KN/m^2

d = Internal diameter of the pipe in m

Water hammer pressure

$$P_{h,max} = \frac{14.6}{\sqrt{1+\frac{Kd}{t}}} \times V$$

Total maximum internal pressure

$$= \text{Static Pressure} + \text{Water Hammer Pressure}$$

Due to this hoop stress and longitudinal stresses will develop.

a) Hoop stress will be, $\boldsymbol{\sigma} = \frac{\mathbf{pd}}{\mathbf{2t}}$

b) Longitudinal stress will be, $\boldsymbol{\sigma} = \frac{\mathbf{pd}}{\mathbf{4t}}$

Uplift Pressure

An uplift pressure is any upward pressure applied to a structure that has the potential to raise it relative to its surroundings. Uplift forces can be a consequence of pressure from the ground below, surface water and so on.

Let U is the force that lifts the pipe. The pipe uplift equation is given by,

$$\boldsymbol{\sigma_p = \gamma(H + D)}$$

Side Pressure Due to Compacted Fill

Pipes are capable of using only the active earth pressures because they do not distort materially under vertical load and the sides of the pipe do not move outward enough to produce any appreciable passive pressure. It is safe to assume that active horizontal pressures about equal to those calculated by Rankine's formula may be considered to act against those portions of rigid pipe which project above the surface of the natural ground adjacent.

At Top level of pipe **Side Pressure =** $\mathbf{K_a\gamma H}$

At Bottom level of pipe **Side Pressure =** $\mathbf{K_a\gamma(H + D)}$

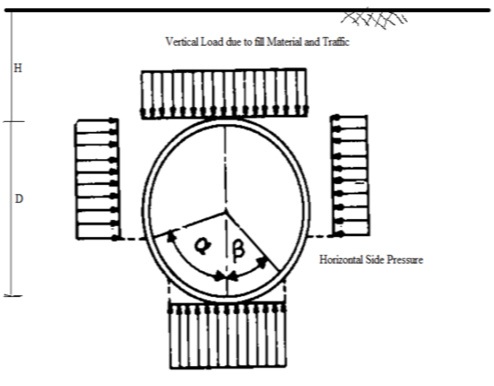

Fig 1. Different load acting on underground pipeline

Effect of Backfill and Impact Load at Top of Pipe

In pipe line design, analyses of minimum soil cover required are essential to protect the integrity of the buried pipe under different loading and environmental conditions. Soil is the major component of a flexible buried pipe system. Soil protects the pipe by holding the pipe in shape and in alignment. The following are analyses of minimum soil covers required for protection against wheel loads, flotation, uplift, and frost.

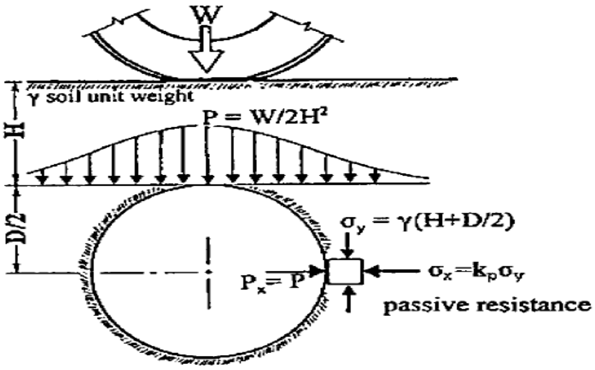

Fig 2. Effect of Backfill and Traffic Load

Pipe Bedding

a) Class "A"

Concrete shall be placed in the trench such that the pipe is supported along its entire length by a layer of concrete. Concrete shall be placed as shown on the plans and as directed by the Engineer. The concrete shall be allowed to cure for no less than three hours prior to backfilling. The pipe shall be backfilled with bedding material approved by the Engineer to a depth not less than 200 mm above the top of the pipe.

b) Class "B"

Bedding sand shall be placed and thoroughly compacted in the trench such that the pipe is supported along its entire length (and under bells and flanges) by a layer of sand, the thickness of which shall be no less than 100 mm. Additional bedding sand shall be placed and compacted around the pipe and to 200 mm above the top of the pipe for the entire width of the trench.

c) Class "C"

Excavated bedding material shall be placed and thoroughly compacted the entire width of the trench such that the pipe is supported along its entire length (and under bells and flanges) by a layer of compacted excavated bedding material the thickness of which shall be no less than 100 mm.

Excavated bedding material shall be placed and compacted around the pipe and to 200 mm above the top of the pipe for the entire width of the trench.

d) Class "D"

The bottom of the trench shall be smooth, such that the pipe is supported along its entire length with cavities provided for flanges, couplings, sleeves or bells of the pipe. Excavated bedding material shall be placed around and to 200 mm above the top of the pipe for the entire width of the trench

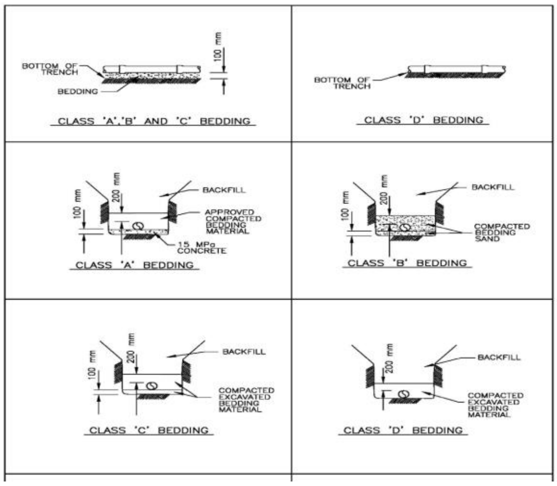

Fig 3. Pipeline Bedding Condition

Pipeline analysis and design steps

1) Assume required data

Internal diameter of pipe (d), Wall thickness or pipe thickness (t), Unit weight of fill material (W), Height of embankment fill over the top of pipe(H), Bedding type and foundation material, Velocity of water in pipe (V), Settlement ratio (r_s) and Projection ratio (P) for embankment

2) Calculation of Internal water pressure and hoop tension acting on pipeline

a) Internal water pressure or Static pressure

$$P_s = 9.81\left(\frac{3\pi}{4}\right)\left(\frac{d^2}{4}\right)$$

b) Water hammer pressure

$$P_{h,max} = \frac{14.6}{\sqrt{1+\frac{Kd}{t}}} \times V$$

c) Total internal pressure acting on pipe

$$\text{Total internal pressure} = \text{Static load pressure} + \text{Water Hammer Pressure}$$

$$P = P_s + P_h$$

d) Hoop stress: $\sigma = \frac{pd}{2t}$

e) Longitudinal stress: $\sigma = \frac{pd}{4t}$

3) Vertical load on pipeline due to fill material

As per IS 783-1983 load due to fill for positive embankment condition is given by,

$$W_e = C_e \gamma D^2$$

4) load on pipe due to superimposed loads (Traffic Load)

S=0.3 m, Wheel load (P)

$$\mathrm{We} = \mathrm{Cp} \times \frac{\mathrm{P} \times \propto}{\mathrm{L}}$$

$$\mathrm{L} = 1.15\mathrm{H} + 2\mathrm{D} + \mathrm{s}$$

5) Horizontal side pressure load due to side support offered by compacted fill:

Let the angle of internal friction for soil is, Ø= 30º

$$\mathrm{K_a} = \frac{1-\mathrm{Sin}\emptyset}{1+\mathrm{Sin}\emptyset}$$

At Top level of pipe $\text{Side Pressure} = K_a\gamma H$

At Bottom level of pipe, $\text{Side Pressure} = K_a\gamma(H + D)$

6) Selection of bedding and find load factor (F_e)

7) Selection of minimum test load and calculate the minimum required strength.

Conclusion

Various types of water pipeline have been studied in this dissertation report. Methods of Seismic analysis of underground water pipeline according to literatures. The effects of burial depth, soil layer thickness, various types of forces and piping material have been studied. If we increase the depth of fill above the pipe then self-weight increases due to fill material above the pipe while traffic load intensity decreases. Empty condition is most critical condition for pipe structure.

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