Floating and subsea installation of an ultra-large diameter sea water intake pipe line

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Abstract: A 360,000 BPSD condensate refinery in Bandar Abbas is being carried out by Persian Gulf Star Oil Company, located in Iran, where a seawater intake system was designed to supply 200,000 cubic meters clean water from 1500m offshore by 4×2.7m diameter steel marine pipelines for cooling purposes. Hence, sea water would be collected at the basin through four steel pipes of 2.7m inner diameter and 22mm thickness which were connected together as a 600m string. The length of the pipeline route is approximately 1.4km, including two strings of 600meters and shore approach line of 130m. Although, this was a huge and a high risk project due to the pipeline’s material and its ultra-large dimensions, it was carried out with the most safety and reliability. All activities related to floating and subsea installation, including offshore tie-ins between two individual strings has successfully completed by Delta offshore Technology in just a few hours that was much less than as the client expected. This paper investigates the floating, installation and flooding processes of the marine pipelines, focusing on challenges and the intellectual solutions to tackle effectively the problems based on several different analyses.

Keyword: sea water intake, pipeline, ultra-large diameter, installation, offshore tie-ins.

1 Introduction

The client planned to install a 360,000 BPSD Condensate Refinery in Bandar Abbas, Iran. This new refinery was installed in the vicinity of existing NIOC refinery. In order to supply cooling water, sea water was the solely source of water supply [1]. Based on both the client requirements and environmental conditions, the maximum intake water temperature was 35°C. Installation of new refinery intake was supposed to be at the depth of 11.5m (CD) to satisfy the required maximum temperature criterion. The purpose of this paper is to describe the installation analyses and procedures for intake submarine pipeline. Regarding to ultra-huge dimension in this project and the material of pipeline, one of the most important problems here was how a 1200m steel pipeline was installed by new developed float and flood method, which pipelines were partially used as buoyancy thanks to distribute the weight of the pipelines equivalent with the buoyancy to reduce the risk of the pipeline bending during sinking. The apparently unique solution was used to grapple with the problem and it was optimized by various analyses. Marine pipeline installation comprises all the activities following the fabrication of the pipe joints, through the preparation of the pipeline for commissioning. In order to construct the complete pipeline it was necessary to perform pipe line strings construction in fabrication yard in two set, floating the strings, towing to the installation position, connecting two floated strings together, flooding the strings and offshore tie-ins between two individual pipe strings. Also it was demanded to be carried out connecting of the pipe lines to water intake basin and installing suction chambers in end of pipe lines. Briefly, this paper illustrates engineering and main operations including floating, installation and flooding processes and also it discusses about the challenges and the related solutions. Delta Offshore Company’s (Delta’s) scope of work was to carry out the engineering and installation activities. The design service life of the pipeline system is 20 years.

2 Acquaintance with the project

2.1 Location

The site location of the project is in the coast of Persian Gulf in Hormozgan province of IRAN close to Shahid Rajaee port. The project general location is shown in Figure 1.

Figure 1. General location of PGSOC submarine pipelines

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Approximate U.T.M. tie-in coordinates are [2]:

Start: \[ E = 409973.60 , \ N = 3000084.98 \]
End: \[ E = 410714.65 , \ N = 2998923.59 \]

2.2 Design data

Pipe specifications utilized in this project are as described below in Table 1 [3-5]:

<table>
<thead>
<tr>
<th>Type</th>
<th>Carbon steel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grade</td>
<td>API 5L–B</td>
</tr>
<tr>
<td>Inner Diameter</td>
<td>2700 mm</td>
</tr>
<tr>
<td>Wall Thickness</td>
<td>22 mm</td>
</tr>
<tr>
<td>Fabrication Type</td>
<td>Spiral Welded Tubular</td>
</tr>
<tr>
<td>Density</td>
<td>7850 ( \text{kg/m}^3 )</td>
</tr>
<tr>
<td>Young's Modulus</td>
<td>( 2.07 \times 10^5 \text{(MPa)} )</td>
</tr>
<tr>
<td>Minimum Yield Strength</td>
<td>241(MPa)</td>
</tr>
<tr>
<td>Ultimate Tensile Strength</td>
<td>413(MPa)</td>
</tr>
<tr>
<td>Poisson's Ratio</td>
<td>0.3</td>
</tr>
<tr>
<td>Linear Thermal Expansion Coefficient</td>
<td>( 11.6 \times 10^{-6} \text{(1/°C)} )</td>
</tr>
<tr>
<td>Structural Damping Coefficient</td>
<td>0.126</td>
</tr>
<tr>
<td>Thermal Conductivity</td>
<td>( 45.0 \text{(W/m°C)} )</td>
</tr>
<tr>
<td>Resistivity</td>
<td>( 180 \times 10^{-9} \text{(ohm.m)} )</td>
</tr>
</tbody>
</table>

2.3 Basic concepts

2.3.1 Sea Water Intake

Sea water intake contains sea water Basin, which was constructed onshore and all pumps and accessories were installed on this Basin, and sea water was collected at the basin through four pipes of 2.7m internal diameter and 22mm thickness. The length of the pipeline route is approximately 1.4 km [1]. The line is so called Submarine pipe line.

2.3.2 Pipe Line Construction Pit

This pit was designed in length of approximately 650 m and width of 50 m with elevation below mean sea level to provide facility for floating the strings after construction and enable transport of the long and heavy strings to the installation location. Pipeline construction pit was protected against wave and high water during string construction by a protection dike. By removing the dike, sea water could enter the construction pit and pipe line strings be floated consequently.

2.3.3 Pipeline Strings

Submarine pipelines were fabricated in two parts. The length of each part is 600 m and includes 4 parallel pipes connected together via link boxes [6]. Each group of 4 pipe lines strapped together was called a string. The strings 1&2 in the construction pit, before floating, are shown in Figure 2.

![Figure 2.Strings 1 and 2](image-url)
2.3.4 Spool
For connecting two pipe line strings together with high accuracy and no deviation, spool and template were utilized. A approximately 2 m module called spool, was welded to each of 4 pipes in string and fixed together as a template, to transfer the dimension of this string to the next one accurately. This spool was disconnected and transferred and welded to the next string and related flanges were connected to the first string in offshore.

2.3.5 Other facilities and equipment
Some other facilities and equipment such as manhole, divider, blind flange, flooding valve and etc. were utilized to carry out the floating, installation and submerging procedures in an easier way.

3 Analyses

3.1 Local buckling
Local buckling of pipeline has been controlled by 3D FEM modeling of pipe line by ABAQUS in critical location. In submerging process of pipe, the major forces are moments. Considering the pipe dimensions, local buckling might be occurred in compression zone. Also yielding in tension side should be prevented. Considering the high ratio of D/t (about 127), code checks are not sufficient for controlling of the local buckling and hence a part of pipe was simulated using 3D FEM method and two end moments were applied to. The pipe is meshed with S4 shell type elements and very fine mesh (0.05×0.178m) was used in middle zone for tracing the probable buckling. The size of other elements was 0.5×0.178m.

Also there was external overpressure due to sea water a pressure load was exerted perpendicular to the wall of the pipe. Herein two models were prepared: one model with overpressure and another one without it. In both of models, initial ovality was also considered due to the mistakes in construction that could increase the probability of buckling. For predicting the yielding moment and critical moment due to the local buckling, two pushover analyses were done by increasing the end moments (the overpressure is kept constant). By increasing the moments, the top and bottom of the pipe were bent and closed together. Therefore the pipe was started to be a deformed oval instead of a circle. The magnitude of this closing can be called “vertical ovalization” which is a good measure in predicting the occurrence of local buckling.

For assurance from the prediction of the local buckling in this FEM models, the exaggerated deformed shape of the pipe with concentration on the middle part is shown in Figure 3 at the end of the analysis that considered overpressure.

![Figure 3. Exaggerated form of the pipe buckling](image)

3.2 3D simulation of the pipe with manhole
Some manholes were located in some regions of pipe for access and maintenance and another usage would be expressed as the following. Because the stress concentration occurred in the main pipe at the regions near manholes, some local analyses were done. The pipe and manhole walls were meshed using S4 type shell elements. The size of elements varied in different parts of the pipe, but the average was about 0.15m. For prevention of yielding, strengthening of regions around manholes was essential such as follows: 1)An added-plate with 20mm thickness and 4m wide around manhole on the top half part of main pipe. 2) Applying a plate with 25mm thickness at the first 1.5m of the manhole. Figure 4-a shows the thicknesses of various parts of the strengthened pattern and distribution of von misses stress and after strengthening are shown in Figure 4-b.
The yielding moment capacity of pipe around manhole was about 0.92M_y (27MPa) after strengthening. The small yielded part was inevitable and was stiffened using some stiffener plates around manhole. Therefore the critical stress was reduced to 0.92×241=221 MPa.

4 Floating and Towing Operation

After construction process, the temporary dike in front of the construction pit was removed [7]. Therefore two strings placed in fabrication yard, were floated. Then the floated pipe lines were pulled out from the pit and shifted to the final installation route in front of basin.

4.1 Floating inside the Construction Pit

To reach this goal, the backhoe was used to remove the temporary dike which had been built in front of the fabrication yard. Hence, seawater filled all construction areas and the pipe lines became float on water. Removing the dike was done somehow the least volume of sediments slid down and filled in the construction pit. Considerations for flooding the fabrication yard were as follow:

- In this operation, it was ensured that all valves are closed (blind flanges).
- Flooding was done in low tide to avoid any construction scour which might cause filling under the pipe lines.
- Before opening the embankment completely, it was removed from backside as much as possible to reduce flooding time.

4.2 Towing the Strings

When the construction pit became full of water and the strings were floated on water, the first string was connected to towing line of a tug boat then tug boat started to tow this, out of the construction area slowly and under control [8]. This string was pulled toward the sea along the guide piles. During pulling out the first pipe string, the second string was kept in place using the onshore anchorage piles. After pulling the first string out of the fabrication yard along the GPOs, it was shifted toward the submerged pipe lines route. For this purpose some tugs and a shore winch pre-located on the basin pulled it laterally (in direction almost perpendicular to the first direction) until the string was situated in the shallower part of final installation route. Then the second string was pulled out of the construction pit and the same process (only with tug boats) was carried out to situate this string in the proper position. The calculations related to toeing forces are available in Appendix A.

4.3 Positioning the Strings in Submarine Pipe Lines Route

Before connecting the strings together, the first string was located in its final position with about 3 meter distance from the shore approach pipes, then the second string was shifted toward lay down area and berthed to the GPIs. Fitting the strings was done by using a spud barge, platform pontoon and some chain blocks which were available in the connecting area.

5 Installation Operation

5.1 Offshore Installation Method

In the present project, Surface towing method [10,11] was used for offshore pipeline installation. Having large pipe diameter in here, floating, towing and flooding system were used for installation, which is called float and flood system. The entire tow string was buoyant and floated on the surface or near the surface until it reached the installation location.
5.2 Mooring Pipe Lines to the Guide Piles

After locating two strings in the submarine pipe lines route and before connecting together such a way became a unique pipe lines with length of 1200 m, these pipe lines were berthed to the guide piles driven in front of the basin (GPIs). It’s worthwhile noting that to avoid extra force on some piles, this berthing was done in a way that all piles resist almost the same load. It means all piles have to be exposed under the same tension and therefore it was tried to effective length of the rope fastened to the pipe lines in each pad eye was equal. To achieve this aim, we utilized bollards close to the mooring pad eyes for adjusting the length of each soft ropes [12].

5.3 Connecting Two Strings Together in Offshore

After locating two strings in the final installation position, then the tie-in flange between the floating strings was connected to form a unique pipe. The two strings were fitted longitudinally in front of basin. It should be noted that any difference in length of four pipe lines strapped together in a string might make problems during tie-in connection. The angular fitness was achieved using swivel flanges in tie-in connections. Also, for connecting two strings without any deviation, it was planned to use a 2m pipe spool.

The strings were fitted together using chain blocks applied between special pad eyes welded at the ends of string1 & 2 on top of the strings. As there might be deviation in level of one string in contrast of the other one, a suitable crane located on a spud barge was stand by in joining position to help for fine adjusting by lifting and adjusting the end of the strings. A floating pontoon was also nearby for carrying some accessories and equipment and personnel to carry out the tie-in connection. Therefore, utilizing this pre-fabricated spool, the bolts could properly be fastened in an easier way and offshore tie-in connection was carried out in the best way and optimum time.

5.4 Connecting Offshore side spools to the second string

After locating and connecting the first string to the second string, spools 9 and 15 & 30 m were connected to the string 2 for installing the suction chambers.

6 Flooding and Laying Operation

6.1 Optimization

As above mentioned, due to the large dimensions here and type of material utilized for pipeline (steel), there was a serious problem in offshore laying process how a 1200 pipe line (including two 600m strings connected together) had a smooth profile in laying that should prevent failing when water enters into it. The only apparently effective solution was dividing 1200m pipeline to some smaller parts which dividers were utilized for this purpose. After several various analyses, the length of each compartment was optimized. In addition, the manholes were extended to a pre-calculated length, because they could be used as the bouncy force resources which could allow the pipeline to have a smooth profile in laying. Applying such solutions in carrying out the laying operation, it was successfully done in the best way.

After final positioning the strings, pipe laying operation was started by filling the pipes with water. The pipes were submerged at their location in a submarine trench. Flooding and laying operation were carried out under complete control. During pipe laying, stresses were limited to the allowable values. Pipe laying stress analysis had been completely performed by ABAQUS and the laying method proposed to achieve the acceptable stresses is illustrated in Figure 5-a,b,c. The results of the software in different times of flooding procedure are shown in this figure.

![Figure 5. Pipe laying scheme in different times of flooding (a) initial time, (b) middle time and (c) final time](image-url)
6.2 Ballasting Procedure

The string consists of four pipes with 108 inches diameter connected together using link beams. Two side pipe lines are fabricated in several compartments in order to be used as ballasting tanks, while two mid pipes have just one part and haven’t been separated by any divider wall. Above mentioned ballast tanks are equipped with some valves. The valves used for water intake were located alternatively near to divider walls (FVS & FVBs) such a way that the compartments could be flooded. The valves were fabricated as a Tee shape pipes with 3 Butterfly valves in each end, the main valve located outside of the pipe line was directly contacted with sea water (FVO), one of them located inside, was used for flooding the same compartment which was bigger than the other part (FVB), and the last one was utilized for flooding the next compartment (FVS). Briefly, this procedure was done in some steps as following:

**Step 1** - Flooding the middle pipes and the first 12m of pipe Line 1 & 4 onshore side

**Step 2** - Flooding the small compartments of side pipes (SMPS) alternatively

**Step 3** - Flooding empty compartments respectively

**Step 4** - Flooding compartments completely
7 Operations after Laying Down

7.1 Connecting the String to Onshore Pipe Lines

As mentioned before, there was about 3 m distance between the first string and shore approach pipes. In the current project, shore approach construction was supposed to be fulfilled prior to offshore installation. For shore approach dry construction, two rock jetties were constructed at the sides of intake.

7.2 Suction Chambers

The suction chambers are composed of two parts. The lower part has rectangular shape in plan. The height of this part is 4m. The weight of this part is approximately 200 ton. For the lifting of the lower part, three trunnions were considered at three sides of it.

The upper part has an irregular octagon shape in plan. The length of these irregular octagons sides are 6.6 and 3.04m. The height of this part is 3.804m. Sea water enters the suction chambers through this part. Thus, a trash rack was considered for this purpose at the upper part. Each opening was fitted with vertical protective screens with bars of 20 mm in diameter, giving a net clearance between two adjacent bars of 150 mm.

Suction chambers were installed at the end of pipeline route. The suction chambers’ location and their schematic view are shown in Figure 6. Lifting analysis of upper and lower part of suction chamber was carried out by SACS.

7.3 Extraction of Piles

After sinking the strings, piles became useless and were removed. To extract these piles, the barge, an appropriate crane and vibratory hammer were mobilized again. Same as the time piles had been driven, the barge was fixed so that it remained immovable and vibratory hammer clamps took the pile firmly. While the crane was pulling the hammer, it vibrated the pile and the pile was taken out. Then it was laid on the barge and transferred back to the shore.

7.4 Trenching and Backfilling

To protect the marine pipelines against environmental and accidental loads during operational period and provide stability, it was necessary to bury the pipelines below natural seabed level. This purpose, took place with excavation of a trench deep enough and placing the pipelines on the bottom of the excavated trench. Thereafter, due to above considerations, the pipelines were buried under backfill material.

After trenching and also prior to installation operation, the dimensions of trenched area was checked by hydrographic operation [13], and the trenching was performed again where the dimensions do not fulfill the project requirements.

8 Conclusion

For a seawater intake system in a huge project, it was planned to supply 200,000 m$^3$ water for cooling purposes via a 130m shore approach line and two 600m strings consisted of 4 steel marine pipelines with a ultra-large dimension as 2.7m, in aggregation of approximately 1500m offshore. By considering such material and dimensions, it was seemed to completely handling on the various processes, especially on the flooding and sub-sea installation was a sophisticated problem. Despite a high risk, the project was successfully performed under the fully controlled circumstance. This paper discussed these steps by focusing on the engineering issues and optimizing the solution through some analyses.
List of symbols

**Abbreviations**

<table>
<thead>
<tr>
<th>DVD</th>
<th>Divider</th>
<th>SMP</th>
<th>Small Part</th>
</tr>
</thead>
<tbody>
<tr>
<td>LIB</td>
<td>Link Beam</td>
<td>BIP</td>
<td>Big Part</td>
</tr>
<tr>
<td>MNH</td>
<td>Manhole</td>
<td>PIP</td>
<td>Pipe Segment</td>
</tr>
<tr>
<td>GPO</td>
<td>Guide Pile on Shore</td>
<td>TPE</td>
<td>Towing Pad eye</td>
</tr>
<tr>
<td>GPF</td>
<td>Guide Pipe in front of the Fabrication Yard</td>
<td>MPE</td>
<td>Mooring Pad eye</td>
</tr>
<tr>
<td>GPI</td>
<td>Guide Pipe in front of the Intake Basin</td>
<td>CD</td>
<td>Chart Datum</td>
</tr>
<tr>
<td>BOF</td>
<td>Bollard for GPF</td>
<td>MSL</td>
<td>Mean Sea Level</td>
</tr>
<tr>
<td>BOI</td>
<td>Bollard for GPI</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Symbols**

<table>
<thead>
<tr>
<th>FVS</th>
<th>Flooding Valve for Small Parts</th>
</tr>
</thead>
<tbody>
<tr>
<td>FVB</td>
<td>Flooding Valve for Big Parts</td>
</tr>
<tr>
<td>FVO</td>
<td>Flooding Valve outside the Pipe</td>
</tr>
<tr>
<td>SPL</td>
<td>Spool</td>
</tr>
<tr>
<td>PLN</td>
<td>Pipeline</td>
</tr>
<tr>
<td>STR</td>
<td>String</td>
</tr>
<tr>
<td>SHA</td>
<td>Shore Approach</td>
</tr>
<tr>
<td>SCH</td>
<td>Suction Chamber</td>
</tr>
<tr>
<td>FIJ</td>
<td>Field Joints</td>
</tr>
<tr>
<td>BFL</td>
<td>Blind Flange</td>
</tr>
<tr>
<td>SFL</td>
<td>Swivel Flange</td>
</tr>
<tr>
<td>FFL</td>
<td>Fixed Flange</td>
</tr>
</tbody>
</table>

| A | Exposed area |
| C<sub>f</sub> | Skin-friction drag coefficient |
| d | Water depth |
| H | Wave length |
| k | Wave number |
| L | Length of object |
| L<sub>l</sub> | Wave length in deep water |
| Re | Reynolds number |
| T | Wave period |
| Z | Particle depth |
| ε | Roughness |

**References**


[7]. I.R. of Iran Meteorological Organization, Bandar Abbas Synoptic Station, 2008.


Appendix A.

A.1 Towing Force

Towing force was calculated based on fluid mechanics fundamentals [14]. It should be mentioned that towing process was scheduled and carried out based on calm sea state (sea state code No. 1 that is calm-rippled, wave height<0.1 m and also current speed<0.3 m/s).

According to the towing procedure, there were two critical conditions that towing force was separately calculated in these situations that here the worst case was just examined. Of course, the calculations were done based on the worst case which might occur never. In these conditions, it was supposed the velocity of current and wave and wind were in the same direction simultaneously and opposite of tug boat speed vector and it was also considered the velocities were normal to the string direction.

Table A.1. The velocities used for the calculations of the towing forces

<table>
<thead>
<tr>
<th>Current</th>
<th>Wave</th>
<th>Wind</th>
<th>Tug Boat</th>
</tr>
</thead>
<tbody>
<tr>
<td>Velocity(m/s)</td>
<td>0.3</td>
<td>0.32</td>
<td>11</td>
</tr>
</tbody>
</table>

In this condition, the drag forces on pipeline and manholes due to wave & current and also wind and frictional forces were applied to the string.

Frictional forces were calculated as below:

\[ \text{if } \varepsilon \geq L \left( \frac{100}{R_e} \right) \Rightarrow \text{Turbulent Case} \]

It was considered that \( \varepsilon \approx 0.0015 \text{mm} \approx 0.046 \text{ ft} \) [14]. Therefore:

\[
\begin{align*}
\text{Re}_{\text{Wave-Current-Tug Speed}} &\approx 1.05 \times 10^6 \Rightarrow \varepsilon = 0.046 \geq 1.87 \times 10^{-4} \text{ ft} \\
\text{Re}_{\text{Wind-Tug Speed}} &\approx 0.4 \times 10^6 \Rightarrow \varepsilon = 0.0098 \geq 4.92 \times 10^{-4} \text{ ft}
\end{align*}
\]

\[ \Rightarrow \text{Turbulent flow} \]

\[ C_f = \left( 1.89 + 1.62 \log \left( \frac{L}{\varepsilon} \right) \right)^{2.5} \approx 3.7 \times 10^{-3} \]

\[ F_{\text{friction}} = \frac{1}{2} C_f \rho AU^2 = \text{Skin-friction drag force (N)} \]

Where \( A \) and \( U \) are exposed area and algebraic summation of all relevant velocities, respectively.

Figure A.1. String direction was is in N.W in shifting procedure to the final route
Exposed Area for wave-current and wind effect are calculated as follows:

\[ \theta = 2.28 \text{ Rad} \Rightarrow \begin{cases} \text{I} = R \times \theta = \text{Wet Circumference Length} = 1.372 \times 2.28 = 3.128 \text{m} \\ \text{I} = R \times \theta = \text{Circumference Length Exposed to Wind} = (D_0 \pi) - 3.128 = (2.744 \times \pi) - 3.128 = 5.49 \text{m} \end{cases} \]

\[ \rightarrow \begin{cases} \text{Wet Exposed Area} = 3.128 \times 600 = 1877 \text{ m}^2 \\ \text{Wind Exposed Area} = 5.49 \times 600 = 3294 \text{ m}^2 \end{cases} \]

Therefore

\[ F_{\text{Wave-Current-Tugboat}} = \frac{1}{2} \times 3.7 \times 10^{-3} \times 1032 \times 1877 \times (1 + 0.64)^2 = 9.6 \text{ kN} \]

\[ F_{\text{Wind-Tugboat}} = \frac{1}{2} \times 3.7 \times 10^{-3} \times 1.25 \times 3294 \times (1 + 11)^2 = 1.1 \text{ kN} \]

Furthermore, the drag forces were calculated as the following:

\[ F_{\text{Wave-Current-Tugboat-Pipeline}} = \frac{1}{2} \times 0.6 \times 1032 \times (1 \times 600) \times (1 + 0.64)^2 = 500 \text{ kN} \]

\[ F_{\text{Wind-Tugboat-Pipeline}} = \frac{1}{2} \times 0.6 \times 1.25 \times (1.744 \times 600) \times (1 + 11)^2 = 56 \text{ kN} \]

According to length, diameter, exposed area and shape coefficient of each manhole, the net force stemmed from exposure to wind for all manholes were simply calculated as 4.1 kN.

Hence the total applied load was:

\[ F_{\text{total}} = 9.6 + 1.1 + 500 + 56 + 4.1 = 570.8 \text{ kN} \approx 58 \text{ ton} \]

This force was resisted by 3 tug boats and 4-6 towing pad eyes. Therefore the lateral towing force on each pad eye was 10-15 tons.

A.2. Wave Velocity

\[ u = \frac{\pi H}{T} \left[ \frac{\text{Cosh}(d + z)}{\text{Sinh} kd} \right] \text{Cos}(kx - \sigma t) \]

For calculating the maximum wave velocity, it was assumed that \( \text{Cos}(kx - \sigma t) = 1 \)

\[ \frac{d}{L} = 0.355 \Rightarrow \text{intermediate water depth} \Rightarrow L = \frac{g T^2}{2 \pi} \tanh\left(\frac{2 \pi d}{L}\right) = 13.76 \text{ m} \]

\[ u = \frac{\pi \times 0.3}{3} \left[ \frac{\text{Cosh} 0.456 (5 - 0)}{\text{Sinh} (0.456 \times 5)} \right] = 0.32 \text{ m/s} \]