Analytical Study of Foundation – Soil – Pipe Interaction

Rafi M. Qasim

Department of Environmental and Pollution Engineering,
Basra Engineering Technical Collage, Southern Technical University, Basra, Iraq.

Abstract
Pipes and pipelines are structural elements that play a vital role in modern life due to their ability to convey any liquid between any system. This paper deals with a problem of pipes buried into soil and pass under spread foundation especially when the pipe locates under the center of foundation or footing at shallow depth when the thickness of superficial soil layer above the pipes can be considered always small. This search includes numerical application to study the static interaction between foundation and pipe due to load transfer by soil layer that covers the pipe. It is required to investigate:

1. Effect of buried depth and embedment ratio on vertical displacement.
2. Effect of foundation thickness on vertical displacement.
3. Effect of static load magnitude on vertical displacement.
4. Effect of pipe diameter, also wall thickness and pipe rigidity on vertical displacement.
5. The shear force and bending moment developed into the pipe.

INTRODUCTION
Pipes and pipelines used to transmit drinkable water or disposal of wastewater and drainage water are used to transmit oil and gas or any liquid they are used as means of service in transport of electric and communication cable. In general, pipes play a very effective and significant role in modern life, especially in controlling of disaster after flood and seismic hazard. The behaviour of a buried pipeline will depend very highly on how its stiffness is compared with the stiffness of the native soil in which it is to be buried in (1). A pipe must have sufficient strength and/or stiffness to fulfill its intended use and must be permanent during the serviceability of life the behavior of buried pipes is much affected by geotechnical soil properties, which are shared in the performance of buried pipes. Evaluation of the behavior and stability of buried pipes are shown in terms of permissible deflection and buckling resistance (2). In modeling of pipe-soil interaction soil can be modeled by an elastic continuum or by winkler model (3). Modeling of buried pipelines can be carried out as: continuum finite element modeling for the pipe and using special beam-type finite elements for the pipe (4).

PROBLEM DEFINITION AND OBJECTIVE
Pipes or Pipelines play a vital role in modern life due to its ability to convey any liquid between any system. This paper deals with a problem of pipes buried into soil and pass under
static load applied on foundation with range between (200-1000) KN with constant load incremental about 200KN.

Table 1: circular steel pipe description

<table>
<thead>
<tr>
<th>Diameter (m)</th>
<th>Thickness (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.25</td>
<td>3 5 10</td>
</tr>
<tr>
<td>0.5</td>
<td>3 5 10</td>
</tr>
</tbody>
</table>

Table 2: engineering properties of circular steel pipe

<table>
<thead>
<tr>
<th>Modulus of Elasticity (MPa)</th>
<th>Poisson’s Ratio</th>
<th>Density (Kg/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>200000</td>
<td>0.3</td>
<td>7850</td>
</tr>
</tbody>
</table>

Table 3: geotechnical data of soil

<table>
<thead>
<tr>
<th>Modulus of Elasticity (MPa)</th>
<th>Poisson’s Ratio</th>
<th>Density (Kg/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>30</td>
<td>0.45</td>
<td>1800</td>
</tr>
<tr>
<td>40</td>
<td>0.45</td>
<td>1800</td>
</tr>
<tr>
<td>50</td>
<td>0.4</td>
<td>1800</td>
</tr>
</tbody>
</table>

Table 4: foundation dimension

<table>
<thead>
<tr>
<th>Dimension (m)</th>
<th>Thickness (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1x1</td>
<td>0.3 0.5</td>
</tr>
</tbody>
</table>

Table 5: concrete properties of foundation

<table>
<thead>
<tr>
<th>Modulus of Elasticity (Pa)</th>
<th>Poisson’s Ratio</th>
<th>Density (Kg/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>25743 x 10⁶</td>
<td>0.25</td>
<td>2400</td>
</tr>
</tbody>
</table>

RESULTS AND DISCUSSION

Effect of buried depth and embedment ratio on vertical displacement.

The effect of buried depth and embedment ratio are inferred by using numerical finite element method. Figures from (1) to (8) review the response of pipe to vertical static load transmitted through soil when the path of pipe located at different depth it is obvious in figures from (1) to (4) as buried depth increase the vertical displacement decrease .also figures from (5) to (8) shows as embedment ratio increase the vertical displacement decrease .
Figure (3) relationship between displacement and buried depth for pipe pass under foundation (1x1x0.5)m

Figure (4) relationship between displacement and buried depth for pipe pass under foundation (1x1x0.5)m

Figure (5) relationship between displacement and embedment ratio for pipe pass under foundation (1x1x0.3)m

Figure (6) relationship between displacement and embedment ratio for pipe pass under foundation (1x1x0.3)m
This is because the load transmitted by foundation and soil to pipe dissipation with depth. If the structural capacity of pipe is greater than the applied load which is combine of four component (static load, foundation weight, soil weight and pipe weight) the pipe displacement will converse its direction. Also, this will appear in first loading condition as shown in figures from (1) to (8).

Effect of foundation thickness on vertical displacement

The effect of foundation thickness is investigated using numerical finite element method. Figures from (9) to (12) shows there is no significant effect on pipe displacement due to change foundation thickness. The obtained result has no comparable values because the change in thickness can be consider small in this paper so this change will not reflect on pipe behavior.
Effect of static load magnitude on vertical displacement

The effect of static load and gradually increase in load magnitude are investigated. Figures from (13) to (16) shows that the displacement increase linearly with increasing in load magnitude regardless of soil type, foundation and pipe configuration respectively. Note that figure (13) represent the path of pipe under foundation (1x1x0.3) m with H/D=1.5 and H/D=3.5. Figure (14) represent the path of pipe under foundation (1x1x0.5) m with H/D=1.5 and H/D=3.5. Also
figure (15) represent the path of pipe under foundation (1x1x0.3) m with H/D=0.5 and H/D=1.5 and figure (16) represent the path of pipe under foundation (1x1x0.5) m with H/D=0.5 and H/D=1.5.

**Effect of pipe diameter, also wall thickness and pipe rigidity on vertical displacement**

Figures from (17) to (20) shows the response of pipe due to change in diameter it is clear as diameter increase the vertical displacement will decrease because the increase in the moment of inertia of the section and this will reflect on displacement regardless of buried depth, embedment ratio, soil type, foundation configuration and value of applied load. If the structural capacity of pipe is greater than the applied load the pipe displacement will converse, it is direction and the pipe diameter and vertical displacement are consider as independent. also figures from (21) to (28) review the relationship between vertical displacement and (t/D) it is clear as the ratio (t/D) increase the displacement will decrease. also figures from (29) to (35) shows the effect of pipe wall thickness as the thickness increase the displacement will decrease due to increase in the moment of inertia of the pipe and figures from (36) to (41) shows that as the pipe flexural rigidity increase the vertical displacement will decrease.

**The shear force and bending moment developed into the pipe**

![Figure (13) relationship between pipe displacement and applied load](image1)

![Figure (14) relationship between pipe displacement and applied load](image2)
Figure (15) relationship between pipe displacement and applied load

Figure (16) relationship between pipe displacement and applied load

Figure (17) relationship between pipe diameter and displacement

Figure (18) relationship between pipe diameter and displacement

<table>
<thead>
<tr>
<th>Load (KN)</th>
<th>Vertical Displacement (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>200</td>
<td>0</td>
</tr>
<tr>
<td>300</td>
<td>0</td>
</tr>
<tr>
<td>400</td>
<td>0</td>
</tr>
<tr>
<td>500</td>
<td>0</td>
</tr>
<tr>
<td>600</td>
<td>0</td>
</tr>
<tr>
<td>700</td>
<td>0</td>
</tr>
<tr>
<td>800</td>
<td>0</td>
</tr>
<tr>
<td>900</td>
<td>0</td>
</tr>
<tr>
<td>1000</td>
<td>0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Diameter (mm)</th>
<th>Vertical Displacement (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>250</td>
<td>0</td>
</tr>
<tr>
<td>500</td>
<td>0</td>
</tr>
</tbody>
</table>

H=0.5m D=250mm
H=0.5m D=500m

H=1m D=250mm
H=1m D=500m
Figure (19) relationship between pipe diameter and displacement

Vertical Displacement (mm) vs Diameter (mm)

Figure (20) relationship between pipe diameter and displacement

Vertical Displacement (mm) vs Diameter (mm)

Figure (21) relationship between displacement and t/D for pipe (250mm) with H/D=1.5

Figure (22) relationship between displacement and t/D for pipe (250mm) with H/D=3.5

- S1, F=200KN
- S2, F=200KN
- S3, F=200KN
- S1, F=400KN
- S2, F=400KN
- S3, F=400KN
- S1, F=600KN
- S2, F=600KN
- S3, F=600KN
- S1, F=800KN
- S2, F=800KN
- S3, F=800KN
- S1, F=1000KN
- S2, F=1000KN
- S3, F=1000KN

- H=0.5m D=250mm
- H=0.5m D=500mm

- H=1m D=250mm
- H=1m D=500mm

- 0.012 0.02 0.04
- -12 -10 -8 -6 -4 -2 0 2 4
- -6 -4 -2 0 2 4 6 8 10 12

- 0.012 0.02 0.04
- -12 -10 -8 -6 -4 -2 0 2 4 6 8 10 12

- 0.012 0.02 0.04
- -6 -4 -2 0 2 4 6 8 10 12

- 0.012 0.02 0.04
- -6 -4 -2 0 2 4 6 8 10 12
Figure (23) relationship between displacement and $t/D$ for pipe (250mm) with $H/D=1.5$

Vertical Displacement (mm) vs. $t/D$

- $S1, F=200$ KN
- $S2, F=200$ KN
- $S3, F=200$ KN
- $S1, F=400$ KN
- $S2, F=400$ KN
- $S3, F=400$ KN
- $S1, F=600$ KN
- $S2, F=600$ KN
- $S3, F=600$ KN
- $S1, F=800$ KN
- $S2, F=800$ KN
- $S3, F=800$ KN
- $S1, F=1000$ KN
- $S2, F=1000$ KN
- $S3, F=1000$ KN

Figure (24) relationship between displacement and $t/D$ for pipe (250mm) with $H/D=3.5$

Vertical Displacement (mm) vs. $t/D$

- $S1, F=200$ KN
- $S2, F=200$ KN
- $S3, F=200$ KN
- $S1, F=400$ KN
- $S2, F=400$ KN
- $S3, F=400$ KN
- $S1, F=600$ KN
- $S2, F=600$ KN
- $S3, F=600$ KN
- $S1, F=800$ KN
- $S2, F=800$ KN
- $S3, F=800$ KN
- $S1, F=1000$ KN
- $S2, F=1000$ KN
- $S3, F=1000$ KN

Figure (25) relationship between displacement and $t/D$ for pipe (500mm) with $H/D=0.5$

Vertical Displacement (mm) vs. $t/D$

- $S1, F=200$ KN
- $S2, F=200$ KN
- $S3, F=200$ KN
- $S1, F=400$ KN
- $S2, F=400$ KN
- $S3, F=400$ KN
- $S1, F=600$ KN
- $S2, F=600$ KN
- $S3, F=600$ KN
- $S1, F=800$ KN
- $S2, F=800$ KN
- $S3, F=800$ KN
- $S1, F=1000$ KN
- $S2, F=1000$ KN
- $S3, F=1000$ KN

Figure (26) relationship between displacement and $t/D$ for pipe (500mm) with $H/D=1.5$

Vertical Displacement (mm) vs. $t/D$

- $S1, F=200$ KN
- $S2, F=200$ KN
- $S3, F=200$ KN
- $S1, F=400$ KN
- $S2, F=400$ KN
- $S3, F=400$ KN
- $S1, F=600$ KN
- $S2, F=600$ KN
- $S3, F=600$ KN
- $S1, F=800$ KN
- $S2, F=800$ KN
- $S3, F=800$ KN
- $S1, F=1000$ KN
- $S2, F=1000$ KN
- $S3, F=1000$ KN
Figure (27) relationship between displacement and \( t/D \) for pipe (500mm) with \( H/D = 0.5 \)

- \( S_1, F = 200 \text{KN} \)
- \( S_2, F = 200 \text{KN} \)
- \( S_3, F = 200 \text{KN} \)
- \( S_1, F = 400 \text{KN} \)
- \( S_2, F = 400 \text{KN} \)
- \( S_3, F = 400 \text{KN} \)
- \( S_1, F = 600 \text{KN} \)
- \( S_2, F = 600 \text{KN} \)
- \( S_3, F = 600 \text{KN} \)
- \( S_1, F = 800 \text{KN} \)
- \( S_2, F = 800 \text{KN} \)
- \( S_3, F = 800 \text{KN} \)
- \( S_1, F = 1000 \text{KN} \)
- \( S_2, F = 1000 \text{KN} \)
- \( S_3, F = 1000 \text{KN} \)

Figure (28) relationship between displacement and \( t/D \) for pipe of (500mm) with \( H/D = 1.5 \)

- \( S_1, F = 200 \text{KN} \)
- \( S_2, F = 200 \text{KN} \)
- \( S_3, F = 200 \text{KN} \)
- \( S_1, F = 400 \text{KN} \)
- \( S_2, F = 400 \text{KN} \)
- \( S_3, F = 400 \text{KN} \)
- \( S_1, F = 600 \text{KN} \)
- \( S_2, F = 600 \text{KN} \)
- \( S_3, F = 600 \text{KN} \)
- \( S_1, F = 800 \text{KN} \)
- \( S_2, F = 800 \text{KN} \)
- \( S_3, F = 800 \text{KN} \)
- \( S_1, F = 1000 \text{KN} \)
- \( S_2, F = 1000 \text{KN} \)
- \( S_3, F = 1000 \text{KN} \)

Figure (29) relationship between displacement and thickness for pipe (250mm) with \( H/D = 1.5 \)

- \( S_1, F = 200 \text{KN} \)
- \( S_2, F = 200 \text{KN} \)
- \( S_3, F = 200 \text{KN} \)
- \( S_1, F = 400 \text{KN} \)
- \( S_2, F = 400 \text{KN} \)
- \( S_3, F = 400 \text{KN} \)
- \( S_1, F = 600 \text{KN} \)
- \( S_2, F = 600 \text{KN} \)
- \( S_3, F = 600 \text{KN} \)
- \( S_1, F = 800 \text{KN} \)
- \( S_2, F = 800 \text{KN} \)
- \( S_3, F = 800 \text{KN} \)
- \( S_1, F = 1000 \text{KN} \)
- \( S_2, F = 1000 \text{KN} \)
- \( S_3, F = 1000 \text{KN} \)

Figure (30) relationship between displacement and thickness for pipe (250mm) with \( H/D = 3.5 \)

- \( S_1, F = 200 \text{KN} \)
- \( S_2, F = 200 \text{KN} \)
- \( S_3, F = 200 \text{KN} \)
- \( S_1, F = 400 \text{KN} \)
- \( S_2, F = 400 \text{KN} \)
- \( S_3, F = 400 \text{KN} \)
- \( S_1, F = 600 \text{KN} \)
- \( S_2, F = 600 \text{KN} \)
- \( S_3, F = 600 \text{KN} \)
- \( S_1, F = 800 \text{KN} \)
- \( S_2, F = 800 \text{KN} \)
- \( S_3, F = 800 \text{KN} \)
- \( S_1, F = 1000 \text{KN} \)
- \( S_2, F = 1000 \text{KN} \)
- \( S_3, F = 1000 \text{KN} \)
Figure (31) relationship between displacement and thickness for pipe (250mm) with $H/D=1.5$

Figure (32) relationship between displacement and thickness for pipe (250mm) with $H/D=3.5$

Figure (33) relationship between displacement and thickness for pipe (500mm) with $H/D=0.5$

Figure (34) relationship between displacement and thickness for pipe (500mm) with $H/D=1.5$
Figure (35) relationship between displacement and thickness for pipe (500mm) with H/D=0.5

Figure (36) relationship between displacement and thickness for pipe of (500mm) with H/D=1.5

Figure (37) relationship between displacement and flexural rigidity for pipe (250mm) with H/D=1.5

Figure (38) relationship between displacement and flexural rigidity for pipe (250mm) with H/D=3.5
Figure (39) relationship between displacement and flexural rigidity for pipe (250mm) with $H/D=1.5$

- $S_1, F=200\, \text{KN}$
- $S_2, F=200\, \text{KN}$
- $S_3, F=200\, \text{KN}$
- $S_1, F=400\, \text{KN}$
- $S_2, F=400\, \text{KN}$
- $S_3, F=400\, \text{KN}$
- $S_1, F=600\, \text{KN}$
- $S_2, F=600\, \text{KN}$
- $S_3, F=600\, \text{KN}$
- $S_1, F=800\, \text{KN}$
- $S_2, F=800\, \text{KN}$
- $S_3, F=800\, \text{KN}$
- $S_1, F=1000\, \text{KN}$
- $S_2, F=1000\, \text{KN}$
- $S_3, F=1000\, \text{KN}$

Figure (40) relationship between displacement and flexural rigidity for pipe (250mm) with $H/D=3.5$

- $S_1, F=200\, \text{KN}$
- $S_2, F=200\, \text{KN}$
- $S_3, F=200\, \text{KN}$
- $S_1, F=400\, \text{KN}$
- $S_2, F=400\, \text{KN}$
- $S_3, F=400\, \text{KN}$
- $S_1, F=600\, \text{KN}$
- $S_2, F=600\, \text{KN}$
- $S_3, F=600\, \text{KN}$
- $S_1, F=800\, \text{KN}$
- $S_2, F=800\, \text{KN}$
- $S_3, F=800\, \text{KN}$
- $S_1, F=1000\, \text{KN}$
- $S_2, F=1000\, \text{KN}$
- $S_3, F=1000\, \text{KN}$

Figure (41) relationship between displacement and flexural rigidity for pipe (500mm) with $H/D=0.5$

- $S_1, F=200\, \text{KN}$
- $S_2, F=200\, \text{KN}$
- $S_3, F=200\, \text{KN}$
- $S_1, F=400\, \text{KN}$
- $S_2, F=400\, \text{KN}$
- $S_3, F=400\, \text{KN}$
- $S_1, F=600\, \text{KN}$
- $S_2, F=600\, \text{KN}$
- $S_3, F=600\, \text{KN}$
- $S_1, F=800\, \text{KN}$
- $S_2, F=800\, \text{KN}$
- $S_3, F=800\, \text{KN}$
- $S_1, F=1000\, \text{KN}$
- $S_2, F=1000\, \text{KN}$
- $S_3, F=1000\, \text{KN}$

Figure (42) relationship between displacement and flexural rigidity for pipe (500mm) with $H/D=1.5$

- $S_1, F=200\, \text{KN}$
- $S_2, F=200\, \text{KN}$
- $S_3, F=200\, \text{KN}$
- $S_1, F=400\, \text{KN}$
- $S_2, F=400\, \text{KN}$
- $S_3, F=400\, \text{KN}$
- $S_1, F=600\, \text{KN}$
- $S_2, F=600\, \text{KN}$
- $S_3, F=600\, \text{KN}$
- $S_1, F=800\, \text{KN}$
- $S_2, F=800\, \text{KN}$
- $S_3, F=800\, \text{KN}$
- $S_1, F=1000\, \text{KN}$
- $S_2, F=1000\, \text{KN}$
- $S_3, F=1000\, \text{KN}$
Vertical Displacement (mm)

Figure (43) relationship between displacement and flexural rigidity for pipe (500 mm) with $H/D=0.5$:

- $S_1, F=200$ KN
- $S_2, F=200$ KN
- $S_3, F=200$ KN
- $S_1, F=400$ KN
- $S_2, F=400$ KN
- $S_3, F=400$ KN
- $S_1, F=600$ KN
- $S_2, F=600$ KN
- $S_3, F=600$ KN
- $S_1, F=800$ KN
- $S_2, F=800$ KN
- $S_3, F=800$ KN
- $S_1, F=1000$ KN
- $S_2, F=1000$ KN
- $S_3, F=1000$ KN

Figure (44) relationship between displacement and flexural rigidity for pipe (500 mm) with $H/D=1.5$:

- $S_1, F=200$ KN
- $S_2, F=200$ KN
- $S_3, F=200$ KN
- $S_1, F=400$ KN
- $S_2, F=400$ KN
- $S_3, F=400$ KN
- $S_1, F=600$ KN
- $S_2, F=600$ KN
- $S_3, F=600$ KN
- $S_1, F=800$ KN
- $S_2, F=800$ KN
- $S_3, F=800$ KN
- $S_1, F=1000$ KN
- $S_2, F=1000$ KN
- $S_3, F=1000$ KN

Figure (45) relationship between shear force and buried depth:

- $H=0.5$ m $D=250$ mm
- $H=0.5$ m $D=500$ mm

Figure (46) relationship between shear force and buried depth:

- $H=1$ m $D=250$ mm
- $H=1$ m $D=500$ mm
Figure (47) relationship between shear force and buried depth

Shear Force (N) vs. Buried Depth (m)

- H=0.5m D=250mm
- H=0.5m D=500mm

Figure (48) relationship between shear force and buried depth

Shear Force (N) vs. Buried Depth (m)

- H=1m D=250mm
- H=1m D=500mm

Figure (49) relationship between bending moment and buried depth

Bending Moment (N.m) vs. Buried Depth (m)

- H=0.5m D=250mm
- H=0.5m D=500mm

Figure (50) relationship between bending moment and buried depth

Bending Moment (N.m) vs. Buried Depth (m)

- H=1m D=250mm
- H=1m D=500mm
The variation of the shear force and bending moment with buried depth are shown in figures from 45 to 52 respectively. All figures show that the variation in shear forces and bending moments due to different load applied and change in pipe diameter take in consideration wall thickness and pipe rigidity. Figures 45, 47, 49 and 51 represent the path of pipe (250mm) under foundation (1x1x0.3)m also figures 46, 48, 50 and 52 represent the path of pipe (500mm) under foundation (1x1x0.5)m. These figures show the maximum value of shear force and bending moment respectively.

Effect of soil type on vertical displacement

Three types of soils are differed in properties are considered in case study it is clear in figures from 53 to 59 as the soil modulus of elasticity increase the response of buried pipe decrease for the same loading condition regardless of foundation configuration except in the case when the structural capacity of pipe greater than the applied load the soil modulus of elasticity has no significant effect.
Figure (54) relationship between pipe displacement and soil modulus of elasticity

Figure (55) relationship between pipe displacement and soil modulus of elasticity

Figure (56) relationship between pipe displacement and soil modulus of elasticity
CONCLUSIONS
The main conclusions from this paper shows, The buried depth and embedment ratio play important role on the response of buried pipe. Foundation thickness has no significant effect on the response of buried pipe. The vertical displacement of pipe increase linearly with increasing in load magnitude. As the pipe diameter, pipe wall thickness, ratio (t/D), and pipe rigidity increase the pipe displacement will decrease. The variation of shear force and bending moment will reflect the behavior of buried pipe. As the soil modulus of elasticity increase the pipe vertical displacement decrease. The structural capacity of pipe will reflect it is behavior under loading condition.

REFERENCE
