Buoyancy Control – Calculated Cost Allowance for 1 Year Study Cost Estimate

Prepared for

Millennium Project

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Executive Summary

This Study addresses the assumptions and cost of buoyancy control for the Millennium Project pipeline sections. A closed pipe of the size and weight that will be utilized in this system has a potential to float relative to the weight of the material in which it is buried. This potential must be mitigated by the addition of weight attached to the pipe or by some other mechanical means of holding the pipe in place such as concrete coating, set-on weights or screw anchors.

Based on discussions with the WEI Project Team assigned to the Millennium project, this study addresses and quantifies only two types of buoyancy control at this time, continuous concrete coating and set-on concrete weights. Though screw anchors may be used successfully in some areas it will not be known until soil samples are taken.

The total length of the pipeline that will require buoyancy control are based on the "*Millennium Pipeline Project Specific Construction Alignment Sheet Notes, Revised 10/31/03, Table W: Wetlands*" and is estimated to be 137,133 feet[1].

It is expected that densities of the soil along the route expressed as specific gravity will fall roughly into three categories:

- 1.15 for small streams and non-turbulent bodies of water
- 1.20 for marshes and wetlands, and
- 1.25 for erodible streams and major rivers

For the purposes of this Study, a specific gravity of 1.20 has been selected and used for calculating the amounts of continuous concrete coating as well as the spacing requirements for set-on weights. These densities should be confirmed by a field geotechnical study. Adjustments in concrete coating thickness and set-on weight spacing can be made at that time.

The amount of concrete required is expressed in two ways, thickness in inches of 165 pound per cubic foot continuous coating and pounds per foot for set-on weight spacing. The continuous concrete coating requirement has been calculated at 3.5" and 232 pounds per foot for set-on weights, based on pipe weight and assumed soil density.

Table 1 in Appendix A quantifies the continuous concrete thickness and set-on weight and spacing for the pipe to be used in this system based on the assumed specific gravity. Tables 2 and 3 in Appendix B contain the detailed calculations for the buoyancy control data, including thickness of concrete coating and size and spacing of set-on weights that are fed into Table 1.

The total recommended cost allowance to be included into the 1 Year Cost Study is $3,057,000. Details of this cost basis are contained in Table 1 of Appendix A.

[1] Includes a 10% allowance for field environmental additions/modifications

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1.0 Introduction

An empty closed steel pipe of the diameter and wall thickness proposed for this system will float in water and has the potential to float in the soil in which the pipe will be buried if it is saturated with water.

Some of the areas that the Millennium pipeline system traverses will require some method of buoyancy control across rivers, streams and wetlands.

The amounts are based on the "*Millennium Pipeline Project Specific Construction Alignment Sheet Notes, Revised 10/31/03, Table W: Wetlands*" and is estimated to be 137,133 feet, which includes a ten percent (10%) addition to the amounts in order to account for field environmental additions/modifications.

There are several commonly accepted methods to circumvent pipe buoyancy including continuous concrete coating, set-on and bolt-on concrete weights and screw anchors. The three primary methods, continuous concrete coating, set-on and bolt-on weights are described below.

1.1. Continuous Concrete Coating

Continuous concrete coating is generally specified at river / creek crossings and/or wetland areas. Concrete coating is preferred over set-on or bolt-on weights at most water crossings because it is a very effective method of buoyancy control and it has the added advantage of providing physical protection to the pipeline. There are many different types of concrete coating and they are typically reinforced with steel, fiberglass or other material. Some coatings are wrapped on; some are sprayed onto the pipe, while others are installed using formwork and conventional concrete pouring techniques.

1.2. Set-on Weights

Set-on weights are generally used in wetland areas, river floodplains and at minor water crossings where sidebooms can easily install the weights. The weights are placed over the pipeline after it is been lowered into the trench and prior to the backfilling. If the ditch cannot be pumped dry, the pipe can be filled with water to allow it to sink prior to placing the weights. This, however, can only safely be done where the water and ditch is shallow and where the ditch has a stable bottom and side walls. If the possibility exists for pipe exposure due to erosion of the overburden, the use of saddle weights is not recommended since the saddle weight requires side wall support to be held over the pipe. Similarly, where pipe movement could occur in soil that does not posses enough shear strength; the saddle may rotate on the pipe and be rendered ineffective.

1.3. Bolt-on Weights

Where set-on weights cannot be installed and concrete coating is not warranted, bolt-on weights can be used. These weights are constructed in two halves which bolt together in the field prior to placing the pipe in the ditch. Since the weights are physically secured to the pipe, these may be used when the trench is filled with water.

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1.4. Coating Method Selected for Study

Continuous concrete coating and set-on concrete weights are the most common mitigation methods and are quantified by this Study per the request of the WEI Project Team.

The amount of weight required is based on adjusting the total pipe weight to neutral buoyancy such that it will not float in areas of potential buoyancy.

The recommended minimum values of the ratio of total pipe weight to buoyant force for various pipeline environments are as follows:

Small Streams and Non-turbulent Bodies of Water	Marsh and Wetlands	Erodible Streams and Major Rivers
1.15	1.20	1.25

These values should be modified for conditions where the subsurface environment has the potential for liquefaction or is subject to changing buoyant forces. Examples are laying in super-saturated salt water where densities may be as high as 80 pcf or saturated mud-slurry, which may have a density as high as 90 pcf.

For the purposes of this Study, an assumption of the specific gravities of the soil (1.20) at the crossing locations along the system has been made. These assumptions may be modified at a later time based on actual field geotechnical investigation.

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2.0 Scope of Work

The scope of work is to quantify the amount and type of buoyancy control that will be required to hold the pipeline in place in areas of varying buoyancy potential and to calculate a recommended cost allowance to be included into the 1 Year Construction Cost Estimate.

The deliverables to be provided are:

- Calculation of thickness of continuous concrete coating, based on the stated assumptions
- Calculation of required weight per foot of pipe for set-on weights, based on the stated assumptions
- Estimate of the amount of each type of buoyancy control based on available data and assumptions made
- Cost estimate to provide an initial allowance into the 1 year construction study, based on the stated assumptions

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3.0 Basis of Study

All calculations are based on the project Design Basis, 51353-114, Rev A. For consistency, it has been assumed that all locations needing buoyancy control will be Class II locations, i.e. 30" OD x 0.429" wt API 5L X70.

3.1. Coating Thickness Calculation Overview

To determine the required thickness of concrete weight coating required to ensure negative buoyancy along a pipeline, the following calculation procedures shall be applied:

Symbols

A_p = Cross sectional area of the pipe (ft^2)

A_c = Cross sectional area of the concrete coating (ft^2)

A_t = $A_{p+}A_c$ (ft^2)

B = Buoyant force per unit length of pipe (lb/ft^2)

t_c = Concrete thickness (ft)

R_w = Density of submergence medium (lb/ft^3)

R_c = Density of concrete (lb/ft^3)

D = Outside diameter of the pipe (ft)

W_p = Weight of the pipe (lb/ft)

W = Total weight of pipe and concrete coating (lb/ft)

f = Negative buoyancy intensification factor

Buoyancy

B = At Rw = 0.785 Rw (D + 2 tc)2

At = 0.785 (D + 2 tc)2

Ap = 0.785 D2

Ac = $0.785\ [(D + 2\ tc)^2 - D^2]$

The total weight of the pipeline must be greater than the upward acting buoyant force.

W = Wp + Rc Ac = Wp + 0.785 [(D + 2 tc)2 - D2] = fB

Wp = $0.785\ R_c\ [(D + 2\ t_c)^2 - D^2] = 0.785\ fR_w\ (D + 2\ t_c)^2$

Solving for tc yields:

$t_c = 0.5\ [(1.273\ W_p - R_c\ D^2) / (fR_w - R_c)]^{0.5} - D/2$

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To check the concrete coating thickness, substitute t_c into the equations for B and W. Those values differ by the factor f. It should be compared with the values given above for adequacy.

This calculation method neglects the weight affect of water absorbed by the concrete coating after submergence, usually about 5 percent by weight, which will add to the negative buoyancy. It also neglects the effect of overburden deadload due to backfill. Additionally, the calculation does not include the weight of the anti-corrosion coating, which further increases the negative buoyancy.

Conversely, since the analysis is based on unit length of pipe, coating cutback, which is normally about 12 inches on each end of the pipe joint, is not considered. This will increase the buoyant force of the total pipe joint, unless a field joint filler of the same unit weight as the concrete coating is applied. Additionally, the anti-corrosion coating thickness marginally increases the effective diameter of the pipeline, which further increases the upward acting buoyant force due to increased displacement. This effect varies from a maximum of about 4 percent for small lines (e.g., 8-inch) coated with conventional wrap coatings to nil for large lines coated with FBE.

3.2. Discussion of Historical Costs

Historic costs for set-on weights and continuous concrete coating for 42" pipe were used and pro-rated to 30" based on the following methodology:

- Set-on weights – 42" were calculated for weight and then compared to the cost per unit, the same cost per unit was applied to the 30" weight. The historic cost for supply-only of the 42" weight was $430. The 30" weight is approximately ½ the size (based on weight) of the 42", hence $215 per unit was used for the 30" weight.

- Coating – a spreadsheet for calculating the cost of concrete coating was used: 1) labor, material, and equipment costs were plugged in to "force" the 42" supply-only coating cost ($80 per foot); 2) the same parameters were used and the figures for 30" were plugged in and it arrived at a cost of $38.55 per foot.

As weight coating is normally a sub-contracted activity, the costs above are inclusive of the sub-contractor contingency and profit, 10% and 15% respectively, but does not include any additional mark up from the prime contractor.

It has been assumed that 165 lbs/cubic foot concrete will be utilized for buoyancy control.

It has also been assumed that all labor and equipment to apply or construct the buoyancy control methods will be done on-site, i.e. no transportation costs have been included. Further, it is assumed that all required labor and equipment to install the pipeline is considered elsewhere, hence, the recommended allowance costs stated in this Study are for the application of buoyancy control only.

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Lastly, it has been discussed and agreed to utilize the field take off footages for wetlands/streams and increase these by 10% to allow for field environmental additions/adjustments. The incremental footage is included in the "*Total footage requiring buoyancy control*" row in Table 1 in Appendix A.

The historic costs used, as well as the costs calculated, have been reviewed and given a "sanity check" by other subject matter experts within the WEI organization and have also been compared against the recent quotes for the 30" Bibiyana Project.

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4.0 Discussion of Results

Based on discussions with the WEI Project Team assigned to the Millennium project, it is recommended to use continuous concrete coating at streams and river crossings and concrete set-on weights in any area where the pipe and set-on weights can be installed in a dry ditch that will later be subject to buoyancy problems.

It was suggested by the WEI Project Team to use the factors of 50% for each type of buoyancy control, i.e. 50% of the total required footage will be assumed to be continuous concrete coating and 50% will assume to receive set-on weights.

For areas where the pipe must be installed into a wet ditch continuous concrete coating will have to be used.

Table 1 in Appendix A contains information quantifying the thickness of concrete required for continuous concrete coating and spacing and weight for concrete set-on weights.

Based on the assumptions used in this Study and historical pricing of buoyancy control, the total estimated cost for a buoyancy control cost allowance in the cost estimate is $3,057,000 (shown in Table 1).

The detailed calculations used to arrive at the thickness of continuous concrete coating as well as the weight and spacing requirements for set-on weights is found in Tables 2 and 3 of Appendix B.

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Appendix A – Supporting Study Data

Table 1 – Calculation Inputs & Cost Results

30" X70 x 0.429" wt		
D	Outside diameter of pipe, in.	30
t	Wall thickness of pipe, in	0.429
t_1	Thickness of concrete coating, in	3.50
W	Lbs per foot for set-on weight	232
W_1	Weight of concrete, lb/ft3	165
W_2	Weight of each set-on weight, lbs	15,150
W_3	Weight of fresh water, lb/ft3	62.4
S	Specific gravity of mud, lb/ft3	1.20
W_4	Weight of mud, ft3/ft	74.88
CL	Spacing centers for set-on weights, ft	35.65
	Total footage requiring buoyancy control, ft	137,133[2]
	Total footage requiring concrete coating, ft	68,566
	Total footage requiring set-on weights, ft	68,566
	Cost per foot for concrete coating, $	$38.55
	Total cost for concrete coating, $	$2,643,231
	Cost per each set-on weight, $	$215.00
	Total cost for set-on weights, $	$413,513
	Total allowance for buoyancy control, $	**$3,056,744**

[2] Based on "*Millennium Pipeline Project Specific Construction Alignment Sheet Notes, Revised 10/31/03, Table W: Wetlands*" plus a 10% addition for field environmental additions/modifications.

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Appendix B – Calculations

Table 2 – Continuous Concrete Coating Calculations

CONTINUOUS CONCRETE COATING

SIZE OF PIPE: 30.000 " O.D. 0.429 " W.T. FLUID S.G.: 1.20

1. Wt. of one cubic foot of concrete	165.00	lbs/cu ft		
2. Wt. of one cubic foot of displaced fluid	74.88	lbs/cu ft		
3. Submerged wt. of one cubic foot of concrete	90.12	lbs/cu ft		
4. Volume displaced by one foot of bare pipe	4.91	cu ft		
5. Wt. of fluid diplaced by one foot pipe			367.38	lbs
6. Wt. of one foot of bare pipe			135.49	lbs
7. Buoyant force on one foot of pipe			231.89	lbs
8. Negative buoyancy required per foot			0.00	lbs
9. Required submerged wt. of concrete			231.89	lbs/ft
10.Volume of concrete required	2.57	cu ft		
11	472.02	sq in		
12.O.D. of pipe, squared	900.00	sq in		
13.O.D. of concrete, squared	1372.02	sq in		
14.O.D. of concrete	37.04	in		
15.O.D. of pipe	30.00	in		
Thickness:	3.52	in		

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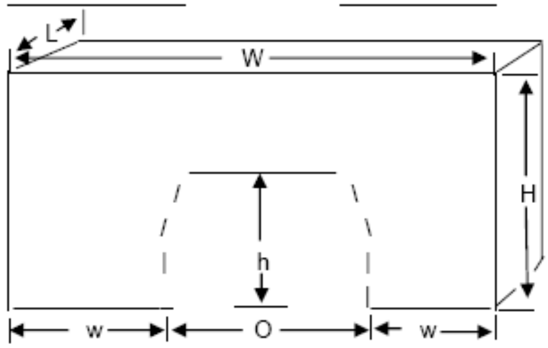
Table 3 – Set-on Weight Calculations

SPACED CONCRETE SWAMP WEIGHTS

SIZE OF PIPE: 30.000 " O.D. 0.429 " W.T. FLUID S.G.: 1.20



W = 2 x O.D."/12 =	5.00 ft	w = (W - O)/2 =	1.13 ft
H = 2 x O.D."/12 =	5.00 ft	O =(O.D."+3")/12 =	2.75 ft
L = 2 x O.D."/12 =	5.00 ft	h =(O.D"/2+1")/12=	1.33 ft

VOLUME =(W x H x L)-(.5 xPIx O^2/4 x L)-(O x h x L) = 91.82 cu ft

CONCRETE DENSITY = 165.00 lbs/cu ft

1. Wt. of each swamp weight		15,149.93 lbs
2. Wt. of one cu ft of swamp weight material	165.00 lbs/cu ft	
3. Volume of swamp weight	91.82 cu ft	
4. Wt. of one cu ft of displaced fluid	74.88 lbs/cu ft	
5. Wt. of fluid displaced by swamp weight		6,875.31 lbs
6. Submerged wt. of swamp weight		8,274.61 lbs
7. Volume per foot of bare pipe based on O.D.	4.91 cu ft	
8. Wt. of fluid displaced per foot of bare pipe	367.57 lbs	
9. Wt. of bare pipe per foot	135.49 lbs	
10.Buoyant force per foot of pipe	232.08 lbs	
11.Negative buoyancy per foot	0.00 lbs	
12.Required submerged wt. of concrete	232.08 lbs/ft	
13.Spacing center to center of swamp weights		35.65 ft