Effects of Pipe stiffness and installation methods on performance Of GRP pipes Based on the latest AWWA M- 45 design methods and critical evaluation of past performance of GRP pipes in Egypt

Eng. Saad ElKhadem (Ms. Ch.E.)

Managing Director
Future Pipe Industries S.A.E.
6th of October City, Egypt

Introduction

GRP pipes are one of the principal pipe materials used in water and sanitary sewerage projects in both gravity and pressure applications. These pipes are inherently corrosion resistant both internally and externally as compared to conventional metallic or concrete pipes.

Controlling pipe deflection within safe limits (usually 5 % long term) is an important factor to insure that the long service life associated with GRP pipes will be realized.

In an attempt to solve many of the problems encountered with these pipes in the past, several agencies have attempted to solve these problems by specifying high stiffness pipe, in spite of the fact that most of these problems are unrelated to the pipe stiffness.

The paper presents an engineering perspective to the cause of these problems and provides solutions and recommendations to preventing these past problems from recurring in current and future projects.

The paper also presents a brief summary of the latest design procedures for GRP pipes contained in AWWA M45 Design manual, which incorporates major updates to the design procedures, which take into account native and backfill soil properties, and trench dimensions in calculating pipe deflection.

Over 170 cases were analyzed using the new procedures to pipe stiffnesses varying from 2500 to 10,000 N/m^2 and the safe limit for using these pipes in various soil conditions and depths was obtained.

The paper presents the summary of these calculations, which allows the Engineer to evaluate the safe limits and appropriate stiffness classes for each project. The effects of live loads at shallow depths are also presented.

The modified Spangler equation is considered the universally accepted equation used to predict deflection of flexible pipes subject to external loads. The Equation is used by most international standards such as ASTM and AWWA in the design of flexible pipe such as GRP, PVC and Steel pipes.

Deflection equation (based on the modified Spangler equation for flexible pipe):

$$\Delta D/D = kx^* (WI + Df^* Wc) / 8 * SN + 0.061 * E' *100$$

WI = Live (Traffic) Load N/m^2
Wc = Soil Load on Pipe N/m^2
$\Delta D/D$ = Deflection - %
SN = stiffness - $N/m^2 = EI/D^3$
E '= backfill modulus - N/m^2
Df = deflection lag factor - accounts for Creep and soil consolidation
Kx = bedding coefficient, function of trench bedding shape
= 0.110 or 0.083 depending on shape of bed
D = Average pipe diameter - m

This equation assumes that the trench width is sufficiently wide that the pipe does not feel the effects of the native soil and that the backfill material type and compaction (E') reflect the actual installation in a realistic way. Many end users felt the equation should factor-in the trench width and the native soil properties in a clear way to insure that calculations presented reflect actual conditions on-site.

As such the American Water Works Association revised the deflection equation in the 1996 edition of the Design manual for Fiberglass pipe "M-45".

Revised equation - 1996 M 45 American Water Works Association
Modified Deflection equation

$$\Delta D/D= kx^* (WI + Df * Wc) / (8 *SN + 0.061 * E'b * Sc)*100$$

WI = Live (Traffic) Load N/m^2
Wc = Soil Load on Pipe N/m^2
$\Delta D/D$ = long term deflection - % (usually 5 % maximum)
SN = stiffness - $N/m^2 = EI/D^3$
E'b = backfill modulus - N/m^2
Df = deflection lag factor - accounts for Creep and soil consolidation
Sc = soil support combining factor
Kx = bedding coefficient, function of trench bedding shape
= 0.110 or 0.083 depending on shape of bed
D = Average pipe diameter - m

The soil support factor ***Sc*** is a new factor introduced that is a function of the ratio of the trench width (***Bd***) to the pipe nominal diameter (***ND***) and the ratio of the native soil modulus (***E'n***) to the backfill material modulus (***E'b***).

AWWA Table 5-4: Soil Support Combining Factor (Sc)

E'n/E'b	(Bd / ND) Value						
	1.5	1.75	2	2.5	3	4	5
0.10	0.15	0.21	0.30	0.60	0.80	0.90	1.00
0.20	0.30	0.36	0.45	0.70	0.85	0.92	1.00
0.40	0.50	0.54	0.60	0.80	0.90	0.95	1.00
0.60	0.70	0.74	0.80	0.90	0.95	1.00	1.00
0.80	0.85	0.87	0.90	0.95	0.98	1.00	1.00
1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1.50	1.30	1.24	1.15	1.10	1.05	1.00	1.00
2.00	1.50	1.42	1.30	1.15	1.10	1.05	1.00
3.00	1.75	1.63	1.45	1.30	1.20	1.08	1.00
5.00	2.00	1.84	1.60	1.40	1.25	1.10	1.00

For values between the table values use straight-line interpolation from adjacent values in the table.

E'n = Native soil modulus of the trench wall
E'b = Backfill soil modulus
Bd = Trench width at spring line
ND = Nominal pipe diameter
Sc = Soil support combining factor

AWWA Table 5-6 Native Soil Classification

E'n MPa	qu Unconfined Compressive. Strength	Blow Count SPT	Soil Group	Soil Type	
				Granular	Cohesive
34.48	192-384 KPa	15-30	1	Compact	Very stiff
20.69	96-192 KPa	8-15	2	Slightly Compact	Stiff
10.4	8-96 KPa	4-8	3	Loose	Medium
4.83	24-48 KPa	2-4	4	Very Loose	Soft
1.38	KPa 12-24	1-2	5	Very Loose	Very Soft

It has been a common misconception that pipe stiffness is related to pressure. This is not true. Pipe stiffness is simply a measure of the pipe's ability to resist external loads at a given deflection (usually 3-5 %), and is no way related to the pipe's working pressure. It is therefore possible to produce a 16 bar working pressure pipe with a stiffness of 1250 N/m^2 and it is also possible to produce a Gravity pipe with a stiffness of 10,000 N/m^2.

Yet some agencies in Egypt have been recently specifying GRP **gravity** pipes to have a minimum stiffness of 5,000 N/m^2 (for all depths) and **pressure** pipes (force mains and water lines) to have a minimum stiffness of 10,000 N/m^2. This policy needs to be re-examined and the specification for GRP pipes must be revised to reflect actual loadings on the pipe based on a proper and sound engineering basis.

The use of higher stiffness pipe should be limited to high external loads applications such as those that are present in **deep gravity** sewer lines. Most pressure pipelines whether for water lines or in sewer force mains are installed at relatively shallow to medium depths that rarely exceed 4 m of cover above the pipes. Over 98 % of pressure pipelines are installed at depths ranging from 1 m to 3 m above the pipe crown.

The move towards high stiffness pipe (such as 10,000 N/m^2) in GRP pressure pipes has resulted from the numerous problems that have occurred with these pipes over the last 20 years. Unfortunately, almost all these problems are unrelated to pipe stiffness and to specify a high stiffness pipe on new projects will in no way eliminate these problems in the future. The only tangible result is a noticeable increase in the cost of the pipe projects at a time when the government is rationalizing public expenditures and most agencies have to operate within tight budget constraints.

Looking back over the last 20 years, we realize that the largest quantity of GRP pipes installed in Egypt by far was in pressure applications such as sewer force mains and as water transmission pipes.

In the first part of the paper we will analyze the major problems that have been observed repeatedly and their causes and recommended remedial action to prevent these problems from recurring on future projects.

Part 1 - Problems encountered in older GRP pipe installations

Several problems were encountered with GRP pipes over the last 20 years. Most of these problems were related to mistakes or errors in installation. Some were related to inappropriate designs of joints and specials used with GRP pipes.

- **Gibault Joints**

Gibault joints have caused numerous problems with GRP pipes in Egypt. This cast iron joint was developed in Europe in the early 1940's for use with early Asbestos cement pipes before A/C couplings were developed in the 1950's and 1960's. GRP coupling joints have been used internationally outside Egypt for over 20 years especially with continuous filament wound and centrifugally cast pipe. In Egypt, local manufacturers of GRP pipes unable to produce a GRP coupling type joint, introduced and forced the Gibault onto the Egyptian pipe market in the early 1980's.

Three major problems are associated with the Gibault joint. The first problem is corrosion. Being made of cheap cast iron of similar quality to cast iron drain pipes cast in Cairo's suburbs, the Gibault is highly prone to external and internal corrosion. Supplying a corrosion resistant GRP pipe with a cast iron joint every 12 meters defeats the primary purpose and advantage for using GRP pipes in the first place.

The second problem with the Gibault joint is its rigidity. The cast iron rings do not deflect under load as do the pipes. While the GRP pipe is allowed to deflect up to 5 % of its diameter, the area around the joint is forced to remain round. This creates possibilities of leaks and introduces high localized stresses around the joint area. The Gibault is also essentially rigid as far as angular deflections are concerned.

The third and major problem with the Gibault is the relative ease with which the joint can be **over-tightened** by the installation contractor. Almost all pipelines with Gibault joints have leaky joints during the first hydrostatic pressure test on-site. This is due to the wide tolerance in the casting and to the fact that the pipe supplied do not have calibrated and hence fixed outside diameters. To fix these leaks, the contractor has to **further tighten** the Gibault tie bolts until the leak hopefully stops. This **over-tightening** invariably leads over a period of time to circumferential cracks on the pipes external surface and eventually to leaks or bursts of the pipe just outside of the Gibault joint.

A GRP coupling on the other hand is manufactured to close tolerances just as the pipe outside diameter at the spigot end is machine to a fixed value with very small tolerances. The GRP coupling utilizes the compression of the rubber gaskets to achieve a watertight joint. There is no chance to over-tighten the joint. The GRP coupling joint is also a flexible joint that is of similar stiffness to the pipe and will deflect with the pipes, thereby eliminating localized stresses around the joint. GRP joints also allow for generous angular deflections.

Many of the leaks, cracks and failures of GRP pressure pipelines can be attributed to the use of the Gibault joint. The use of this cast iron joint and its derivatives such as Vicking-Johnson joints as a standard pipe joint must be stopped. The use of all GRP joints such as the coupling type or integral bell and spigot GRP joints must be enforced to realize the long-term benefits of an all-GRP piping system. It should also be noted that using high stiffness GRP pipe such as 10,000 N/m^2 will not solve any of the problems associated with the Gibault-type cast iron or steel joints.

- **Use of crushed stones & gravel as backfill in high water table areas**

Numerous cases of over-deflection (6 % and above) and buckling of GRP pipes have been reported such as the problems with the *Helwan* GRP Sewers. These over-deflections can be attributed to many causes:

- Poor compaction of pipe bedding and backfilling material.
- Use of *very* low stiffness pipe in very deep lines
- Use of gravel & stones in the bedding and backfill in high ground water table areas.

Poor compaction by the Contractor results from inadequate supervision from the owner and from lack of a representative of the manufacturer on site to monitor installation. This can be easily solved and is no longer a problem with present day practices.

The use of very low stiffness pipe (as low as 800 N/m^2) was common in the late 70's with some manufacturers who did not realize the burial limitations of such low stiffness pipe. Today the situation is totally different with manufacturers and design manuals such as AWWA M-45 available to enable end-users to evaluate the suitability of pipe of various stiffness classes to meet individual project requirements.

The third cause above still occurs today. Many present day installation specifications still require the bedding and backfill material to be crushed stones or gravel. In dry native soils, this is an excellent and self-compacting material and gives higher burial depth capability than compacted sand. However, when used in high ground water areas, the gravel/stones backfill acts as a 'French' under drain that collects the ground water and washes away the fines from the trench walls. The migration of fines and sand causes a loss of support to the sides of the pipes and will lead to severe over-deflection of the pipes (as much as 20 %). This is illustrated on the following pages.

Installation specification must be revised so as to disallow the use of crushed stones or gravel for backfilling GRP pipes in locations where the ground water table is above the trench bottom level. In such cases only well graded and compacted sand should be used. Sand is compatible with the native soils and no migration can occur. In high ground water areas, crushed stones and gravel can only be used if the trench bottom and sides are lined with a filter 'geotextile' membrane that prevents migration of fines; this solution is however rather expensive.

Once again it should be pointed out, that even if high stiffness pipes were used, the pipes would still be significantly over-deflected if installed with this type of backfill in a high ground water installation. Other types of pipe materials will also be damaged in this type of installation. Large diameter ductile iron pipe cannot withstand the external loads in deep installations with little or no side support and will over deflect, cracking the cement lining and leaking through the joints. Rigid pipes like reinforced or pre-stressed concrete will also suffer from reduced load bearing capacity in this type of installation due to the design bedding angle (typically 90 or 120^o) not being achieved on site due to loss of side support.

This type of installation should be discontinued for all types of pipe materials.

- **Use of GRP-coated flanged steel fittings with GRP pipes**

Numerous failures have also occurred in GRP pressure pipelines due to the use of coated and lined (with Fiberglass) steel flanged fittings.

Many designs of valve chambers utilize ductile cast iron flanged fittings inside the chamber, and terminate outside the chamber with a flanged wall pipe. To connect the GRP pipes to the chamber, some local manufacturers (unable to produce a fiberglass flange) utilized a flanged steel pipe in which a GRP pipe was inserted and laminated to the flange face and to the outside of the steel pipe (see the drawing of the following page). The mechanical bond between steel and GRP is not particularly strong and invariably cracks develop through the lining and corrosion of the steel begins. Within a few years many of these pieces corrode and fail, such as the case with *El Sherou*q city water supply pipeline. The thin lamination of the steel flange face invariably cannot withstand high pressures and many large diameter fittings on PN 12 and PN 16 pipelines leak during pressure testing on-site such as the case with the *Zaafarana* pipeline.

The solution to this problem is to stop the use of fiberglass coated and lined steel fittings and require the use an all-GRP flanged fitting system. Almost all reputable manufacturers produce GRP flanged pipe suitable for this application to connect with the ductile iron flanges.

Consideration should also be given to using valve chamber wall pipe with a spigot ends outside the chamber thereby eliminating the external flanged connection all together.

Once again, this problem is in no way related to pipe stiffness and specifying a high stiffness pipe will not solve the problem or even reduce it.

- **Connection of GRP pipes to concrete structures without using short flexible pipes**

Numerous failures of GRP pressure pipelines have resulted from the direct connection of standard lengths of pipe to the valve chamber without using a short flexible pipe (a short length of pipe between two joints). Invariably large concrete valve chambers will settle after a few months from casting and without a flexible pipe outside the chamber, the first pipe outside the chamber will fail by shear.

Many projects are still being tendered at present with the chamber drawings showing direct connection of the pipes. The following pages illustrate the typical chamber connection detail and the recommended layout, which incorporates a flexible pipe.

The use of a flexible pipe is a good engineering practice that is recommended by manufacturers of almost all types of pipe materials. Even in pipe materials like

Ductile or Concrete pipes, excessive joint deflection, leaky joints and damage to the cement mortar lining or joint grout can easily occur when no flexible pipes are used outside chambers.

It should also be noted that flexible pipe lengths must be used not only outside valve chambers, but also on both sides of elbows inside concrete thrust blocks. Any large structure in the pipeline will eventually settle.

Again, in this case this problem is unrelated to pipe stiffness. GRP pipes will shear and fail without flexible pipes near structures irrespective of their stiffness. While GRP pipe bend (deflect) very little longitudinally, the use of high stiffness thick pipe induces higher strains in the pipe wall and actually makes matters worse.

Part 2

- **Evaluation of the performance 2500 Stiffness pipe**

The performance of this stiffness class pipe was evaluated in spite of misconception that pipe of this stiffness will not perform satisfactory. The use of this pipe in pressure applications up to 4 meters of cover was evaluated for all 5 native soil groups; from good, stable native soil to very weak unstable native soils. Standard sand backfill was used as the backfill material with compaction of only 80 % standard proctor in order to make the results even more conservative. Almost all project specifications require compaction of at least 90 % SPD. The cover depth used in the calculations was fixed at 4m of cover above the pipes which covers 99 % of all pressure pipeline application in Egypt.

Results summary

DN "mm"	Stiffness N/m^2	Backfill type	Backfill Compaction	Native soil Group	Trench Width m	Depth of cover	Calculated deflection % Long term
1000	2500	Sand	80 % SPD	1	OD + 1 m	4 m	2.2
1000	2500	Sand	80 % SPD	2	OD + 1 m	4 m	2.4
1000	2500	Sand	80 % SPD	3	OD + 1 m	4 m	2.8
1000	2500	Sand	80 % SPD	4	OD + 1 m	4 m	3.7
1000	2500	Sand	80 % SPD	5	OD + 1 m	4 m	4.8

From the above table, we can see that the long-term deflection for the 2500 N/m^2 stiffness pipe does not exceed 5 % even for soil group 5. The maximum safe cover of 4 meters above the pipes covers the vast majority of sewer force main and water projects in Egypt. This pipe will perform satisfactorily even with poor installation practices such as the 80 % SPD compaction of the backfill.

- **Evaluation of the performance 5000 Stiffness pipe**

Over 60 calculations were performed to determine the long-term deflection for the 5 native soil groups while varying the degree of compaction from 80 to 90 % standard proctor density. For each set of conditions, the maximum safe depth at which the long-term deflection does not exceed 5 % was determined.

Results summary

DN "mm"	Stiffness N/m^2	Backfill type	Backfill Compaction	Native soil Group	Trench Width m	Maximum safe Depth of cover at which deflection does not exceed 5 %
1000	5000	Sand	80 % SPD	1	OD + 1 m	10.0 m
1000	5000	Sand	85 % SPD	1	OD + 1 m	13.0 m
1000	5000	Sand	90 % SPD	1	OD + 1 m	16.5 m
1000	5000	Sand	80 % SPD	2	OD + 1 m	9.0 m
1000	5000	Sand	85 % SPD	2	OD + 1 m	11.5 m
1000	5000	Sand	90 % SPD	2	OD + 1 m	15.0 m
1000	5000	Sand	85 % SPD	3	OD + 1 m	9.5 m
1000	5000	Sand	90 % SPD	3	OD + 1 m	11.0m
1000	5000	Sand	85 % SPD	4	OD + 1 m	7.0 m
1000	5000	Sand	90 % SPD	4	OD + 1 m	8.0 m
1000	5000	Sand	85 % SPD	5	OD + 2 m	7.0 m
1000	5000	Sand	90 % SPD	5	OD + 2 m	9.5 m

From the above table, it can be seen that 5000 N/m^2 stiffness pipe can be buried safely in even the worst native soil condition (group 5) to a depth of cover of 7 meters above the pipe crown with only 85 % SPD compaction of the backfill. In good native soils, the pipe can be buried with close to 10 m of cover safely with a compaction of 85 % proctor only. These depths will meet 99.99 % of all pressure pipeline requirements with respect to installation maximum burial depth of cover.

- **Evaluation of the performance 10 000 Stiffness pipe**

Over 60 calculations were also performed to determine the long-term deflection for the 5 native soil groups while varying the degree of compaction from 80 to 90 % standard proctor density. For each set of conditions, the maximum safe depth at which the long-term deflection does not exceed 5 % was determined.

Results summary

DN "mm"	Stiffness N/m^2	Backfill type	Backfill Compaction	Native soil Group	Trench Width m	Maximum safe Depth of cover at which deflection does not exceed 5 %
1000	10000	Sand	80 % SPD	1	OD + 1 m	10.5 m
1000	10000	Sand	85 % SPD	1	OD + 1 m	13.5 m
1000	10000	Sand	90 % SPD	1	OD + 1 m	17.0 m
1000	10000	Sand	80 % SPD	2	OD + 1 m	9.7 m
1000	10000	Sand	85 % SPD	2	OD + 1 m	12.0 m
1000	10000	Sand	90 % SPD	2	OD + 1 m	15.0 m
1000	10000	Sand	80 % SPD	3	OD + 1 m	8.7 m
1000	10000	Sand	85 % SPD	3	OD + 1 m	10.0 m
1000	10000	Sand	90 % SPD	3	OD + 1 m	12 + m
1000	10000	Sand	85 % SPD	4	OD x 3	8.7 m
1000	10000	Sand	90 % SPD	4	OD + 1 m	9.0 m
1000	10000	Sand	85 % SPD	5	OD x 3	7.9 m
1000	10000	Sand	90 % SPD	5	OD x 3	10.0+m

From the above table, it can be seen that 10000 N/m^2 stiffness pipe can be buried safely in even the worst native soil condition (group 5) to a depth of cover of 10 meters above the pipe crown with a 90 % SPD compaction of the backfill. In good and moderate native soils, the pipe can be buried to over 15 m of cover. This pipe is suitable for very deep sewer lines where depths can reach over 10 meters above the pipe crown.

Effects of Live (truck) loads on pipe performance

Some engineers might argue that a high stiffness pipe is required for projects where the pipes are installed relatively shallow; i.e. the depths are 1 to 1.5 m above the pipes and that truck loading might constitute a significant overload that requires a higher stiffness pipe. To investigate this situation several calculations were performed to study the common AASHTO* H-20 truck loading (7.2 metric ton wheel loading) plus a heavy 60 Ton truck (HT-60) having a wheel load of 10 metric tons.

It was determined that at one meter depth of cover above pipes, that total load (earth + truck) equals the earth load alone at a depth of cover of 2 meters for the AASHTO H-20 loading.

* American Association of State Highway Transportation Officials.

For the HT-60 loading, at 1.5 m depth of cover above pipes, the total load (earth + truck) was found equal to the earth load alone at a depth of cover of 2.5 m.

It is therefore concluded that live loads at depths of cover around 1-1.5 m above the pipes do not represent a significant surcharge load that requires a higher stiffness pipe, since at these depths the loads equal earth loads for depths of cover of 2 to 2.5 m which are easily withstood even by 2500 N/m^2 stiffness pipes.

Conclusions and Recommendations

The design procedures contained in the AWWA design manual M-45, allow designers to determine accurately the expected deflection of GRP pipes for a given installation, taking into account, pipe properties (i.e. stiffness), native soil properties, bedding & backfill material properties and trench configuration (width & depth) in addition to live loads and vacuum conditions expected in the pipeline.

Pipe stiffness is unrelated to pressure and is related only to the external load bearing capability of the pipe. As such, only conditions with high external loads such as very deep gravity sewers would justify the use of a high stiffness GRP pipe.

Most of the problems encountered with older installations of GRP pipes in Egypt are unrelated to stiffness and increasing pipe stiffness today will not prevent these problems from recurring in the future.

Major changes and improvements must be made to current project specifications with regard to valve chamber connection designs, backfill material selection and native soil compatibility.

Manufacturers must provide corrosion resistant and reliable GRP flanged connections to ductile iron flanges. Only standard flexible GRP joints such as gasketed couplings or integral bell and spigot joints must be used for joining GRP pipes. The use of metallic joints such as the Gibault and its modern derivates such as V-J couplings discontinued.

The performance to SN 2500 N/m^2 pipe was evaluated and it was determined that this class of GRP pipe can be installed in all native soil conditions including very weak soils up to the depth of cover of 4.0 m above the pipe crown with moderate compaction, without exceeding the maximum safe long term deflection of GRP pipe which is 5 %.

For 5000 N/m^2 stiffness pipe, it was determined that the pipe can be safely used in even the worst soil conditions up to a depth of cover of 7 meters above the pipe crown. In moderately stable native soils, the pipe will withstand earth cover close of 10 m.

The 10,000 N/m^2 stiffness pipe is suitable for very deep lines usually associated with very deep gravity sewer lines.

Current GRP pipe specifications should be revised conservatively as follows:

- SN 5000 N/m^2 to be used for **pressure & gravity** pipes up to **7** m cover *above pipe crown*.

- SN 10000 N/m^2 to be used for **pressure and gravity** pipes; installed at **over 7 m** depths of cover *above pipe crown.*