Republic of Iraq

Ministry of Higher Education and Scientific Research

University of Karbala

College of Engineering

Civil engineering department

Evaluation of Deflection for Sewage Trunk Line (GRP) Embedded in Main Roads

Submitted to the Collage of Engineering of Kerbala University in partial Fulfillment of the Requirement of the Degree of Master in Infrastructures Engineering

By

Abbas H. Ali

B.Sc. in Civil Engineering 2011

Supervised by

Asst. Prof .Dr. Basim Khalil Nile

Prof. Dr. Mohammed Abbas Aljumaili

November 2017 A.D 1439 A.H

Dedication

To my country

To my family

To my friends

Abbas H. Ali

Acknowledgments

In the name of Allah the most compassionate the most merciful.

First and foremost, I thank and pray to God who gave me the health and the strength to do this research

I would like to express my gratitude to my supervisors :

Asst.Prof.Dr. Basim Khalil Nile and Prof.Dr. Mohammed Abbas Aljumaili

For them advice, guidance, and constant supervision during the work of this thesis.

I would like to thank Dr.Asaad Mohamed to provide us a copy from plaxis software.

I would like to thank Eng. Sajjad Al-Ansari for his technical support .

I would like to thank everyone how support me during this research.

Abbas H.Ali

Abstract

Design and analysis of buried infrastructure like buried pipe need efficient methodology is applicable in practice. In this research, a buried GRP pipe was evaluated under dead and live loadings. The (IOWA) equation and three-dimensional finite element simulation were carried out to examine structural behavior of the GRP pipe. The 3D-finite element analyses were performed using a software package called Plaxis-3D, 2014. Three types of soil (clay, sand and silt) and two pipe diameter size (1 and 1.4) m with a fixed pipe stiffness of (10000) N/ m^2 were investigated in the analysis. Additionally, various burial depths were considered in this work. The initial depth was 2 m, and then the depth was increased at 2 m interval in each case, until maximum depth of 12 m was achieved. Plaxis 3D comparison done to ensure results is conformed to field test. Same properties of soil and pipe as input in plaxis program and comparing with field test done by author. The results compare well with those collected from field measurements, whereas the margin of error was approximately (0.5) % as diameter deflection percent. This comparison step can be adapted to model all cases with Plaxis software. The results of (IOWA) formula showed that maximum deflection of 1.4 m pipe placed in a clay soil is 5.343%. This deflection value is considered unsafe according to the standard limit which is equal to(5)% of the results also indicated that maximum deflections were 3.674 % and 3.495% for the pipe founded in sand and silt soils, respectively. These deflections were determined at maximum depth 12 m. The granular soils (silt, sand) show more stability than clay soil. According to plaxis analyses clay soil was weakest material reach maximum deflection of 2.06 %, where sand reach 1.256 % and silt reach 0.9737 %.one more time granular soils prove more stability against loading condition.

Contents

List of symbols

Symbols	Definition
(σy)eff	Effective vertical soil stress (psi)
Δx	horizontal deflection of pipe %
Δy	Vertical deflection of pipe %
AWWA M 45	American water work association code
d	burial depth of pipe
DL	direct to the long term deflection after many years because of deflection increasing the additional soil load, arching step by step decreasing due to wetting and drying times
E	modules of elasticity of soil
E'	Modulus of soil reaction
FRP	fiber reinforced pipe
GRP	Glass fiber reinforced pipe
HS-20	AASHTO wheel load dual wheel load configuration
kx	represents constrained of side support degree at the bottom of the pipe and reaction distract
L1	load width parallel to direction of travel
L2	load width perpendicular to direction of travel
PS	the product of flexural modules of elasticity of the pipe wall and moment of inertia
PVC	Polyvinyl chloride pipe
U	Pour water pressure
UPVC	Unplasticized polyvinyl chloride
W	concentrated surface load (dual-wheel)
WC	Considers the weight of prism of soil above pipe and calculate as earth cover.
WL	by assuming four lane road with ASSTHO HS-20truck load configuration with 12 ft wide lane
Ϭy	Total vertical soil stress
PS	Pipe stiffness
	represent the applied load
Δy	Deflection percent from pipe diameter
p	live load pressure
vS	Poisson's ratio of soil
HT-60	AASHTO wheel load dual wheel load configuration 32000 ibs
HS- 25	AASHTO wheel load dual wheel load configuration 40000 ibs
HS- 30	AASHTO wheel load dual wheel load configuration 48000 ibs
Cooper’s E-80	Railroad Loading

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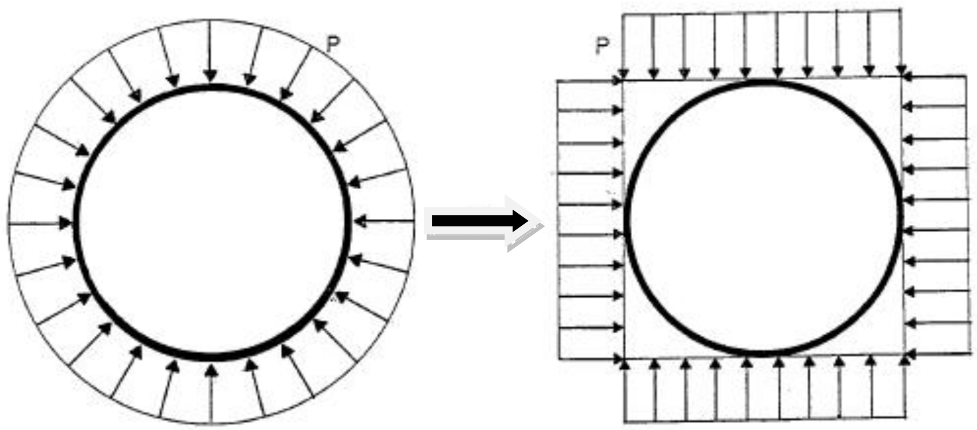
Chapter One
Introduction

1.1. General introduction

Piping system work with gravity or pressurized operating system according to use. Pipes are classified into two categories according to behavior and materials: (1) flexible pipe, and (2) rigid pipe. The flexible pipe introduced as a pipe deflects at least 2% without structural damage, while rigid pipe cannot deflect 2% without distress(Watkins and Anderson, 1999). Pipeline made from different materials and geometric shapes .Pipe serves for many purposes , such as sewer lines, water supply system, telephone and electrical conduit, highway drainage system, railway culvert, oil field and industry field(Rajkumar and Ilamparuthi, 2008)and (Prof. Dr. Mosa Jawad Al-Mosawe, 2013). Structural materials available in market for the rigid pipe are clay, cast iron reinforced concrete and reinforced concrete pipes. While, structural materials available in market for the flexible pipe are PVC, steel, ductile iron and glass fiber reinforced (GRP) (Prof. Dr. Mosa Jawad Al-Mosawe, 2013). In this research, attention will be paid for the (GRP) composite material application in main sewer line under major roads.

The glass fiber reinforced plastic pipe has ideal properties, including smoothness, high damping resistance to internal pressure, and high corrosion resistance (Chen et al., 2013). Also GRP pipe need least maintenance operation(Karbhari et al., 2003). All this properties qualified pipe to use for most infrastructure. Studies has been done to determine pipe behavior, therefore stability properties must be known to maintain the geometric shape of the pipe circular as possible to prevent leakage between joint, which cause instability under pipe with making voids in soil around and under pipe, therefore made weakness in pipe foundation. As known all flexible pipes materials need to confinement against deformations spatially for sides. To determine pipe stability, the performance limit and stress distribution around the pipe should be investigated. Figure (1.1) shows typical stress distribution around a pipe.



A=Stress distribution of pipe B= most convenient of stress distribution for analysis purpose.

Figure(1-1): Equivalent total stress distribution around pipe(Watkins and Anderson, 1999)

The ring deflection is a ratio of original diameter to deflected diameter, this parameter, ring deflection, depends mainly on pipe stiffness. The pipe stiffness is defined as an ability to resist deflections, this property is well explained and discussed in (ASTM D-2412) specification found in appendix (A).Deformation of a pipe can be neglected for most of the pipe in case of stability of ring deflection because controlled flexible pipe stability. Collapse may be occurred even stress limit not reach critical value because of ring deflection. Pipe failure related to soil strength and behavior usually the problem is indeterminate due to irregular soil properties in all directions, so that controlling ring deformation is better than control soil stress. The limitation will be maximum ring deflection. Therefore, ring stability must be defined as the ability of pipe ring to withstand external pressure, soil arching mechanism carried part of a load above the pipe.

1.2. Problem statement

Design and analysis of a flexible pipe are controlled by pipe deflection and buckling failure. Difficulty of installation and measuring field reading for each case need to find way out and immediate solution to make evaluation for structural performance of buried pipe before applied any filed condition to ensure best pipe performance (Guedes, 2009). The vertical and horizontal deflections of the pipe due to service loads are influencing pipe stability. Therefore soil above pipe will be still, this soil support road layer which also will be deformed under traffic load. This mutual effect of the soil _ pipe soil road effect will destroy infrastructure both of pipe and road layer. Also soil failure under imposed load must be considered to ensure road layer safety and protection against wearing and disintegration. For flexible pipe under main road traffic loading will be caused soil deformation if stress exceeded expectation.

1.3. Aim of research

Main idea of research is to investigate the (GRP) pipe stability by obtaining pipe deflection for different soil type using different pipe diameter and different depths due to traffic loading and gravity loading.

1.4. Objectives of the study

The main objectives of the present study are:

1. Evaluate pipe deflection under the road to keep deflection of pipe beyond risk and continue using this infrastructure to serve intended purpose by predict structural and hydraulic stability of a piping system in horizontal and vertical directions.

2. Investigate the influence of dead and live loads on road and pipe stability

3. Make finite element simulation to determine stability parameters of a pipe. Then, the FE results will be compared with field measurements.

1.5. Methodology

General overview of this study is to examine a complete infrastructure of road pipe combination with the following conditions:

1. select three type of soils (clay, sand, and silt) and calculate stability parameter deflection by using AWWA M45 equation known as sprangler formula with different burial depth of pipe (2,4,6,8,10 and12) m .

2.Build a finite element model using plaxis 3D geotechnical analysis software to simulate field conditions including: location of water table, traffic loading, distribution and type of soils (clay, sand, silt) with using same depth (2,4,6,8,10 and12) m.

Chapter Two
Literature Review

2.1. Introduction

In this chapter, a review of literature will be presented for studies related to the structural and hydraulic stability of a pipe under a main road. It can be noticed that there are no specific studies related to this research, however most of researchers join together with some related general concepts. This chapter will be contained four sections according to working methods of related studies, the first category is theoretical concept of buried pipe, second category is field testing on buried pipe , third category is numerical modeling in estimating deflection and forth section is compatibility of sewer pipe with road performance .These studies used all of this approaches in their work. Therefore it will be seen mixed of method used, for present study the methods used will be theoretical concept of buried pipe and numerical modeling in estimating deflection.

2.2. Theoretical Concept of Buried Pipe

This part explain a detailed discussion about theoretical approaches used in evaluating and predicting pipe deflection, which is considered as an indicator of pipe stability.. Most of researchers used widely known equation like modified Iowa formula or (AWWA) M 45 equation (Lee et al., 2015).

(Ch.E.,2001) studied two AASHTO vehicle design types (H20 and HT-60) with wheel load of 7.2 and 10 ton, respectively to simulate the effect of truck over loaded pipe line in low cover area with different native soil group classification with different compaction degree (80,85,90)% using numerous pipe stiffness of

(2500,5000,10000) pa to determine pipe performance under heavy live loads then determine the proper stiffness for each condition. Deflection equation was based on the modified (IOWA) equation for a flexible pipe. This equation assumed wide trench which pipe didn't feel native soil effect and compaction degree which is not reflect real behavior of soil, many researchers believe that touched trench width and backfill soil properties must be considered to ensnare the calculations result to reflect actual real condition in site. In this case (AWWA) American Water Works Association revised the deflection, new factor introduced into this equation soil support factor function of the ratio of the trench width to the pipe nominal diameter and the ratio of the native soil modulus to the backfill material modulus. In this study more than 170 cases were examined of GRP pipe with used five standard soil groups good, stable native soil to very weak unstable native soils with depth range reaching to 4 m, used pipe stiffness varying from 2500 to 10000 pa, in this study attention was paid to evaluate pipe deflection for all commercial stiffness found in market he was stat from 2500 pa with used 5 native soil type. Researcher found that 4-meter depth is good protection even with poor backfill 80% standard proctor density, were used 5000 N/m2 pipe stiffness calculation shows that if 7-meter depth used this pipe withstands in worst native soil used (group 5) found in Appendix (A). Author cheek performance 10000 pa stiffness pipe with different degree of compaction from 80 to 90 % calculation shows that it can be withstanding even worst native soil used (group 5) if burial depth was 10 m. The researcher reaching result for the depth those live loads considers not very important to use high stiffness pipe to develop the pipe performance because the distributed load area is enough to support the pipe stability and protects the pipe from high deflection percentage. For given load (HT-60, H-20) calculation show that the cover depth from (1-1.5) m is good enough to support a low stiffness pipe usage in sandy soil backfill materials.

(Olliff et al.,2001) analyzed a pipe soil interaction as a strip foundation component to avoid the mistake of uniform pressure distribution assumption. This approach presented by (Olliff et al., 1994) involved calculation of vertical soil loads and predicting settlement by "common European method" some steps of this method (Spangler based methods). Pipe depth is specified method of analysis. A case study was taken for GRP pipe worked as intake pipe line in pump house, the embedment soil was a sandy silt with maximum pipe depth up to10 m .Field investigation was performed through making 7 boreholes. Various types of soil cases have been invastigated from loose to very loose and soft to very soft. These cases provide several wanted geotechnical properties for pipe installation.

GRP pipe installed was 2.7 m diameter with 12m length stiffness of pipe was 2500 N/m^2 with wall thickness of 0.030 m the ground setelment was 0.030 m for 2 meter cover at distance of 36 m from intake wall, increasing to 0.090 m for 6 m cover. Researcher used finite difference analysis used FLAC 3D software. Analysis of settlement value result settlement value of 0.129 m. As a conclusion pipe line design procedure not take into account the under estimating of soil mass, pipe, structure. Failure of old pipe line is more significant factor in new pipe line failure.

(Francisca and Redolifi, 2003) examined collapsible soil in Argentinean country. Effect of weak soil modules due to low soil stiffness is recognized, when soil is wet. The work was done by increasing backfilling by using cement treated soil. In this study, the analytical approach used to compute pipe deflection was based on Marston-Spangler's formula. This equation does not include soil saturation or collapse. Presentation of pressure distribution inefficient, while finite element presentation allows simulating soil and logical pressure distribution. Model used to simulate this case will be found in figure (2-1) .trench depth was (3.25) m with compacted soil 0.25 m as pipe base. Diameter of installed pipe is (1 m). Depth of pipe is 2m from pipe top. Refill with soil cement mixture or natural soil applied surface load 100kps at area of load 2 m one meter each side. Using ratio of trench with to pipe diameter 2, 3 and 4 used three pipe materials steel, FRP and PVC.

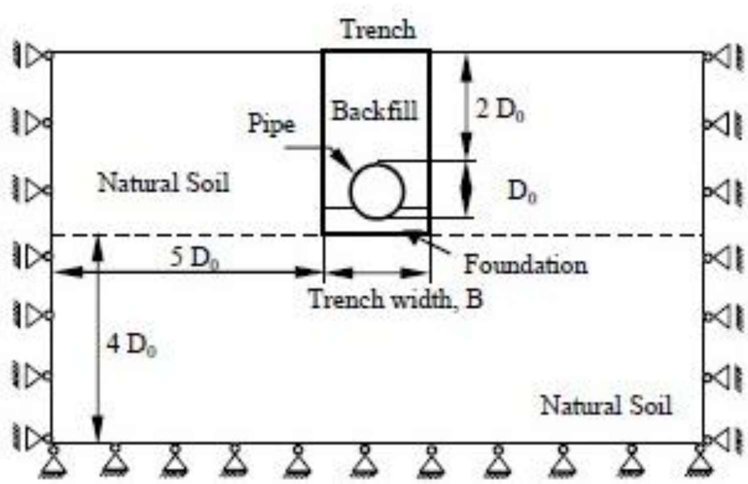


Figure (2-1): soil pipe model (Francisca and Redolfi, 2003)

resualt shown that deflection increase when soil stifness decrease by water effect on soil .type of pipe materail also effect on pipe deflection when soil is wet were steel pipe shows higher deflection valuse 0.2% , FRP reach 0.15%and PVC pipe shows more stabel pipe reach 0.1 % as deflection percent . pipe deflection can be decrease if trench wide engouh or used harder backfill material with high elastic modulus, deflection value increase when cavity form under pipe.

(Kraus et al., 2011) performed calculation model used for axle load (AASHTO –H20) 7.2 metric ton wheel load and (HT-60) 10 metric ton wheel load in his work to simulate the effect of truck over loaded pipe line with small pipe cover area, various native soil with different degree of compaction (80,85 and 90)% have been used. Also, numerous pipe stiffness have been used is (2500, 5000 and 10000) N/ $m^2$to determine pipe performance under heavy live loads, and then identify a proper stiffness for each condition. The researcher reaching result for the depth that live load consider not very important to use high stiffens pipe to develop the pipe performance because the distributed load area is enough to supported the pipe stability and protects the pipe from high deflection percentage . For given load (HT-60, H-20) calculation show that the cover depth from (1-1.5) m is good cover to supported low stiffness pipe usage in sandy soil backfill material in this study various load combination has been examined HS-20 , HS- 25 , HS- 30 figure(2-1),also different compaction degrees has been used 85, 90, 95% based on AASHTO standard compaction , using three pipe materials PVC, ductile iron and vitrified clay of 0.60 m diameter, cover depth using is 1, 1.5, 2, 3, and 6m (Kraus et al., 2011). .

Figure (2-2): AASHTO standard load configuration (Kraus et al., 2011)

For axel load HS- 25, HS- 30, the different between H, HS symbol is the number of axel as shown in figure (2-2) where H contains only single heavy load, while HS contains 2 heavy axel with same weights. The analyses were done using Iowa formula, plaxis 2D and 3D simulation. CANDE program was also used to calculate pipe deflections.

The results showed that there higher damage ratio occurs in PVC pipe (1.7)% , (1.6)% for ductile pipe and lower damage ratio (1.6)% for clay pipe . Several affecting factors, the most affected factor is axle weight, three HS configuration: 20, 25, and 30. It was also found that the damage ratio of deflection increase with increasing axle weight. Also cover depth effect on pipe stability where this study examined depth 1, 1.5, 2, 3, and 6m. Damage ratio for pipe deflection increased when small cover depth used, therefore suggest (0.9 m) minimum depth cover to satisfy 5% pipe deflection ratio. Pipe material and wall thickness were significant factors that effect on stability, case study was taken in Hawaii, three pipe materials as mentioned above 0.6m pipe diameter with a cover depth of 0.6 m. It was seen that damage ratio decrease when material used changed from PVC to ductile iron to vitrified clay. Backfill compaction degree was discussed by taken 0.6m PVC pipe buried 0.660 m underground and examined compaction ratio 95, 90, 85%

from laboratory density resulted by proctor test. From this data, it was found that pipe's deflection decreases with increasing the compaction degree of the soils.

(Bryden et al., 2014)exploit two methods to compute the stability parameter of the pipe. These theories are: (1) simple ring compression theory by (Watkins 1975). (2) Gumbel's solution (1983). The work was done by using centrifuge facility ready to test 0.150 m pipe diameter with using strain gage illustrated in figure (2-3) embedded in a sandy soil. The pipe was divided into five zones including: (crown, shoulder, spring line, haunch and invert) as shown in figure (2-3) below.

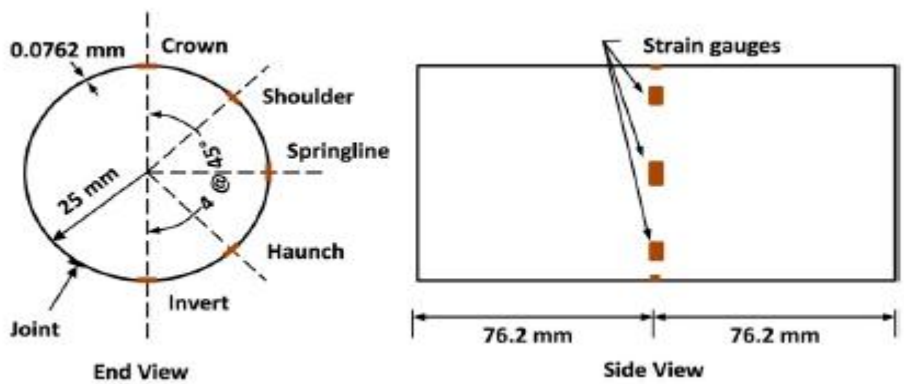
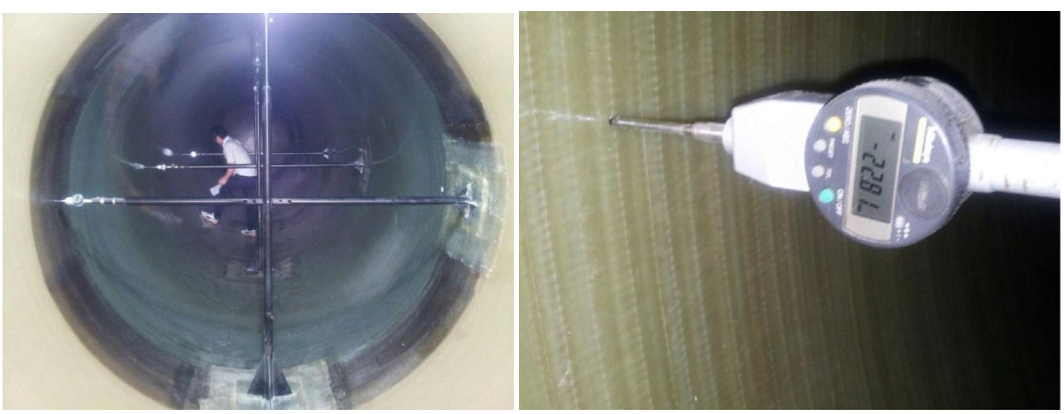


Figure (2-3) : Model pipe with strain gauge**(Bryden et al., 2014)**

The simple ring compression theory considers compression stress only and no bending moments. Gumbel (1983) calculates thrust and bending moments in a flexible pipe. The work was done by using same parameter of soil and pipe to calculate the stresses in each zone of the pipe using these two theories and comparing the result with a model in centrifuge facility. The cases used are full slippage interaction condition of soil pipe and no slippage of soil pipe interaction. The result showed that the measured bending moments is greater than the calculated moments in all cases of slippage condition of soil pipe interaction at ratio of (30-35) %. It was also found that a cover diameter ratio is an important factor to distribute surface load area; therefore the stress will be smaller when the cover diameter ratio is more than one time. The control part of pipe is the crown because this location carries most of the load ratio. The stresses of the pipe are distance dependent function from center line of the pipe, whenever the load move more than two times the pipe diameter the load effect will be un risky .

2.3. Field Test of Buried Pipe

It is necessary to explain exactly what is meant by field testing for pipe stability. its mean that measured deflection record to evaluate exact value of deflection with pipe working under live load and service condition .Most studies go to model real pipe case with instlation of dail gague as shown in figure (2-4).



Plate(2-4): Field test measurement terminology(Kim et al., 2012)

(Faragher et al., 2000) Examined six types of flexible piping system. Native soil is relatively flat stiff native soil was found consist of gravely clay occasional cobbles (boulder clay) .Ground water level was under trench bottom. Pipe diameter investigated was 0.6 m and 1.050 m diameters because this diameter most used in (U.K). Trench width for 0.6 m pipe was 1.200 m and trench for 1.050 m pipe was 1.6 m wide. Pipe cover depth1 m. Backfill material used was well-graded angular crushed rock. This system installed under haul road which consists of 0.25 m sub base layer placed on sub grade with geotextile to reduce lateral deformation .Two different surrounding materials were used gravel and sand. After pipes installation, a repeated load imposed by tractor towing a two-wheeled trailer, selected because its ability to travel slowly, measured axel load of vehicle was 108 kN, wheel load 54 kN , contact surface area was (450 × 290) mm contact stress generated by this vehicle was 413 kPa., and travel speed was (0.9 km/ h). Linear potentiometer figure (2-5) at top of each six pipe to read vertical diametral strain (VDS) change in noticed diameter (deflection), vehicle was pass 1000 times above each pipe. From felid measurement data it was fond that maximum deflection value measured was 4.32% for HDPE twin wall annular-corrugated pipe the second deflection value was for PVC-U smooth profile pipe single wall, consider safe value. From this study, it can conclude that sand surrounding material is more proper than gravel in installation process for low stiffness pipe. It can be installed with using sand around pipe with proper compaction which can be produced negative deflection useful for resistance positive deflection in loading stage. This explained low deflection for U-PVC when used sand surrounding material 0.48% even used same pipe material and relatively same stiffness for surrounding material.

Plate (2-5): Linear potentiometer for displacement measurement

(Arockiasamy et al., 2006) Presented a full scale test of six flexible pipes. Pipe material was PVC, HDPE, aluminum pipe and steel pipe. Pipe length was 6.1m. Diameter used was 0.9m and 1.2m; three of 0.9m pipe was tested at depth of 0.5 ×diameter and 1× diameter, and 2× diameter which is corresponding to0. 457, 0.914, and 1.829 m for 0.9 m pipe diameter and 0.610, 1.219, and 2.438 m 1.20m pipe diameter. Trench width limited to be 1.5× diameter plus 0.305 m, with 0.152 m bedding layer at the bottom consist of 0.019 m crushed limestone. Backfill was poorly grade sand. Maximum axle load was 154 kN for 2D depth, 72 and181 kN for 1×D and 0.5×D this is for 0. 9 m pipe figure (2-6), for 1.2 m pipe maximum axle load was142, 166, and 177 kn. Linear variable differential transducers _LVDTs_ were installed thought installation of pipe in order to measure vertical pipe deflections when imposed live load of truck figure (2-7). Also pressure cells have been installed above the pipe on different elevation of backfill, the results of pipe deflection showed that deflection value increase during placement and compaction of backfill soil. Deflection values were approximately 0.2, 1.1, and 0.5% for the steel, aluminum, and HDPE 1.20m, respectively. where deflection after repeated load measured was 0.6%, as a conclusion addition of 0.152 m cover over pipe crown reduce soil pressure twice to three times.

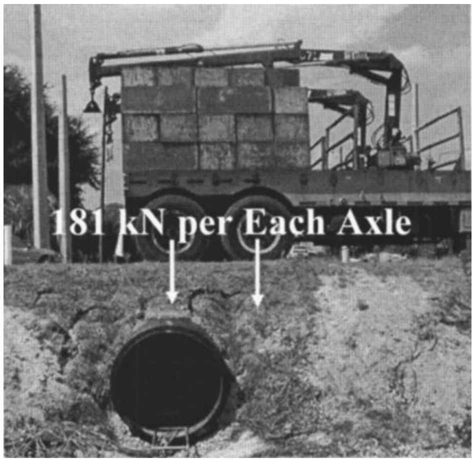


Plate (2-6) :Applied axle load in felid (Arockiasamy et al., 2006)

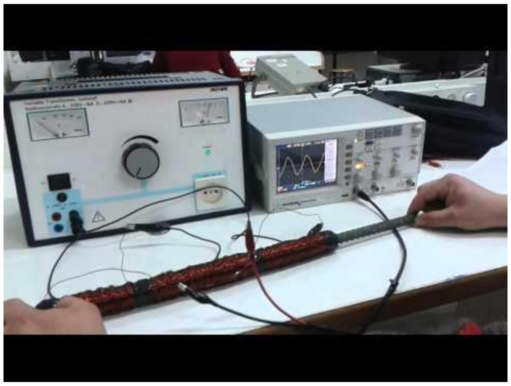


Plate (2-7): Linear variable differential transducers used to read deflection(Arockiasamy et al., 2006)

(Kim et al., 2012) investigated various pipe ,the first part is by setting some variables such as 2.40 m pipe diameter with variable depth ,compaction degree (95%) ,for different time using dial gauge to read the vertical and horizontal deflection in different locations of the pipe line. The second part of the study was testing 4 specimens of GRP pipe that have a diameter of 1.5 m and length of 0.3 m to find pipe stiffness at 5% deflection and failure load deflection value. The third part was to obtain long term ring deflection by the method adopted by (ASTM D 5365) to predict long term deflection in this technique the strain and deflection is measured with elapsed time with large scale of readings and making regression analysis. Installation process is shown in Figure (2-8). Field test of deflections value which measured in three different location of the pipe, in the edge and center of pipe, where the result of vertical deflection was at range from 2.37% to 4.00%. Horizontal deflection range was from 2.24% to 2.72%. Vertical and horizontal deflection measured at pipe center was the largest value, less than at edge because of double thickness in connection zone. Ring deflection measured until 218 days of loading condition.

Plate (2-8): installation of pipe in site(Kim et al., 2012)

(Lee et al., 2015) Studied the installation of 2.4 m diameter pipe, with good compaction degree. Each layer 0.3 m at depth (5,10 and 16) m .Set up dial gauge to read horizontal and vertical deflection at multiple locations .For a period more than one year to know the effect of age loading relationship and stress relaxation effect then comparing with analytical solution of (Iowa) formula. From the results measured in filed the deflection of pipe become constant after 10 days of loading and testing condition .The vertical deflection almost equals to horizontal deflection according to (Iowa) formula .The compaction degree and backfill materials is significant variables to deflection value. The result of this study is listed as flow: The value of deflection in (Iowa) formula is over estimated with respect to field test the predicted long-term ring deflection is safe value for this case study condition not exceeding the standard allowable value of deflection for next 60 years by using shift factor method.

2.4. Numerical Modeling in Estimating Pipe Deflection

When field test is difficult to apply for buried pipes such as in design and checking stage, it is reasonable to performs a simulation process by one of finite element modeling program Plaxis 3D, CANDE and ANSYS. These programs give reasonable estimation of stress-strain generated in buried pipes, and have been used lately for these purposes, numerical solution is significant indicator for any physical problem specially engineering problems because the comparison between field and numerical approach is close for most of engineering case study, therefore many researchers go to use numerical analysis with using computer programs to simulate the original case. Some the studies used this model will be presented as follow.

(Sargand and Masada, 2000) Performed finite element analysis using CANDE-89 analysis software which considers spatial edition of original program CANDE with few added feature. The program generating 2D mesh that can simulate half the problem ,see figure (2-9) which shows trench condition, backfilling, native soil and boundary condition of the entire problem. Also, explain material used to backfilling and bedding.

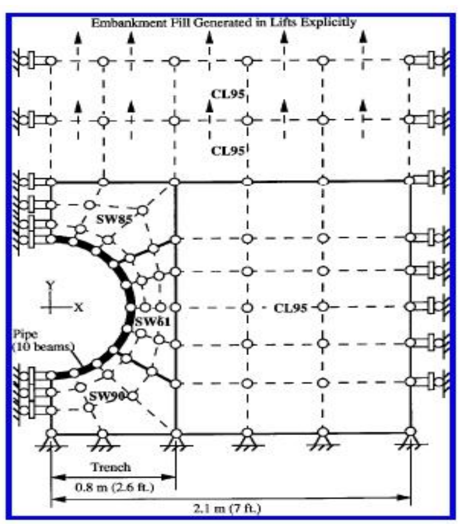


Figure (2-9): Half mesh case used for analysis stage(Sargand and Masada, 2000)

Soil types used shown in figure (2-14) denotes soil used in model. Were sand well grade SW surrounding pipe. Native soil was clay low plasticity (CL) as backfilling material. Re backfilling above pipe bedding with clay low plasticity, unite weight of (SW) 90 was 17.3 kN/m^3, SW61 unite weight 14.2 kN/m^3, unite weight of SW 85 was 15.7 kN/m^3 unite weight of clay was 20.4 kn/m^3. This soil parameter is standard soil model in *CANDE-89* program. HDPE pipe were used with 1and 0.7 m pipe diameter, wall thickness0.0 479 m, trench width 1.58m, depth over pipe backfill 2.1m, total depth 15.9 m, modulus of elasticity for pipe 257.8 mPa, Result of finite element solution was less than 2%as deflection percent from original diameter when comparing with field test data measured.

(Babu and Srivastava,2010) carried out a numerical analysis using FLAC5 finite difference code for 1.4 m diameter flexible pipe system. Elastic-perfectly plastic, Mohr-Coulomb model have been used to represent case study. The pipe was simulated as a structural beam material assuming an elastic material, full-bound buried with flowing condition, trench width = 1.8m, height of backfill was 3.4m and pipe wall thickness was 0.006m. , trench shape and pipe terminology shown in figure (2-10).

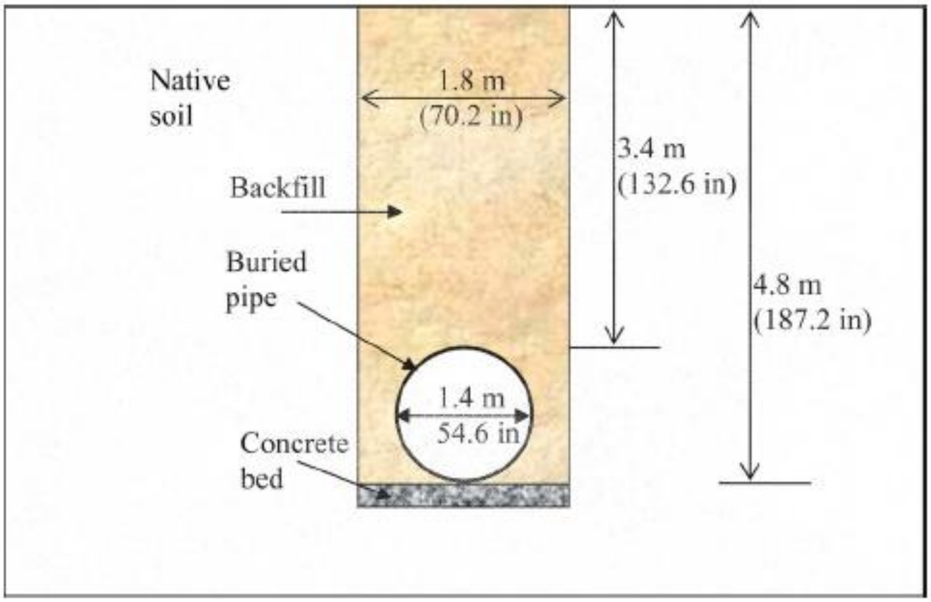


Figure (2-10): geometric detail of buried pipe(Babu and Srivastava, 2010)

a soil with a unit weight of 20 kN/ m^3, modulus of elasticity was $6.770 * 10^6$ Pa, Poisson's ratio equals to 0.34, cohesion was 5.0 kPa; friction angle was 30˚, modeled using Mohr-Coulomb failure condition. Backfill materials have 16 kN/m3 unit weight, 2.39×10^6 Pa modulus of elasticity, Poisson's ratio υ = 0.21 friction angle was 26˚. When finite difference model was run result was 1.2% as a pipe deflection from original diameter which considers safe value with respect to standard value. Soil arching factor help flexible pipe to decrease deflection by 20%.

(Akinay and kilic, 2010) Introduced a numerical analysis of buried flexible pipe, PVC and HDPE pipe using Plaxis 2 D. Six pipes were considered in this analysis, where backfill height was 6.1 m for two of this pipe and the other one was 12.2m. Soil was modeled as hardening soil model and Mohr–Coulomb soil model. Flexible pipe modeling and simulation was tunnel structure figure (2-11) interface between backfill and native soil assumes to be rigid. Also interface element between pipe and backfill to be semi rigid. First layer of embankment with thickness of 0.92m compacted with sheep foot roller. Other layers to be 60 cm compacted by light weight construction compactor. Time need to reach 6.1 m was 32 days, time for finish all embankment work 12.2 m was 38 days. Native soil stiffness was used in analysis various from 5000 kPa – 20000 kPa, to simulate effect of different native soil stiffness.

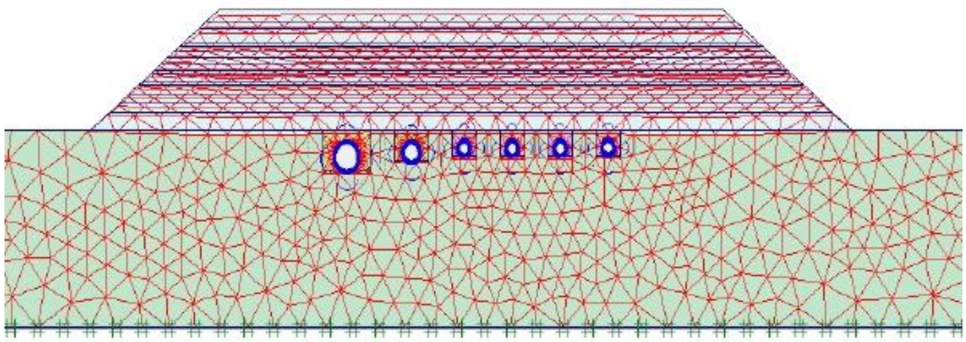
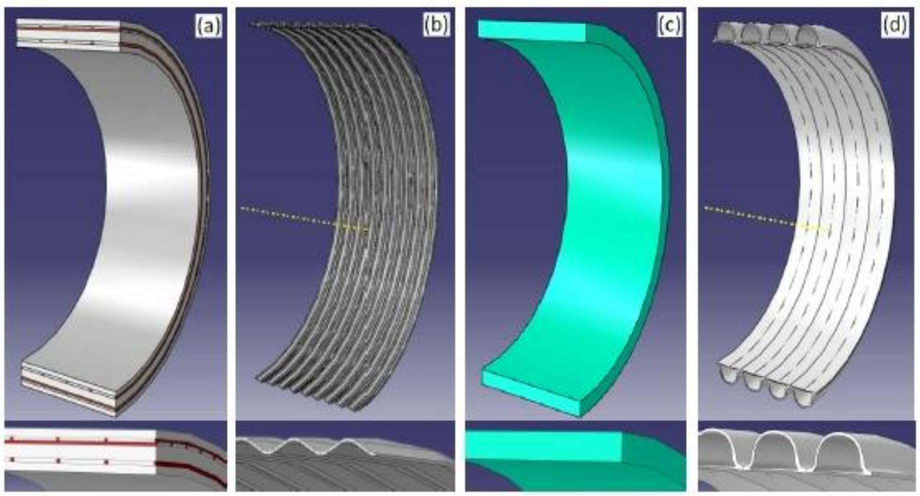


Figure (2-11): Finite element mesh for tunnel case(Akinay and Kilic, 2010)

Result varied according to elastic modulus of soil, where result of case one with low stiffness 5000 kPa was eliminated because value larger than field test value, case two with 20000 kPa modules, consider two small, it can be say that case one is most compatible case with field test result.

(Barbato et al., 2010) Performed 3D finite element analysis by ABAQUS software. Four types of pipe materials, reinforced concrete pipe, steel pipe, (PVC) pipe, and HDPE pipe were simulated and analyzed, see figure (2-12). Trench simulation is illustrated in figure (2-13).



Pipe profiles: (a) RC pipe, (b) steel pipe, (c) PVC pipe, and (d) HDPE pipe

Figure (2-12): Pipe material used in analysis(Barbato et al., 2010)

Pipe diameters used in this study were 1.07and 1.5 m. For each pipe material cover height was 1.07 m for reinforced concrete pipe and 1.07 m for steel pipe. Other types were 1.5 m. Result for steel pipe 1.07 diameter was 0.33% as deflection percent. For 1.5 m diameter was 0.339% as deflection percent. For PVC pipe 1.07m diameter actually neglected. But for 1.5 m diameter deflection was 0.3411%. HDPE 1.07 m pipe indicates 0.334%. For 1.5 m diameter deflection value reach to 0.238%, for RC pipe material consider rigid pipe resulted deflection can be neglected.

Figure (2-13) : sub region in finite element model(Barbato et al., 2010)

(Bryden et al., 2014) investigated finite element approach with assistance of plaxis 3D program. By dividing the pipe two symmetrical section vertically allocate of five nodes as shown in figure (2-14) .simulation of this case near to the centrifuge facility used in this study. The boundary conditions of the case stady used in the plaxis code are: 30 m from each lateral direction ,30 m from ground surface with pipe length of 20 m , two cover diameter ratio have been used (C/D= 0.5 and 1.0). Pipe material used was FRP with with flexural rigidity EI 1.582 kN×/m^2, axial rigidity EA 7.8* 10^7kN/m, and Poisson's ratio 0.3. These values are typical for very flexible pipes(Bryden et al., 2014).

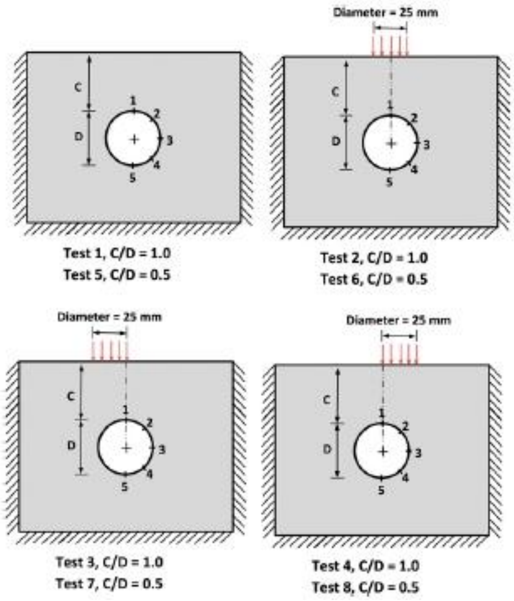


Figure (2-14): Test configurations(Bryden et al., 2014)

Dimension selected so that the converging analysis become between centrifuge facility and finite element code .The program used more than 435000 element to simulate the case . as a resualt soil arching factor computed by incresed ablity of pipe to supourt the load and recomanded method is Gumbel's approach to evaluate arching factor of soil . effect of load disperd when distance of load 2×Diameter of pipe .

2.5. Compatibility of Sewer Pipe with road Performance

Performance of infrastructure is related with operational circumstance. For infrastructure under study important to study mutual effect on each other. This is exactly the idea of current study and how to connect effect of performance failure to perform the function as required of each infrastructure. This reason presupposes study of structural performance of buried pipe to examine pipe stability. For condition of pipeline examined in current research there is no structural failure, however if failure is found in pipe line, the defect will influence on road stability and safety(Kuliczkowska, 2016). The most defect of pipe line is excessive deflection. Different sewer defects can be attributing of road failure or damage. Figure (2-15) shows defects named (Kuliczkowska, 2016). This damage or defects of buried pipe with numbering each defect type.

Figure (2-15) :example of pipe defects(Kuliczkowska, 2016)

(Kuliczkowska, 2016) Most defects harm pavement structure those related to leakage of a pipe. The probability of pavement damage terms of size and type of sewer defect. Buried pipe defect has a series of consequence on road serviceability index and safety for road users, see Figure (2-16). These consequences provide calibration values to covers eleven factors (f = 11). These factors are explained as diameter of a circular, sewer burial depth, type of soil over the sewer, sewer function, water table level, road type, intensity of road traffic, land use, backflow or overflow of wastewater, access for repair and environmental impact(Kuliczkowska, 2016). The factors adopted in this analysis are classified into five categories according to their effect on road serviceability:

1 – Negligible

2 – marginal

3 – considerable

4 – Serious

5 – Very serious

Figure (2-16) road consequences by pipe defects(Kuliczkowska, 2016)

In present study, there are some theoretical rules that must be followed according to operational conditions of road and sewer system in order to maintain a stable infrastructure and predicting failure before period of time, as well as to prepare the infrastructure for proper maintenance operation. These rules help infrastructures developers to think about future maintenance

Pipe deflection under road layer is one of the major factors affected road stability. In this chapter, the pipe deflection and the factors effect on it were discussed in details. It will be used deflection values obtained from this study from AWWA formula and plaxis simulation. Deflection value more than 2% will be used because this value presented limitation of initial deflection of pipe (Veritas, 2008, Watkins and Anderson, 1999, Moser and Folkman, 2001) .

Traffic loading has significant role on road and pipe line stability because of large effects. Traffic load larger than HS-20 will be considered because of this configuration has moderate effect on pipe and road infrastructure as examined before in this chapter.

Pavement deformation has a significant role on infrastructure stability because the failure effected on pavement layers subsequently effect on pipe stability. Even the pipe deflected but within limitation still stable if deflection percent no exceed 5 %, but when pavement surface has cracks. The cracks will allow water to enter through soil composition, and thus washout operation occurs and pulls fine material from a soil structure creating cavities which lead to collapse pipe line and pavement structure.

Traffic volume concentration dependent on vehicle speed. For low speed section it was noticed larger damage amount on pavement surface and under layer system. Low speed concentrate loading over small area cannot withstand. For speed less than 24 km/hr. damage will be large(Huang, 1993).therefore low speed section need to be protected from high load density . Concrete protection and georgride can be used or transfer pipe direction to gutter zone .In Iraq these problems appear in intersections (nodes) and main entrance cheek points.

2.6. Concluding Remarks

From previous studies listed in this chapter, it was noted that there are several methods used in calculation and evaluation method of deflection. Most papers used empirical or semi-empirical equations like Iowa formula together with field test, finite element and finite difference solution or three approaches together. Regarding to field test if applicable some cases researchers cannot cover this part spatially in design stage. Most accurate and appropriate method to find out stress parameter is filed test. About empirical method used consider acceptable credibility for design stage and it works for this purpose with giving a good indication and high safety factor as reviewed high predicted values by this approach. Finite element evaluation considers convenient practice with possibility of representing water effect of soil, elasticity of materials and make need modification to avoid such problem appear in analysis and design stage. Deflection values obtained from finite element simulation were lower than those recorded during field tests. Sometime results greater than field test result. This is controlled by modeling methodology, model size, and a number of elements used and accurate in modeling field condition.

Chapter Three
Theory of Pipe Deflection

3.1 Introduction

In this chapter, considerable methods to compute pipe deflection, factor influencing pipe deflection will be presented also two methods to predict deflection will be performed and compared to each other. The first method is Spangler's Iowa formula (1941) which is known as AWWA M4-5 equation. Second method is finite element approach with aid of computer program (PLAXIS 3D 2014). Figure (3-1) describes deflection concept. As known deflection items measured as ratio from nominal diameter and comparing with standard limit, which it reaches 5% of pipe diameter for flexible pipes (Buczala, 1990, Watkins and Anderson, 1999, AWWA, 1995).

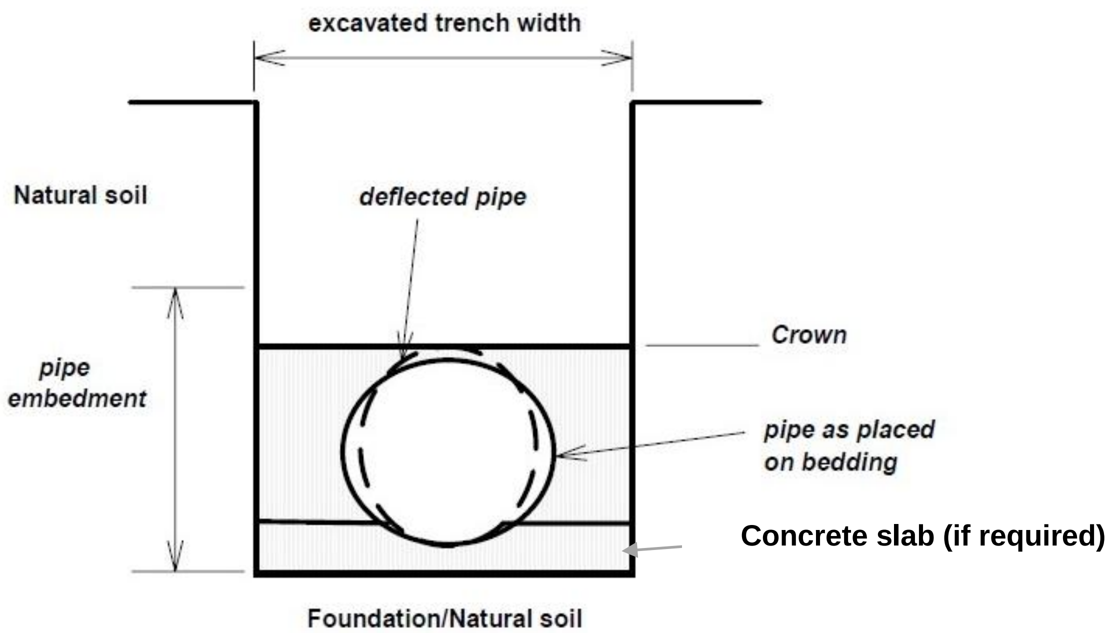


Figure (3-1): Deflection of pipe terminology(Moser and Folkman, 2001)

3.2 Deflection Theory

Pipe stability is represented by ring deflection which means the change or decrease in vertical and horizontal diameter of the pipe due to earth load and external load (Watkins and Anderson, 1999, Moser and Folkman, 2001) . Deflections depend on some factors like stiffness and type of pipe material, live load side support, degree of side support constrained, soil stiffness ,depth of excavation and trench width . The deflection divides into two stages initial deflection and long-term deflection. The initial deflection occurs when the backfill road layer and pavement complete, while long-term deflection defines as the value of deflection after some years of the design age of the structure installation. Initial deflection may be equal twice or more times long term deflection.

3.3. Factors controlling pipe deflection

Pipe stability is influenced by various factors of infrastructure combination of road pipe terminology. This mutual effect happened between layers of pavement and pipe surrounding materials affected each other along service life of infrastructure therefore understanding of these factor helps to simplify problem and find best methods to solve.

3.3.1. Installation method

Engineering codes provide standard methods to install general pipe materials and (GRP) pipe included in these methods. Where installation method must be appropriate for a selected pipe. Any method passing through three stages, trench preparing, digging, pipe embedment, and final backfill reaching natural soil surface. Differences in installation modes in embedment layers, materials used in embedment zone and trench width(Hovland and Najafi, 2009). Installation methods found marked as a class (A), class (B), class (c) and class (D) will be found in appendix (A).

Each step of pipe installation has significant impact on the pipe stability. It will be discussed each factor effected pipe deflection started with dimension of trench controlled load intensity on pipe. When trench is narrow load is so large when trench is wide load is less. The weight of soil prism reduced by friction of trench wall, trench width must be able to initialize and aliens pipe line. There is minimum width required for proper soil distribution around pipe. Other factor is cover depth when soil cover decrease over pipe line pressure over buried pipe is contracted and reaches high and unexpected values. If soil cover is not enough according to manufacture code, an excessive damage will happen. Pipe depth is important because distance of traffic load influence from contact area to spring line of the pipe. Pavement structure remain constant in construction stage, but when pipe placed in liquefied soil the minimum cover depth to prevent floating equal to pipe diameter with soil density must be more than critical density of soil. Flotation is an important issue for stability of pipe. Installation condition of this research will be included in appendix (A).

3.3.2. Mechanical properties of pipe

Pipe material used in present study is (GRP) pipe because most local pipe materials used for trunk purposes. Mechanical properties and strength parameters of flexible pipes have a large effect on the pipe stability and its performance. These properties represented by tensile, flexural strength, specific gravity, compressive strength and pipe stiffness. Most important property effecting pipe deflection is pipe stiffness. The stiffness is defined as the load applied on top of pipe to generate deflection percent (5%) from original diameter(Buczala, 1990, Watkins and Anderson, 1999).Stiffness depends on pipe wall thickness and mechanical properties of pipe's material. In this research pipe stiffness used is (496 kPa). Stiffness of pipe can be calculated as:

$$\mathrm{ps} = \frac{\mathrm{f}}{\Delta \mathrm{y}} \qquad \text{…….. (3-1)}$$

Where

ps: Pipe stiffness kPa

f : represent the applied load (kN)

Δy : Deflection percent from pipe diameter for unite length. This operation done by test named parallel plate load test according to ASTM (D2412) included in appendix (A).

3.3.3. Total applied load

As known buried pipes carry two types of loadings: (1) dead load represented by soil prism load and (2) live load represented by traffic load imposed above road surface by axle load. Details of that load are explained below.

3.3.3.1. Dead load

Many problems happen because of the soil failure due to excessive dead loads. (Suleiman, 2002, Watkins and Anderson, 1999) . For flexible pipes, vertical load makes ring deflection with a large effect on horizontal soil support pipe laterally. The soil load is calculated by multiplying a soil density by depth of the soil layer.

3.3.3.2. Live load (traffic load)

Imposed live load is important factor controlling pipe stability and deflection because of large effect and damage produce for road and pipe infrastructure. There are many load configurations used for road way design and analysis, where (AASHTO) standards adopted truck live load configurations like HS-20, HS-25 and Cooper's E-80 and other large number of truck live load configurations. Most live load used to evaluate pipe performance and stability is HS-20(Moser and Folkman, 2001, AWWA, 1995), see figure (3-2). In this work, HS-20 truck configuration will be used for analysis of pipe performance and stability.

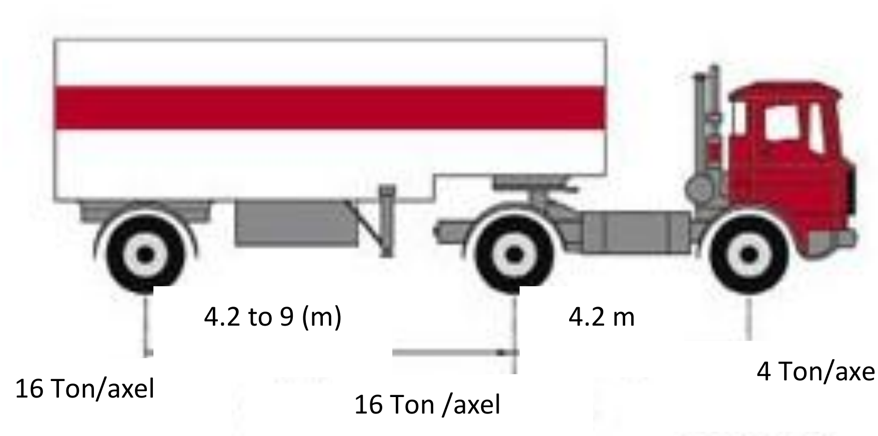


Figure (3-2) :HS-20 truck load configuration(Huang et al., 1984)

This configuration acting on pavement and soil layers is a rectangular area which has dimensions of (0.50×0.25) m , see figure (3-3). AASHTO standards adopted procedure to calculate distributed load area above pipe depth. (AWWA, 1995) the equations below describe how to calculate loading area.

$$L1 = (0.83 + 1.75\ H) \quad \text{........ (3-2)}$$

$$2\ \text{ft.} < H < 2.48\ \text{ft. Then } L2 = (1.67 + 1.75\ H) \quad \text{........ (3-3}$$

$$H \geq 2.48\ \text{ft. Then } L2 = (43.67 + 1.75H)/8 \quad \text{........ (3-4)}$$

Where

*L*1= load width parallel to direction of travel (ft.)

*L*2= load width perpendicular to direction of travel (ft.)

H = burial depth of top of pipe (ft.)

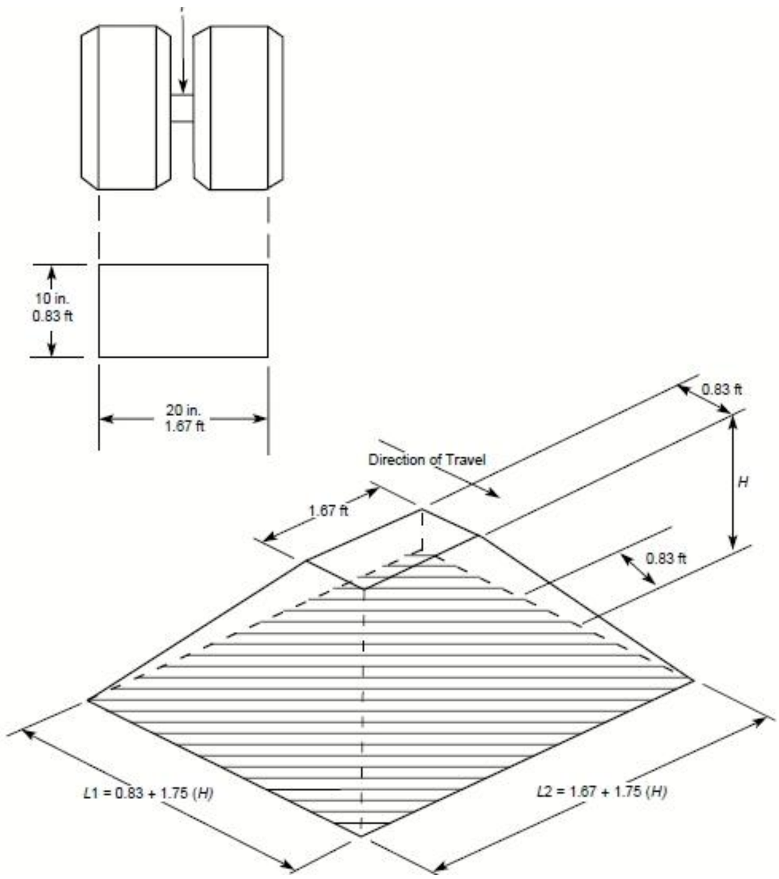


Figure (3-3): distributed live load of HS-20 configuration(AWWA, 1995)

For present study, distributed area reaching pipe for 2m burial depth as shown below.

L1=0.83 + 1.75× 6.561=12.312 ft. =3.7 m

For L2 using equation (3-4) because burial depth >2.48 ft.

L2 = (43.67 + 1.75×6.561)/8 = 6.873 ft. =2.06 m

Follow this proceeded to evaluate rest of burial depth distributed area from 2 to 12m result as shown in table (3-1). Noticed that this procedure applies to four lane road (lane's width is 3.7 m) and for HS-20 configuration only whatever pipe direction in site installed.

Table (3-1): Distributed live load area for HS-20 truck dual wheel configuration

Depth of burial (m)	L1 (ft.)	L2 (ft.)
2	12.31	6.87
4	23.79	8.32
6	35.27	9.76
8	46.75	11.19
10	58.23	12.63
12	69.71	14.06

Whenever pipe buried deeply load and stress reaches values less than shallower depth. Minimum cover calculation is necessary to limiting live load effect on top pipe. Pipe damage will be occurring because truncated cone is punched through soil so that pyramids used to evaluate punching effect of load figure (3-4). Pyramids presented as pedestal support pipe from contracted load equation (3.5).

$$p = \frac{w}{(B+H)(L+H)} \qquad \text{……….} (3.5)$$

p =live load pressure (kPa)

W = concentrated surface load (dual-wheel) (kN)

H = height of soil cover over the top of the pipe (m)

B= 0.180m, L=0.560 m. for HS-20-wheel load dual wheel load configuration.

It can be solve the same equation (3-5) for (H) to find critical soil cover above pipe or named minimum cover by setting stress value(Moser and Folkman, 2001). When soil cover decrease over pipe line pressure over buried pipe is concentrated and reaches high unexpected values if soil covers not enough according to standard specifications and manufacture recommendation. Excessive damage will be happening. Traffic load also effectively relative to depth of pipe and soil cover, pipe depth is important because distance of traffic load influence from contact area to spring line of the pipe. For pavement structure road remain constant in construction stage.

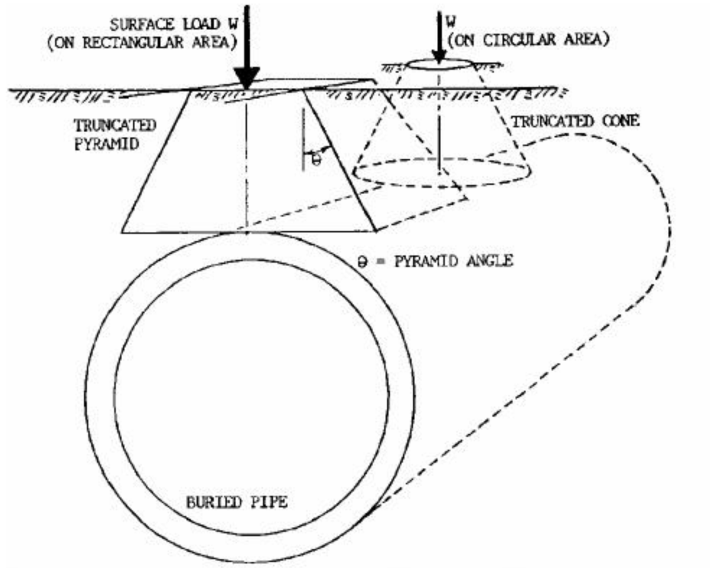


Figure (3-4) :Stress distribution of truncated soil pyramid on pipe (Moser and Folkman, 2001)

Resultant of this work dead load increasing with burial depth increment conversely for live load is lees with deeper burial depth of pipe figure (3-5) shows distributed of live and dead load above pipe.

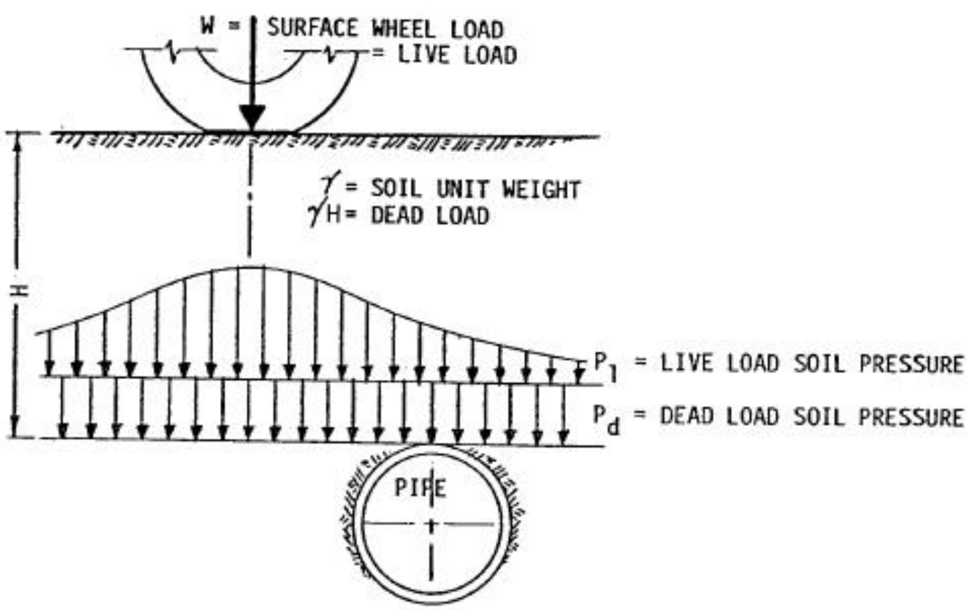


Figure (3-5): Live and dead load distribution on pipe(Watkins and Anderson, 1999)

3.3.4. Water table effect and hydraulic stability

Buried pipe usually placed at depth below ground water, see figure (3-6). In this case, a flotation may occur; therefore a high soil cover helps to stabilize pipe weight against uplift pressure produced from the water table. Water problem typically occurs when excavation performed below water table. A concrete slab is often used to stabilize pipe line with or without anchors and may be with straps in granular embedment pipe zone(Moser and Folkman, 2001). In addition, when bouncy force exceeds pipe weight there is limitation to pipe flotation by setting up minimum soil cover at least H= D/2 (Watkins and Anderson, 1999) ,but soil density must be greater than critical density for safety reasons (Moser and Folkman, 2001).set minimum soil cover equal to H=D .Side fill strength is effective strength equals to

$(\sigma y)ef = \sigma y - U$ …….. (3-6)

Where

(σy) eff= Effective vertical soil stress (kPa)

σy= Total vertical soil stress (kPa)

U= Pore water pressure (kPa)

In this research, it will be assumed a worst case which is an empty pipe neglect water weight inside the pipe. This makes the pipe less stable against flotation.

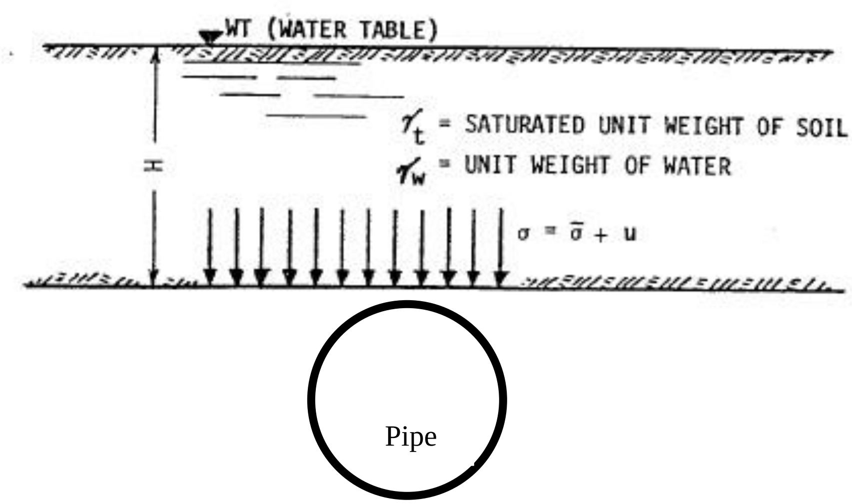


Figure (3-6) :Water load distribution(Watkins and Anderson, 1999)

When used fine grade material to fill hunching zone or initial back fill with water seepage fine particles can immigrate into course particles downward. In this case pipe support will be lost and the downward flow can wash trench wall fine material to the course grained. Pipe placed in liquefied soil in which water table is above pipe minimum cover necessary to prevent floating figure (3-7) with soil density must be more than critical density of soil. Flotation is an important issue for the stability a of pipe. Soil imagination important factor for pipe stability because soil cavity formation figure (3-8). There is some rules must have followed to avoid particle imagination. Controlling size particles, open grade course material should not be used for embedment zone and layer of the road layer of pipe filling.

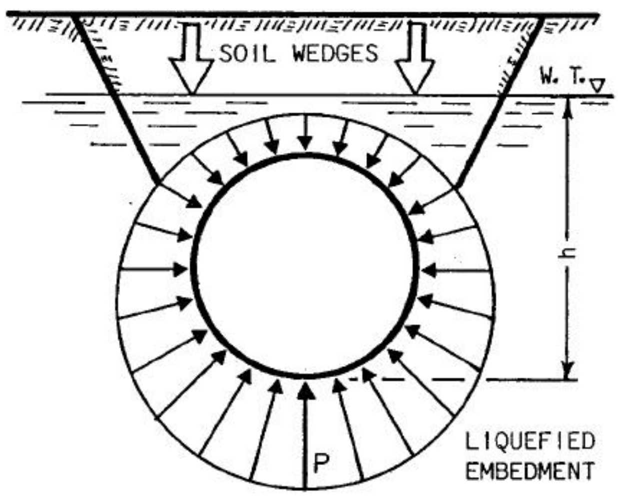


Figure (3-7) :Up lift pressure acting on pipe bottom(Buczala, 1990)

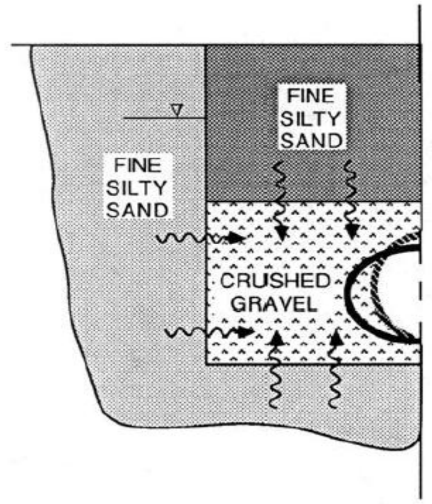


figure (3-8) :imagination of fine partial to course soil(Buczala, 1990)

3.3.5. Soil pipe interaction

The basic function of overall pipe performance is the ratio of pipe stiffness to soil stiffness(Barbato et al., 2010). Soil in embedment zone should be able to reach specific soil condition and density to prevent stresses concentration. Soil in embedment zone should be uniformly placed and compacted. Soil is principle part of soil pipe interaction concept. Narrow trench with only enough space is difficult to compact in hunching zone. Arching helps to support load, see Figure (3-9), whereas soil acts like masonry building arch(Chughtai and Zayed, 2008). Side fill of the pipe must be well compacted to generate arching action. The compaction process must be far at least from top of the pipe to avoid pressure concentration. Instillation quality also important factor influencing pipe deflection(Arockiasamy et al., 2006).

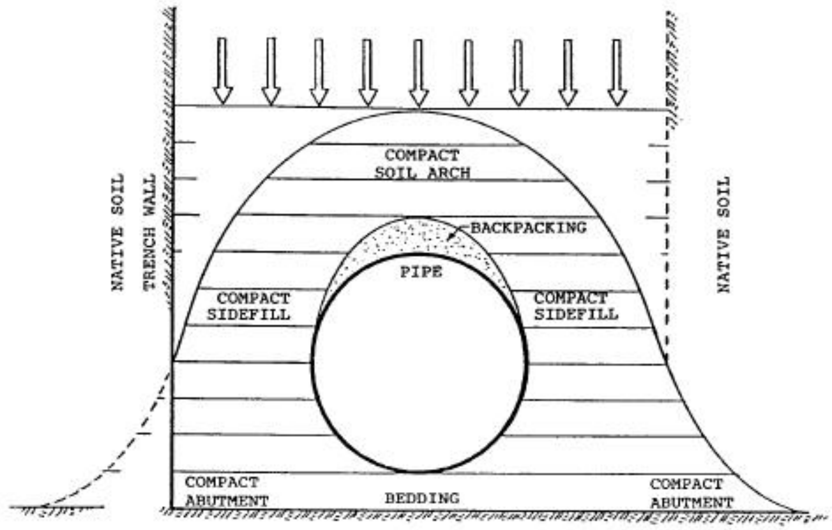


Figure (3-9) :Soil arching mechanism(Sargand and Masada, 2003)

3.4. Deflection prediction method AWWA M-45

Deflection calculated by multi methods and techniques to estimate or predict deflection. Most of these methods assume horizontal decrease equals to vertical decrease. The approach used in this research is modified IOWA formula.

$$\frac{\Delta y}{D} = \frac{(DL\,WC+WL)KX}{0.149\ PS+0.061\ \acute{E}} * 100\% \qquad \text{.........} (3\text{-}7)$$

Where

Δy : Deflection percent from original pipe diameter

Deflection lag factor (DL)**:** represents direct to the long-term deflection after many years because of deflection increasing the additional soil load, arching step by step decreasing due to wetting and drying times. These phenomena appear at the beginning of installation from few months to a couple of years. Also, consolidation of embedment soil with time and the crawl in the soil above embedment soil at side support for long term deflection it is recommended to use DL value >1 appropriate(AWWA, 1995)e. In this research, it will be used (1) as deflection lag factor(AWWA, 1995).

Bedding coefficient kx: represents constrained of side support degree at the bottom of the pipe and reaction distract. The value of kx equal to (0.1) will be adopted in calculation of deflection(AWWA, 1995).

Soil load WC (psi): considers the weight of prism of soil above pipe and calculate as earth cover.

Traffic load WL (psi): by assuming four lane roads with AASTHO HS-20 truck load configuration with 3.6m wide lane, pipe may be perpendicular or parallel to the pipe direction. Also, there are different load configurations that can be used like cooper E-80load according to project requirements.

Pipe stiffness PS (psi): is defined as the product of flexural modules of elasticity of the pipe wall and moment of inertia. This parameter can be obtained from the parallel plate load test according to ASTM D2412. Pipe stiffness used in this research is (496 kPa).

Modulus of soil reaction E'(psi): load on flexible pipe make depression in vertical diameter and increase in horizontal diameter. Horizontal motion develops by passive soil resistance help the pipe supporting. Soil resistance depends on type of soil and compaction quality. To calculate soil reaction uses equation (3-8). ASTM D2487 classified soil type and prepare tables to calculate modulus of soil reaction to make calculation easier for researchers this tables found in appendix (A).

$$E' = 1.5 \times \frac{\text{Es}\,(1-VS)}{(1+VS)(1-2VS)} \qquad \text{………… (3-8)}$$

Where

E'= Modulus of soil reaction (kPa)

Es= modules of elasticity of soil (kPa)

v_S=Poisson's ratio of soil =0.3(Chen and Lui, 2005)

AWWA formula developed by M.G.SPANGLER student of AMSON MARSTON, the researcher noticed that Marston solution is not efficient for flexible pipe, as well as he observed that flexible pipe has an ability to resist compression resulted from inherit stiffness of pipe. The deflection will appear after loading applied by soil and traffic load. Decrease in vertical diameter effect by soil weight, traffic load, native soil properties, embedment material, trench dimension, and hunching zone stiffness effect. Calculated value from this approach may vary from those obtained from field tests because of variation in installation method in real case with planed- method, interaction and reaction difficulty of representation in a field case. This equation is the best proposed because the sufficient method to represent soil properties in native and embedment material zone. Calculated values represent short and long-term ring deflection. The assumption of this theory is the standard native soil classification and backfill used within good practices of field condition by using sufficient equipment. Deflection value may vary more than or less than field test if the assumption not applied.

3.5. Simplification of AWWA M-45 formula

For present study, it can substitute parameters in original equation (3-7) to get simplified equation can performed cases calculation. These parameters are: Deflection lag factor (DL) to be (1)(AWWA, 1995) , Bedding coefficient(kx) to be(0.1)(AWWA, 1995)and pipe stiffness of 72 psi,

$$\frac{\Delta y}{D} = \frac{0.1(WC+WL)}{10.728+0.061\,É} * 100\% \qquad ..... (3\text{-}9)$$

By using three soil types (clay, sand and silt) and two pipe diameter 1m and 1.4 m and change burial depth from 2 to 12 m (increasing depth at 2-m increment), this leads to generate 36 case study. Where soil and pipe properties are presented in appendix (A).

3.6. Soil failure mechanisms

Principle concept of soil load mechanism is dissipation energy come from distributing the load between particles in case of granular soils, and with plate's action in case of fine soils. The difference in soil behavior according to types of soil and soil strength parameter which reflect ability of soil to support and transmit loading applied (Kramer and Seed, 1988, Barden et al., 1973). The influenced factors controlled soils to transmit the load are water content and soil texture. The types of soils used in this research will be discussed below. Soil composition is shown in figure (3-10).

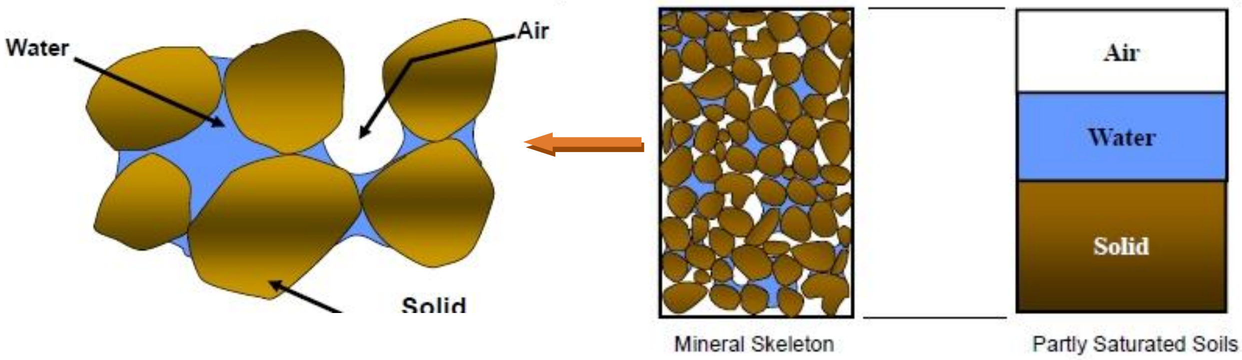


Figure (3-10): Soil composition in nature (Kramer and Seed, 1988)

Clay soil composition consists of some possible agreement of plates may be parallel plate. Clay soil load support is complicated to predict support magnitude because of electro –chemical effect and capillary properties action. The behavior of clay soils with wetting conditions depends on plasticity index of the clays. Also, optimum water content affected of clay support. Aggregate support have a strong microstructure than clay and more effective in bonding and supporting imposed load .This micro structure formation by clay plates shown in figure (3-11). As result collapse of clay soil resulted by an open flocculated of clay plates or granular structure effect. In general, saturated soil collapse more than dry soil (Kramer and Seed, 1988).

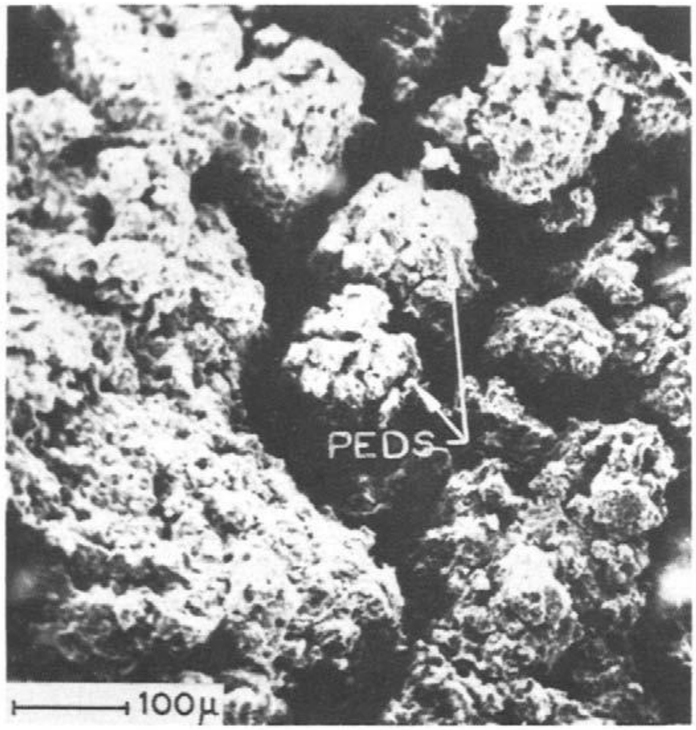


Figure (3-11): micro structure formation of granular soil (Kramer and Seed, 1988)

Sand and silt soils composition consists of grains which transfer load by interlocking between particles. Figure (3-12) shows normal and shearing force between particles, and how is contact force between partials analyses into normal and shearing force. Sand and silt soils are different in particles size and micro structure; see Figure (3-13). Water content and proctor density are important parameters which effect on air volume and void ratio between soils particles. These values are controlling soil strength aging load. In general, saturated soils loss bounding strength between particles, resulting in a weakness of soil against load. Silt soil is more stable than sand soil because of the bonding between its particles is stronger than sand bonding particles. In addition, smaller size of silt grains made larger contact area which producing a high bonding strength. Gradation of soil influences on bounding strength, whereas, well grade soil gives more strength from poorly grade soil(Kramer and Seed, 1988).

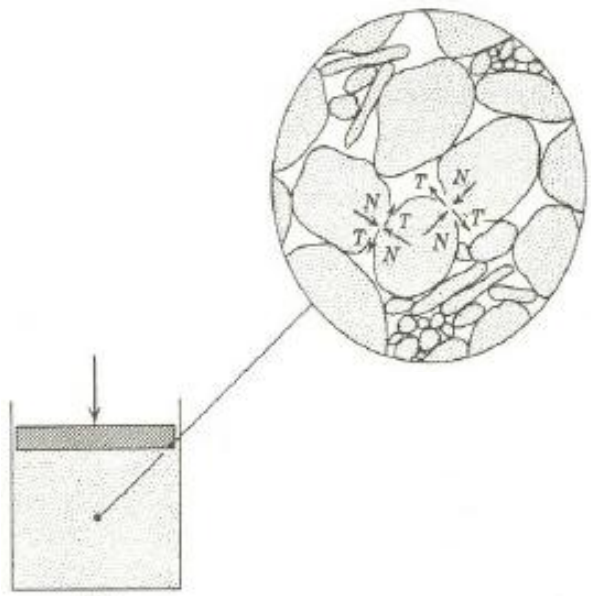


Figure (3-12): Shear and normal force generated by particle interlocking (Kramer and Seed, 1988)

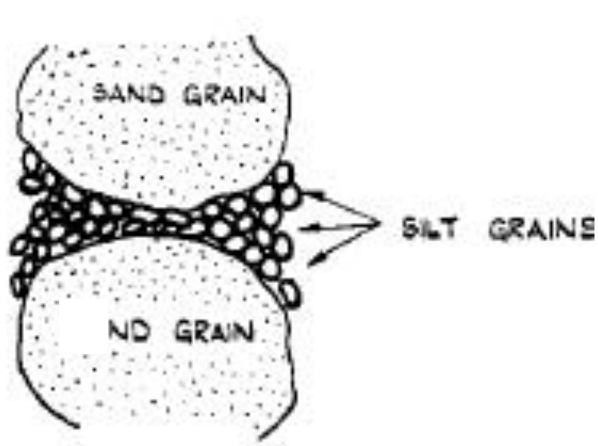


Figure (3-13) Different of grain size between granular soils(Barden et al., 1973)

3.7. Simulation of finite element modeling

Finite element technique was developed to solve complex problem in structural analysis in different infrastructure like dams, buildings, bridges, groundwater flow and other applications. There is many software serve this research purpose like Plaxis 3D, FLAC3D, CANDE, ANSYS, and other software. The Plaxis 3D 2014 will be used in this research because this software originally intended to analysis of geotechnical issues including tunnel structure, so that benefit of using this program is high and it will give valuable results.

3.7. 1. Deformation simulation with plaxis 3D 2014

Geotechnical code works with three-dimensional simulation application based on theoretical equation and failure modes for soil and groundwater conditions with considering material properties for elastic and plastic stage analysis(Brinkgreve et al., 2014, Plaxis, 2013). In this analysis, the structural stability of a buried pipe with traditional approach installation condition is not considered in real practice of pipe line. Also, the interface between a soil and pipe not include. Stresses through construction stage and movements ,water condition inside pipe effect ,implication of compaction quality .possibility to construct multi-layer method mode with different failure mode .Random mesh generation with possibility to change or modify mesh dimensions to conform with required accuracy .Dynamic loading are available as choice of loading conditions . Model dimensions selected are (8×12) m to eliminate boundary condition effect on computed results

3.7.1.1. Deformation theory

Static deformation of soil model are formulated with continuum mechanics theory, formulated with finite element method the basic equation of continuum deformation is

$$\underline{\underline{L}}^{T} = \underline{\sigma} + \underline{b} = \underline{0} \qquad \text{............ (3-10)}$$

$\underline{\sigma}$ Include six stresses component collected in this vector; $\underline{b}$ represent three forces acting on soil body, and $\underline{\underline{L}}^T$ transpose of different operator.(Plaxis, 2013, Brinkgreve et al., 2014)

$$\underline{\underline{L}}^T = \begin{bmatrix} \frac{\partial}{\partial x} & 0 & 0 & \frac{\partial}{\partial y} & 0 & \frac{\partial}{\partial z} \\ 0 & \frac{\partial}{\partial y} & 0 & \frac{\partial}{\partial x} & \frac{\partial}{\partial z} & 0 \\ 0 & 0 & \frac{\partial}{\partial z} & 0 & \frac{\partial}{\partial y} & \frac{\partial}{\partial x} \end{bmatrix}$$

In addition to the equilibrium equation the dynamic relation can be performed as

$\underline{\boldsymbol{\varepsilon}}=\underline{\underline{L}}\,\underline{U}$ ……….. (3-11)

The above equation represent six strain component collected in vector_ , $\underline{U}$ collect three displacement component ,$\underline{\underline{L}}$ differential operator.

The connection between two equations is costive relation between rates of stress.

Depending on finite element method solution the soil model divide to number of volume element, each element contain number of nodes ,every node have number of degree of freedom that corresponding to displacement component .

3.7.1.2. Global iteration procedure

Relationship between stress-strain increments is non-liner therefore, stiffness cannot be formulated exactly, and for that, reason iteration is necessary to achieve equilibrium condition

$\underline{\underline{k}}^j \boldsymbol{\delta}\underline{v}^j = \underline{f}^i_{ex} - \underline{f}^{i-1}_{in}$ ……… (3-12)

Where j represents iteration number,$\underline{v}^j$ represent sub incremental displacement, which contribute to incremental displacement.

3.7.1.3. Structural elements simulation

The program deals with specified structural elements, beams, plates, interface, pile and other elements. Structural element used in this research is a plate to simulate pipe elements .Plates represent semi-two dimensional element with flexural rigidity and plate stiffness with 3 or 5 nodes each node have three degree of freedom for every node. Plate element is integrated numerically with 2 point Gaussian integral(Adedapo, 2007, Plaxis, 2013).

3.7.2. Soil models

The soil is a complex material difficult to predict how to act is non-approachable because soil consists of solid particles, water and air. These components make soil properties and behavior very complex and required method to simplification real material action with focus on major aspect in simulation process. There are number of models used in analysis as illustrated below.

3.7.2.1. Linear elastic perfectly plastic (Mohr -Coulomb) model

Plasticity related with development of final strain to ensure plasticity occur in calculation a yield function is performed as stress strain function(Adedapo, 2007) .Stresses is elastic and all strain irreversible .The moment which arrive top stress limits or yield stress that its represent by two terms, Young's modulus E and passion's ratio υ. Stiffness increase with depth can be taken into account.

3.7.2.2. Linear elastic model

This model is based on Hooke's law of isotropic elasticity that consists of two elastic constants Young's modulus E, and Passion's ratio υ. This model is not recommended to use in soil analysis and may be used in stiffer volumes such as asphalt and concrete materials or rock foundation. Also, a stress simulation in this model is high nonlinear and irreversible(Adedapo, 2007).

3.8. Plaxis 3D comparison

As known field measurements have a true representation for different engineering problems. Therefore need to check any method with filed measurement to ensure if the difference is acceptable with real tests. in this research vertical deflection will be checked with paper(Lee et al., 2015). This paper performed field test of deflection with using finite element software using FALC 3D. Also, AWWA M45 equation was used in analytical approach of this work. In this paper, a pipe diameter of (2.4) m GRP pipe was used. This pipe was examined under three burial depths (5, 10 and16) m. Method used is fill application of native soil; first stage is filling until to 5 m and measure pipe deflection. Second stage is continuing to fill until depth of 10 m and measure deflection. Differences between field test and plaxis modeling shown in figure (3-14). Final stage is complete native soil filling up to reach 16 m depth and measure deflection. Properties of soil and pipe martial are presented in appendix (A). Setting properties of pipe and soil material and made simulation model exactly same condition of filed in plaxis 3D modeling program using same depth, putting the result from this operation and filed test in one figure (3-15) to know different between two methods. Also to see difference between equations, filed test and plaxis modeling figure (3-15).

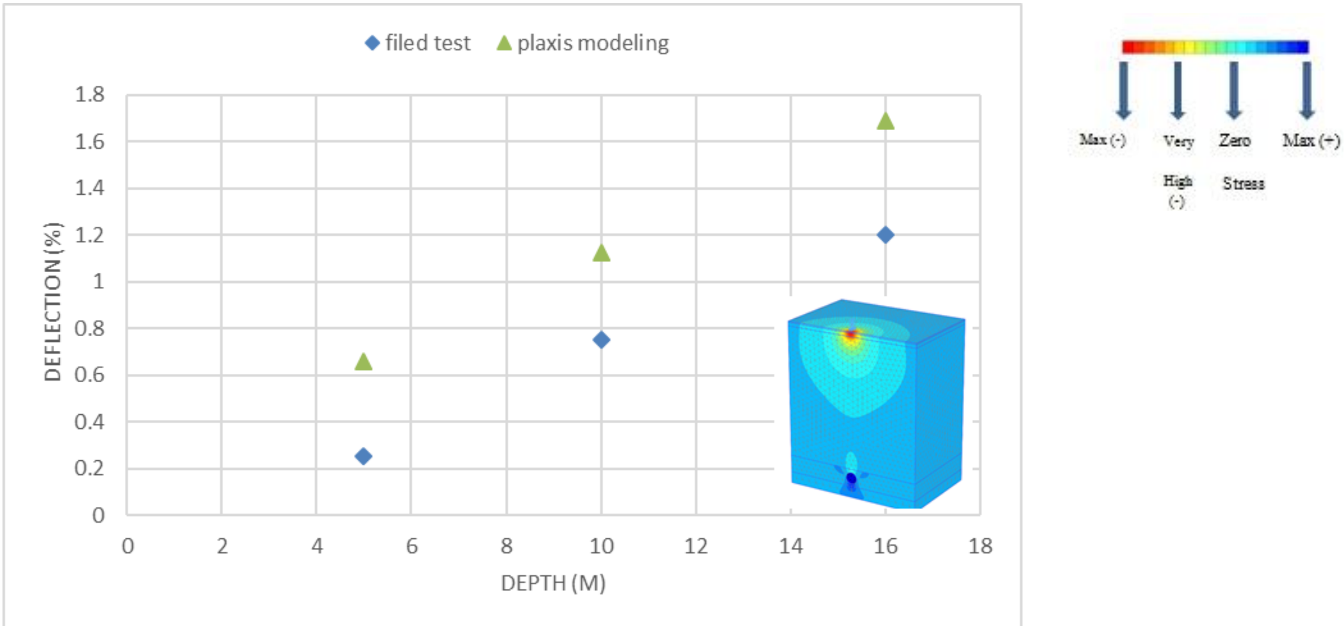


Figure (3-14) :comparison result of plaxis 3D

Figure (3-15) shows differences between three methods to predict deflection clearly apparent differences because of methodology of each and considerations taking into account. As figure (3-15) shows high safety factor of AWWA equation because this method used for design. Plaxis modeling give appropriate estimation near to real state value of deflection as mentioned before filed test is best method to measured deflection. Most cases this approach is not applicable because of site condition or pipe line need to check in design stage.

Figure (3-15): Comparison of plaxis 3D with AWWA equation

Chapter Four

Result and Discussion

4.1. Introduction

In this chapter, the calculation of pipe deflections using equation will be presented and discussed. GRP pipes with two different diameters: 1 m and 1.4 m, placed at depth 2, 4, 6,8,10 and 12m will be evaluated in this work. Three soil types will be simulated in this work: clay, sand and silt soil. Engineering problems are often controlled by input parameters; therefore the selection of parameters must be carefully done. In present study parameters selected for soil done by taking average values from typical parameter to avoid maximum and minimum parameter selection (Moser and Folkman, 2001)

4.2. Equation results

This formula is widely used in pipe stability evaluation (Moser and Folkman, 2001, AWWA, 1995, Watkins and Anderson, 1999). Consider acceptable approach to design and analysis buried pipe. Provided high safety factor using in design and analysis of buried plastic pipes. With time researcher made some modification on this formula to be more efficient. This modification includes representation of soil pipe interaction by using modules of soil reaction factor. In this research it will be used modified version of AWWA formula.

4.2.1. Clay soil results

In the section, all calculation of clay soil will be presented by using AWWA, formula. Soil properties will be presented in appendix (A). Calculation method used is AWWA M45.

$$\frac{\Delta y}{D} = \frac{0.1(\,WC+WL)}{10.728+0.061\,\acute{E}} * 100\% \qquad \text{......... (3-9)}$$

Equation items mentioned in chapter three and calculation result will be presented in appendix (A). Results will be visualized in figure (4-1) and (4-2) for (1m) and (1.4) m pipe diameter, respectively. Figure (4-1) shows a liner relation that links burial depth with vertical deflection, the relation has strong determination coefficient, for this relation R^2 was 0.9995.

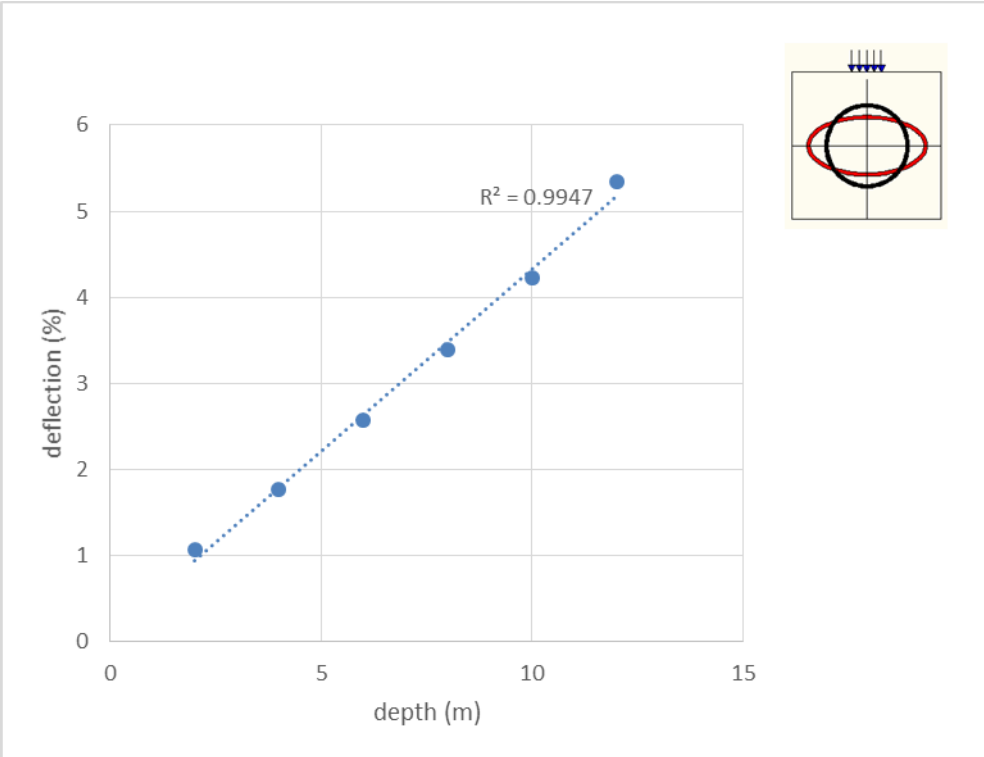


Figure (4-1): AWWA result for clay soil (1 m) pipe diameter

Figure (4-1) indicates a good determination between vertical deflection and burial depth of pipe 12 m clay soil gradual each (2m). Soil in trench composite for native clay consist of 10 cm asphalt layer, sub base course 30 cm , bedding material layer covered diameter of pipe 30 cm from top and bottom, total bedding up to 1.6 meter. Clear that deflection value start from (1.0633)% percentage for 2m depth with gradual deflection increment controlled by relation shown in figure (4-1). These deflection values are acceptable until depth reaching to 10m value reach deflection value 4.463% over this depth when reaching to12 m deflection level reach 5.00% which consider acceptable level of deflection because deflection percent not exceed 5% according to standard is satisfied with using 496 kPa stiffness value. The results are shown in Figure (4-2) for 1.4-meter pipe diameter using clay soil. Pipe embedded under asphalt layer of thickness 0.10 m, 0.30 m sub base layer, native clay soil, and 2 m thick bedding material. In addition, deflection percent calculated from 2 to 12 meter. Deflections percent reach value 5.34% for 12 m depth which consider critical value, figure (4-2) represent deflection depth relation with high determination factor with linearity equation, R^2 = 0.9993 for same stiffens value and size of pipe diameter effect on pipe stability parameter. When comparing result of 1 and 1.4 meter diameter there is difference in result for example for depth (12) m deflection percent increase by 0.34% from 1m diameter and make pipe stability condition fallow from safe to unsafe value at the same soil and pipe properties.

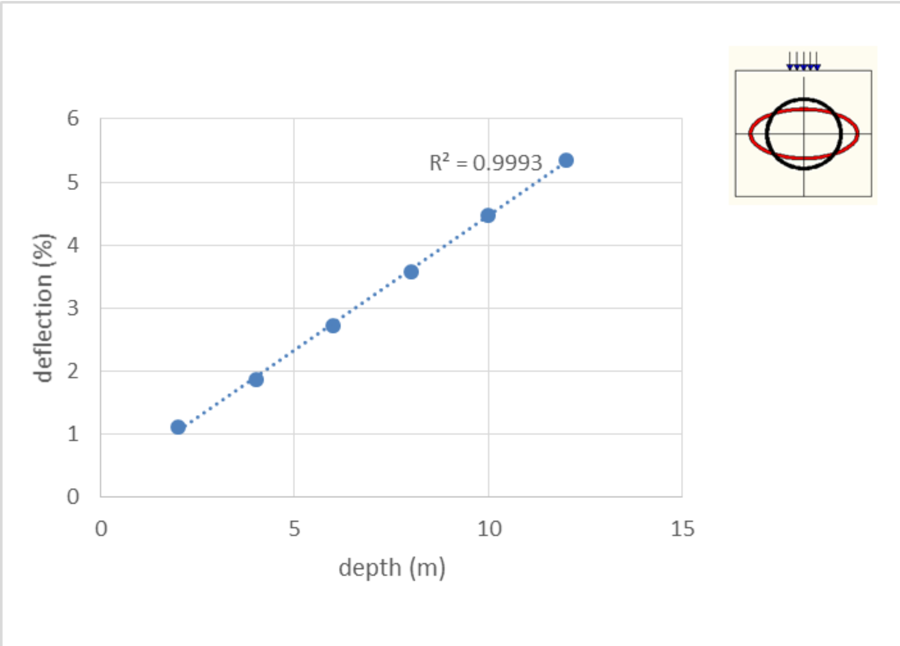


Figure (4-2): AWWA result for clay soil (1.4 m) pipe diameter

4.2.2. Sandy soil results

Calculation of sandy soil will be presented by using AWWA formula. Soil properties will be presented in appendix (A). The results will be visualized in Figure (4-3) and (4-4). Second native soil used to predict and examine deflections which relay pipe stability is sandy soil by using AWWA m- 45 equation figure (4-3) shows result for 1m diameter pipe. Sandy soil which indicate good deflection percent and getting better. Result for 1m diameter and 2m depth was 0.72664% until reach 12m depth deflection percent found to be 3.5% with good linear relationship, $R^2 = 0.9994$. Noticed that large different of deflection value between same pipe diameter and different soil. Where result of clay soil and 12-meter depth was 5% the different is 1.5% is large different for same depth, pipe materials and stiffness. This variation because of soil behavior difference to respond with load, shear strength parameter friction angle, cohesion soil unites weight water table effect.

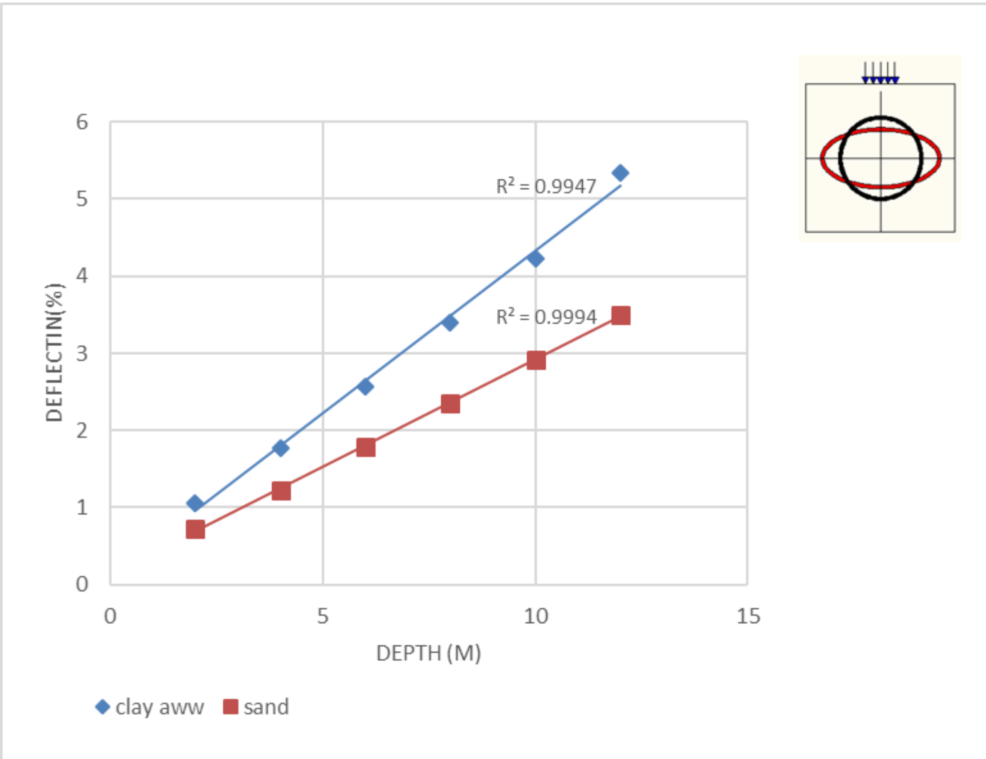


Figure (4-3): AWWA result of sand (1m) pipe diameter

The difference between clay and sand soil at 2 m depth is about (0.336%) and (0.963%) for 12 m depth. This difference is obtained from the variance in soil strength parameters clay and sand surrounded the pipes. As a result when soil in site is clay it must be carefully selected proper bedding material and observance compaction quality for pipe zone embedment reaching to surface layer of asphalt pavement. Apply some improvement on soil like soil stabilization using various methods or using higher stiffness for pipe to prevent excessive deflection.

Figure (4-4) shows sandy soil case with 1.4-meter pipe diameter by taking depth of burial pipe from 2 to 12 meter; deflection result was visualized and summarized. Also using same pipe material and stiffness with using same bedding material and native soil properties. By making deflection prediction to this case noticed that deflection percent for 2 m depth to be (0.7628) %. Where for the same pipe properties and soil and bedding material for 1m diameter deflection was found to be 0.7266%. Where the difference percent is 0.0362% this indicates diameter size effects on pipe deflection remember that same stiffness for this two different pipe diameter. In fact, this formula consider vertical and horizontal deflection is the same percent which is not true. From figure (4-4). It can obtained liner relation between depth and deflection with determination coefficient R^2 = 0.9994, indicate real good relation.

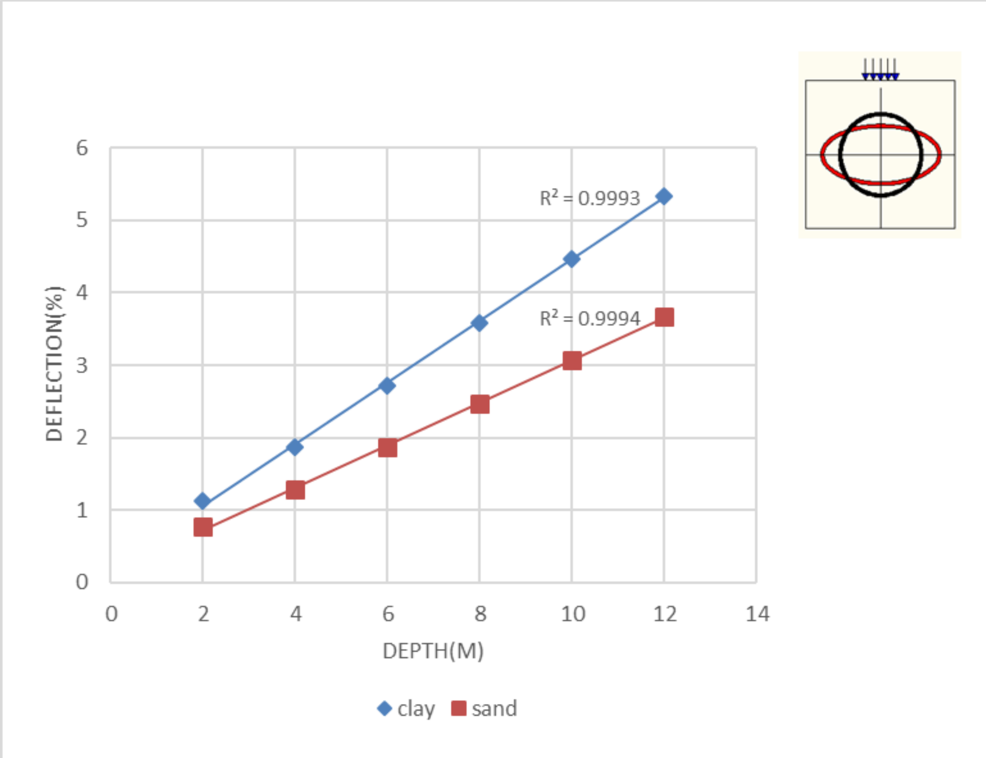


Figure (4-4) :AWWA result of sand (1.4m) pipe diameter

The difference of1.4 m pipe between clay and sand soil because of stability parameter difference is (1.669%) for 12 m depth. According to this result for clay soil stability circumstance transform from stable condition for 1 m diameter to unstable state for 1.4 m pipe diameter, this because of soil strength effect and geometric effect of pipe diameter of pipe. This problem solved using stabilized soil to get higher modules of elasticity for native soil taking into account the compaction quality of soil layers.

4.2.3. Silt soil results

Calculation of silt soil will be presented by using AWWA formula. Soil properties will be presented in appendix (A). Plotted result will be visualized in figure (4-5) and (4-6). This type of soil is the third type used in this analysis to identify different soil behavior under loading condition. Easy to comparing each other and include all type of soil in this analysis. Liner relationship obtained can be used to find deflection value of any depth using these properties without using formula. Linear relation can be obtained from figure (4-5), with good determination coefficient $R^2 = 0.9993$.

Results of silt soil more stable according to sand and clay soils because of soil strength parameter of silt contain cohesion strength and friction angle which enhanced overall strength of silt. So that it will be seen deflection or stability parameter of silt is lower than other soils. For 1 m pipe diameter deflection of pipe equal to (3.329) %for silt and (3.5and 5) % for sand and clay respectively. For 1.4 m pipe diameter deflection equals to (3.495) % and (3.674and 5.343) % for sand and clay soils respectively. This difference related to behavior of soil under dead and live load (Veritas, 2008).

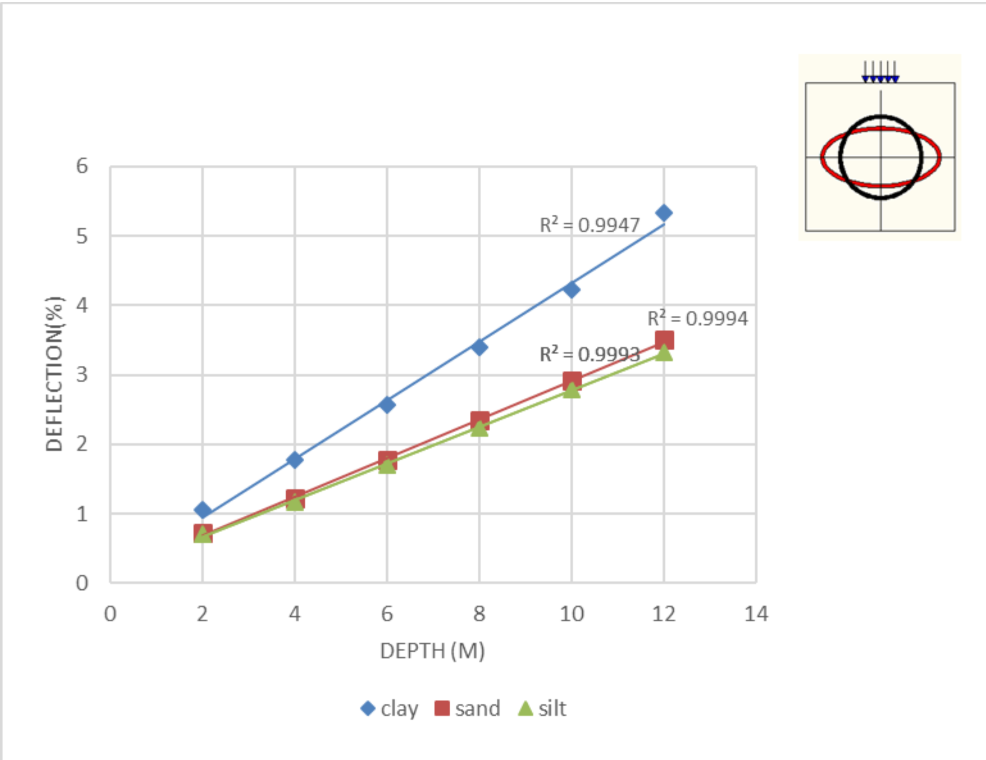


Figure (4-5): AWWA result of silt (1m) pipe diameter

Deflection result for 1.4 pipe diameter silt soil pipe embedded under asphalt layer of thickness 10 cm, 30 cm sub base layer, clay native soil and 2 m thick bedding material. In addition, deflection percent calculated from 2 to 12 meter. Deflections percent reach value 0.733% for 2 m depth. Deflection reaches maximum value of 3.459% for 12 m depth. These values consider safe values comparing with standard limit 5%, and linear relationship can be obtained from figure (4-6).

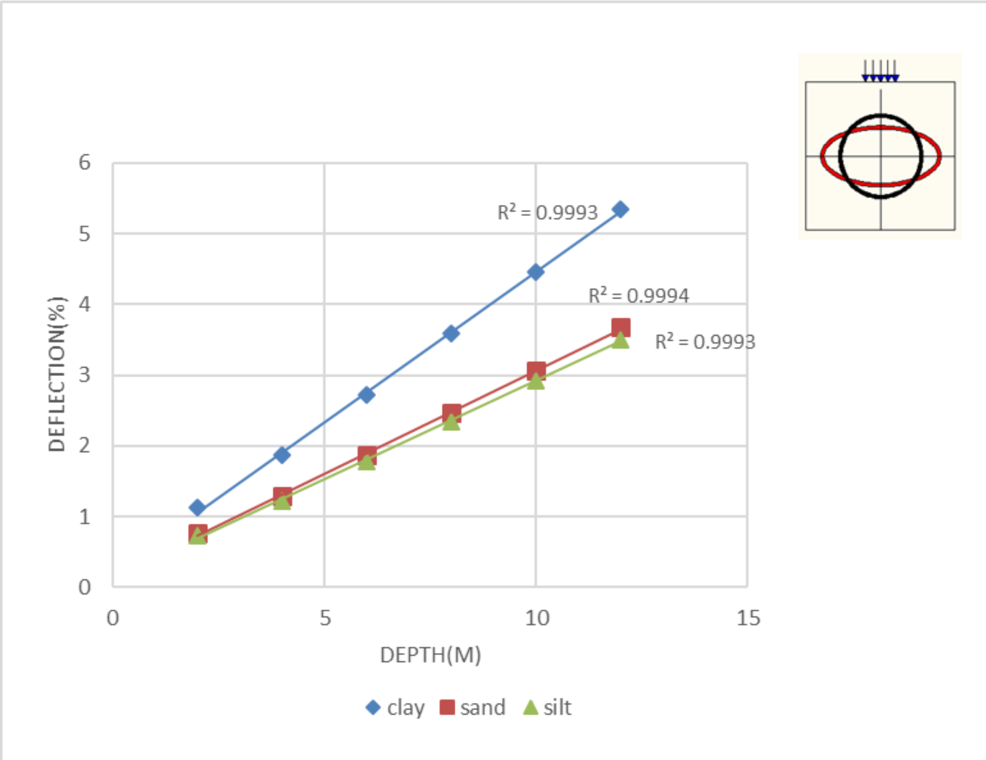


Figure (4-6) :AWWA result of silt (1.4m) pipe diameter

4.3. Plaxis 3D Modeling and Result

In this part, the modeling using Plaxis 3D will be presented for soil type (clay, sand and silt) soils. Properties of pipe before performing this simulation and modeling comparison will be presented for plaxis software to ensure simulation result compatible with other methods and software section (4.3.1) will be include comparison details. Soil will be used same condition for depth, soil properties and pipe properties. The results of each soil type are presented below. Deflections will be calculated in both vertical and horizontal direction for (1 and 1.4) m pipe diameter.

4.3.1. Clay Soil Modeling and Results

The F.E. results of horizontal and vertical deflections of a 1 m pipe embedded in a clay soil are illustrated in Figure (4-7) and (4-8), respectively. Linear relation between vertical deflection and depth was identified and displayed in Figure (4-7). The vertical deflection values increased with depth. The results indicated that a deflection of 0.449 % is produced at depth 2m, while the deflection reaches 2.06% at depth 12m. This difference might be attributed to the difference in soil properties used in F.E. simulation(Barden et al., 1973) .Figure (4-8) shows horizontal deflections obtained from FE modeling. The results showed that horizontal deflection was 0.0424% and 0.1871% for depth 2 and 12 m, respectively.

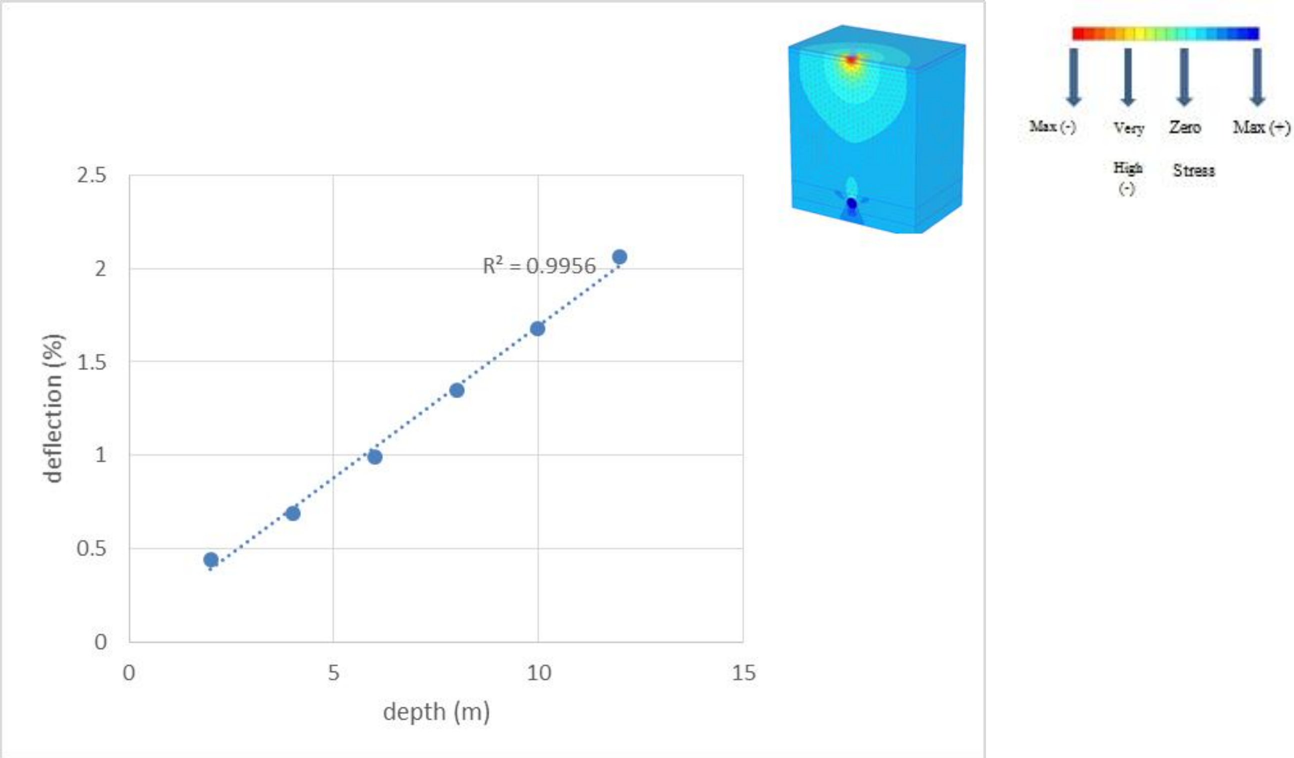


Figure (4-7): vertical deflection 1_m Pipe

Figure (4-7) shows a linear relationship between burial depth and vertical deflection with good determination coefficient $R^2 = 0.9956$. This equation can be used to find any deflection value if burial depth is known for same properties of pipe and soil.

Figure (4-8) shows a linear relation between burial depth and horizontal deflection with a good correlation coefficient equal to $R^2 = 0.985$

Deflection value has been reviewed consider safe values because stay in standard limit 5%.

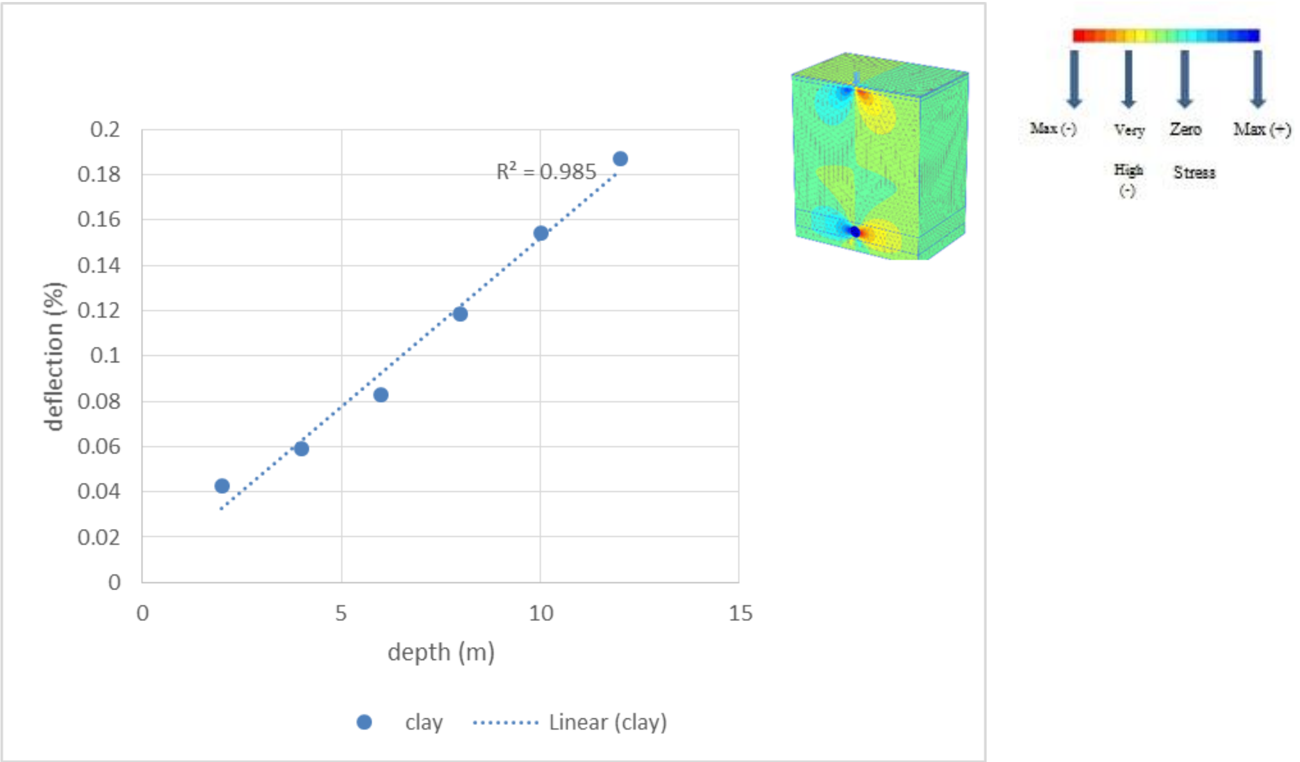


figure (4-8):Horizontal deflection 1-m pipe

The results of horizontal and vertical deflections are shown in Figure (4-9) and (4-10), respectively. As illustrated in Figure (4-9), the vertical deflection value for 2-m depth of burial was (0.364571) %, while the deflection was (1.627)% for maximum depth of 12 m .The deflection of 1.627 falls within safe limits and does not exceed 5%. Liner relation can be found with good relation R^2 = 0.998.

The horizontal deflections were (0.035571) % and (0.165143) %for a burial depth equal to 2 m and 12 m, respectively. Figure (4-10) shows horizontal deflection curve obtained from Plaxis modeling approach. A linear relationship was found with good relation R^2 = 0.998, this relationship can be used to predict deflection value at any depth.

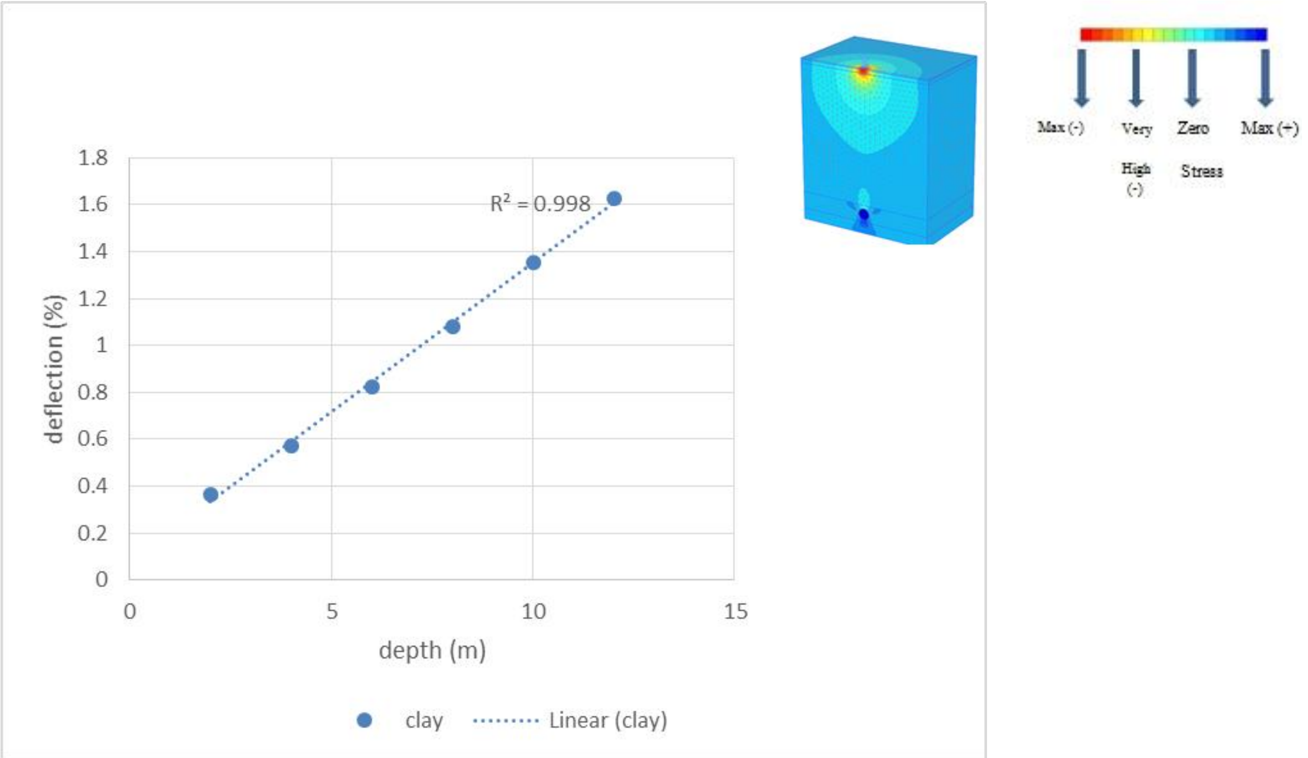


Figure (4-9): Vertical deflection of 1.4-m pipe

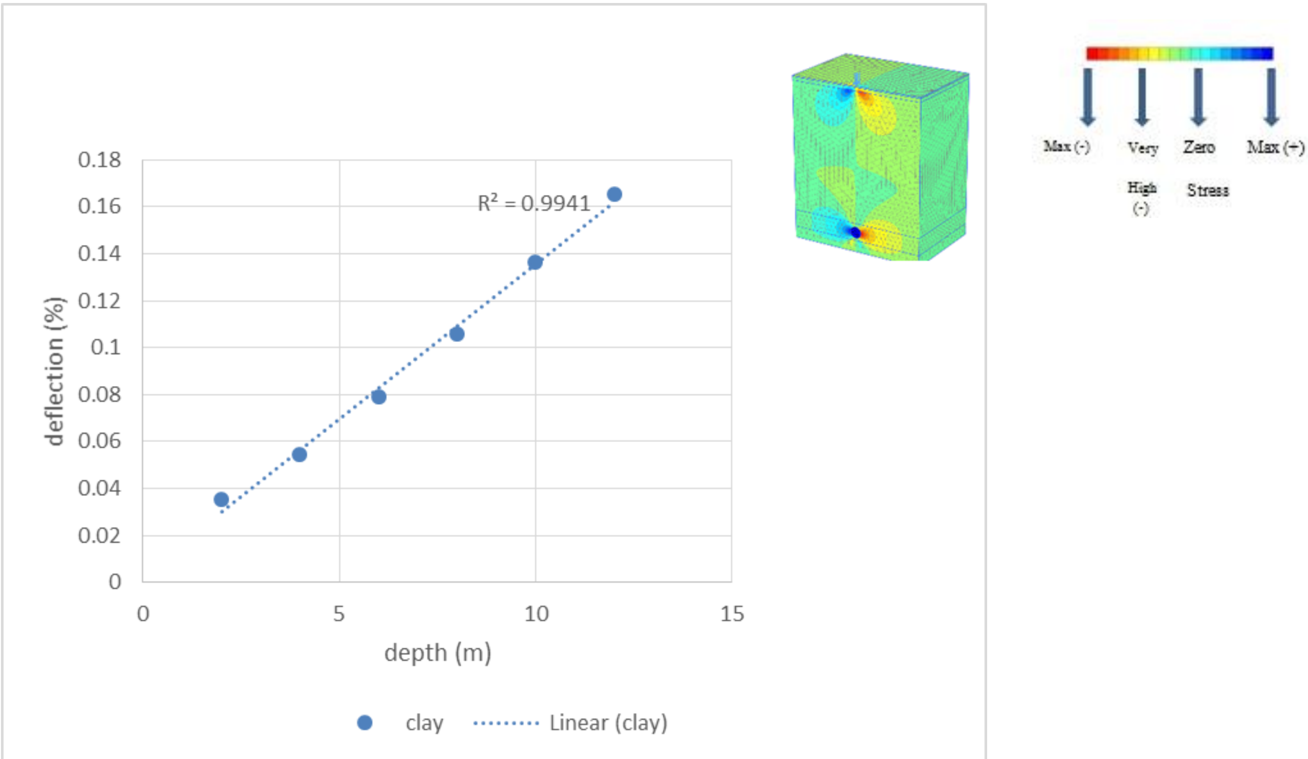


Figure (4-10): Horizontal deflection 1.4-m pipe

4.3.2. Sandy Soil Modeling and Results

Sandy soil stability examined by using plaxis 3D modeling and simulation for pipe diameter (1, 1.4) for vertical and horizontal deflection. Deflection value will be found in appendix (A) for each diameter for vertical and horizontal deflection. For vertical deflection 1-m pipe diameter 2-m burial depth figure (4-11) start with value (0.3631) %, but when comparing clay soil at same depth reaches to (0.4449 %) which indicates more stability for sandy soil because of inherit properties and shear strength parameter of sand is higher than clay soil. Deflection increased with depth increment every 2-m to be (1.256) % at maximum depth 12-m which consider safe value according to standard limit. In addition, linear relationship can be found from figure (4-11) with good relation $R^2 = 0.9992$ so that deflection value can be found for any burial depth. Horizontal deflection figure (4-12) at 2-m burial depth (0.04052) comparing with clay soil deflection reaches value of (0.0424) slightly more than sandy soil. This difference not noticeable percentage and reach value of (0.1293) % at maximum depth 12-m for sand, (0.1871) % for clay soil clear that deflection difference increased with earth load increment . Also linear relation can be found with high determination $R^2 = 0.991$ to find horizontal deflection for any burial depth.

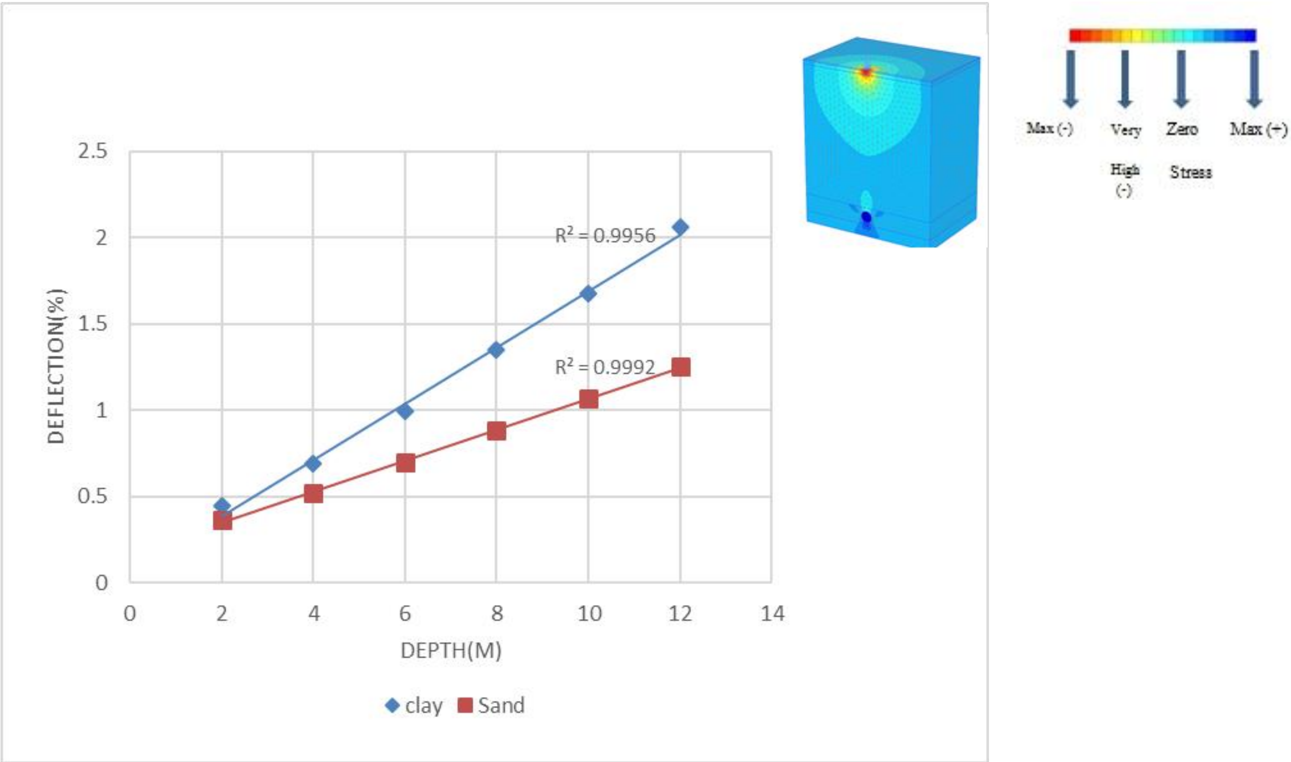


Figure (4-11): Vertical deflection 1-m pipe diameter

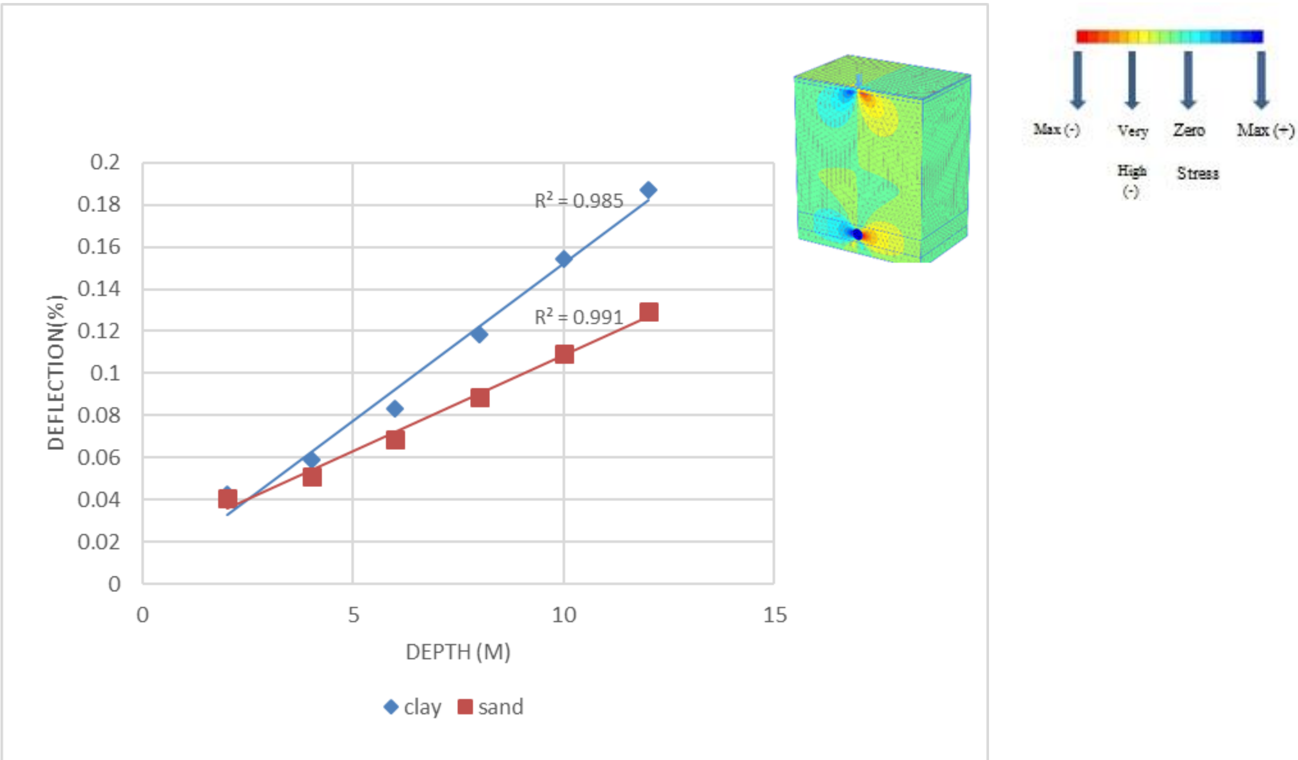


Figure (4-12): Horizontal deflection 1-m pipe diameter

For 1.4 m-pipe pipe diameter simulation have been done to evaluate vertical and horizontal deflection figure (4-13) and figure (4-14) respectively, for vertical deflection start from (0.301) % for sand and (0.364) % for clay at 2-m burial depth gradually reach to value of (1.0185) % for sand and (1.627) % at maximum depth 12-m, these values consider safe. Linear relation can found with high determination factor $R^2 = 0.9993$ deflection can be found if burial depth known according to standard limit. Also there is difference between two pipe diameters because of geometric properties of 1.4 m pipe using 72 psi stiffness, 1 m pipe has more strength if fixed stiffness used. With regard to horizontal deflection figure (4-14) deflection value start from (0.034143) % for sand and (0.0355) % for clay soil at 2m depth, end with (0.119214) % for sand and (0.165) % for clay soil, also there is differences caused by soil strength parameter and geometric shape weakness of 1.4 m pipe. At maximum depth 12-m of burial depth, relationship can found from figure (4-14) with good linear relation $R^2 = 0.9972$. All these values consider safe with regard to standard limit.

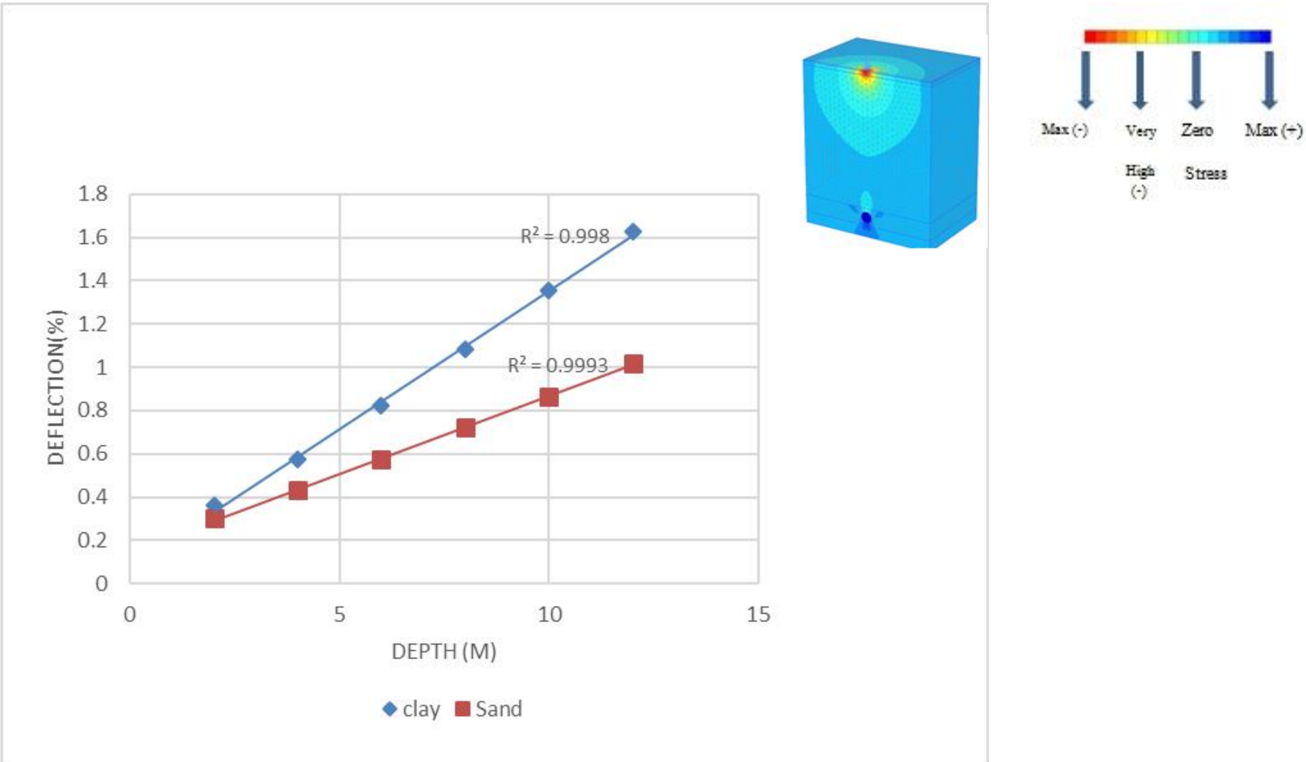


Figure (4-13): vertical deflection 1.4-m pipe diameter

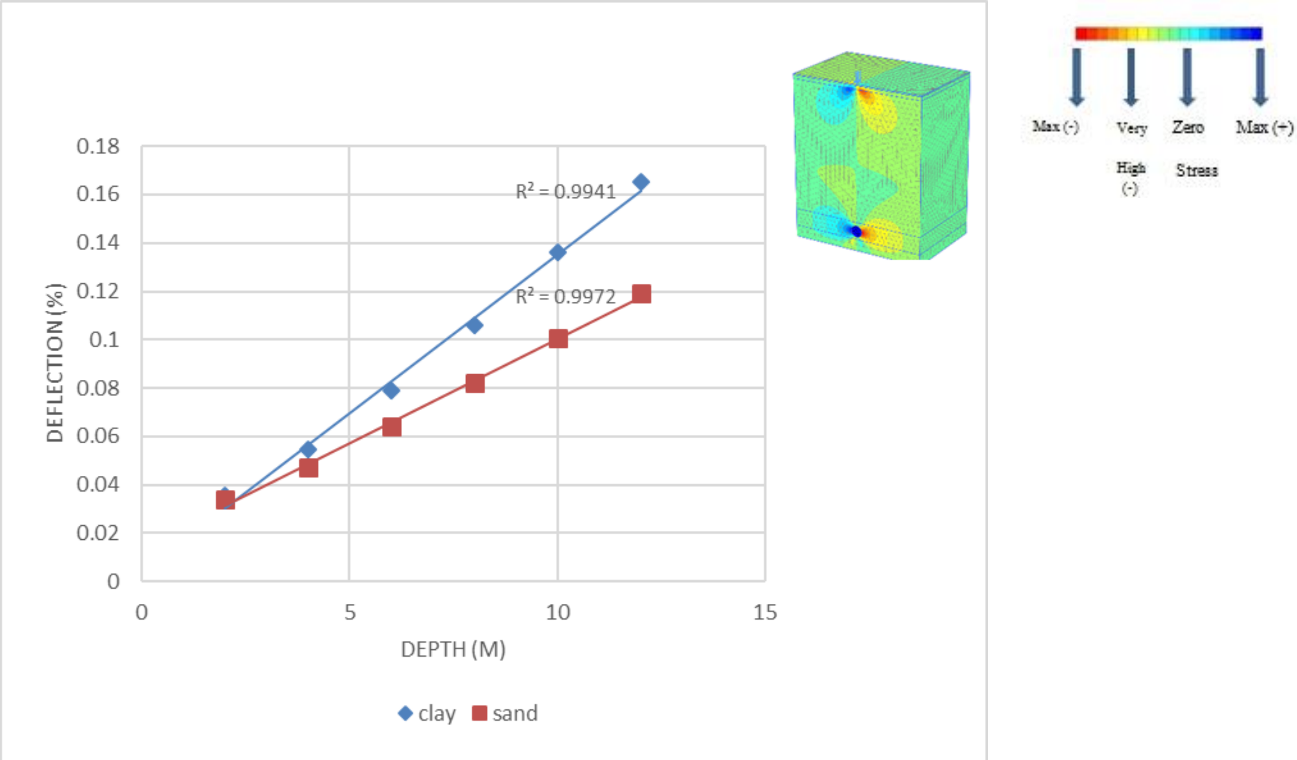


Figure (4-14): Horizontal deflection 1.4-m pipe diameter

4.3.3. Silt Soil modeling and Results

Silt soil is part of this analysis and modeling by using plaxis 3D. This type of soil indicates sufficient results with respect to other type of soil. Results of 1-m pipe shown in figure (4-15) for vertical deflection analysis. Deflection values start with (0.391) % for silt, (0.4449) % for clay and (0.363) % for sand at 2-m burial depth. silt and sand is more stable than clay affected by soil behavior under loading condition which mean that granular soil is more stable because of load transfer mechanism from particle to another, that's why pipes manufactures always used granular soils as bedding materials. Deflection reach value of (0.9737) % for silt, (2.06) % for clay, (1.256) % for sand at maximum depth used in this analysis 12-m. It can be noticed that variation of result from soil type to another and combined soil strength parameter found in silt soil. Friction angle and cohesion strength is enhancement for pipe and carry well load percent and have more sufficient arching factor. From figure (4-15) it can be find linear relation with good relationship $R^2 = 0.9974$ used to evaluate vertical deflection for any burial depth with condition of used same properties for soil and pipe.

For horizontal deflection where used same pipe and soil properties in analysis result shown in figure (4-16) which deflection start with value of (0.0382) % for silt ,(0.0424)% for clay , (0.04052)% for sand at 2-m of burial depth reach value of (0.07495) % for silt ,(0.1871)% for clay ,(0.1239)% for sand at maximum depth 12-m. it noticed that very small values because of soil behavior in horizontal direction from figure (4-16) relationship can found with good determination coefficient $R^2 = 0.964$.

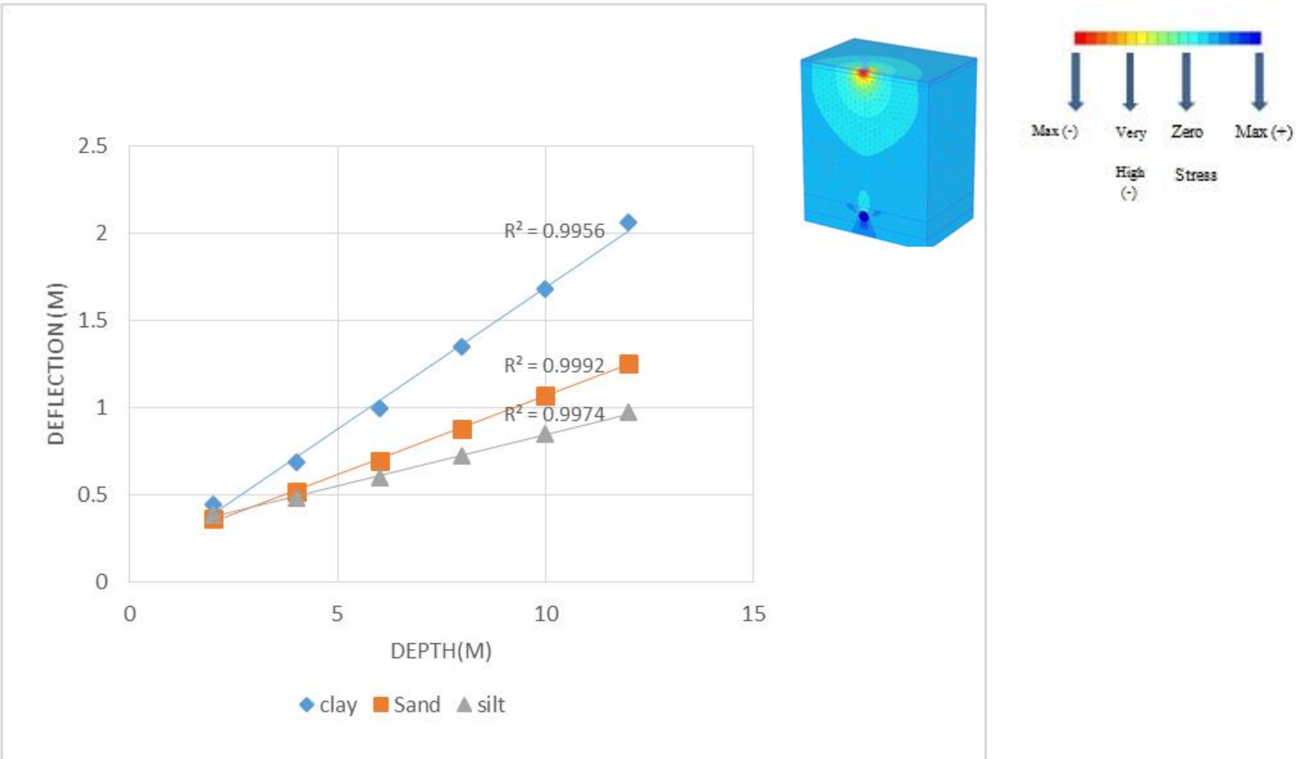


Figure (4-15): vertical deflection 1-m pipe diameter

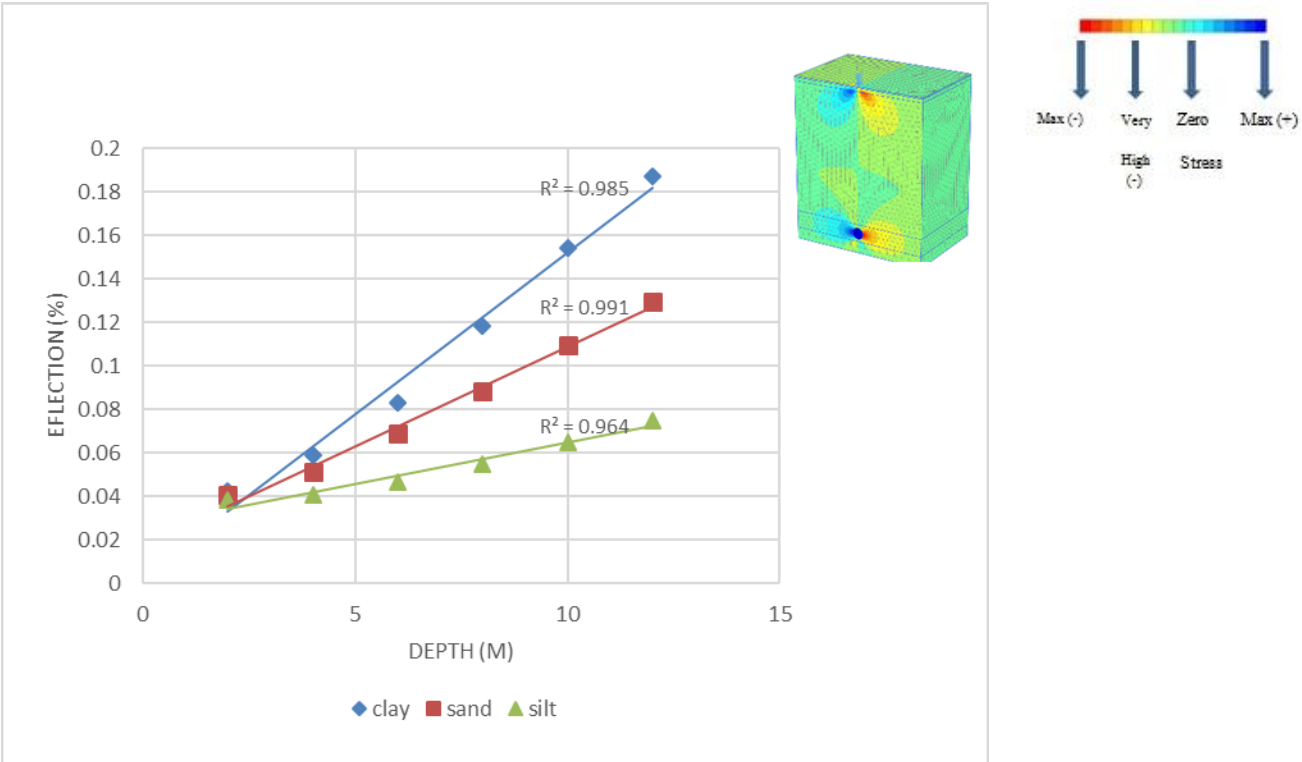


Figure (4-16): Horizontal deflection 1-m pipe diameter

For 1.4 pipe diameter analysis results found in figure (4-17) for vertical deflection and figure (4-18) for horizontal deflection. With regard to vertical deflection analysis results begin at 2-m depth with value of (0.300) % for silt, (0.364) % for clay and (0.301) for sand soil. Reaching value of (0.767) % for silt, (1.627) % for clay and (1.018) % for sand soil at 12-m. Linear relation can be found from figure (4- 17) with good relation R^2 = 0.997 so that any deflection value can be found using this equation or curve.

In addition to vertical analysis horizontal deflection have been modeled for 1.4 –m pipe diameter result found in figure (4-18). where deflection start with value of (0.0326)% for silt,(0.0355)% for clay and(0.0341)% for sand at 2-m depth reaches value of (0.0747)% for silt ,(0.165)% for clay and (0.1192)% sand soil at maximum depth 12-m. Also clay soil has been weakest soil in this group according to stability parameter values by this analysis. Linear relation can be found with good relation R^2 =0.9556.

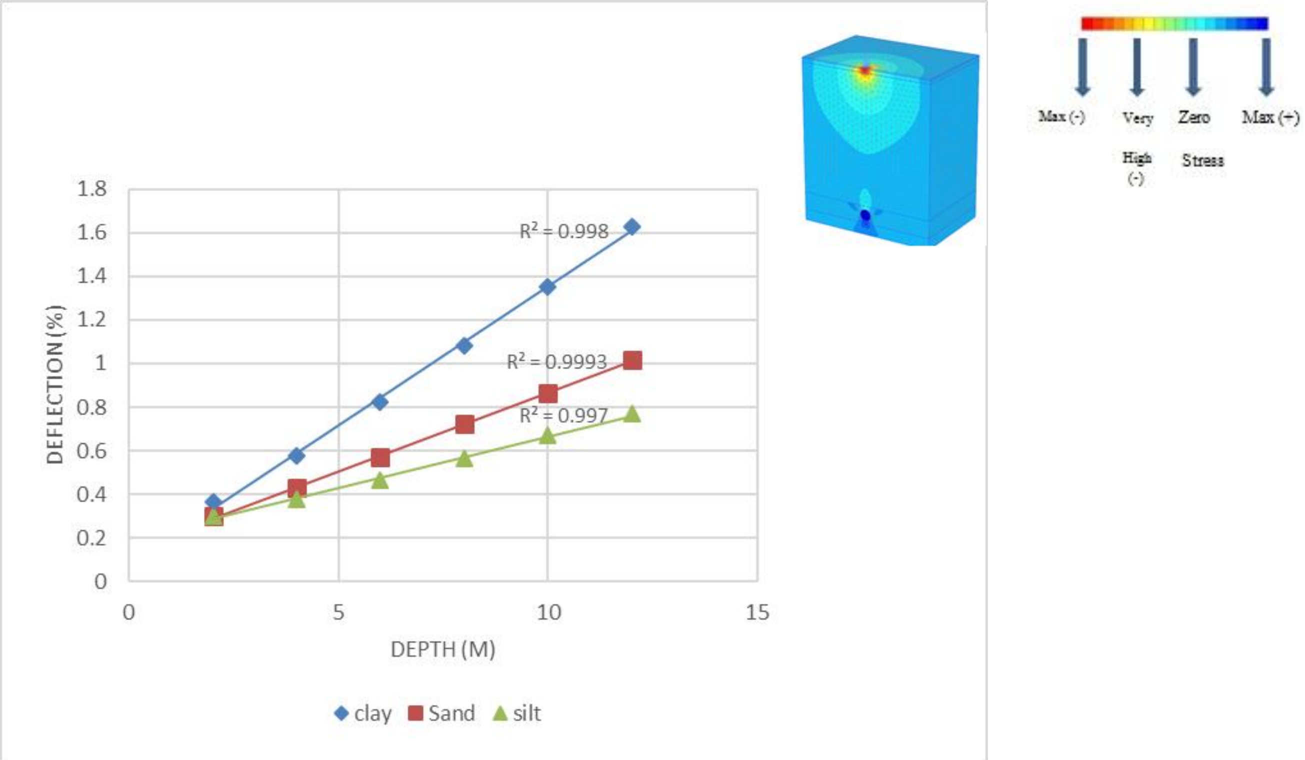


Figure (4-17): vertical deflection 1.4-m pipe diameter

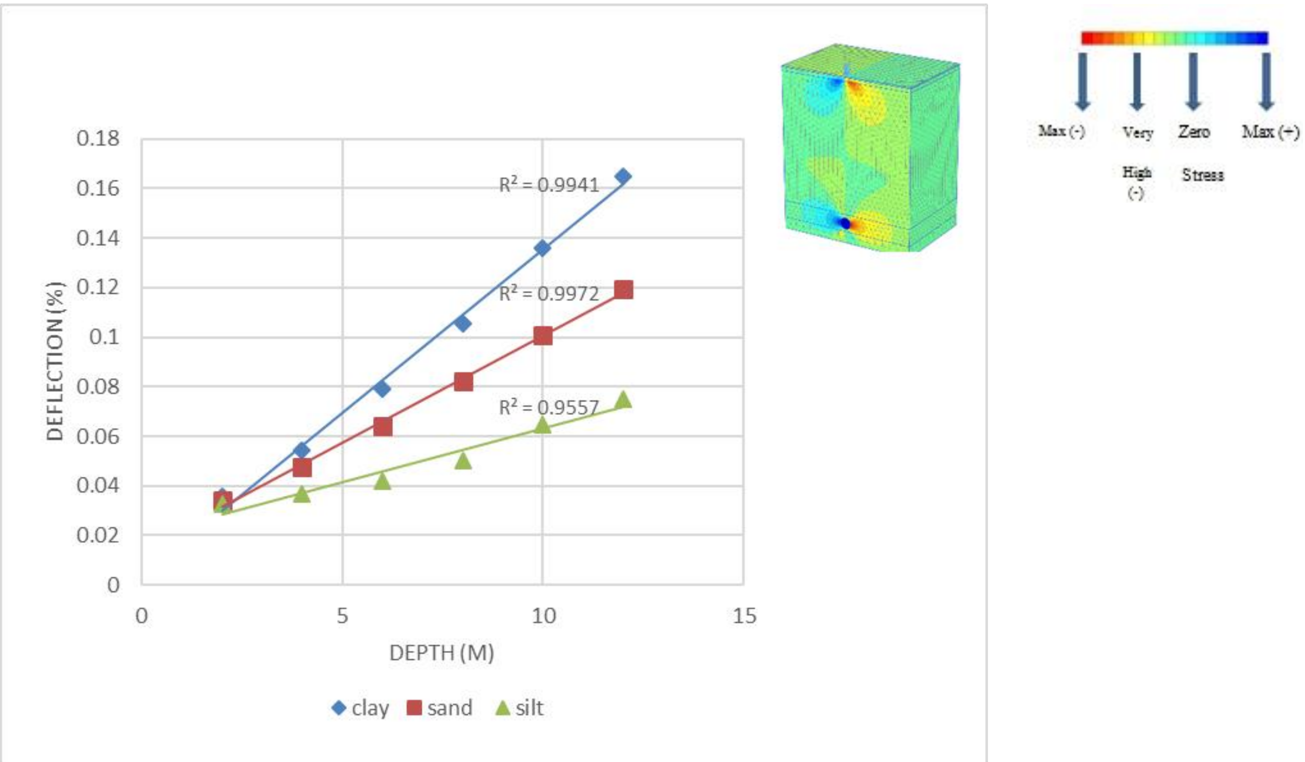


Figure (4-18): horizontal deflection 1.4-m pipe diameter

4.5. Case study

Above calculation and method, investigate standards soil found in nature and results can be used to predict pipe stability when soil and pipe condition used same in this study. Case study in Iraq – Karbala for sewage network trunk line .pipe diameter used in this line is (1.4) m .Soil layers contain of silty sand for first layer, dense sand for second layer figure (4-19) shows borehole profile of soil layers with high water table elevation (-0.3) from ground level .Pipe stiffness used 496 kPa , pipe and soil properties found in appendix (A). Start analysis this case with AWWA formula with burial pipe depth start at (2) m up to (12) m with (2) m increment. Used these properties of soil and pipe as input for plaxis simulation to get near result of filed measurements of pipe deflection according to comparison mentioned in this chapter. Result of AWWA formula and plaxis modeling are shown in Figure (4-20). Location of case study is shown in Figure (4-21).

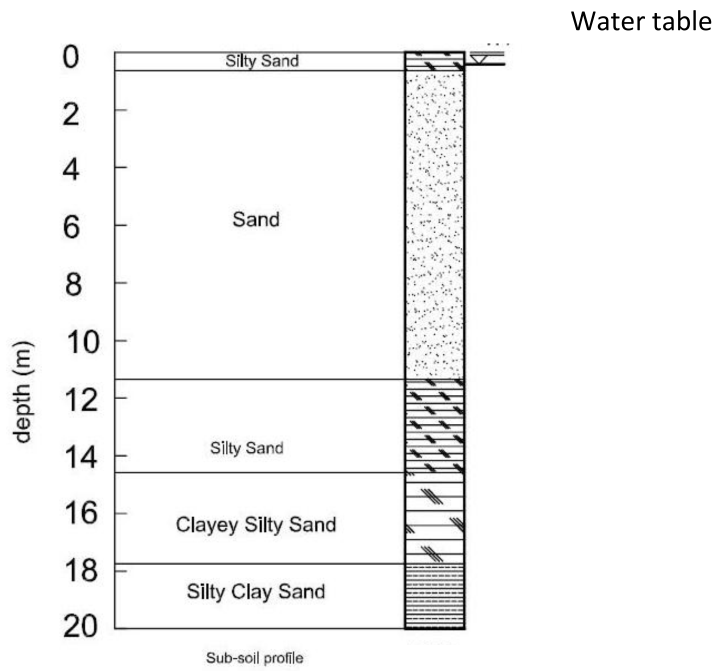
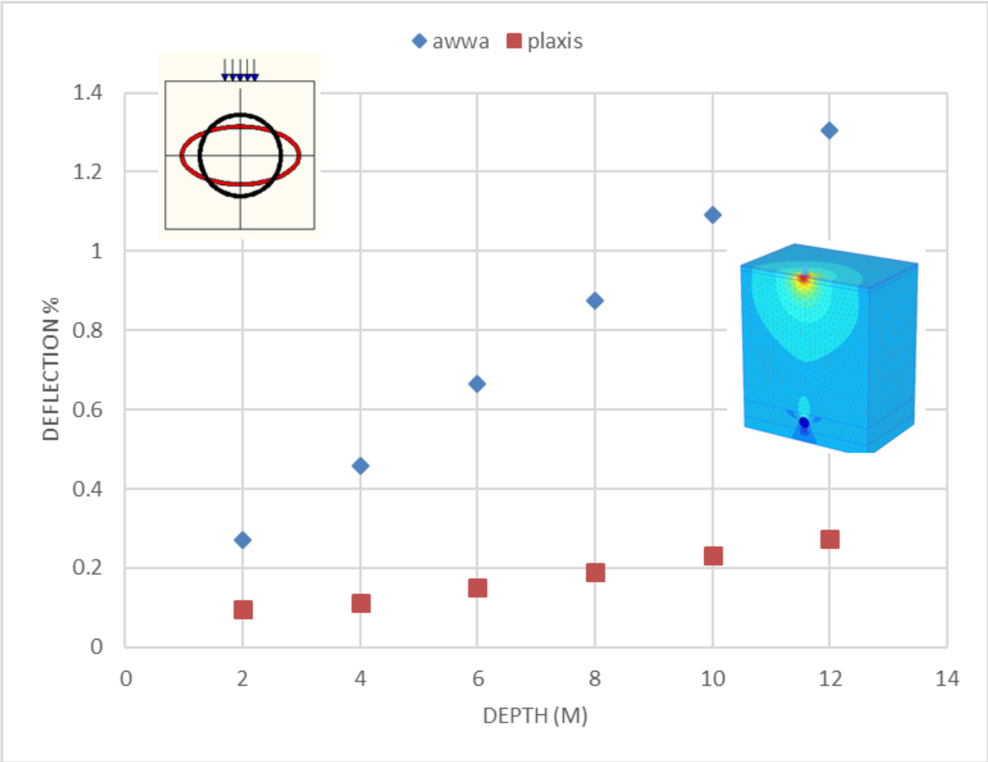


Figure (4-19):Soil layer profile(kufa, 2008)



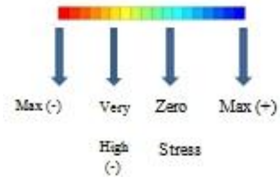


Figure (4-20): Vertical deflection results of case study

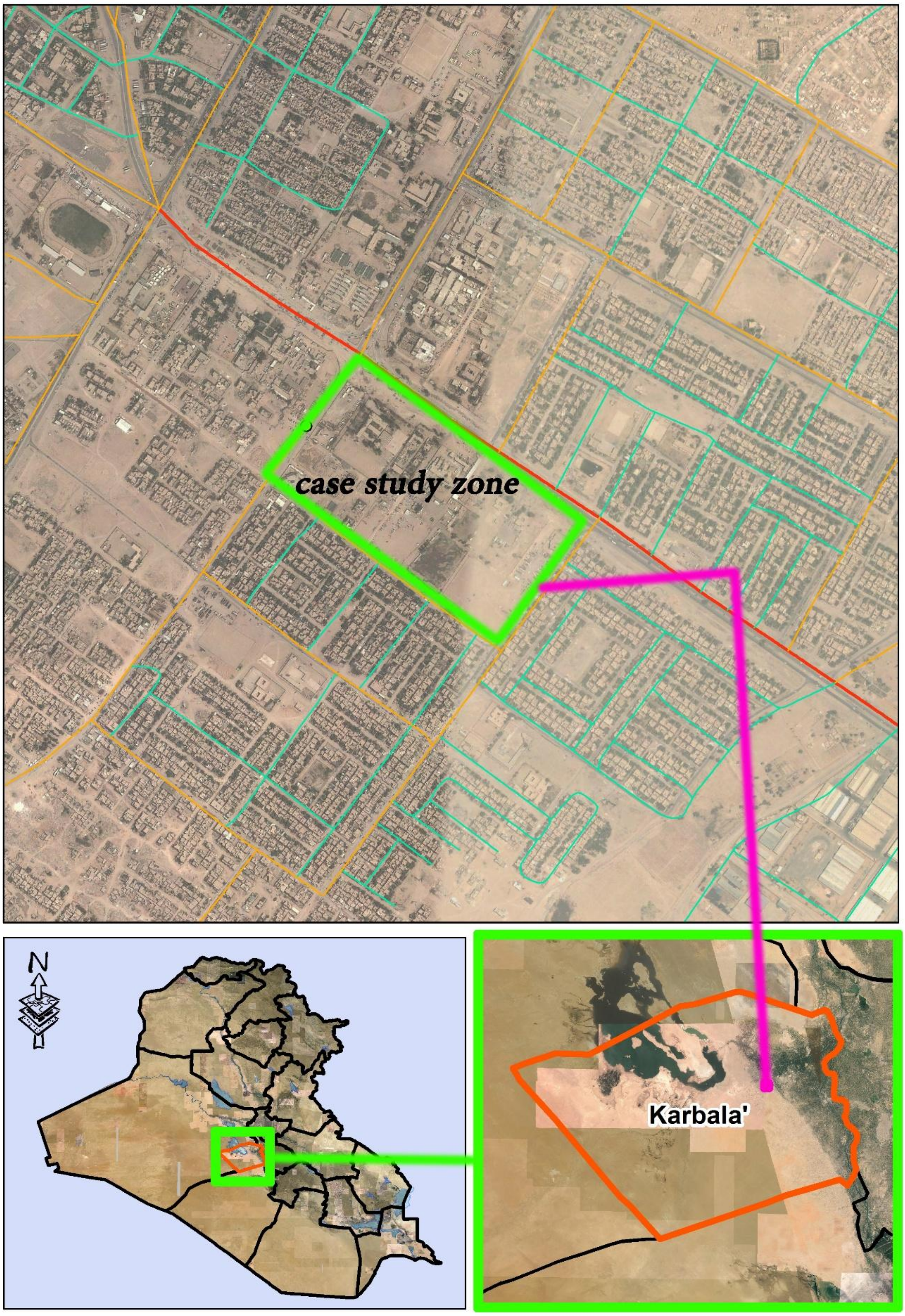


Figure (4-21): Case study location

Chapter Five

Conclusion and Recommendation

5.1. Introduction

In this chapter conclusion and recommendation will be presented for cases have been analyzed with AWWA formula and Plaxis modeling simulation to explain main findings achieved and condition cannot be made to include in future research.

5.2. Conclusions

According to analysis methods this section will be divided into three parts: (1) AWWA formula analysis, (2) plaxis modeling and simulation, and (3) effect of pipe stability on road.

1- The deflection values are considered safe for sand and silt soils, and not safe for clay soil at depth greater than or equal to 12-m. Most stable soil in this analysis is silt soil.

2- For a 1-m pipe diameter, a deflection of pipe embedded in clay soil is greater than (30) % and (34) % from deflection of pipe embedded in sand and silt soil, respectively.

3-For a 1.4 m pipe diameter, deflections of pipe embedded in clay soil are greater than (32) % and (35) % from sand and silt soil respectively. Silt and sand soil have more stability against earth and live loads because of load carrying mechanisms and soil behavior.

4- Maximum deflection value for a 1.4 m pipe buried in clay soil is (5.343) %, while and minimum deflection value is (1.124) %.

5-Modelling of pipe embedded in clay soil reach maximum vertical deflection value of (2.06) % and minimum value (0.4449) % for 1m pipe . clay soil reach maximum horizontal deflection of (0.1871) %and minimum horizontal deflection of (0.0424) %for 1 m pipe diameter. Clay soil reaches maximum horizontal deflection of (0.165%).

6- The results obtained from 3D-finite element analyses performed using Plaxis are more suitable for design and analysis purpose than the results predicted from AWWA formula.

7-Plaxis modeling calculate 3D deflections for model and gave stress conversely AWWA formula, strains and displacement in each node of model.

8-pipe deflection directly affected on road stability, large deflection values causes unstable layer under pavements structure.

9-pavement surface cracks caused infiltration of surface water into pavement layer reaching into pipe embedment soil and made immigration of fine particles.

5.3. Recommendations for future studies

1-In present study there is a lot of area to expand in this title most important thing is cavity formation under road. Therefore, this effect must be including in further research.

2- Make experimental work together with theoretical approach to compare each other.

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Appendix (A)

include necessary information about soil properties, pipe properties, Results of all soil type and supplementary data which considered and involved in AWWA equation calculation, plaxis modelling, simulation and case study. Information listed according to the sequence of mentioned in research.

1- Stiffness test

ASTM (D2412) parallel-plate loading tests for calculate pipe stiffness

$$Ps = \frac{f}{\Delta y}$$

Where:

F = load per unit length, lb/in.

Δy = vertical pipe deflection, in.

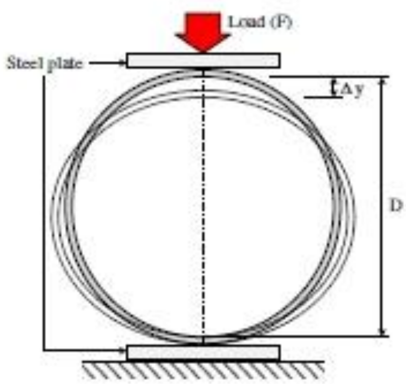

Table (A-1) Modules of soil reaction for all soil groups

Soil Stiffness Category	Soil Type Primary Pipe Zone Backfill Material (Unified Classification System)*	Dumped	Slight <85% Proctor <40% Relative Density	Moderate 85–95% Proctor 40–70% Relative Density	High >95% Proctor >70% Relative Density
Sc 5	Highly compressible fine-grained soils (CH, MH, OL, OH, PT), or borderline soils (CH/MH), or any dual symbol or borderline soil beginning with oneof these symbols	Soils in this category require special engineering analysis to determine required density, moisture content, and compactive effort.	Soils in this category require special engineering analysis to determine required density, moisture content, and compactive effort.	Soils in this category require special engineering analysis to determine required density, moisture content, and compactive effort.	Soils in this category require special engineering analysis to determine required density, moisture content, and compactive effort.
SC4	Fine-grained soils with medium to no plasticity (CL, ML, ML–CL), or borderline soil (ML/CL), or any dual symbol or borderline soil beginning with one of these symbols, with <30% coarse-grained particles	50 (0.34)	200 (1.4)	400 (2.8)	1,000 (6.9)
SC3	Coarse-grained soil with fines (GM, GC, SM, SC, GC–GM, GC/SC) or any dual symbol or borderline soil beginning with one of these symbols, containing more than 12% fines	100 (0.69)	400 (2.8)	1,000 (6.9)	2,000 (13.8)
Sc2	Coarse-grained soils with little or no fines (GW, GP, SW, SP, GW–GC, SP–SM) or any dual symbol or borderline soil beginning with one of these symbols, containing 12% fines or less	200 (1.4)	1,000 (6.9)	2,000 (13.8)	3,000 (20.7)
Sc1	Crushed rock with □15% sand, maximum 25% passing the 3□8 in. sieve and maximum 5% fine	1,000 (6.9)	3,000 (20.7)	3,000 (20.7)	3,000 (20.7)

Table (A-2) Modulus of soil reaction values

Native in Situ Soils				
Granular			Cohesive	
Blows/ft	Description	qu(Tons / sft)	Description	E'n(psi)
>0-1	Very ,very loose	>0-0.125	Very ,very soft	50
1-2	very loose	0.125-0.50	very soft	200
2-4		0.25-0.50	soft	700
4-8	loose	0.50-1.0	medium	1.500
8-10	Slightly compact	1.0-2.0	stiff	3.000
15-30	compact	2.0-4.0	Very stiff	5.000
30-50	dense	4.0-6.0	hard	10.000
>50	Very dense	>6.0	Very hard	20.000

Table (A-3)Soil support combining factor Sc value

'E b /'E n 1	bd/ D 1.5	bd/ D 2	bd/ D 2.5	bd/ D 3	bd/ D 4	bd/ D 5
0.1	0.15	0.30	0.60	0.80	0.90	1.00
0.2	0.30	0.45	0.70	0.85	0.92	1.00
0.4	0.50	0.60	0.80	0.90	0.95	1.00
0.6	0.70	0.80	0.90	0.95	1.00	1.00
0.8	0.85	0.90	0.95	0.98	1.00	1.00
1.0	1.00	1.00	1.00	1.00	1.00	1.00
1.5	1.30	1.15	1.10	1.05	1.00	1.00
2.0	1.50	1.30	1.15	1.10	1.05	1.00
3.0	1.75	1.45	1.30	1.20	1.08	1.00
>=5.0	2.00	1.60	1.40	1.25	1.10	1.00

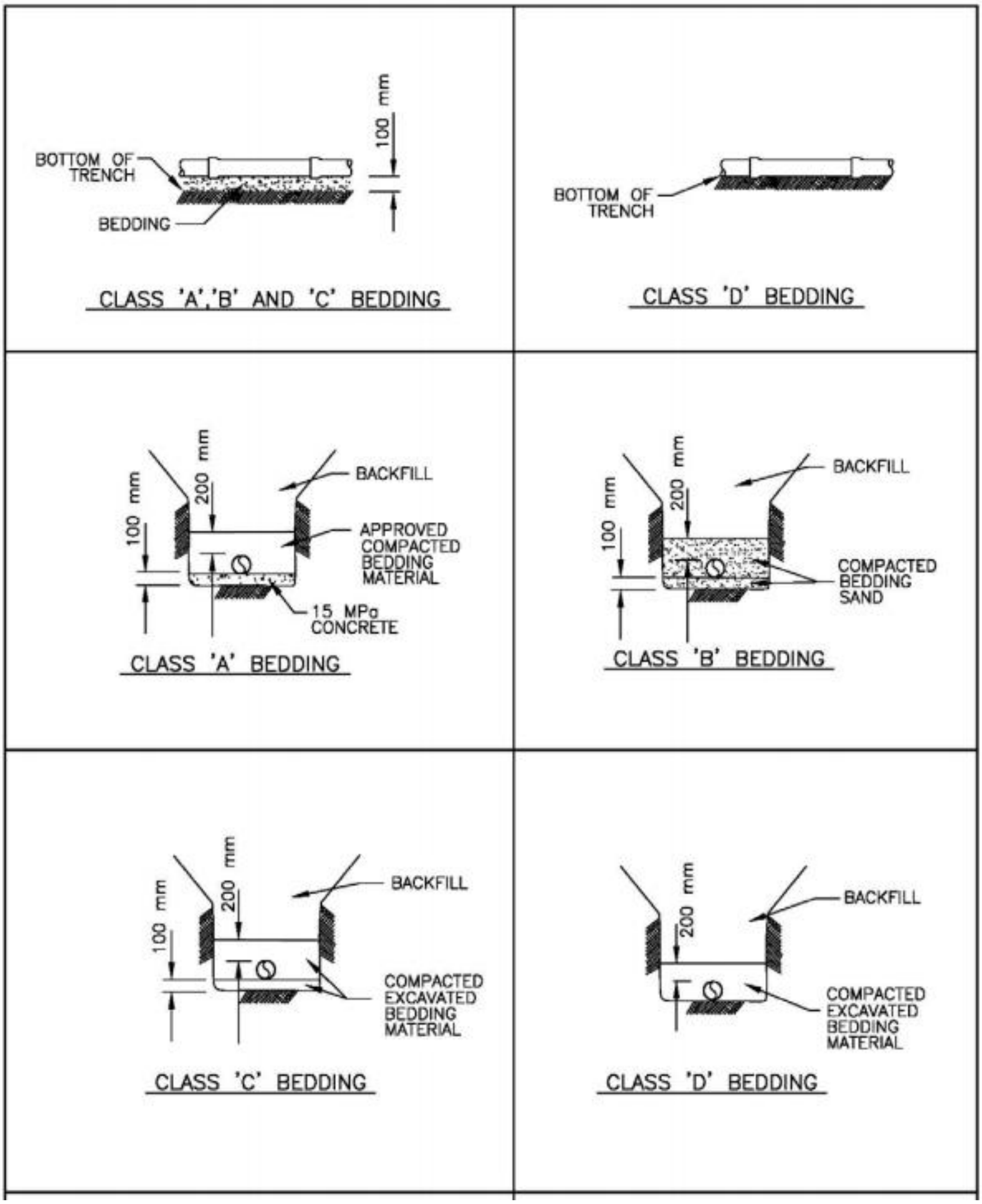

Figure (A-1) Standard installation methods for pipe

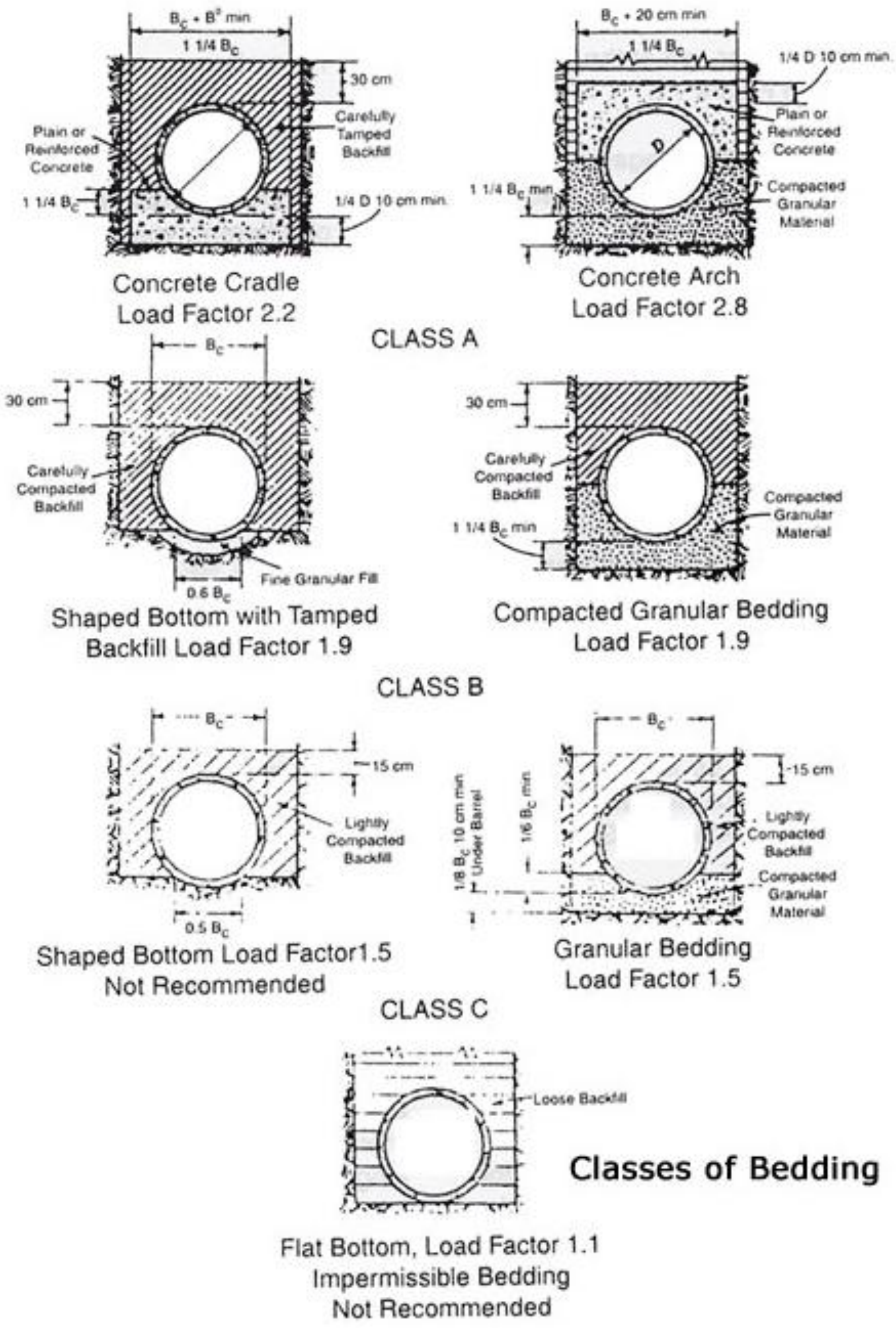

Figure (A-2) Standard installation methods for pipe cross sections

Table (A-4) Results of calculation for AWWA and plaxis

Soil type	Pipe diameter(m)	Depth of burial	AWWA solution	Plaxis modeling	
				Vertical deflection	Horizontal deflection
Clay	1	2	1.0633	0.4449	0.0424
		4	1.7738	0.6892	0.05916
		6	2.5718	0.9949	0.08313
		8	3.3917	1.35	0.1184
		10	4.22	1.677	0.1543
		12	5.052	2.06	0.1871

Soil type	Pipe diameter(m)	Depth of burial	AWWA solution	Plaxis modeling	
				Vertical deflection	Horizontal deflection
Clay	1.4	2	1.124	0.364571	0.035571
		4	1.876	0.573857	0.054421
		6	2.72	0.821429	0.079
		8	3.587	1.082143	0.105714
		10	4.463	1.354286	0.136214
		12	5.343	1.627143	0.165143

Soil type	Pipe diameter(m)	Depth of burial	AWWA solution	Plaxis modelling	
				Vertical deflection	Horizontal deflection
sand	1	2	0.7266	0.3631	0.04052
		4	1.2247	0.5203	0.05106
		6	1.7795	0.6993	0.06882
		8	2.3485	0.8833	0.0886
		10	2.923	1.07	0.1096
		12	3.5	1.256	0.1293

Soil type	Pipe diameter(m)	Depth of burial	AWWA solution	Plaxis modeling	
				Vertical deflection	Horizontal deflection
sand	1.4	2	0.7628	0.301071	0.0341
		4	1.285	0.43	0.0474
		6	1.868	0.571929	0.0643
		8	2.465	0.721429	0.0823
		10	3.068	0.864286	0.1009
		12	3.674	1.018571	0.1192

Soil type	Pipe diameter(m)	Depth of burial	AWWA solution	Plaxis modeling	
				Vertical deflection	Horizontal deflection
Silt	1	2	0.698	0.391	0.0382
		4	1.167	0.4842	0.0405
		6	1.694	0.5978	0.0460
		8	2.234	0.7218	0.0550
		10	2.78	0.8471	0.0650
		12	3.329	0.9737	0.0749

Soil type	Pipe diameter(m)	Depth of burial	AWWA solution	Plaxis modeling	
				Vertical deflection	Horizontal deflection
Silt	1.4	2	0.733	0.3005	0.0326
		4	1.226	0.3743	0.0672
		6	1.778	0.4666	0.0421
		8	2.346	0.5631	0.0502
		10	2.919	0.6699	0.0648
		12	3.495	0.7678	0.0747

Table (A-5) Comparison materials and pipe properties

Native soil properties	
Density ((kN/m3)	20.19
Poisson's ratio	0.3
Internal friction˚	35
soil modulus (kN/m2)	40000
Bedding soil properties	
Density ((kN/m3)	17.85
Poisson's ratio	0.3
Internal friction˚	30
soil modulus (kN/m2)	30000

Table (A-6) Pipe properties

Pipe diameter (m)	2.4
Pipe stiffness (kN/m2)	619
Poisson's ratio	0.159

Table (A-7) Case study soil properties

AWWA M-45	E´(psi)	ɤ s (ib/ft)	live load(ib)	sc
	3780	114.8674	16000	1.89

Plaxis modelling and simulation					
Sand					
ɣ (KN/m3)	ɣ sat. (KN/m3)	E´(KN/m2)	ν'	C(KN/m2)	Ø˚
16	19.6	60.00E3	0.3	0	35

Plaxis modelling and simulation					
Silty sand					
ɣ (KN/m3)	ɣ sat. (KN/m3)	E´(KN/m2)	ν'	C(KN/m2)	Ø˚
15.9	19	21.00E3	0.3	0	30

Table (A-8) Soil properties used in this research for plaxis and AWWA M-45

Bedding materials					
ɣ (KN/m3)	ɣ sat. (KN/m3)	E´(KN/m2)	v'	C(KN/m2)	Ø°
20	20.03	1.00E+05	0.3	0	30
sand					
18.4	18.6	2.00E+04	0.3	0	30
sub base					
21	21.12	1.50E+05	0.3	15	10
clay					
17.2	19.7	1.50E+04	0.3	25	0
silt					
17.75	19.25	1.40E+04	0.3	20	26

soil type	diameter	E´(psi)	ɤ s (ib/ft)	live load(ib)	sc
clay	1 m	1230	114.8674473	16000	1.23
	1.4m	1300	114.8674473	16000	1.3
sand	1m	780.1	107.3760921	16000	0.7801
	1.4m	728	107.3760921	16000	0.728
silt	1m	1300	109.2489309	16000	1.3
	1.4m	1230	109.2489309	16000	1.23

Table (A-9) Asphalt properties

Asphalt properties		
ɣ (KN/m3)	E´(KN/m2)	v'
23	3.50E+06	0.35

Appendix (A)

Appendix (A)

الخلاصة

تصميم وتحليل البُنى التَحتية مثل الانابيب تحتاج الى طريقة فعالة قابلة للتطبيق عملياً. في هذا البحث تم تقييم انبوب (GRP) مدفون تحت تأثير احمال التربة والاحمال الحية. استعملت معادلة (Iowa) وكذلك اسلوب المحاكاة باستخدام العناصر المحددة لإختبار التصرف الانشائي للانبوب . التحليل بالعناصر المحددة تم باستخدام برنامج حاسوبي يدعى(Plaxis-3D, 2014) وهو ثلاثي الابعاد. ثلاثة انواع من التربة (طين ,رمل ,غرين كذلك قطرين للانبوب (1,1.4)م باستخدام قيمة جساءة ثابتة للانبوب (10000)كيلو باسكال تم التحري عنها وتحليلها. اعماق مختلفة للانبوب تم اعتمادها في هذا البحث.العمق الابتدائي كان 2م وبزيادة تدريجية 2م وصولاً الى العمق النهائي 12 م.للتأكد من نتائج التحليل بإستخدام (Plaxis-3D, 2014) تم مقارنة نتائج هذا البرنامج مع النتائج الحقلية للتأكد من توافقية نتائج التحليل مع النتائج الحقلية. استُخدمت خواص الانبوب والتربة والاحمال كمدخلات في البرنامج ومقارنتها مع النتائج العملية. نتيجة المقارنة مع النتائج الحقلية كانت بهامش خطا (0.5)% من قطر الانبوب كنسبة إنحراف عمودي. نتائج المقارنة تم اعتمادها لعمل نماذج لكل الحالات المتضمنة بالبحث. نتائج المعادلة اظهرت اعلى انحراف لانبوب مدفون بالتربة الطينة مع استخدام (1.4)م كقطر للانبوب وكانت نسبة الانحراف % (5.343).هذه النتيجة تعتبر غير امنة مقارنة مع المواصفة القياسية البالغة (5)% من قطر الانبوب. اعلى نتائج بالنسبة للتربة الغرينية و الرملية كانت (3.674)و(3.495) %على التوالي. نتائج هذه الانحرافات كانت بالعمق الاقصى (12)م. اظهرت التربة الحبيبية (الرمل والغرين)نتائج اكثر استقرارية من التربة الطينية. حسب التحليل بأستخدام البرنامج التربة الطينية مرة اخرى كانت اضعف تربة وصولاً الى نسبة انحراف (2.06) %, بينما وصلت نتائج الرمل الى (1.256) % والتربة الغرينية وصلت لنتيجة (0.9737) %. مرة اخرى اثبت التحليل استقرارية الترب الحبيبية لتأثير الاحمال المسلطة.

جمهورية العراق

وزارة التعليم العالي والبحث العلمي

جامعة كربلاء –كلية الهندسة

قسم الهندسة المدنية

تقييم الهطول لخط صرف صحي(GRP) تحت طريق رئيسي

رسالة مقدمة لكلية الهندسة في جامعة كربلاء كجزء من متطلبات نيل درجة الماجستير في الهندسة المدنية تخصص البنى التحتية

من قبل

عباس حسين علي

بكالوريوس هندسة مدنية 2011

اشراف

ا.م.د.باسم خليل نايل السعيدي

أ.د.محمد عباس الجميلي

1439 هجرية   November 2017 A.D