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FULL SCALE EVALUATION OF THE CORE TUBES GROUT INJECTION METHOD FOR LARGE DIAMETER HDPE OFFSHORE PIPELINES SINKING

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SHORT SUMMARY

The grout injection weighting method evaluated by full scale bending tests and the ratio of initial tangent and secant values of the Ring Stiffness Modulus for Grouted-pipe to non-Grouted pipes obtained 2.57 and 1.42, respectively. This could be related to the crushing of the grout body in the larger deformations which the rigid grout would be destroyed. Also, the bending radius ratio to the pipe diameter obtained 32 and 34 for the Grouted and Non-Grouted pipes, respectively. The pipeline installation by using the grout injection in the pipes has been done successfully in the project and it could be recommended as a good experience, with advantages such as: no local load exerted by ballasting weights, uniformly weighted pipe which decreases possibility of free spanning occurrence, despite the using of concrete ballast which can increase it.

KEYWORDS
Offshore Pipeline S-Lay, Core Tubes Grouting, Bending Tests.

ABSTRACT

Seawater intake/outfall systems in nine lines with 1400/2200 m length and large diameter polyethylene pipelines (O.D. 2700 mm dia.) had been designed and fabricated to supply 4,200,000 cubic meters per day seawater into a basin in northern coast of Persian Gulf, Bandar Abbas/IRAN. The usual sinking by additional concrete ballasts had been considered for installation of the pipelines in basic engineering phase. During the detailed installation engineering an alternative method considered which was grouting the core tubes in the pipe wall instead of the use of the concrete ballasts. This novel method evaluated by performing two bending tests on 30 m strings. Based on the tests results, grouting the core tubes has no significant effect on the initial deformation of the strings under pipe's own weight in comparison to the situation of the Non-grouted pipes with concrete ballasts. Furthermore, it could be predicted that the grouting would have no significant effect on the pipe string's stiffness in the sinking conditions that string will experience a great deformation. The bend radius ratio to the pipe diameter obtained 32 and 34 for the Grouted and Non-Grouted pipes, respectively, and no defect have been observed in both strings. Therefore, no difference would be observed regarding the bending behavior of the grouted pipes in comparison to the non-grouted pipes. The pipeline installation with using the grout injection in the pipes has been done successfully in the project and it could be recommended as the lessons learned for similar projects which PE pipes will be installed in shallow water conditions, considering advantages such as uniformly weighted pipe, no local loading exerted by ballasting weights, faster construction, and decrease the possibility of free spanning occurrence.

INTRODUCTION

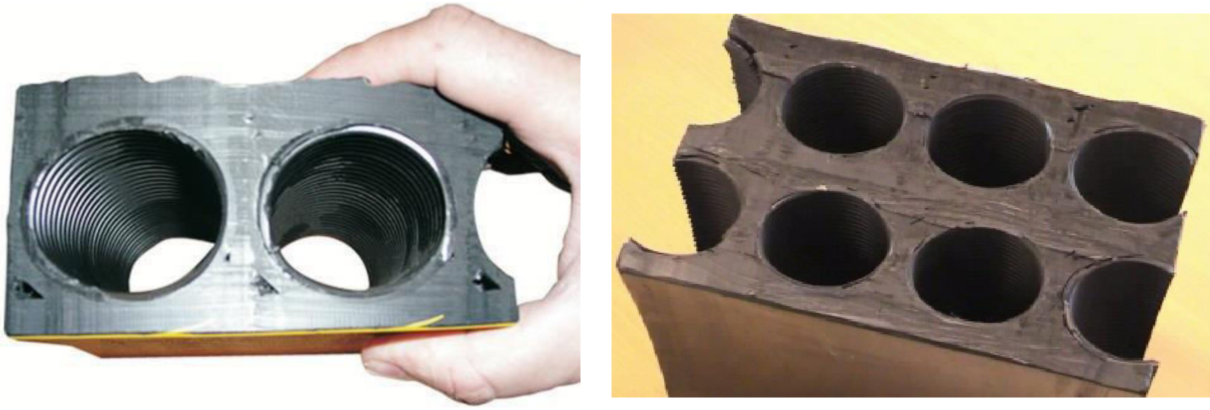
Seawater desalination facilities require an intake pipeline that is endure against seawater to ensure that the plant production targets can be met and also an outfall pipeline to discharge the brine water with minimal environmental impacts. For selecting pipe materials, designers, owners and contractors specify materials that provide reliable, long-term service durability, and cost-effectiveness. Some materials may be used in pipeline construction, such as steel, PVC, GRP, concrete and polyethylene. In offshore pipelines, the Polyethylene (PE) pipe has advantages such as less weight, more chemical resistance against salty seawater environment, five to six times more resistance to abrasion in comparison to the Steel pipes (Venkatesh (2012)). The expected service life values for PE are 2 – 3 times greater than that of steel pipe due to non-corrosion property. In comparison to the Concrete pipe, the Polyethylene (PE) pipe has advantages such as; 10% weight of an equivalent concrete pipe, more chemical resistance, three to five times more abrasion resistant than concrete pipes.

Various offshore pipeline installation methods can be selected considering pipeline size and material, working depth, available offshore installation vessels and equipment, availability of sufficient fabrication area and etc. Bottom or off-bottom tow of prefabricated pipeline strings, lifting and subsea installation of individual pipe joins and float & flood method are some of the most recognized installation methodologies but the last one has been widely used round the world due to its excellent advantages from cost and time standpoints (Brown 2006). In this method the pipeline is fabricated and blocked at the both end with blind flanges. Then the fabricated strings are launched into the seawater. The floated pipeline string is towed to the installation location in the intake line route and submerged by flooding through one end. To sink HDPE pipes which have specific weight approximately equal to water, in addition to the flooding water, more weight is required. So, providing required weight to ensure pipe sinking and stability is one of the main concerns related to pipelines. One of the conventional methods in this field is using Ballasting Concrete Blocks (Figures 1, 2).

Figure 1. Typical view of concrete ballast

Figure 2. Typical view of the Installed Concrete Ballasts

Two types of wall section are prevalent in PE pipes, solid and profile. Solid wall PE pipes are beneficial in shallow cover regions, but in medium or deep installations the usage of profile wall PE pipes is more beneficial and preferred. Fabricating the pipe with a profile wall provides desirable stiffness at overall weights that are approximately 40% less than solid wall pipes. Therefore, it is preferred to use profile wall PE pipes instead of solid wall. Some kinds of PE pipe wall cross-sections illustrated in Figure 3.



(a) **(b)**

Figure 3. HD Polyethylene Pipe Sections having Core tube wall, a. Single layer and b. Double layer

This hollow profile is a continuous circular cross section tube, which spirally wrapped around the whole PE pipe length within wall thickness. As estimation, for a 6m length PE pipe with 2.5m inner diameter, the length of this spirally wrapped tube is about 650m to 800m.

As an alternative for the concrete ballasts (shown in Figures 2, 3), this hollow profile could be filled with cement-based grout. The grout should have maximum density to weight up pipe as much as possible, maximum consistency to minimize the injection pressure and maximize workability to fill the profile. Considering the innovation of the filling hollow profiles especially in the offshore pipeline installation projects, in this article results of two set of tests on pipeline strings with and without grout filled core tubes profile are presented.

PROJECT DESCRIPTION

The SAKO site is located in northern coast of Persian Gulf, approximately 35 km southwest of “Bandar Abbas”, Iran. This project is one of the world’s largest integrated water and power plants. The SAKO project consists of desalination units with total capacity of 1,000,000 m^3/day, i.e. 42,000m^3/hr desalinated water and a power plant rated at 1000 MW. A sea water intake system with a capacity of 3,000,000 m^3/day, i.e.125,000m^3/hr is constructed to provide the required seawater. The sea water intake facility is based on a gravity filled pumping basin, which supplies the required water for desalination plant. Approximate location of the project area is presented in Figure 4.

Figure 4. Approximate Location of SAKO Power and Desalination Plant

In the present project, seven intake pipes with internal diameter of 2500mm extract raw water from sea depth of -12.0m CD to the desalination plant. The concentrated discharge of the desalination plant will be released to the sea in water depth of -9.0m CD through three pipelines with internal diameter of 2500mm. Depth and location of the intake and discharge have been obtained based on the hydrodynamic studies and also considering recommendations in Missimer et al. (2015). The discharge pipeline will be situated next to the intake pipelines and in one trench from the desalination plant to the desired water depth. Schematic position of pipes can be seen in Figure 5.

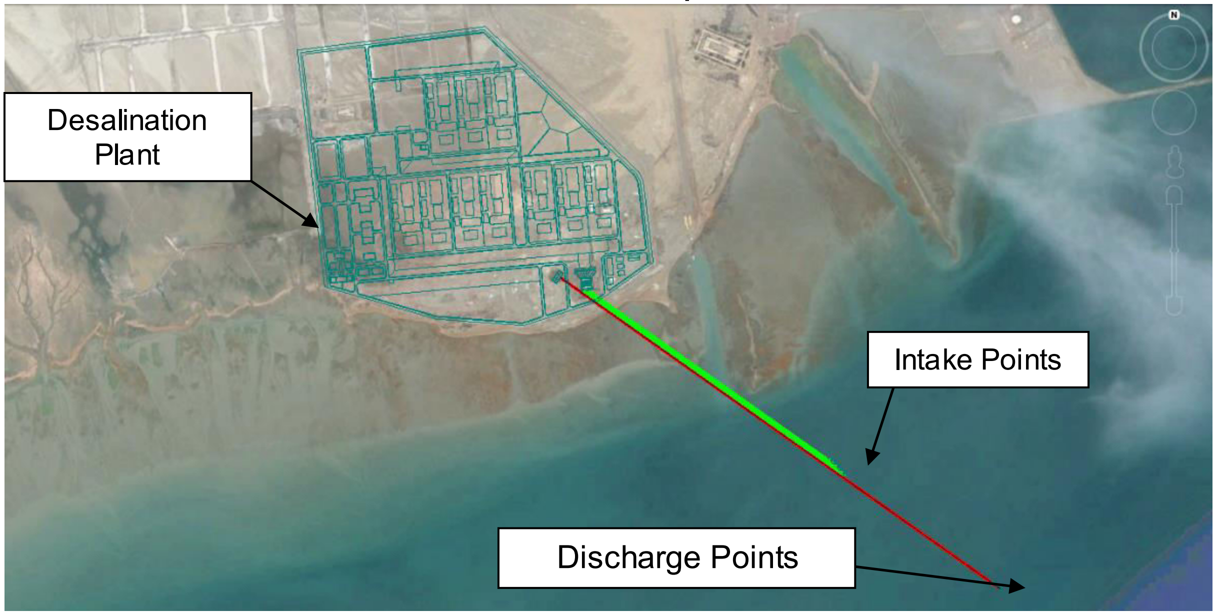
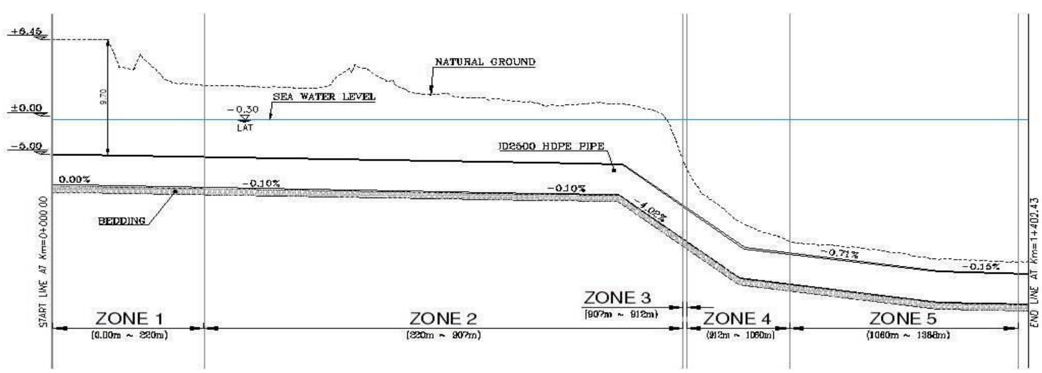


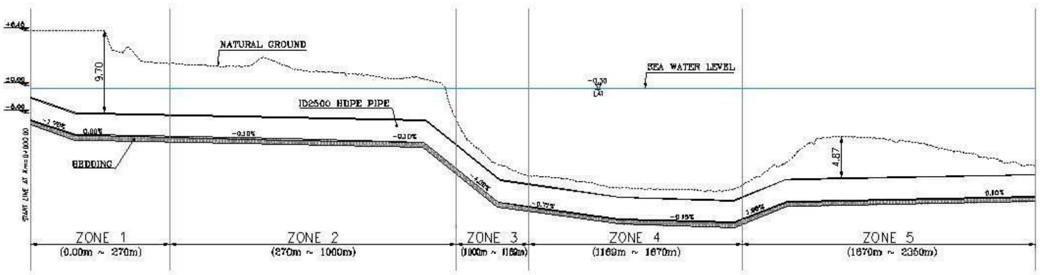
Figure 5. Schematic pipes and the desalination plant position

Considering the above-mentioned advantages of PE pipes, it's preferred to use profile wall PE pipes in the project.

For the purpose of pipe wall section calculation, installation zone of PE pipes should be categorized depending on the depth of cover, surface loading, and water level and pipe diameter. Each category involves slightly different equations for determining the load on the pipe and the pipe’s reaction to the load. At the present project, the burial depth varies along the pipeline route. The most height of the soil on the pipe is at shore side of pipelines and decreases along pipeline route toward the sea. A schematic longitudinal profile of intake pipeline route and discharge pipeline route are shown in the Figure 6. Various zones in each pipeline rout also indicated in the figure.



(a)



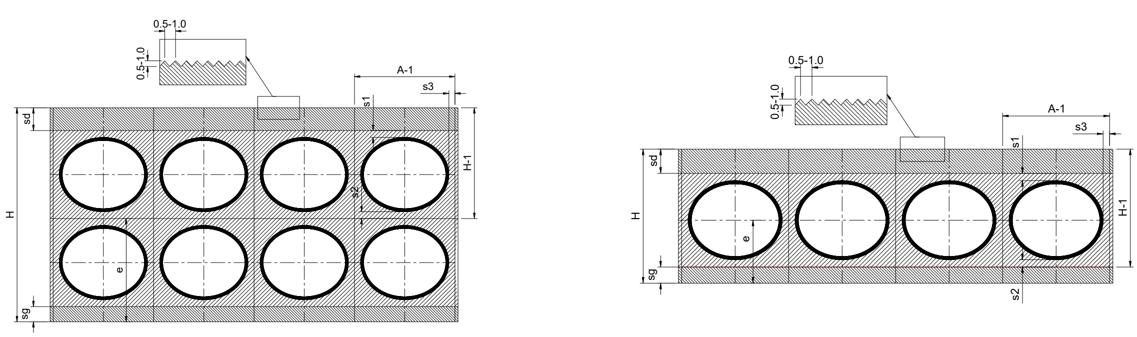
(b)

Figure 6. Longitudinal Profile of a. Intake Pipe and b. Discharge Pipe

Design of pipe profiles has been done based on recommendations in ISO 12162 (2009), ATV-DVWK-A 127E (2000), and Plastic Pipe Institute (2008). The designed sections for various zones of offshore pipelines are summarized in Table 1 and Figure 7 illustrates the characteristics of the Pipe wall sections.

Table 1. Dimensions of pipe wall sections in various zones

Designed for Zone		Zone 1 of intake and outfall	Zones 2, 3, and 4 of intake and Zone 2 of outfall	Zone 5 of intake and Zones 3, 4, and 5 of outfall
Profile Type		Double Layer Profile	Single Layer Profile	Single Layer Profile
Profile Abbreviation		SM-515	SM-550	SM-530
Profile Dimensions	H	126 mm	87 mm	78 mm
	Sg	10 mm	10 mm	10 mm
	Sd	0 mm	20 mm	10 mm
	A-1	66 mm	66.5 mm	66.5 mm
	H-1	58 mm	58 mm	58 mm
	S1	4.5 mm	4.5 mm	4.5 mm
	S2	4.5 mm	4.5 mm	4.5 mm
	S3	4 mm	4 mm	4 mm



(a) **(b)**

Figure 7. Characteristics of the Pipe wall sections, a. Double Layer Profile Wall section, b. Single Layer Profile Wall section

After considering the overburden pressure of the soil in design of the pipeline sections, another important parameter of the pipes design is selection of the installation method and evaluation of the effect of the installation loads as temporary loading and its requirement on the pipes. Considering the depth of installation, the S-lay installation method has been selected for this project as suggested by (Guo, 2005) for shallow water depths. The configuration of this method is illustrated in Figure 8.

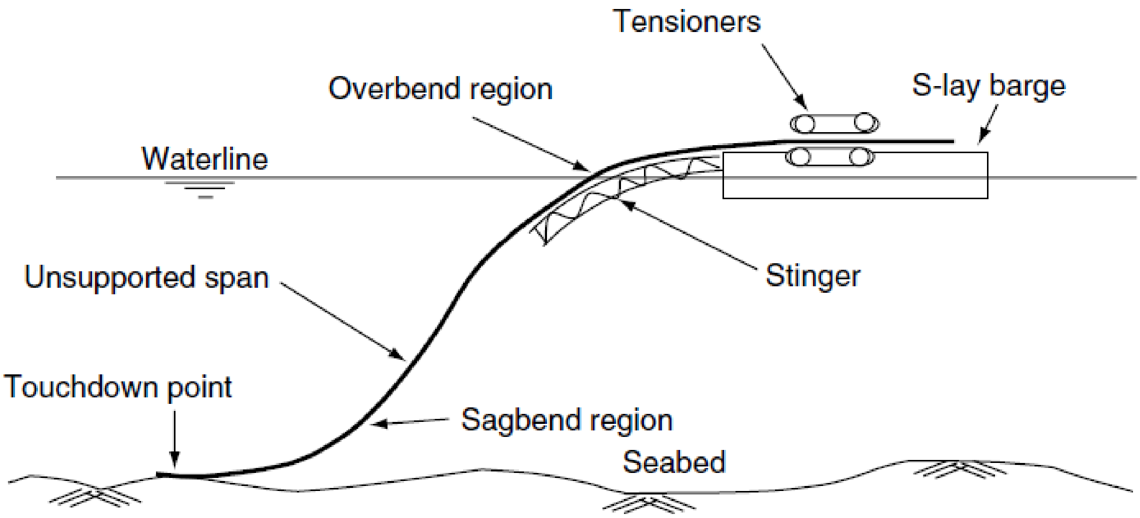


Figure 8. Typical pipe configuration during S-lay installation (Bai, 2001)

Pipeline could damage and fail in the laying process from vessel to seabed (Zinovieva, 2011). The most challenging issue during the installation is maybe the controlling of the pipeline s-curve to prevent undesired bending moments causing over stressing the pipe wall (Palmer et al. 1974; Ovunc 1982). The challenge of avoiding pipe-kinking and excessive-bending, while staying within the stress limits of the pipeline is ever present and important to overcome. This problem results from the difficulty of lowering very long continuous lengths of pipeline, typically ranging in hundreds of meter, from the surface of the water to the sea bed, under a controlled movement. Various systems have been devised to facilitate control of the long lengths of pipe line during the laying thereof in deep bodies of water (Da Silva et. al, 2009). During installation, the pipe system is bent under its weight or added weights as concrete blocks, into a stretched “S-curve”, causing bending stresses in the pipe (Rigzone, 2016). The value of the bending stress is directly related to the bending radius of the pipe. Various recommendations presented for minimum allowable elastic bending radius. The limiting deflection to avoid kinking is estimated to 20% ovality. Table 2 summarizes recommendations for bending ratio of pipes:

Table 2- recommendations for bending ratio of pipes (PPI TN-27/2009)

SDR (Ratio of the outside diameter to Pipe wall thickness)	Minimum Allowable Bending Radius
41	> 52 Times Outside Diameter
32.5	> 42 Times Outside Diameter
26	> 34 Times Outside Diameter
17, 21	> 27 Times Outside Diameter
11, 13.5	> 25 Times Outside Diameter
9 or less	> 20 Times Outside Diameter

Considering the characteristics of the SM-530 pipe and the above-mentioned recommendations; the minimum bending radius calculated is equal to 71.712 m (> 27 Times Outside Diameter). This value of the bending radius considered as target and two tests on pipes with and without grouted profiles have been done.

TESTS PROGRAM

Considering the innovative method for increasing the pipes weight by grout injection in the wall profile, some concerns require to be evaluated. The most important concern is the effect of the grouting of core tubes on the permissible bending radius of the pipes. In order to evaluate the above-mentioned concern, two bending moment tests have been done. Tests were done on 30 m strings with and without grouted core tubes of the pipeline wall, with section of those which will be used in Zone 5 of the intake pipeline, named SM-530. Figure 9 shows the schematic view of the test string.

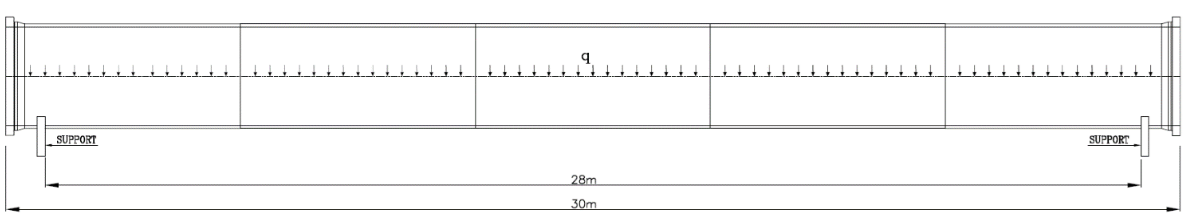


Figure 9. Schematic view of the 30 meter test string which fabricated by welding five pipes with 6 m length

Loading of the string has been done by pumping seawater in to the pipeline. In order to provide open span in the string length, two supports installed with 28 m distance beneath the pipeline. Supports lubricated in order to minimize the friction between pipe and supports (Figure 10).

(a)

(b)

Figure 10. Supports beneath pipeline string, a. Typical view, and b. lubrication in order to minimize the friction

After installation the pipeline string on the supports, the seawater pumped in to the pipe and amount of water injected into the strings, measured by flow meter (Figure 11).

Figure 11. Injection water hose and flow meter view

The bending of the middle point of the string measured by a survey camera and an indicator connected to the center line of the string. Figure 12 shows the string without grout injection in the beginning and end of the test. The volume of the water pumped in to the string and recorded deformation for two tests is summarized in Table 3.

(a)

(b)

Figure 12. The tests of string without grout injection a. in the beginning, and b. end of the test

Table 3- Volume of the water pumped in to the strings and recorded deformation for two tests

Non-Grouted Pipe		Grouted Pipe	
Volume of the injected Water (Lit.)	Deformation in the Centerline of the string (mm)	Volume of the injected Water (Lit.)	Deformation in the Centerline of the string (mm)
0	60	0	300
6495	210	1100	310
11646	360	2000	320
16685	520	3000	340
16909	590	4400	360
18477	670	6000	390
20380	880	7300	420
22508	970	8500	440
24300	1140	9700	470
		11300	510
		13300	570
		15800	640
		17600	700
		20000	790
		20700	820
		23900	1060

The Load Deformation curves for two tests are shown in Figure 13.

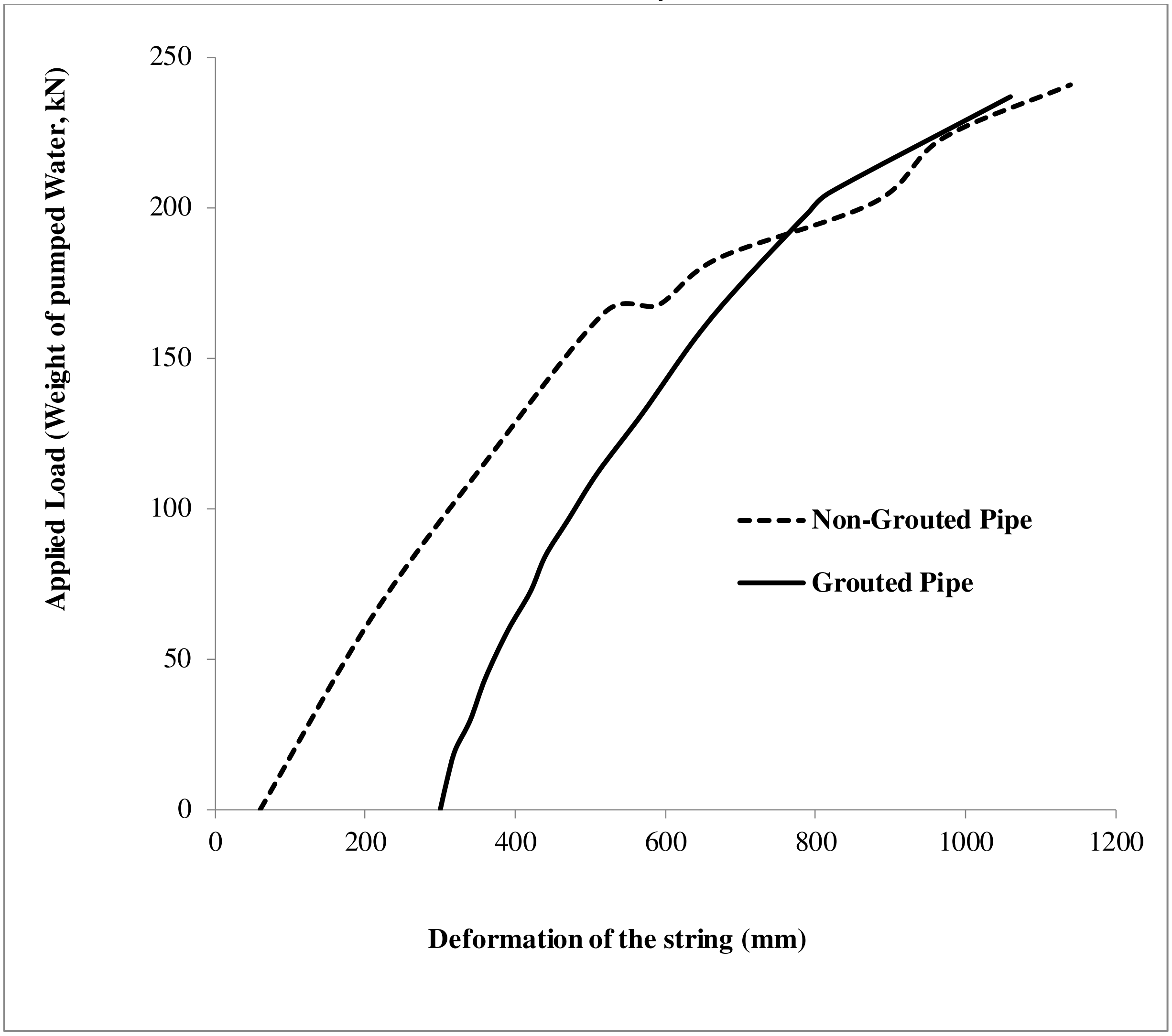


Figure 13. Load-Deformation curves for grouted and non-grouted strings

It could be seen that in Grouted and Non-Grouted pipes, the defomation under pipe weight is equal to 300 and 60 mm respectively. In order to comparison of curves under filling water load, these initial defomations under pipe weight deducted from the recorded values and results presented in Figure 14.

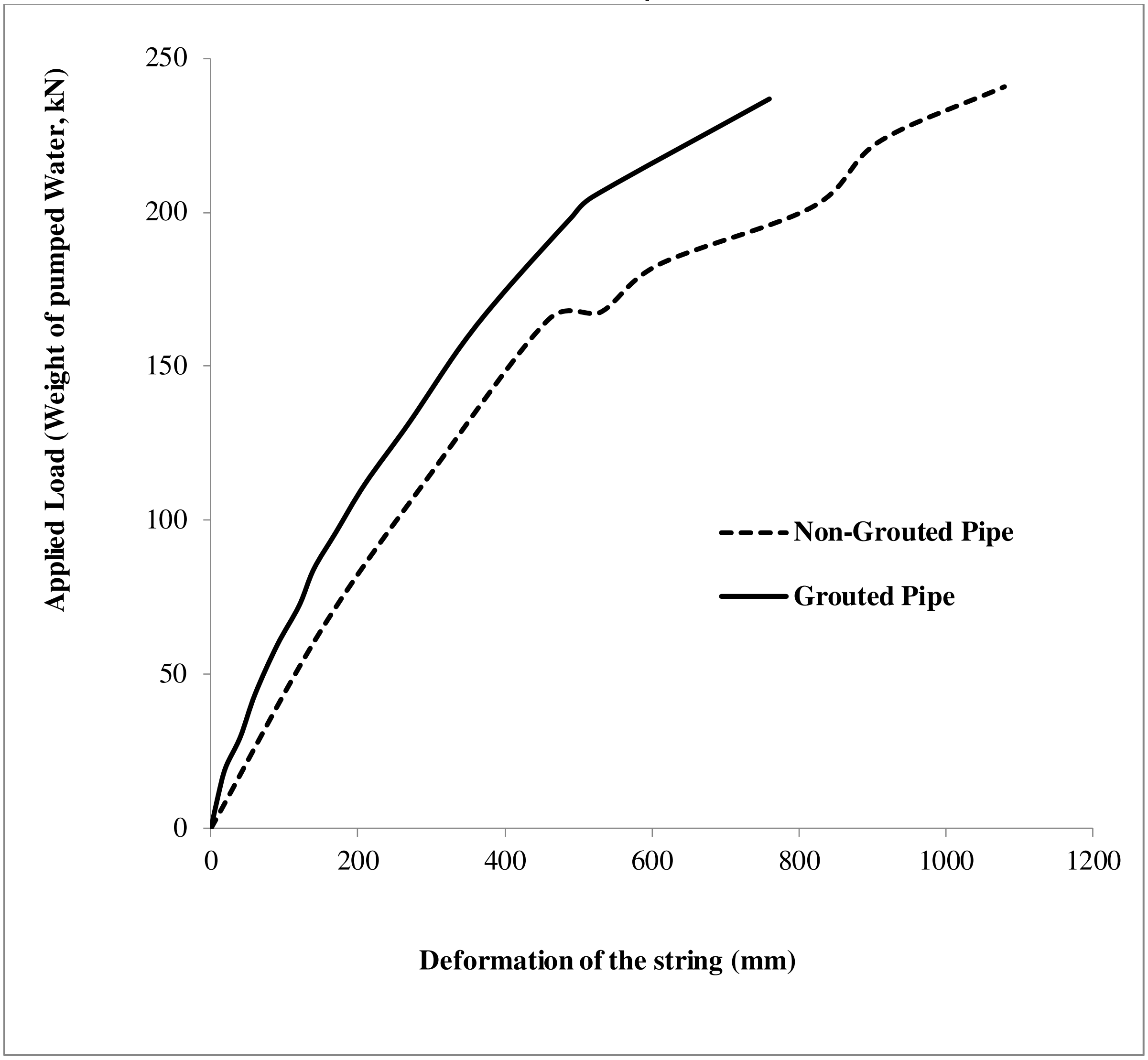


Figure 14. Load-Deformation curves for grouted and non-grouted strings after deduction of the deformation induced by pipes weight

DISCUSSION

Considering data presented in the previous section, the following matters could be concluded:

- The initial deformation of the strings under pipe weight;
  Considering the larger special weight of the grouted pipe, the initial deformation of the grouted string has been 5 times greater than that for Non-Grouted string. The special weights of the grouted and Non-grouted pipes were 7900 kN/m and 3900 kN/m respectively. It should be considered, if in the installation phases the grouting does not applied, the Non-Grouted pipes will need the concrete ballasts

to compensate the lack of weight, and as a result for loading of the weight of concrete ballasts, it could be predicted the initial deformation values will be equal to those for the Grouted pipe.

- The Ring Stiffness Modulus
  After omission the initial deformations, the initial tangent values of the Ring Stiffness Modulus for Grouted and Non-Grouted pipes obtained 0.991 and 0.385 kN/m respectively. But the secant value for this parameter in the end of the tests, obtained 0.31 and 0.22 kN/m for Grouted and Non-Grouted pipes, respectively. There could be related to the crushing of the grout body in the larger deformations, causing rigid grout break down. So it could be summarized that the grouting will have no significant effect on the behavior of the pipe strings stiffness in the sinking conditions which string would experience large deformations.

- The Bending Radius
  Considering the final deformation values in the tests, the bending radius ratio to the pipe diameter (O.D.) obtained 32 and 34 for the Grouted and Non-Grouted pipes, respectively. In these amounts of bending radius, no defects have been observed in both strings, and it could be summarized no difference will be observed regarding the bending behavior of the grouted pipes in comparison to the non-grouted pipes. It also could be related to the small differences between secant stiffness modulus in large deflections.

CONCLUSIONS

In the S-lay installation method of offshore pipelines, the weight of the PE pipes shall be increased in order to facilitate sinking procedure. As an innovative method instead of the using concrete ballasts; grouting of the core tubes in the pipe wall profile have been selected and effect of the grouting on the permissible bending radius of the pipes evaluated and following outcomes found;

- The initial deformation of the strings under pipe weight in the grouted string has been 5 times greater than that for Non-Grouted string, because the unit weight of the grouted string was larger than Non-grouted string. But if during the installation phases the grouting had not apply, the Non-Grouted pipes require concrete ballasts to reach the required sinking weight, and consequently it could be predicted the initial deformation will be equal.
- The initial tangent values of the Ring Stiffness Modulus for Grouted pipe obtained 2.57 times to the Non-Grouted pipe. But the ratio of the secant value for this parameter obtained 1.42 and could be related to the crushing of the grout body in the larger deformations which the rigid grout would be destroyed. So it could be predicted that the grouting will have no significant effect on the pipe strings stiffness during the sinking conditions which strings would experience large deformations.
- The bending radius ratio to the pipe diameter obtained 32 and 34 for the Grouted and Non-Grouted pipes, respectively. In these amounts of bending radius, no defects have been observed in both strings, and it could be summarized no

difference will be observed regarding the bending behavior of the grouted pipes in comparison to the non-grouted pipes. It also could be related to the small differences between secant stiffness modulus in large deflections.

- The pipeline installation by using the grout injection in the pipes has been done successfully in the project and it could be recommended as a good experience for similar projects which PE pipes would be installed in shallow water conditions.

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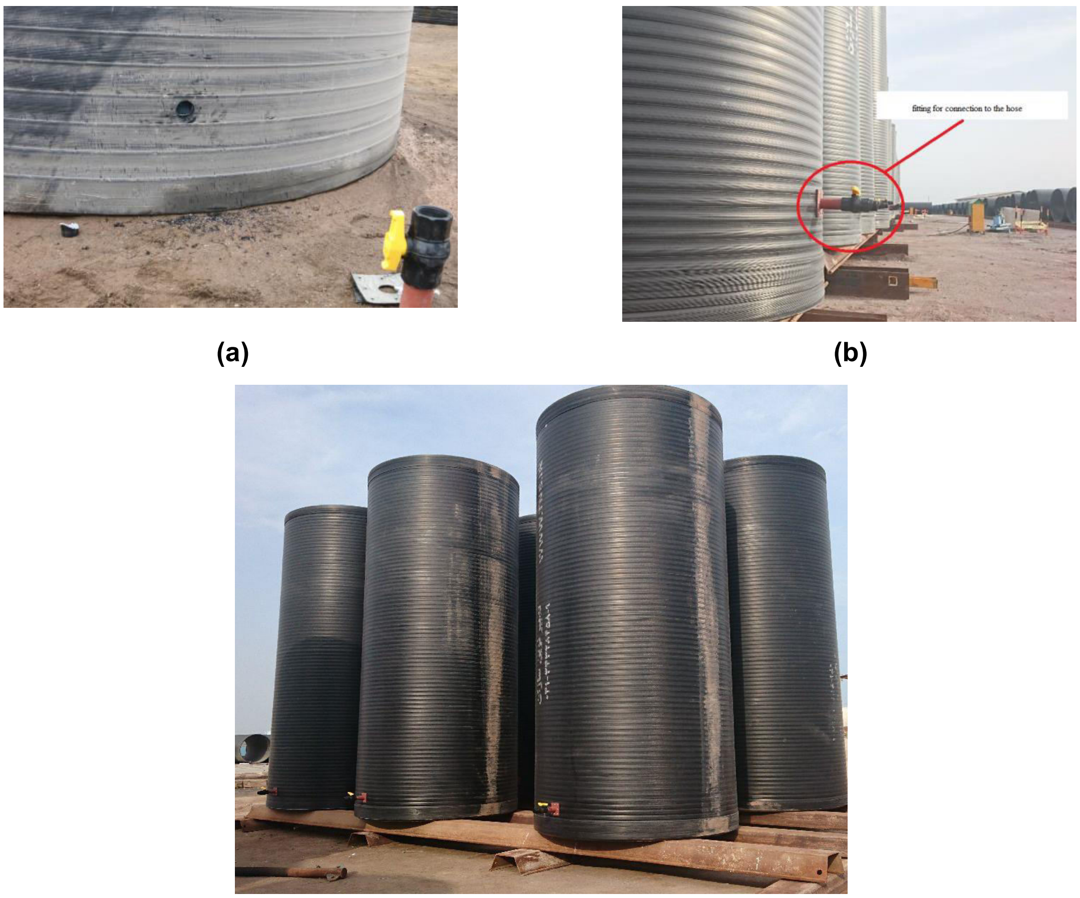
ANNEX A
EXPERIENCES IN THE INSTALLATION OF THE PIPELINE STRINGS

Considering the technical results of the tests and advantages of execution of the grouting; this method has been selected and offshore pipeline strings profile filled with grout. Two circular holes created in each end of the 6 m pipes and then pipes were placed vertically. Then the grout injection started from bottom hole and continued till the grout pour out from the top hole (Figure A1).



(a) **(b)**

(c)

Figure A1. The pipe grouting sequences, a. injection hole, b. fitting for connection to the grouting hose, and c. vertical position of pipes for grout injection

The mixture design of the grout was as the followings;

- Water Content: 670 kg/m^3
- Cement Content: 800 to 930 kg/m^3
- Lubricant and Fast hardener: 27 to 40 kg/m^3

In order to grout injection, considering the thickness of the solid part of the wall and also core tubes characterizations, three types of raptures evaluated:

- Crush stress: this is equal to the injection pressure
- Longitudinal Stress $\sigma_l = \frac{P.r}{2t}$
- Radial Stress $\sigma_r = \frac{P.r}{t}$

Where P, r and t are injection pressure, internal radius of the pipe, and pipe wall thickness, respectively.

Considering injection pressure (P) equal to 10 bars the stress in various types of pipes calculated as listed in below table. As it could be summarized from Table A1, the stress values are smaller than allowable ones, and injection by 10 bar pressure could be done.

Table A1- Results of stress calculation for 10 bar injection pressure

Pipe Profile	Wall Thickness (mm)	Core Tube Diameter (mm)	Crush stress (MPa)	Longitudinal Stress (MPa)	Radial Stress (MPa)
SM-515	4.5	50	1	2.78	5.56
SM-550	14.5	50	1	0.86	1.72
SM-530	14.5	50	1	0.86	1.72

After grout injection, pipes remained vertically for seven days in order to slurry setting. Then pipe strings were weighted and based on the exact weight of each pipe, pipes in the strings would be located and welded to fabricating a string. Afterward stings launched in to the sea and transferred to the installation location. By sinking water in to the string, without concrete ballasts, the pipeline strings have been installed successfully. Figure A2 shows a string during sinking process.

(a)

(b)

Figure A2. The pipe string during sinking process, a. at the beginning of sinking, and b. during S-Lay Sinking

As shown in Figure A2 in comparisons to Figure 2, there was no need to use the concrete ballasts because of the injection of grout in to the pipe wall core tubes. The selected weighting method (grout injection), in comparison with common concrete ballast weighting technique (as shown in Figure 3) has some advantages such as:

- Presents uniformly weighted pipe
- No extra area exposed to environmental load

- No local load exerted by ballasting weights
- Comparatively faster construction
- No concerns about probable fracture and sliding of concrete ballasts in sinking process or in long-term
- Decreases possibility of free spanning occurrence, despite the using of concrete ballast which can increase it.