International Journal of Civil Engineering and Technology (IJCIET)
Volume 9, Issue 7, July 2018, pp. 1201–1214, Article ID: IJCIET_09_07_127
Available online at http://www.iaeme.com/ijciet/issues.asp?JType=IJCIET&VType=9&IType=7
ISSN Print: 0976-6308 and ISSN Online: 0976-6316

STRUCTURAL PERFORMANCE OF PVC LARGE-DIAMETER GRAVITY SEWER PIPES INSTALLED IN MAYSAN PROVINCE ACCORDING TO IRAQI PROCEDURE

Abbas O. Dawood
Department of Civil Engineering, College of Engineering,
Misan University, Maysan Province, Iraq

ABSTRACT

Sewer system is one of main underground pipelines infrastructures in most areas of Iraq. The present study focused on the structural performance of PVC large-diameter gravity sewer pipes installed in Maysan province according to Iraqi procedure. The pipe deflection and wall buckling are considered as performance parameters. Modified Iowa Formula is used to determine the pipe deflection using both conventional and corrected soil modulus. It is concluded that granular sidefill compacted to 85% and more or uncompacted crushed gravel satisfy deflection and buckling allowable limits, while 80% side is safe for depth not more than 6m. In case of uncompacted sidefill the pipe is subjected to excessive deflection at depth greater than 3m.

Key words: Deflection, Gravity Sewer, PVC Pipes, Pipe Installation, Wall Buckling.

Cite this Article: Abbas O. Dawood, Structural Performance of PVC Large-Diameter Gravity Sewer Pipes Installed In Maysan Province According To Iraqi Procedure, International Journal of Civil Engineering and Technology, 9(7), 2018, pp. 1201–1214.
http://www.iaeme.com/ijciet/issues.asp?JType=IJCIET&VType=9&IType=7

1. INTRODUCTION

A sewer system comprises a network of pipelines that collect and transport waste- and stormwater to a wastewater treatment plant. Pipes for underground sewer construction are generally classified in two classes rigid and flexible. Cast iron, concrete, asbestos cement concrete and vitrified clay pipes are rigid pipes while plastic and steel pipes are flexible pipes. Rigid type depends on strength, rigidity, and stiffness of the pipe to maintain its structural strength while the flexible type is designed to use the side fill soil stiffness to limit the outward deflection. The buried plastic pipes (PVC) are flexible, and participate the soil in a favorable pipe-soil interaction that reduces stress concentrations. The strength of all buried plastic pipe systems depends on the quality and placement of the bedding and backfill material [1]. Plastic pipes are lightweight, long lengths, tight joints, resistance to normal atmospheric corrosion, easily fabricated and easily joined in the field [2]. It is possible to manufacture plastic pipes in various shapes, and with corrugations, ribs, fillets, etc. Some of the materials used for plastic piping are polyethylene PE , polyvinyl chloride PVC and polypropylene PP. The PVC pipes have long service life. It is completely inert to water and to chemicals commonly encountered in sewage and soil environments. It is not attacked by hydrogen sulfide or the resulting sulfuric acid. PVC pipes are not subject to biological degradation. Abrasive resistance is excellent and the dimensional control is excellent [3, 4]. The three most important parameters for flexible pipe analysis and design are (i) load, (ii) soil stiffness, and (iii) pipe stiffness. Excessive deflection may disturb the integrity of the pipe joints, and may also cause leaks. Large deflections may also cause loss of pavement support or lead to the restriction in the use of standard size pipe cleaning equipment.

This paper explores the performance of flexible plastic PVC sewer pipe installed in Maysan Province southern Iraq according to Iraqi procedure with dry granular backfill materials (SW, SP or crushed gravel) and subjected to earth loading. Primarily the study reported here is an attempt to check the adequacy of Iraqi procedure although its deviates from the standards procedures.

2. RELATED WORK

There are limited studies related to analysis and investigation of sewer pipelines in Iraq. In 2012 Dawood [5], presented a comprehensive Analytical, numerical and experimental study on behavior and installation of unreinforced concrete pipes under both earth and traffic loadings and he presented several conclusions related to backfilling and bedding materials, compaction and installation procedure. Dawood [6] 2013, investigated numerically and experimentally the minimum backfill cover above unreinforced concrete pipes installed according to local practice of Iraq, he found that a minimum cover of 60 cm is suitable for most concrete pipe practice and the costs of installation could be minimized dependent of backfill selection and construction monitoring. Hussien [7] 2014, presented an field and theoretical study on minimum backfill cover above large diameter buried GRP pipes installed according to Iraq procedure under traffic loadings. He is concluded that buried GRP pipes is strongly influenced by backfilling methods.

3. SUITABLE BACKFILL MATERIALS FOR PLASTIC PIPES

The deflection of a flexible pipe is highly dependent on the stiffness of the soil embedment. The horizontal diameter increases as the pipe deflects, and this affects the region within 2.5 pipe diameters of the pipe side wall. Therefore, the strength of the backfill as well as the insitu material is important. The design criteria for installation flexible pipes focus on the pipe zone (soil surrounding the pipe). Design and installation standards for flexible pipe generally divide the soil types into four or five general groups. ASTM D2321 [8] describes five soil Classes. Class I is manufactured coarse graded material, Class II is gravel or sandy soil with less than 12 percent fines, Class III is gravel or sandy soil with 12 percent to 50 percent fines, and Classes IV and V are silts and clays, and organic soils, respectively. Classes I,II and III are considered good backfills for embedment zone [9].

4. IRAQI PROCEDURE FOR INSTALLATION OF PVC PIPES

The installation procedure of PVC pipes of small or large diameters is identical according to the requirements of Iraqi Ministry of Municipalities and Public Work, which summarized by surrounding the pipe with 30 cm granular material in dry conditions or used gravel or crushed gravel with maximum particle size not exceed 10 mm in regions that can not be dried as shown in Fig.(1). Thus the width of trench is equal to the pipe diameter plus 600 mm (D+600 mm). Then backfilling with compacted layers of native soil (or borrow clean soil if native soil not suitable for backfilling) till the ground level or design level is reached. The granular materials or soils used to surround PVC pipes (pipe zone) are available naturally in different regions of Iraq. Based on maximum particle size limitations, the Iraqi specifications, SORB/R6 [10] classify these granular soils into four classes A, B, C , and D as shown in Table 1. In practice, the commonly used materials for PVC pipe zone are either within Class C or D due to Class A and B have large particles greater than 1". Class C and D of granular soils of Iraqi specifications are classified according to ASTM D2321 as Class II soil, with soil group either SP (Poorly graded sand with gravel) or SW (Well- graded sand with gravel). According to AASHTO [11] it is classified as either A-1-a or A-1-b soil class. Thus embedment zone that surrounding the pipe with 30 cm granular material (Class II soil of ASTM D2321) according to Iraqi procedure is satisfy the ASTM D2321 requirements and also satisfy AASHTO criteria with respect to material type.

According to soil investigations of many boreholes in different areas of Maysan Province, the top 10 m soil is Fine-Grained Soils (inorganic) with soil group either CL (Inorganic clays of low to medium plasticity, gravely clays, sandy clays, silty clays, lean clays) or CH (Inorganic clays of high plasticity, fat clays) and it is classified as Class IV soils of ASTM D2321. Thus the backfill with native soils in Maysan province lies within Class IV soils of ASTM D2321.

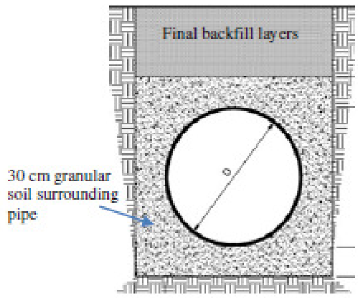


Fig 1 Trench Conditions According to Iraqi Procedure

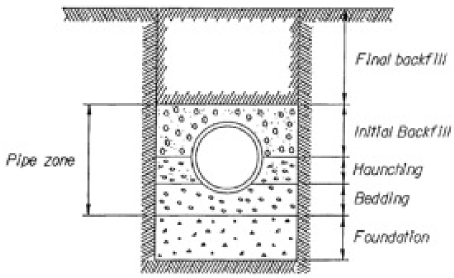


Fig 2 Typical Pipe Backfilling according to ASTM2321

5. COMPARISON OF IRAQI PROCEDURE WITH STANDARD INSTALLATION OF PLASTIC PIPES OF ASTM D2321

The typical plastic pipe installation zones according to ASTM D2321 is illustrated in Fig. (2).

- **Bedding**: Bedding is used to support the pipe directly over the foundation material. For plastic pipe, the bedding material is typically granular [1]. The 30 cm granular material bedding (Class II soil of ASTM D2321) according to Iraqi procedure is satisfy the ASTM D2321 requirements for bedding.

Table 1 Granular soil classification according to Iraqi Specifications SORB/R6.

Sieve No.	Sieve mm	Iraqi standards Classification, % Passing			
		Class A	Class B	Class C	Class D
---	75 (3in)	100	---	---	---
---	50 (2 in)	95-100	100	---	---
---	25 (1 in)	---	75-100	100	100
---	9.50 (3/8 in)	30-65	40-75	50-85	60-100
No. 4	4.75	25-55	30-60	35-65	50-85
No. 8	2.36	16-42	21-47	26-52	42-72
No. 50	0.30	7-18	14-28	14-28	23-42
No. 200	0.075	2-8	5-15	5-15	5-20

- **Haunching**: Haunching is the volume of backfill supports the pipe from the top of the bedding to the springline of the pipe. Compaction of the pipe haunch areas is critical to the successful installation of plastic pipes and prevents pipe sagging in the haunch area. The Iraqi procedure do not satisfy haunching compaction requirements due to in practice there are no any compaction for haunching region and its fill by equipments and its density depends on dropping height only.
- **Initial backfill:** Initial backfill is the material placed above the springline and 305 mm (12 in.) over the pipe. Completion of this zone with well-compacted granular material ensures that the pipe strength is developed. The 30 cm granular material bedding (Class II soil of ASTM D2321) according to Iraqi procedure is satisfy the ASTM D2321 requirements for initial backfill material but do not satisfy compaction requirements. .
- **Final Backfill:**In general Iraqi procedure for final backfilling which consist of compacted layer of native soil satisfy ASTM D2321 requirements for flexible pipe installation but the settlement of road or final grade should be checked. Therefore, a well compacted backfill is required for the pipe to function properly [1].
- **Trench Width :** Rigid pipes, does not depend on sidefill stiffness, so the trench can be as narrow as the installer needs to make joint connections. While PVC Sewer Pipe is dependent on sidefill stiffness to limit deflections. ASTM D2321 recommends a trench width of the pipe shall be not less than the greater of either the pipe outside diameter plus 400 mm or pipe outside diameter times 1.25 plus 300 mm .The reason for the increased width is to allow compaction equipment to operate in the spaces between the trench walls and the pipe. Thus Iraqi procedure limit trench width with pipe outside diameter plus 600 mm not satisfy the trench width requirements.
- **Compaction of Backfill** :PVC Sewer Pipe design is dependent on sidefill support to gain stiffness to control deflections within acceptable limits. Compaction in six inch maximum layers is required to the springline of the pipe. Compaction around the pipe must be by hand. As noted earlier, trench width must be sufficient to allow this compaction. Depending on soil type, minimum density compaction can range from 85% to 95% as per ASTM 2321.

Thus, the Iraqi procedure is deviated from standard installation of ASTM D2321 in two aspects:

- Trench Width
- Compaction of materials around the pipe (pipe zone).

6. EARTH LOADING ON FLEXIBLE PIPES

Marston Theory of loads on underground conduits is commonly used in determination of earth loading on buried pipe. the basic concept of the theory is that the weight of the soil load seen or carried by the buried pipe is not simply the weight of the soil column or prism that is above it but the load due to the weight of the column of soil above a buried pipe is modified by the response of the pipe which depends on the relative movement of columns of soil directly over the pipe and adjacent to the pipe [12].

Flexible pipes has the ability to deflect without cracking, this produces a situation that allows the central prism of soil (directly over the pipe) to settle more than the adjacent soil prisms (between the pipe and the trench wall). This settlement produces shearing forces which reduce the load on a flexible pipe to an amount less than the weight of the prism directly over the pipe [12]. While for rigid pipes, such as concrete pipe the prism above the pipe imposes a greater load than the weight of the prism itself. The reduction in load imposed on a pipe because of its flexibility is sometimes referred to as arching. However, the overall performance of a flexible pipe is not just due to this so-called arching, but is also due to the soil at the sides of the pipe resisting deflection. Thus the minimum earth load on plastic (flexible) pipes is obtained by so called the Marston-Spangler load equation for flexible pipes [4].

$$W_d = C_d \gamma B_c B_d \quad (1)$$

Where: W_d = load on the pipe, kN/m, w = unit weight of backfill, kN/m^3, B_c = outside diameter of pipe, m, B_d = width of trench at top of pipe, m, C_d= load coefficient for conduits installed in trenches. The maximum earth load is the prism embankment load is given by the following equation [4]

$$P = \gamma H \quad (2)$$

where P= pressure due to weight of soil at depth H, γ= unit weight of soil, H = depth at which soil pressure is required. Research data indicate that the effective load or actual load on a flexible conduit lies somewhere between the minimum predicted by Marston and the prism load. On a long-term basis, the load may approach the prism load. Thus to calculate the effective load on a flexible conduit, the prism load is suggested as a basis for design [4]. Thus in the present study the earth loading on PVC pipes is calculated based on prism load.

7. PARAMETERS THAT AFFECT PERFORMANCE OF FLEXIBLE BURIED PIPES

Three parameters are most essential in the design or the analysis of any flexible pipe installation: (i) load (depth of burial), (ii) soil stiffness in pipe zone and (iii) pipe stiffness.

7.1. Load (depth of burial)

The design load on the pipe is easily calculated using the prism load theory. Research has shown that the long-term load on a flexible pipe approaches the prism load [4].

7.2. Soil stiffness in pipe zone

The soil stiffness is usually expressed in terms of effective soil modulus E' (MPa). Experience has shown that soil density is the most important parameter influencing soil stiffness. Many research efforts have attempted to measure E'. Howard [13] developed a table of values for the modulus of soil reaction, E' for use with the Iowa formula for deflection of flexible buried pipes. Howard's table divides soils into four principle groups and assigns values of E' as a function of the soil group and the density, which is expressed as function of the maximum density determined as a reference test, such as AASHTO T99. The Water Research Centre WRC [14] in the United Kingdom published table similar to the Howard table. In the present study both Howard and WRC are used to estimate E'.

7.3. Pipe Stiffness

Flexible pipe stiffness is the measurement of the load carrying capacity of the pipe itself subjected to loading condition. Pipe stiffness is a function of the material type and the geometry of the pipe wall. The pipe stiffness (PS) is defined as the ratio of the applied force (F) in kN per linear m over the measured change of pipe inside diameter (Dy). Pipe stiffness can also be defined as the slope of the load deflection diagram [15]. The pipe stiffness at 5% vertical ring deflection, i.e., the change in vertical diameter divided by the original pipe diameter, is typically used as the design value of stiffness. For flexible pipes, pipe stiffness rather than crush strength is usually the controlling pipe material property. Pipe stiffness may be expressed in terms of various parameters as follows (pipe stiffness terminology) [4]:

$$\text{Stiffness Factor} = EI \quad (3)$$

$$\text{Ring Stiffness} = \frac{EI}{d^3} \tag{4}$$

$$\text{Pipe Stiffness} = \frac{F}{\Delta y} = 53.7\frac{EI}{d^3} \tag{5}$$

where *E*= modulus of elasticity, MPa, *I*= moment of inertia of wall cross-section per unit length of pipe, m^4/m, *d* = mean diameter of pipe, m, *F* = force, kN/m, *Δy*= vertical deflection, m. The most commonly used terminology is pipe stiffness (F/Δy). For a given pipe product, this term is readily determined in the laboratory by a parallel plate loading test.

8. PARALLEL PLATE LOADING TEST

The pipe stiffness of flexible pipe specimen is usually measured in the laboratory according to the parallel-plate load test method which considered a basic quality control test often performed in the laboratory. ASTM D 2412 [20] provides complete specifications for the test method. Also the modulus of elasticity E can be also obtained from the parallel plate test [1]. In this test, a PVC pipe sample of diameter 800 mm is placed between two horizontal parallel plates in a testing machine as shown in Fig. (3). A compressive load is applied and increased until the vertical deflection Δ*y* reaches 5 percent of the diameter. And *F*/Δ*y* is the load at 5 percent divided by the sample length and divided by the vertical deflection Δ*y* is 397 kpa (satisfy ASTM D2412 minimum requirements 356 kPa.

9. DETERMINATION THE DEFLECTION OF PVC SEWER PIPE BY MODIFIED IOWA FORMULA

There are several elastic approaches for buried flexible pipe deflections are available. The common approach is the modified Iowa formula derived by Spangler (1941) [39].

Spangler in 1941 [16] developed the equation, known as the "Iowa Formula", the formula was modified later by Watkins and Spangler in 1958 [36] to include a more realistic value for the soil parameter, [17] and called "Modified Iowa Formula" which gained acceptance. The modified Iowa formula which uses the modulus of soil reaction E' as the principle soil parameter is given as .:

$$\frac{\Delta x}{D} \approx \frac{\Delta y}{D} = \frac{D_L\,K\,W}{0.149\,PS_o + 0.061\,E'} \tag{6}$$

$$PS_o = 53.7\frac{EI}{d^3} \quad \text{or} \quad PS_o = \frac{F}{\Delta y} \tag{7}$$

Where Δx and Δy = Horizontal and vertical deflections (or change in horizontal and vertical diameters) respectively, m, DL = deflection lag factor, K = bedding constant W= Prism load on pipe , per unit length of pipe, kN/m, R = mean radius of pipe, m E = modulus of elasticity of pipe material, MPa, I = moment of inertia of pipe wall per unit length, m^4/m, E'= modulus of soil reaction, MPa., PS_o= Pipe Stiffness, kN/m. The horizontal deflection of pipe (may be

Fig. (3): Parallel Plate Loading Test

taken also as the vertical deflection with negligibly small error). The bedding constant K varies with the width and angle of the bedding achieved in the installation, as a general rule, a value of K = 0.1 is assumed. If the prism load is used for design, a design deflection lag factor D_L=1.0 should be used.

Iowa formula (linear elastic theory) assumed the soil and the pipe structure to be linear elastic materials. The assumption that the soil is elastic can lead to large errors [4]. The previous modified Iowa formula used only a constant elastic modulus for the soil. The possibility for the soil modulus to change as the depth of cover increases should be included. In this modified version, the effective soil modulus increases as the soil height over the top of the pipe is increased. This is sometimes called the overburden-dependent soil modulus. Therefore, a modulus correction is needed that allows for precompaction and will allow for the slope of the load-deflection curve to approach that of the Iowa formula. The corrected soil modulus is such that a bilinear load-deflection curve results [4].

$$E'_{eff} = \begin{cases} 2.5\ E' & \text{If } H \le b \\ \dfrac{2.5\,E'H}{[b + 2.5(H - b)]} & \text{If } \quad H > b \end{cases} \tag{8}$$

Where E'_{eff} = effective soil modulus, E′= traditional soil modulus, H = height of cover

b = break height (where the curve, load-deflection curve, changes slope), A suggested values by Moser and Folkman [4] for b is shown in Table (2)

Table (2) Break height as suggested by Moser and Folkman, [4]

Proctor density, percent	Soil modulus E'	Break point b
80	1.73–3.45 MPa (250–500 lb/in^2)	1 m (3 ft)
85	3.45–4.82 MPa (500–700 lb/in^2)	1.5 m (5 ft)
90	4.82–6.89 MPa (700–1000 lb/in^2)	3 m (10 ft)
97	6.89–11.02 MPa (1000–1600 lb/in^2)	9 m (30 ft)

10. PERFORMANCE PARAMETERS OF LARGE DIAMETER PVC SEWER PIPE

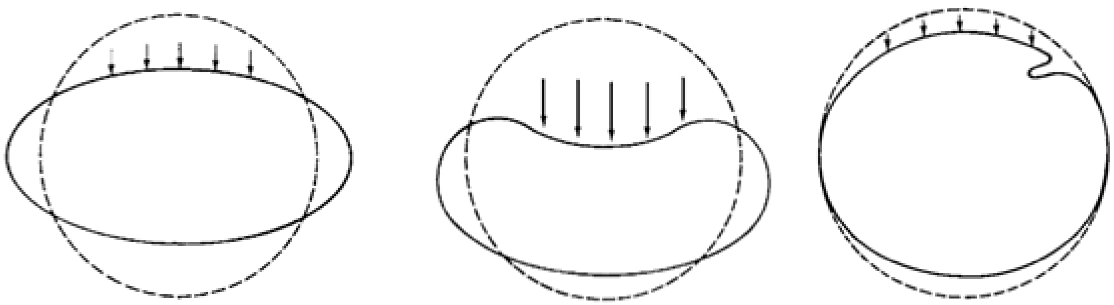
For buried pipes, as for most structures, performance limits are directly related to stress, strain, deflection, or buckling. In general, flexible pipes are less likely to fail by rupture, cracks or crushing. Plastic materials, endure deformation to the point of total collapse without cracking or rupture [12].

Deflection and wall buckling are primary performance parameters in the design of PVC sewer pipe, due to other parameters not critical (wall crushing is critical for rigid pipes and strain limitation is important for brittle or composite materials). Wall crushing occurs when the in-wall ring compression stress reaches the yield stress of the pipe material. Wall crushing is likely to be limiting only for stiffer plastic pipes installed in highly compacted backfill and subject to deep cover. Thus for PVC sewer pipes performance parameter that are considered in resent study are: (i) Deflection and (ii) Wall buckling.

10.1. Performance based on Pipe Deflection

Deflection of a pipe is defined as the reduction in diameter from the nominal due to construction and dead loads, divided by the nominal diameter, expressed as a percentage. PVC Sewer Pipe depends on the installer to limit deflection by compacting the sidefill support. The added stiffness from the sidefill plus the pipe stiffness combine to resist the earth and live loads while limiting the deflection. Deflections can be used as a method for determining the stress strain conditions within the pipe wall; large deflections are indicative of large stresses and strains within the pipe which may indicate that collapse is imminent.

The deflection as a design limit is based on reversal of curvature. Reversal of curvature is a deflection phenomenon occur due to over deflection as shown in Fig.(4). Thus the calculated design deflection should always be equal to or less than the design deflection limit. Buried PVC sewer pipe may develop recognizable reversal of curvature at a deflection of 30 percent.



Ring deflection Reversal of curvature due to over deflection Localized wall buckling

Fig.(4) Design limits of flexible pipe

Research at Utah State University has demonstrated that the load carrying capacity of PVC sewer pipe continues to increase even when deflections increase substantially beyond the point of reversal of curvature. With consideration of this performance characteristic of PVC sewer pipe, engineers generally consider the 7.5 percent deflection limit recommended in ASTM D 3034 [18] to provide a very conservative factor of safety against structural failure.

Buckling failure and excessive bending strains do not occur until the deflections in the pipe are about thirty percent. According to European and American field experience, deflections of 5 to 7.5 percent can be tolerated without detrimental effects to the functioning and joints of the pipe [12].

10.2. Wall Buckling parameter

Wall buckling (as shown in Fig.(4)) indicates that the pipe stiffness is not adequate. It may govern the design when the pipe is subjected to internal vacuum, external hydrostatic pressure, or high soil pressures in compacted soil [4].

The summation of external loads should be equal to or less than the allowable buckling pressure. The allowable buckling pressure qa may be determined by the following [4]:

$$q_a = \frac{1}{FS}\sqrt{32 R_w B' E' \frac{EI}{d^3}} \tag{9}$$

$$FS = \begin{cases} 2.5 & \text{For } \frac{H}{d} \geq 2 \\ 3 & \text{For } \frac{H}{d} < 2 \end{cases} \tag{10}$$

$$R_w = 1 - 0.33\left(\frac{H_w}{H}\right) \quad 0 \leq H_w \leq H \tag{11}$$

$$B' = \frac{4(H^2 + dH)}{(1+\upsilon)[(2H+d)^2 + d^2(1-2\upsilon)]} \tag{12}$$

Where q_a= allowable buckling pressure, kN/m, *FS*= design factor, *d*= diameter of pipe, m, R_w= water buoyancy factor, *H* =height of ground surface above top of pipe, m, H_w= height of water surface above top of pipe, m, B'= empirical coefficient of elastic support (dimensionless).

For determination of external loads in normal pipe installations for buckling analysis, the following equation is used

$$\gamma_w H_w + R_w \frac{W}{d} \leq q_a \tag{13}$$

where γ_w= specific weight of water = 9.807 kN/m^3 (0.0361 lb/in^3), W= vertical soil load on pipe per unit length, kN/m

11. PREDICTION PERFORMANCE OF LARGE DIAMETER PVC SEWER PIPE IN MAYSAN PROVINCE

A PVC pipe of diameter 800mm and thickness 21.5 mm was used for prediction its performance according to Iraqi procedure in Maysan Province. The structural properties of the pipe is as following: modulus of elasticity = 4000 MPa, Poisson ratio = 0.35, unit weight=9.3 KN/m^3 [15]. The analysis is accomplished for six cases to compare Iraqi procedure with typical installations of ASTM 2321. The first three cases represent PVC pipes installed according to ASTM 2321 procedure while the rest represent the traditional installations of PVC pipes in Iraq, as shown in Table (3). The soil types for buried pipes backfilling in Iraq is either SP and SW. In general SP and SW gives the same soil stiffness so the analysis will be limited to SW class only. Dumped soil means that the backfill just fill the pipe trench by machines without any compaction.

Large dimeter PVC pipe should decrease in the horizontal diameter and increase in the vertical diameter during compaction of the backfill according standard installation, this deformation aids significantly in the reduction of deflection during service life, where typically the vertical diameter reduces and the horizontal diameter increases, but according the author experience, in local installation in Iraq there is neglected change in pipe diameter during construction due to light compaction process.

Table (3) Installation cases of PVC pipes for analysis

No.	Case	Description	Soil surrounding Pipe	Compaction of maximum density
1	Case I	Install according to standard procedure of ASTM 2321	SW	95%
2	Case II	Install according to standard procedure of ASTM 2321	SW	90%
3	Case III	Install according to standard procedure of ASTM 2321	SW	85% Min
4	Case IV	Install according to standard procedure of Iraqi procedure	SW	Dumped
5	Case V	Install according to standard procedure of Iraqi procedure	SW	80%
6	Case VI	Install according to standard procedure of Iraqi procedure	Crushed Gravel	Dumped

In this study the soil stiffness (E') of backfill materials is used in analysis and neglecting the native soil participation on pipe performance due to the surrounding sidefill (haunch area and lower side) for a flexible pipe provides the main support to pipe.

Soil properties includes soil modulus E' is shown in Table (4) based on both Howard and WRC recommendations. In case of crushed gravel marital used in Iraq, Howard gave better estimation for soil modulus than WRC, so the soil modulus of 6.89 MPa is used for crushed gravel backfill in this study.

Table (4) Soil Modulus E' for analysis cases

No.	Description	Pipe Embedment Material	Compaction	E'	
				Howard MPa	WRC MPa
1	Install according to standard procedure of ASTM 2321	SW	95%	10.2	14
2		SW	90%	6.8	7
3		SW	85% Min	4.8	5
4	Install according to Iraqi procedure	SW	Uncompacted	1.38 (200psi)	1
5		SW	80%	N/A	3
6		Crushed Gravel	Uncompacted	6.89 (1000psi)	3

12. RESULTS AND DISCUSSION

12.1. Performance Based on Pipe Deflection

Modified Iowa Equation is used to calculate pipe deflection as a percent of pipe diameter. In the present study the soil depth above pipe crest was ranged from 1-10 meters as a practical depths of sewers in Maysan Province.

In general, the deflection is decreased if the corrected soil modulus is used in Iowa equation in comparison with traditional soil modulus in which large reduction in deflection in case of well-compacted backfill in comparison with slightly reduction in case of uncompacted backfill as shown in Tables (5) and (6). To compare the deflection calculated based on corrected soil modulus versus traditional soil modulus (Tables (5) and (6)) it's clearly that the deflection is decreased by about 50% in well compacted conditions of Case I to about 10% for uncompacted backfill Case IV, i.e. in uncompacted conditions the using corrected or traditional soil modulus has negligible effect of deflection values. Thus using corrected soil modulus present more reasonable results, therefore the next discussion will be limited to results based on corrected soil modulus.

Table (5) Deflection Percent based on corrected soil modulus E'_{eff}

Installation Case	Compaction	Height of Cover , %									
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Case I	95%	0.1	0.2	0.3	0.5	0.6	0.7	0.8	1.1	1.3	1.6
Case II	90%	0.2	0.3	0.5	0.9	1.3	1.7	2.2	2.6	3.0	3.4
Case III	85%	0.2	0.6	1.2	1.7	2.3	2.8	3.4	3.9	4.4	5.0
Case IV	Dump	1.1	2.8	4.4	5.9	7.5	9.1	10.7	12.3	13.9	15.5
Case V	80%	0.4	1.2	2.0	2.8	3.6	4.3	5.1	5.9	6.7	7.5
Case VI	Dump	0.2	0.3	0.5	0.9	1.3	1.7	2.1	2.5	3.0	3.4

Table (6) Deflection Percent based on traditional soil modulus E'

Installation Case	Compaction	Height of Cover , mm									
		1	2	3	4	5	6	7	8	9	10
Case I	95%	0.3	0.6	0.8	1.1	1.4	1.7	2.0	2.2	2.5	2.8
Case II	90%	0.4	0.8	1.2	1.6	2.0	2.4	2.8	3.2	3.6	4.0
Case III	85%	0.5	1.1	1.6	2.2	2.7	3.2	3.8	4.3	4.9	5.4
Case IV	Dump.	1.5	3.2	4.8	6.3	7.9	9.5	11.1	12.7	14.3	15.8
Case V	80%	0.8	1.6	2.4	3.1	3.9	4.7	9.4	6.3	7.1	7.8
Case VI	Dump.	0.4	0.8	1.2	1.6	2.0	2.4	2.8	3.2	3.6	4.0

According to Table (5) the backfill compaction has great effect on PVC pipe performance. For example at depth 5m the deflections are 0.6%, 1.3%, 2.3%, 3.6% and 7.5% for compaction degree 95%, 90%m 85%m 80% and uncompacted (dumped) respectively. Thus increasing compaction of pipe sidefill from 90% to 95% the deflection will reduce to about 50%. If the backfill (especially haunch region) is bad compacted 80% , the support becomes weak and the deflection is increased by more than three times of that of well compacted sidefill (95%) for the same height. This is due to the higher value of modulus of soil reaction of compacted backfill than that of uncompacted conditions.

Uncompacted crushed gravel present deflection close to gravelly sand soil compacted to 90% (SW 90%) which present good option for installation of PVC pipes in narrow trenches or where the compaction of side fill is difficult.

It has commonly been proposed that the deflection limit for flexible pipe buried in earth should be between 5% and 10%. This limit is intended to provide a factor of safety against failure by collapse at a deflection of about twenty percent. However, since soil exhibits nonlinear stress strain characteristics, the factor of safety is actually much higher [19]. According to European and American field experience, deflections of 5 to 7.5 percent can be tolerated without detrimental effects to the functioning and joints of the pipe [19]. In the present study the deflection of PVC pipe installed with compacted backfill between 90% to 95% or with crushed gravel is less than the failure limits, while for 85% compaction the 5% limits is reached at depth of 10m.

In case of bad compaction backfilling the deflection limit 5% is reached at depth of 7 m for 80% compaction and at depth less than 4 m in case of uncompacted backfill. While the limit of

7.5% is reached at depth of 10 m for 80% compaction and at depth less than 5 m in case of uncompacted backfill.

Thus from above discussions its clealy that lack of adequate backfill compaction to the springline of the pipe can result in excessive deflection, since this compaction must help support vertical loads on the pipe.

Thus in general the Iraqi procedure is critical for depth greater than 5m and there should be attention for compaction process if gravelly sand soils are used (as commonly) or in depth greater than 5m a crushed gravel backfill should be used.

12.2. Performance Based on Pipe wall Buckling

In general pipe wall buckling is not critical for all cases except in case of uncompacted backfill in which the wall buckling limit is exceeded at depth of 8 m as shown in Table (7), in which wall buckling is critical at deflection of more than 12%, Taprogge [16] stated that bucking deflection and excessive bending strains do not occur until the deflections in the pipe are about thirty percent.

Table (7) External loads and the allowable wall buckling pressure

Installation Case	Compaction	Height of Cover , m									
		1		2		3		4		5	
		P	q_a	P	q_a	P	q_a	P	qa	P	q_a
Case I	95%	0.02	0.44	0.04	0.54	0.06	0.55	0.08	0.53	0.1	0.51
Case II	90%	0.02	0.36	0.04	0.44	0.06	0.45	0.08	0.43	0.1	0.42
Case III	85%	0.02	0.30	0.04	0.37	0.06	0.38	0.08	0.36	0.1	0.35
Case IV	Dump.	0.02	0.14	0.04	0.17	0.06	0.17	0.08	0.16	0.1	0.16
Case V	80%	0.02	0.24	0.04	0.29	0.06	0.3	0.08	0.29	0.1	0.28
Case VI	Dump.	0.02	0.36	0.04	0.44	0.06	0.45	0.08	0.43	0.1	0.42

		Height of Cover , m									
		6		7		8		9		10	
		P	q_a	P	q_a	P	q_a	P	q_a	P	q_a
Case I	95%	0.12	0.50	0.15	0.50	0.17	0.49	0.19	0.49	0.21	0.48
Case II	90%	0.12	0.41	0.15	0.41	0.17	0.40	0.19	0.4	0.21	0.40
Case III	85%	0.12	0.35	0.15	0.34	0.17	0.34	0.19	0.33	0.21	0.33
Case IV	Dump.	0.12	0.16	0.15	0.16	**0.17**	**0.15**	**0.19**	**0.15**	**0.21**	**0.15**
Case V	80%	0.12	0.27	0.15	0.27	0.17	0.27	0.19	0.26	0.21	0.26
Case VI	Dump.	0.12	0.41	0.15	0.41	0.17	0.40	0.19	0.4	0.21	0.40

To improve buckling strength of PVC pipes of larger diameters installed at depth greater than 7 m and when the compaction for haunch region is not guaranteed thus its recommended to use pipes with corrugated walls instead of smooth walls because of the greater buckling stiffness and ring bending stiffness that they provide.

Thus according to deflection and buckling limits in previous tables, PVC pipe are less likely to fail by rupture, cracks or crushing.

13. CONCLUSIONS

- The behavior of PVC pipes installed according to Iraq procedure is controlled mainly by deflection and excessive pipe deflections could be avoided if the pipe is properly installed and backfilled with well compacted granular materials.
- Compaction degree of sidefill have great effect of deflection of PVC pipes at the same height and using the same materials.
- Deflection of PVC pipe backfilled with dumped crushed gravel is close to the deflection of pipe backfilled with 90% compacted SW soil for the same pipe and represent good alternative for

compaction of granular backfill materials especially in cases of compaction process be difficult or the trench is narrow to movement compaction machine.

- Wall buckling failure is not critical granular backfill with even slightly compacted (80%) and its limits is exceeded only in case of dumped backfill at depth of 8m.
- PVC pipe installed according to Iraqi procedure with backfill compaction not less than 85% or uncompacted crushed gravel are both satisfy deflection and wall buckling requirements and could be consider as safe installation.
- PVC pipe installed according to Iraqi procedure with backfill compaction of 80% is safe installation for depth not greater than 6 m depth beyond this depth the pipe is suffered to excessive deflection which may affect the structural performance of the pipe.
- PVC pipe installed according to Iraqi procedure with uncompacted backfill (dumped) is consider as unengineering installation and the pipe may subjected to excessive deflection or wall buckling in depth greater than 3m. roughly a factor of 2.0 [1].

REFERENCES

[1] EM 1110-2-2909, "Engineering and Design : Conduits, Culvert and Pipes", Manual No.1110-2-2909, U.S.Army Corps of Engineers, 1998, Washington, USA.

[2] Watkins, R. K. and Anderson, L. R., "Structural Mechanics of Buried Pipes", CRC Press LLC, 2000, USA.

[3] Rajkumar, R. and Ilamparuthi, Dr. K., "Experimental Study on the Behaviour of Buried Flexible Plastic Pipe", EJGE journal, Vo. 13, Bund. C, 2008.

[4] [4] Moser A. P. and Folkman S. "Buried Pipe Design" Third edition, McGraw-Hill, 2008.

[5] Dawood, A. O. " Experimental and Theoretical Investigation of of Concrete Buried Pipes" Ph.D. Thesis, Baghdad University, Baghdad, Iraq , 2012

[6] Dawood, A. O. "Experimental And Numerical Analysis Of Minimum Backfill Cover Of Buried Concrete Pipes According To Local Practice Of Iraq" The Seventh International Structural Engineering and Construction Conference (ISEC-7), Honolulu, Hawaii, USA, June 18 - 23, 2013

[7] Hussain, Y. J. "Experimental And Analytical Investigation Of Minimum Backfill Cover Of Grp Pipes", M.Sc. Thesis, Baghdad University, Baghdad, Iraq, 2014.

[8] ASTM D2321, "Standard Practice for Underground Installation of Thermoplastic Pipe for Sewers and Other Gravity-Flow Applications", American National Standard, USA, 2000.

[9] Federal highway Administration, FHWA "Pipe Interaction with the Backfill Envelope" Publication No. FHWA-RD-98-191, June 1999.

[10] SORB/R6 "Iraqi Standards for Roads and Bridges" General Organization for Roads and Bridges, Baghdad, Iraq, 1983.

[11] AASHTO LRFD (2005). “AASHTO LRFD: Bridge Design Specifications", SI Units, Third Edition, 2005.

[12] Amarasiri A. L. "Evaluation of Granular Backfill Materials for Large-Diameter, High-Density Polyethylene Pipe" M.Sc. Thesis, Texas Tech University, 2000.

[13] Howard, A. K., 1977, " Modulus of Soil Reaction for Buried Flexible Pipe", Journal of Geotechnical Engineering, ASCE, Vol. 103, No. GT1, New York, USA.

[14] De Rosa, P. J., Hoffman, J. M. and Ollif, 1988 " Pipeline Metrials Selection Manual", Water Research Centre, Swindon, UK.

[15] Park J.S., Hong W. H., Lee W., Park J. H. and Yoon, S. J. " Pipe Stiffness Prediction of Buried GFRP Flexible Pipe" Journal of Polymers and Polymer Composite, Vol. 22, No. 1, 2014.

[16] Spangler, M. G., " The Structural Design of Flexible Pipes Culverts", Bulletin No.153, Engineering Experiment Station, Iowa State College, Iowa, USA, 1941.

[17] Watkins, R. K. and Spangler, M. G. "Some Characteristics of the Modulus of Passive Resistance of Soil: A Study in similitude, Highway Research Board Proceedings, Vol. 37, 1958.

[18] ASTM D3034, "Standard Practice for Type PSM Poly (Vinyl Chloride) (PVC) Sewer Pipe and Fittings", American National Standard, USA, 2000.

[19] Taprogge, R. H., "Large Diameter Polyethylene Profile-Wall Pipes in Sewer Application", Proceedings of the Internationl Conference on Underground Plastic Pipes, Jay Shorck, B., Ed., ASCE, New York, USA, 1981.

[20] Joginder Singh and Dr. M R Tyagi, Analysis of Stresses and Deflections In Spur Gear, International Journal of Mechanical Engineering and Technology, 8(4), 2017, pp. 461-473.

[21] Prakash Jadhav, Damage Assessment In A Wall Structure Using Resonant Frequencies and Operating Deflection Shapes, Volume 8, Issue 3, March 2017, pp.97-107, International Journal of Mechanical Engineering and Technology (IJMET)

[22] ASTM D2412, "Standard Practice for Determination of External Loading Characteristics of Plastic Pipe by Parallel-Plate Loading", American National Standard, USA, 2000.