CASE STUDY

Labuan Pipeline Installation Engineering

By: Leighton Contractors (M) Sdn Bhd, ZEE Engineering Sdn Bhd

Abstract *: Labuan pipeline was installed to supply water from the mainland to Labuan Island. The pipe diameter is 26 inch, with an approximate length of 23 km. The line is designed with a wall thickness of 9.5 mm. The material grade is API-5L-X52, and for stability a concrete coating thickness of 125 mm and 75 mm was required. This thin walled heavily coated pipeline was a challenge for offshore installation. In fact the first contractor had to abandon the job due to the line buckling at each joint.*
This paper presents a case study of the pipeline installation engineering procedures carried out. The determination of the effective stiffness of the composite section was the critical issue. Model testing, computer simulations and empherical methods were used to compare various values of effective stiffness. At the installation stage Computer results were compared with field data

Key words : Effective Stiffness, Composite Section, Model Testing, Tensioner Optimization

1.0 BACKGROUND

Kencana Leighton Joint Venture (KLJV) was awarded the contract for the installation of the submarine pipeline from the mainland Sabah to Labuan Island to transport water. The submarine pipeline is 26 inches in diameter with an approx. length of 23.0km. The owner of this project is Kementerian Tenaga Teknologi Hijau dan Air (COMPANY). The consultant for the COMPANY was SMHB Sdn. Bhd. (CONSULTANT).

ZEE Engineering Sdn. Bhd. (ZEE) was appointed by KLJV to carry out residual engineering for the installation of the pipeline. This project had been earlier awarded to another contractor who had abandoned the work. It was revealed that during the earlier installation the pipeline had buckled almost at every joint.

As the supply of water to Labuan Island was critical the COMPANY headed by the Minister was greatly concerned, and together with the CONSULTANT kept a very close watch on the progress of the project. Due to the impending arrival of the monsoon season the urgency to complete the offshore segment of work was vital.

2.0 OBJECTIVE OF PAPER

This paper summarizes the pipeline analysis carried out. It describes the problems faced and the actions taken to mitigate these risks. It also compares analytical results with actual field data

3.0 SUMMARY AND CONCLUSSIONS

The pipeline was large diameter, but thin walled with a very heavy reinforced weight coating. Though the pipeline section was adequate for the service condition it posed a challenge for offshore installation.

The critical issue was the realistic determination of the effective stiffness of the composite pipeline. Two scenarios were considered. The first being the full stiffness of the composite section which gave a value of approximately 400% of that of the bare pipe, and the method proposed by the ASME paper 71-Pet-26 " Effective Stiffness of Concrete Coated Line Pipe" gave an approximate value of 148 % of the bare pipe.

To resolve this issue a model test was carried out as outlined in the ASME paper. The test was carried to the point where the pipeline buckled. From the test results, which was independently verified by computer simulations, It was decided to adopt an effective stiffness of 145% which was very close to the ASME value.

Two analyses were carried out considering the effective stiffness of the line as follows;

1. Uniform effective stiffness of 145% of the bare pipe, with each line pipe divided in two finite elements.
2. Varying Effective stiffness along a line pipe as recommended by the ASME paper. This resulted in a line pipe being divided into a number of elements for each varying stiffness segment.

The results of these analyses showed that for the first case the stress distribution was smooth, but for the second case the stress distribution was staggered at the stiffness variation points and peaked at the field joint section. The second case gave a significant lower stress distribution than the first case. The computer process time for the second case was very significantly greater than the first case. Considering the strict engineering schedule it was decided to adopt the methodology of the first case for the complete installation engineering. This was a conservative assumption.

Detailed analysis showed that buoyancy tanks were required to maintain the pipeline system during installation. As the system stresses were sensitive the derating of the air bags for water depths was taken into consideration. During installation field measurements were taken and compared with computer simulation values and the differences were found to be acceptable.

4.0 PIPELINE STIFFNESS

4.1 Pipeline Effective Stiffness

It seems that the pipeline had been designed without due consideration for lay ability. The pipeline is 660mm OD with wall thickness of 9.5mm. The steel grade used for the pipeline is API 5L X52. For on-bottom stability considerations concrete coating thickness of 125mm and 75mm thickness with density of 2.4MT/m^3 had been adopted. The concrete coating had been reinforced with a steel cage comprising of 32 no 8mm diameter radial rods tied with 8mm diameter rings at every 80mm. For cross sectional detail refer to Figure 4.1.

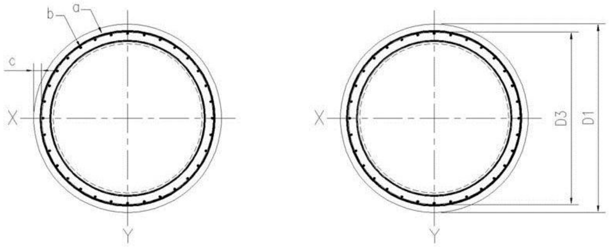


Figure 4.1 Cross Sectional Detail

Notes:

a (Bar 'a' Diameter (Circumferential Bar)) = 8.00mm (every 80mm)
b (Bar 'b' Diameter (Longitudinal Bar)) = 8.00mm (32 nos.)
c (Nominal Cladding Thickness) = 45.00mm
D1 (Outer Diameter Concrete) = 922.40mm
D3 (Circumferential Diameter of 'b' Bars) = 808.40mm

The concrete had been cast in a mould and compacted. It was seen that the smooth concrete surface when wet would cause the pipeline to slip at the tensioner. To overcome the slippage the pipelines were sand blasted.

Due to the earlier experience of the pipeline buckling at each field joint the CONSULTANTS were of the opinion that the full composite stiffness must be considered for pipe lay analysis. ZEE disagreed and proposed that the equivalent stiffness of the pipeline should be calculated as per the guidelines set in ASME paper 71-Pet-26, “Effective Stiffness of Concrete Coated Line Pipe”. The resulting stiffness calculations from these two options are summarized in table 4.1

Source	Stiffness Value (mm^4)	% of Bare Pipe
Bare Pipe	1.029E+09	100.000
Full Composite Section	4.318E+09	419.631
ASME Paper	1.520E+09	147.716

Table 4.1 Resulting Stiffness

4.2 Model Test For Pipeline Effective Stiffness

As there was a large discrepancy for the recommended pipeline effective stiffness value between the CONSULTANT and ZEE, It was decided to carry out a full scale model test to arrive at an acceptable stiffness value for computer modeling. Computer simulation was also carried out to verify the model test results.

4.2.1 Model Test

Two pipeline joints with 125mm concrete coating was field welded to be used as the model for testing. The test model was set up similar to the one adopted in the ASME paper. Refer to Fig. 4.2 for the testing rig arrangement. The test results showed the pipeline had an initial stiffness of 2.074E+09 mm^4 which was purely due to self-weight. As the load increased the pipeline started to bend thereby gradually de-bonding the reinforcing bars and the cracking the concrete. This would result in a gradual decrease of stiffness till the pipeline buckled. At collapse the effective stiffness was very close to that of the bare pipe.

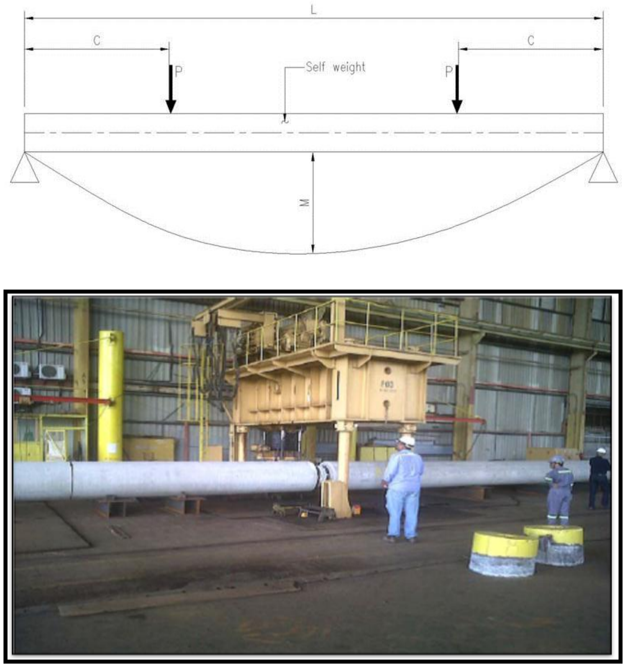


Figure 4.2 Model Test Rig Arrangements

4.2.2 Computer Simulation

Computer simulation of the model test was carried out to compare results obtained from physical testing. Refer to Fig 4.3 for computer model sketch. Same pipeline properties, boundary conditions and loading increments used in the model testing were adopted for the computer simulation.

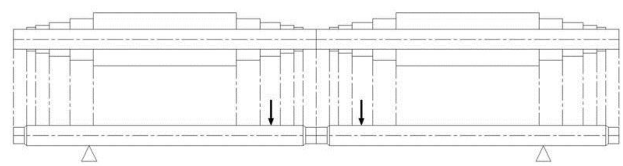
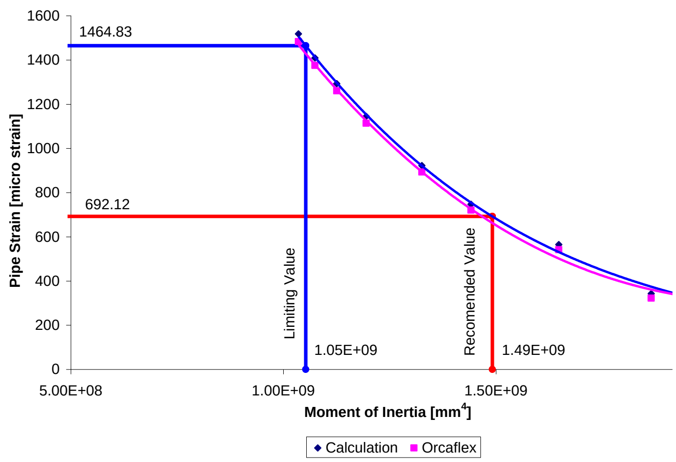


Figure 4.3 Computer Model for Stiffness Evaluation

4.2.3 Comparison of Stiffness Result

Comparison of results of pipeline stiffness from model test to computer simulations were made and summarized in Strain vs. Stiffness Graph as shown in Fig 4.4.

Figure 4.4 Graph Comparisons of Results



From the strain stiffness graph it is seen that the model test and computer simulation values are very close.

4.2.4 Pipe Stiffness Adopted

The criteria set for pipe lay is 85% of SMYS, which gives a value of 304MPa. The corresponding value of micro strain is 1464.83. From model test results the related pipeline stiffness value for limiting installation stress is 1.05E+09mm^4.
This stiffness is approximately equal to 200% of the bare pipe value. At this stage the pipeline bending radius is minimal. It was decided to adopt an effective stiffness at the maximum bending range, which is 145% of the bare pipe value. This is a conservative estimate as the corresponding stress in the pipeline for this stiffness is 143.27 MPa and corresponds to the value from ASME paper.

5.0 ANALYSIS METHODOLOGY

5.1 Selected Computer Program

Due to the critical, and the sensitivity of the lay conditions of the line, ZEE carried out a number of analyses using currently available industry- approved software programs. At the conclusion of this study it was decided to adopt OrcaFlex software package for the project. The reasons for this are as follows;

- Capability to carry out state of the art fully integrated coupled dynamic analysis,
- Option for carrying out irregular wave dynamics,
- Capability to model pipeline segmental physical properties, and unlimited number of elements for Finite Element analysis,
- Accurate calculation of the roller reactions. This is based on line clashing forces due to the dynamic behavior of the pipeline which simulates the impact forces on the rollers.
- The capability to model the physical conditions of the rollers,
- Ability to model the depreciation of buoyancy in air bags for external pressure related to water depth.
- Interactive graphical input of data which is less prone to errors,
- Graphical presentation output

5.2 Computer Model for Preliminary Analysis

For preliminary analysis 2 computer models were adopted as shown in Table 5.1

Analysis	F.E Model	Weight Coating (% of Bare Pipe)	Stiffness Source
Simulation 1	Standard	145.0 uniform	Model Test
Simulation 2	Detailed	148.0 variable	ASME Paper

Table 5.1 Analysis Case

Pipelay barge (PLB) Leighton Stealth was nominated for the project. Detail modeling was carried out for the physical characteristics of the LB which included RAO's, QTF, and Damping.

The pipeline was modeled as a standard OrcaFlex line element (homogeneous pipe), the air bags were modeled as clump buoy attachments. The de-rating of buoyancy due to external water pressure with depth was considered. The stinger and deck rollers were modeled as line elements with clashing behavior.

Two simulations were carried out adopting Standard and Detailed Finite Element (FE) models. For both cases the bare pipeline physical and steel properties of concrete coating was modeled with the physical properties of concrete for weight and buoyancy considerations. In the standard FE model the composite stiffness was overridden by inputting a specific uniform stiffness value of 145.0 % of bare pipe. In the case of the detailed analysis to simulate a varying stiffness along the line as recommended in the ASME paper a number of elements with varying stiffness values were adopted.

Refer to Fig 5.1 for details of standard and detailed Finite Elements to Fig 5.1 and Fig 5.2 respectively.

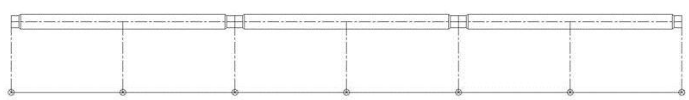


Figure 5.1 Standard FE Model

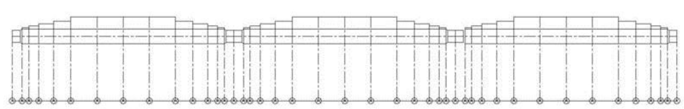


Figure 5.2 Detailed FE Model

5.3 Preliminary Analysis Result

To compare the response of the 2 models preliminary analyses were carried out with full dynamic simulation. For both the analyses the tensioner was set at 750.0kN and the wave heading at 0.0 deg was applied. Maximum water depth of 24.14m was adopted. The results for preliminary analysis are shown in Table 5.2. The related stress plots are shown in Fig 5.3 and Fig 5.4.

Analysis	Max OB Stress (MPa)	Max SB stress (MPa)	Touch down Point (m)
Standard	695.4	453.2	238.5
Detailed	412.0	399.6	172.5

Table 5.2 Result of Preliminary Analysis

(Pipelay without buoyancy)

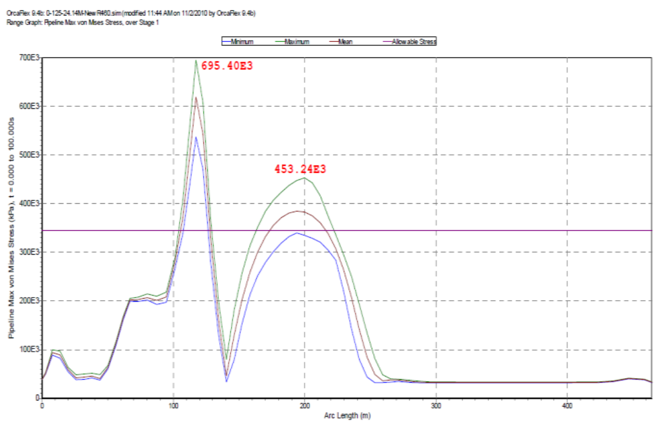


Figure 5.3 Stress Plot Standard Simulation

(Pipelay without buoyancy)

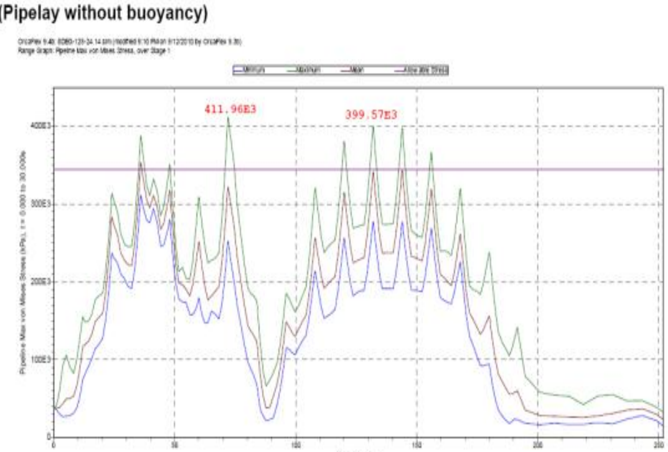


Figure 5.4 Stress Plot Detailed Simulation

The results show that the detailed simulation with varying pipeline stiffness gave the least stress in the pipeline system spiking up at the field joint locations. This is realistic as the field joints had the minimum stiffness which is equivalent to that of the bare pipe. The standard simulation produced a smoother stress curve due to the uniform stiffness adopted.

To process standard simulation took 21/2 hours of computer real time, whilst the detailed analysis took over 14 hours. Due to the time constraint in the project it was decided to adopt standard simulation computer model which gave conservative results.

6.0 ANALYSIS

Standard Pipe Lay analysis was carried out along the pipeline route taking into consideration the water depth and varying concrete coat thickness. As shown in preliminary analysis it was seen that buoyancy bags were required to minimize the system stress. Attaching and dismantling buoyancy bags take time. Hence an optimization in buoyancy bag attachment was carried out resulting in different arrangements of buoyancy bags for different depths and weigh coating. The deflation in buoyancy bags relative to water depth were taken into consideration. The buoyancy bag deflation rate per water depth was obtained from the manufacturer. For analysis the stinger and deck roller configuration was optimized, followed by startup, Lay and termination studies. Contingency and emergency repair methods, for each significant water depth was also considered.

6.1 Tensioner Optimization

Tensioner optimization was carried out considering composite moment of inertia determined for 125mm concrete coated pipeline from model testing which is 145.0% the bare pipe. Based on tensioner optimization study, it was concluded that the stinger radius of 460m should be applied to all water depths along the pipeline route.

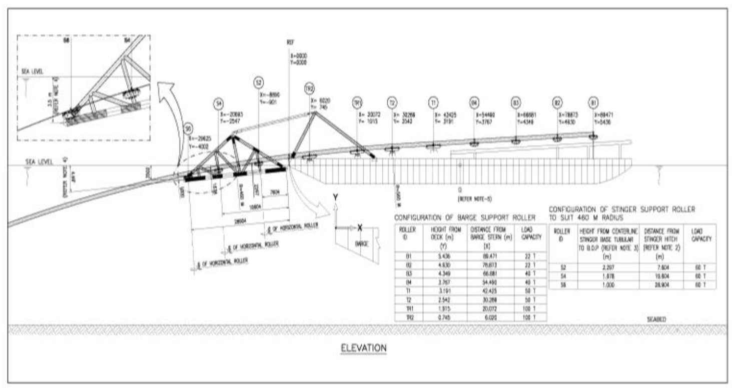


Figure 6.1 Recommended Stinger / Deck Roller Configuration

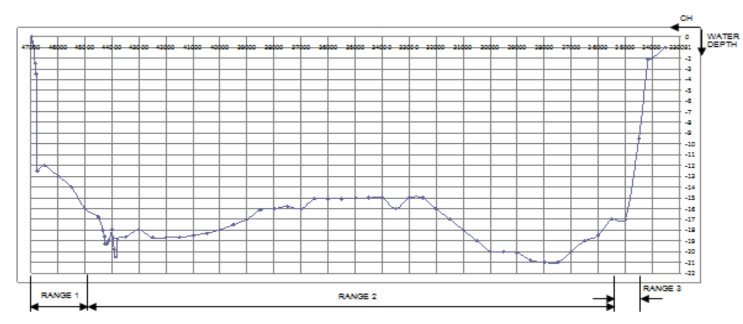


Figure 6.2 Pipeline Length Range for Tensioner Setting

Based on the water depth profile as shown in Figure 6.2, it was found that approx. 88% of the total pipeline length falls in water depths of more than 16m w.r.t CD (19.52km). Hence, three (3) pipeline water depth ranges have been considered for tensioner setting as described in Table 6.1 and figure 6.2.

CH Range	Concrete Coating Thickness (mm)	Water Depth LAT (m)	Max. Water Depth HAT (m)
46.98 – 44.88 (2.1 km)	75 125	16.00	18.64
44.88 – 25.36 (19.52 km)	125	21.50	24.14
25.36 – 24.76 (0.6 km)	75 125	13.36	18.64*

Table 6.1 Pipeline range for Tensioner Setting

6.2 Pipelay Analysis

Considering Figure 6.2 and Table 6.1, the following analysis cases were considered for normal lay operations as shown in Table 6.2.

Analyses Case	Concrete Coating Thickness (mm)	Maximum Analyzed Water Depth (m)	Remarks
Case 1	75	18.64	The result will be applicable for start up operation and normal lay operation from CH 46.78 to CH 44.88 36 (also from CH 25.36 to CH 24.76 when the 75mm concrete coating pipe is used).
Case 2	125	18.64	The result will be applicable for normal lay operation from CH 46.78 to CH 44.88 also from CH 25.36 to CH 24.76 when the 125mm concrete coating pipe is used.
Case 3	125	24.14	The result will be applicable for normal lay operation from CH 44.88 to CH 25.36.

Table 6.2 Normal Lay Analysis Cases

The analysis showed that Air Bags were required to keep the stress at acceptable values for limiting Lay Barge Allowable Maximum tension. The analysis results are summarized in Table 6.3.

CASE	STRESS (% of SMYS)				AIRBAG ARRANGEMENT
	STATIC		DYNAMIC		
	OB	SB	OB	SB	
1	55	44	61	62	TYPE 1
2	62	57	67	89	TYPE 2
3	59	57	80	84	TYPE 3

OB = Overbend
SB = Sagbend

Table 6.3 Summary Results

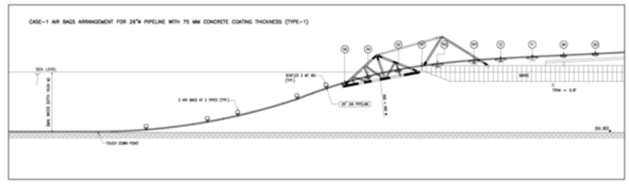


Figure 6.3 Airbag Arrangements for Type 1 for Case 1 (75mm Concrete Coating)

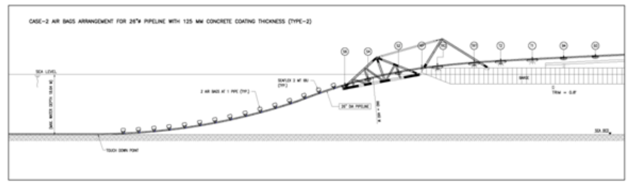


Figure 6.4 Airbag Arrangements for Type 2 for Case 2 (125mm Concrete Coating) for 18.64m Maximum Water Depth

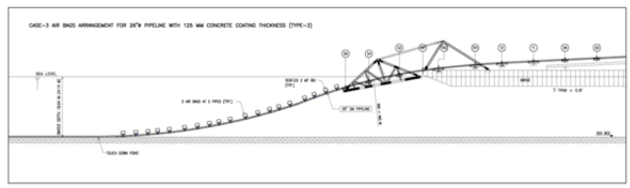


Figure 6.5 Airbag Arrangements for Type 3 for Case 3 (125mm Concrete Coating) for 18.64m to 24.14m Water Depth

6.3 Comparison Between Analytical Results and Field Data

Comparison between analytical results and field data are shown in Table 6.4.

Kp	Water depth (m)		Touch Down (m)		Tensioner (MT)		Stress (% of SMYS)	
	A	F	A	F	A	F	OB	SB
46	18.64	15.6	188.7	194	60	55	61	62
45	18.64	17.7	188.7	230	60	65	67	89
44	24.14	19.2	177.5 - 207	191	80	78	77	84
43	24.14	20.2	177.5 - 207	183	80	80	77	84
42	24.14	20.6	177.5 - 207	187	80	80	77	84
41	24.14	20.4	177.5 - 207	176	80	80	77	84
40	24.14	20.2	177.5 - 207	183.7	80	80	77	84
39	24.14	18.2	177.5 - 207	187	80	80	77	84
38	24.14	18.5	177.5 - 207	176	80	75	77	84
37	24.14	17.9	177.5 - 207	181.2	80	75	77	84
36	24.14	17.3	177.5 - 207	205	80	77	77	84

A=Analysis F=Field Measurement OB=Overbend SB=Sagbend

Table 6.3 Comparison between analytical results and field data

The analytical and measured touches down values are seen to be close. The differences can be mitigated as follows

1. In the computer model the water depth is taken as the highest tidal level plus half the "installation" wave height. Whilst at location it is the actual measured value which may not capture the design "installation" wave height and the maximum tide
2. In dynamic analysis two touch down values are given. Further in a dynamic simulation the Lay Barge motion due to the worst environmental action such as non linear wave trains are taken into consideration, whilst during actual operations the effects of such action may be reduced.
3. The air bag deflation (loss of buoyancy) as modeled may not be correct
4. For computer analysis a range of water depths were taken for a single Tensioner setting. In field the values were measured for a range of actual water depths.
5. For analysis the wave and the current attack directions were considered for 0, 45, 90, 135 and 180 Deg directions. During installation these directions were not recorded, hence there will be a variation on actual results

ACKNOWLEDGMENTS

The success of the project was mainly due to the project team who acted very closely and in a professional manner

The Project team was made up as follows;

1. Kementerian Tenaga, Teknologi Hijau dan Air
   a. Ir. Dr. Hasnul bin Mohamad Salleh (Ketua Pengarah, Jabatan Bekalan Air)
2. SMHB Sdn Bhd
   a. Datuk Ir. Teo Chok Boo (Managing Director)
   b. Ang Eng Kiat (Principle Engineer)
3. Kencana HL Sdn Bhd (Project Management Team)
   a. Christopher Ow
   b. Shahrul Izam
4. Leighton Contractors (M) Sdn Bhd
   a. Peter Furness (Regional Engineering Manager)
   b. Edgar Rahmani (Project Manager)
   c. Jaiprakash Gangadharan (Engineering Manager)
   d. Phil Reid (Construction Manager)
   e. Matthew Haronga (Barge Superintendent)
5. Zee Engineering Sdn Bhd
   a. Herman Perera (Engineering Supervisor)
   b. Yuly Setiawan (Engineering Coordinator)
   c. Syed Muslim (Project Engineer)
   d. Cecep Hendra (Lead Engineer)
   e. Pipeline Engineers
      1. Agus Budiono
      2. Fahmi Ariffin
      3. Fajar Rachmardianto
      4. Akmad Rafiudin

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