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Bulbous Pier: Alternative to Bridge Pier Extensions

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BULBOUS PIER: ALTERNATIVE TO BRIDGE PIER EXTENSIONS

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ABSTRACT

Bridge deck splashing causes deterioration to the bridge structure and renders the bridge unsafe for motorist and pedestrians. The traditional countermeasure for bridge deck splashing is pier extension, the pier extension moves the pier wave away from the bridge deck, but retrofitting existing bridges with pier extensions is costly. This research proposes the bulbous pier concept as an alternative to pier extension.

The decrease in the pier wave produced by the bulb is due to energy subtracted by the bulb via two forces, the viscous resistance, and the wave-making resistance. The proposed mathematical model for the bulbous pier design follows the model used for a mono hull ship. Under the mono hull model, the bulb length follows under the region were the viscous resistance is dominant. This allows for omitting the wave-making resistance. Since the wave-making resistance is obtained via modeling, the proposed set of equation do not requires modeling to calculate the pier wave reduction.

The proposed equations to calculate non-bulb pier wave height (PL_{nb}) are based in the assumption that the water energy is converted into potential energy at the pier- bulb intersection and determines the pier wave height. This assumption ignores the complex water-air interactions and the energy losses due to the water flow change of direction. The proposed equation introduces a correction factor, this factor account for the underestimation of the PL_{nb} and provides a safety factor in the design bulbous piers.

ACKNOWLEDGEMENTS

To The United States of America, were all dreams are possible.

To UNLV for 10 years of learning.

DEDICATION

To my parents Lila and Amilcar

To my wife Linda

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CHAPTER 1: INTRODUCTION

1.1. BACKGROUND

The impact of supercritical water flow with a pier nose creates a wave (pier wave) which might cause the flowing water to be projected onto the bridge deck as shown in Figure 1. This phenomenon, called bridge deck splashing, can endanger motorists and pedestrians on the bridge. One solution is extending the pier in front of the bridge structure (Figure 2). One of the problems with pier extension is the cost of retrofitting an existing bridge with pier extensions. The proposed bulbous pier addresses this problem by eliminating the need for large structural modifications to the pier.

For ships, a bulbous bow (Figure 3) is used to mitigate ship deck splashing and reduce the power required to propel the ship (Ventura, 2010). The bulbous bow is a flow-modifying feature on the ship bow. It creates a wave system that interferes with the ship natural wave system (see Figure 3) which in turn leads to a near-zero wave at the hull-bulb intersection. The reduction in the water wave height due to the bulbous bow is considered as a countermeasure for ship deck splashing (Ventura 2010). A ship moving through water is similar to water passing a partially submerged bridge pier. Thus, the concept of a bulbous bow (see Figure 4) can potentially work as a countermeasure to bridge deck splashing; the bulbous pier can reduce the energy available for the pier wave, reducing the deck splashing. The experimental results show that the bulbous pier reduces the pier wave height (Figure 5) and the proposed set of equation provide a practical method to calculate the pier wave ratio.

Figure 1. Duck Creek flood channel, Las Vegas metropolitan area.
(Provided by CCRFCD, 2013)

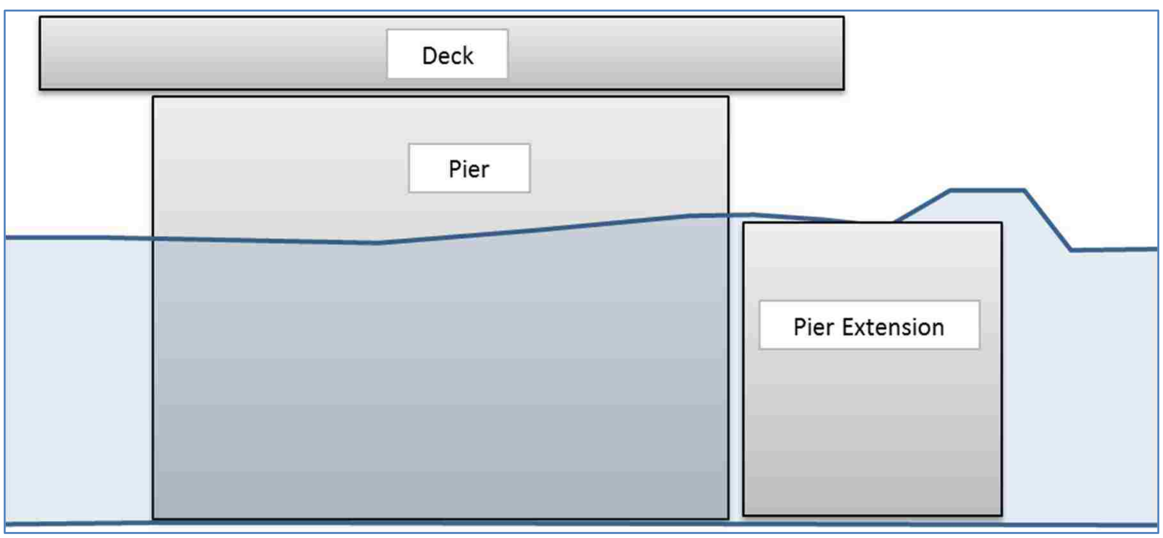


Figure 2. Bridge with pier extension

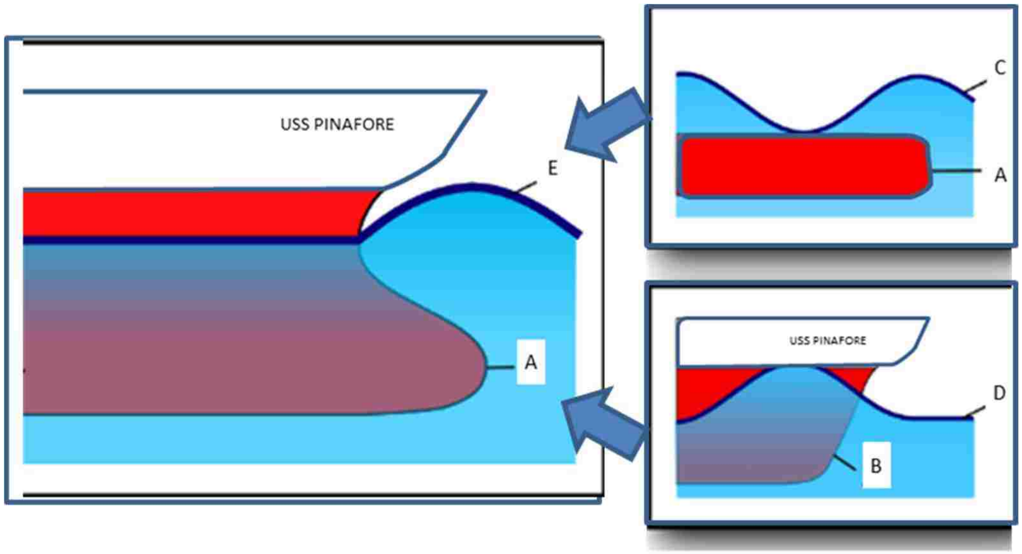


Figure 3. Bulb wave interference principle.
(A) bulb, (B) bow, (C) bulb wave, (D) bow wave, (E) combined wave = bow wave – bulb wave.

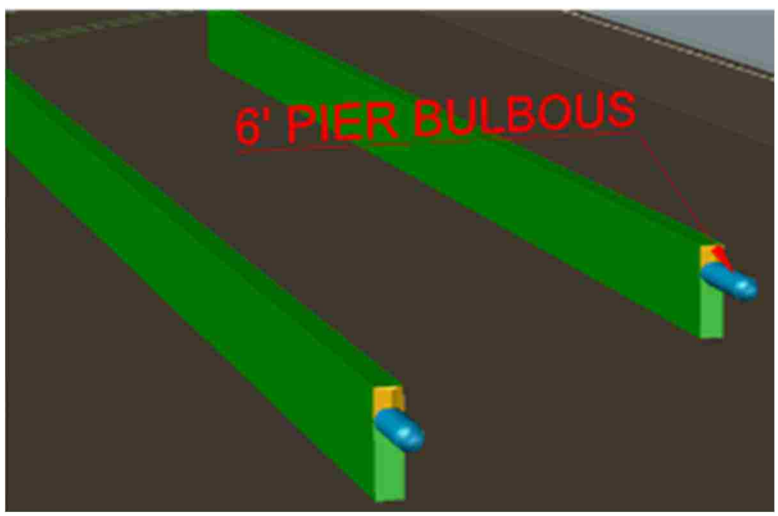


Figure 4. Proposed bulbous pier.

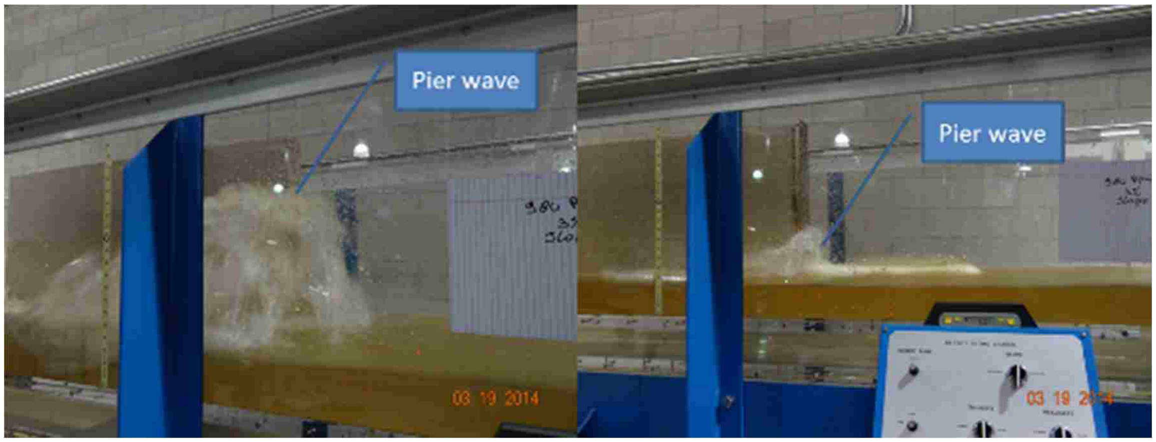


Figure 5. Typical non-bulb pier (left) and bulbous pier (right)

1.2. STUDY OBJECTIVES

The bulb interference technique has not been considered as a countermeasure to solve the bridge deck-splashing problem. It is believed that the bulbous pier can reduce the pier wave height. Accordingly, this study focuses on pier wave height reduction due to a bulb attached to a pier under a bridge. The specific objectives of this research are as follows:

1. Perform experimental tests to understand the effect of a bulbous on the reduction in the pier wave height.
2. Develop a mathematical model that predicts the effects of the bulbous pier on the reduction in the pier wave height basing upon bulb geometry and location.

CHAPTER 2: LITERATURE REVIEW

2.1. GENERAL

For moving ships, the length of the ships is the governing parameter in the Froude number (see Equation 1); while for flows in open channels, the governing parameter is the depth of the water (see Equation 2).

$$F_{r\ ships} = \frac{v}{\sqrt{gL}} \qquad \text{Equation 1}$$

$$F_{r\ open\ channel} = \frac{v}{\sqrt{gy_h}} \qquad \text{Equation 2}$$

Where Fr is the Froude number, v is speed of the ship (or velocity of the water in open channels in ft/s), g is gravity acceleration in ft/s^2, L is length of the ship at the water line level in ft, and y_h is hydraulic (water) depth in ft.

Since the length of ships is usually very large, the Froude number (F_r ships) is typically less than one even for speeds comparable to open channel supercritical conditions. Similarly, due to their large lengths, the pier's Froude number (F_r ships) is typically less than one for open channel supercritical condition as well. Accordingly, this literature review is focusing on the researches carried out to study the effect of bulbous bow for ships having speeds similar to the water velocities in open channels with supercritical conditions.

The study of bulbous bows for high speed ships is documented for ship speeds up to 55 knots (92.83 ft./sec) with a Froude number (F_r) in the supercritical range (F_r >1). Table 1 compares speeds and F_r values for high-speed ships and the Duck Creek Bridge pier, Las Vegas, Nevada. The comparison between the Duck Creek bridge pier and the high-speed ships indicates that the bulbous pier will fall into the speed range used for bulbous bow.

Table 1 Froude number calculation for high-speed ships and bridge piers.

	Fr	v(ft./sec)	L (ft.)
USS Sea Fighter (FSF-1)	1.06	92.83	239.5
USS Swift (HSV-2)	0.75	75.95	321
USS Independence (LCS 2)	0.62	72.00	418
Duck Creek Bridge Pier	0.31	22.00	152

2.2. BULBOUS BOW DESIGN RESEARCH

The studies on the effects of bulb for high-speed vessels with the Froude numbers, F_r, less than one pioneered by Hoyle et al. (1986). The parameters used by Hoyle et al. (1986) to define the bulb shape are still used to study vessel in a supercritical range ($F_r > 1$); these parameters were previously proposed by Kracht (1978). Hoyle et al (1986) defined the bulb geometry parameters as per Figure 6.

Some of the bulb geometry parameters in Figure 6 are not translatable to the bulbous pier (Equation 6, Equation 7, and Equation 8); for example, C_{ABT} (Equation 6) measure the relation between the hull and the bulb cross sectional areas, under the criteria that the hull is wider than the bulb. In the bulbous pier case, the bulb shall be as wide as the pier to mitigate the pier wave. In consequence, the literature review was narrowed to researches the used equation 1 to Equation 5 as predictors for the equivalent to the pier wave.

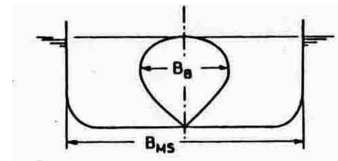
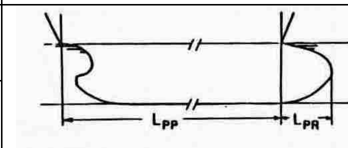
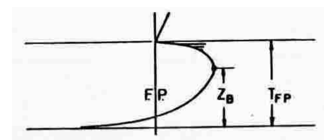
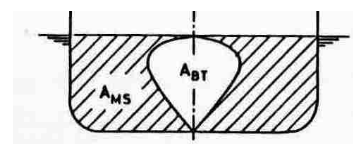
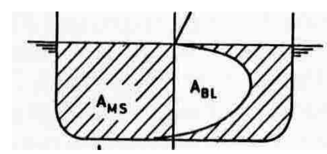
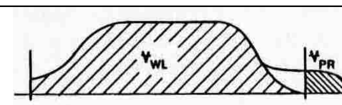
$C_{BB} = B_B/B_{MS}$	Equation 3	
Breadth parameter (C_{BB}): The maximum breadth (maximum width of the bulb - B_B) of bulb area (ABT) at the forward perpendicular divided by the beam of the ship at amidships (BMS)		
$C_{LPR} = L_{PR}/L_{PP}$	Equation 4	
Length parameter (C_{LPR}): The protruding length (L_{PR}) divided by the length between perpendiculars (L_{PP}) of the ship		
$C_{ZB} = Z_B/T_{FP}$	Equation 5	
Depth parameter (C_{ZB}): The height (Z_B) of the foremost point of the bulb over the baseline divided by the draft (T_{FP}) at the forward perpendicular		
$C_{ABT} = A_{BT}/A_{MS}$	Equation 6	
Cross-section parameter (C_{ABT}): The cross-sectional area (A_{BT}) of the bulbous bow at the forward perpendicular divided by the ship's midship section area (A_{MS})		
$C_{ABL} = A_{BL}/A_{MS}$	Equation 7	
Lateral parameter (C_{ABL}):The area (A_{BL}) of the protruding bulb in the longitudinal plane divided by the midship section area of the ship (A_{MS})		
$C_{VPR} = \nabla_{PR}/\nabla_{WL}$	Equation 8	
Volumetric parameter (CVPR): The volume (∇PR) of the protruding part of the bulb divided by the volume of displacement (∇WL) of the ship. NOTE: Protruding is used here to mean that part of the bulb which extends forward of the forward perpendicular		

Figure 6. Bulb geometry parameters (Hoyle, Cheng, & Hays, 1986)

Kracht (1978) studied the effect of the bulb in relation to the total power required to move a ship. The power required to move a ship is directly related to the total hull resistance; the hull resistance is the force that the ship experiences opposite to the motion of the ship as it moves. The total hull resistance (R_t) has three main components (Equation 9).

$$\boldsymbol{R_t = R_v + R_w + R_A} \qquad \text{Equation 9}$$

Where R_t is the total resistance (in pound force), R_v is viscous resistance, R_w is wave-making resistance, and R_A is air resistance.

Kracht (1978) concluded that introduction of the bulb creates a wave system that interferes with the hull wave system producing a water system with smaller wave height. A smaller wave height conduces to a smaller wave-making resistance and consequently a smaller Rt. The wave-making resistance is defined as the resistance caused by the waves created by the ship while moving, this is different from the wave resistance; the waver resistance is the one caused by the ocean waves hitting the hull.

Havelock (1909) studied wave-making resistance and defined wave resistance as per Equation 10, with a solution for shallow water bases in experimental values (Equation 11).

$$\boldsymbol{R_w = \frac{1}{4} w a^2 \frac{(v-u)}{v}} \qquad \text{Equation 10}$$

Where Rw is the wave-making resistance, a is the wave amplitude in ft., w is the weight of a unit of volume in lb/ft^3, v is the ship speed in ft/s, and u is the wave group velocity in ft/s.

$$\boldsymbol{R_w = \beta \times \left(1 - \gamma cos\left(\frac{m}{v^2}\right)\right) e^{\frac{-n}{v^2}}} \qquad \text{Equation 11}$$

Where α, β, and ϒ depends on the form of the hull and m and n are constants obtained via experimentation.

It is unclear under what open channel conditions Equation 10 or Equation 11 may apply to the bulbous pier. For the flume-pier design used in this research, the shallow water case is likely to apply with equivalent parameters for α, β, n, and ϒ.

The United States Naval Academy (2015) defines the total resistance (R_t) as the result of two main components, the viscous resistance ($R_{v)}$, and the wave-making resistance (R_w). The viscous resistance and wave-making resistance are a functions of a coefficient; C_w in the case of the wave-making resistance and C_v in the case of the viscous resistance. Equation 12 to Equation 16 defines R_t, R_v, R_w, C_v and C_w in term of the ship speed and hull properties.

$$R_t = 0.5\rho S_{as} C_t v^2 \qquad \text{Equation 12}$$

$$C_t = C_v + C_w \qquad \text{Equation 13}$$

$$R_v = 0.5\rho S_{as} C_v v^2 \qquad \text{Equation 14}$$

$$R_w = f(S_{as}, C_w, v) \qquad \text{Equation 15}$$

$$R_w = R_t - R_v \qquad \text{Equation 16}$$

Where Rt is total resistance in pound force, Sas is ship area submerges in ft2, v is the velocity in ft/s, C_t is total resistance coefficient, ρ is water density (1.94 lb-s2/ft4), C_v is viscous resistance coefficient, C_w is wave-making coefficient, R_v is viscous resistance, and R_w is wave-making resistance.

The United States Naval Academy (2015) states:

> "The calculation of the wave-making coefficient (C_w) is too complex for a simple theoretical or empirical equation, because mathematical modeling of the flow around ship is very complex since there exists fluid-air boundary and wave-body interaction. Therefore model test in the towing tank and Froude expansion are the best way to calculate the C_w of the real ship."

The United States Naval Academy (2015) describes the ship total resistance components in relation to the ship velocity (Equation 6), were the wave-making resistance (R_w) becomes more relevant as the ship speeds increases.

Figure 7. Typical hull resistance components

An alternative approach to calculate C_w is the use of computational fluid dynamics (CFD). Raven (1996) and Zhang et. al. (2009) documented the use computational fluid dynamics to study wave-making resistance. For the goal of developing a low cost alternative to the pier extension, CFD is a cost that will be avoided.

For mono hull ships at subcritical speeds, Kyriazis (1996) measured the bulb's effectiveness in terms of resistance to the ship movement. It was concluded that as the bulb volume increased, the resistance to the ship movement reduced.

For a multi-pier bridge, it is important to determine if the bulb concept was viable; the closes ship hull resembling a multi-pier bridge is a catamaran. Yun and Bliault (2012) discussed the Small Water Plane Twin Hull Catamaran (SWATH) designs able to reach the speeds required for supercritical flow. They found that, for these ships, the total resistance (R_t) marginally decreases for the same ship equipped with a bulbous bow. The marginal R_t reduction is a consequence of two competing forces, the R_v increasing with the bulb length and the reduction of R_w due to the increase of the bulb length.

Moraes et al. (2004) evaluated the wave resistance (C_w) for Wigley and Chime hull catamarans with S/L ratios form 0.2 to 1 and Froude numbers up to 1 and proposed an equation for C_w (see Equation 17). S is the distance between the hulls, and L is the ship's length. They found that the Chime catamaran C_w was independent of water depth for large F_r numbers. They also found that the bulb reduced the C_w for the catamaran with S/L ratio of 0.2. Connecting the works of Moraes et al. (2004) to this study, the shape of a Chime catamaran, due to its almost rectangular central section, is similar to the bridge pier (Figure 8).

$$\boldsymbol{C_w = C_t - (1 + \beta k) C_v} \qquad \text{Equation 17}$$

Where C_w is wave resistance, C_t is total resistance coefficient, βk is hull form factor, and C_v is viscous resistance coefficient.

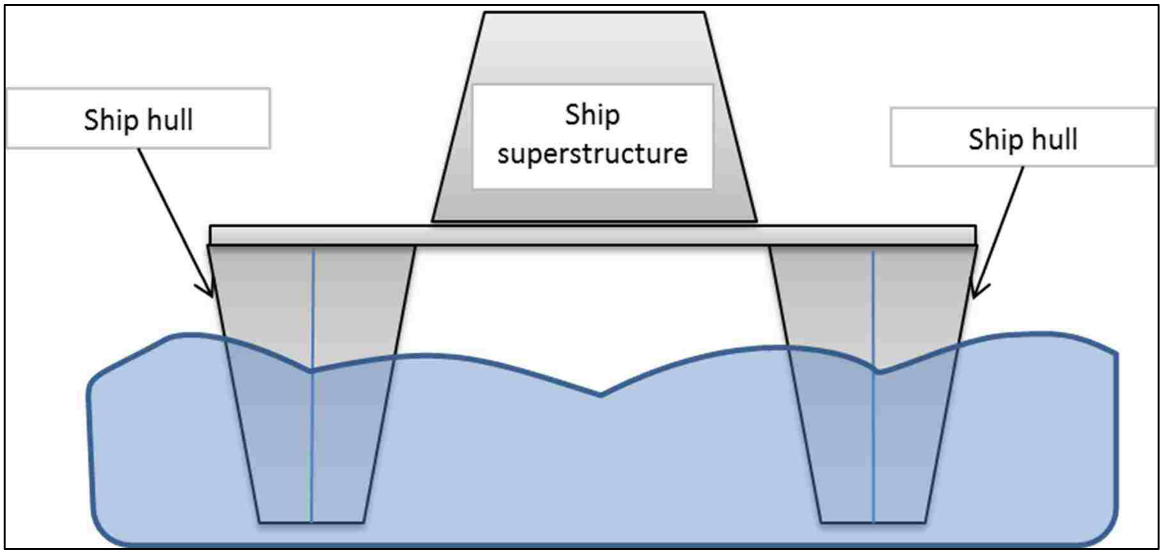


Figure 8. Chime catamaran hulls geometry

Abdul Ghani et al. (2006) used H_{nd} (non-dimensional maximum wave height, see Equation 18) and C_w to evaluate a series of "O" shape bulb (see Figure 9). The "O" bulb shape was selected due to its simple construction. Equation 18 was expressed as follows:

$$\boldsymbol{H_{nd}} = \left(\left(\frac{\boldsymbol{H_{max}}}{\boldsymbol{B}}\right)\left(\frac{\boldsymbol{x}}{\boldsymbol{L}}\right)\right)^{\frac{1}{3}} \qquad \text{Equation 18}$$

Where H_{nd} is non-dimensional maximum wave height, H_{max} is maximum wave height, L is ship length, B is ship breadth (width of the vessel at the water line), and x is distance from sailing line (the sailing line defines a vessel's path through the flow field). It was concluded that t hull with a long bulb has lower H_{nd} compared to a hull with no bulb.

Table **2** shows the parameters used by Abdul Ghani (2006) to design the bulb. According to the results, as shown in Figure 9, the longer bulb (higher values of C_{LPR}) and wider bulb (higher values of C_{ABL}) showed better H_{nd} performance.

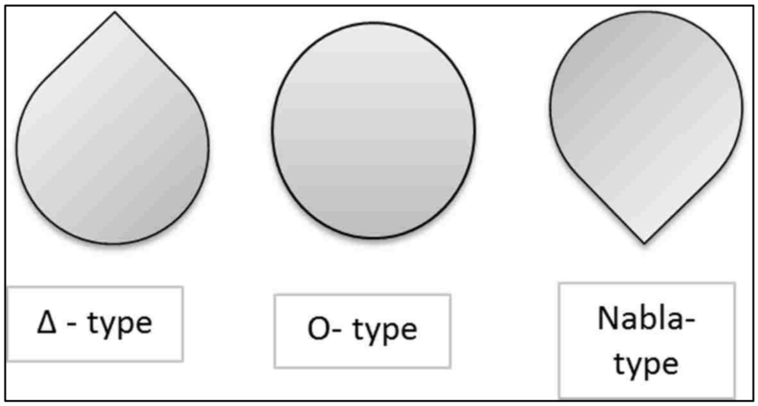


Figure 9. Bulb types.
(Left: Delta, Center: O, Right: Nabla) (Abdul Ghani, 2006)

Table 2 Bulb geometry parameters (Abdul Ghani 2006)

Bulb	C_{BB}	C_{LPR}	C_{ZB}	C_{ABT}	C_{ABL}	C_{VPR}
Bulb1	0.331	0.013	0.329	0.303	0.019	0.0032
Bulb2	0.331	0.028	0.329	0.303	0.320	0.0098
Bulb3	0.331	0.044	0.329	0.303	0.521	0.0163
Bulb4	0.331	0.063	0.329	0.303	0.763	0.0241

Ghani & Wilson (2009) correlated the cross section of the bulb (A_{BT}) to the bulb wave horizontal size, the bulb length (L_{PR}) to the bulb wave phase in relation to the hull wave, and the volume of the bulb to the wave amplitude. These findings provided will provide guidance in sizing the bulbous pier.

2.3. HIGH SPEED SHIPS VERSUS BRIDGE PIERS

The literature review for ship bulb concluded that bulbous bow reduce the R_t under similar conditions as a pier in an open channel. Long bulbous bow reduces the ship H_{nd}. The reduction of H_{nd} can be compared the pier wave ratio. Therefore, the bulb that causes more reduction in H_{nd} will be considered as the basis to determine the initial bulbous pier geometry.

The wave-making resistance is independent of the water depth at high Froude numbers; these high Froude numbers are within the open channel range.

However, the literature review did not show any study on the effects of bulbous bow on the reduction of the water shear stress. From the Navies-Strokes equations, a reduction in the viscous forces is expected due to reduction the turbulence attributed to the bulb (Equation 19).

$$\overrightarrow{F_{grv}} + \overrightarrow{F_{prs}} + \overrightarrow{F_{visc}} = m\,\vec{a} \qquad \text{Equation 19}$$

Where F_{grv} is gravity forces, F_{prs} is pressure forces, F_{visc} is viscous forces, m is mass, and a is the gravity acceleration.

CHAPTER 3: RESEARCH METHOD

3.1. GENERAL

From Figure 10, the bulb wave (B_w) is the difference between the pier water level non-bulb (PL_{nb}) and with bulb (PL_{bb}), Equation 20. Since the bulbous bow, analysis is based in the principle of superposition; the bulb can be analyzed as a standalone ship where the bulb hull resistance is proportional to $B_{w.}$ The addition of bulb to a pier reduces pier wave by removing energy from the water, making this energy unavailable to contribute to PL_{bb}.

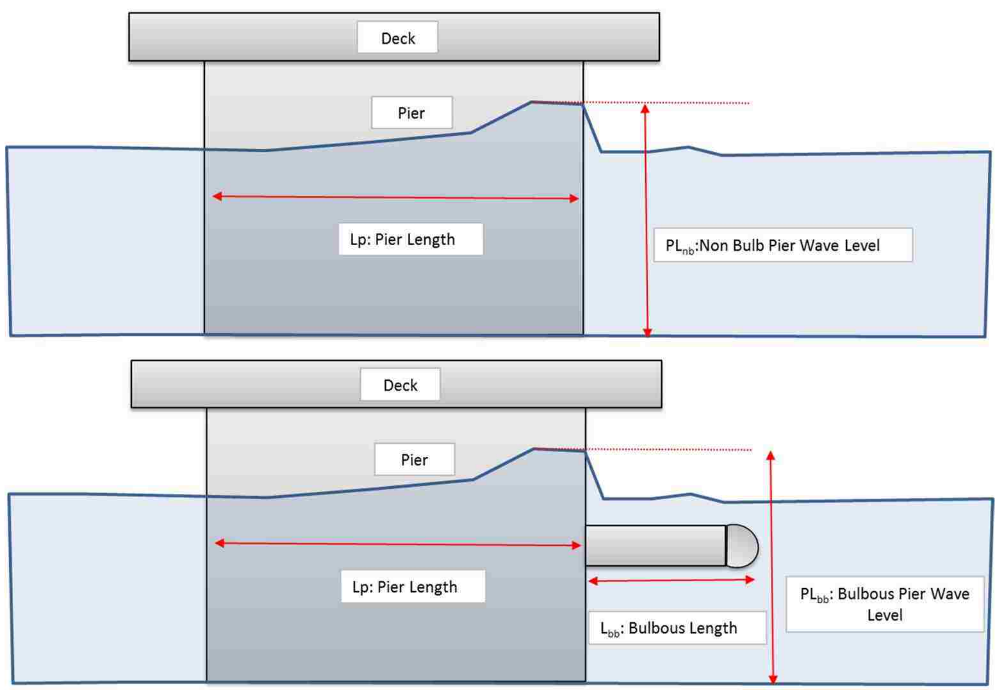


Figure 10. Pier with bulb and without bulb

$$B_w = PL_{nb} - PL_{bb}$$ Equation 20

3.2. THEORETICAL FORMULATION

From early bulbous pier experiments (Figure 11) it is clear that B_w resembles the typical curve of total hull resistance. The hump in the total resistance curve is the result of the mutual interference between the ship bow and the stern waves (US Naval Academy, 2015); this equals the bulb tip and the sides' waves.

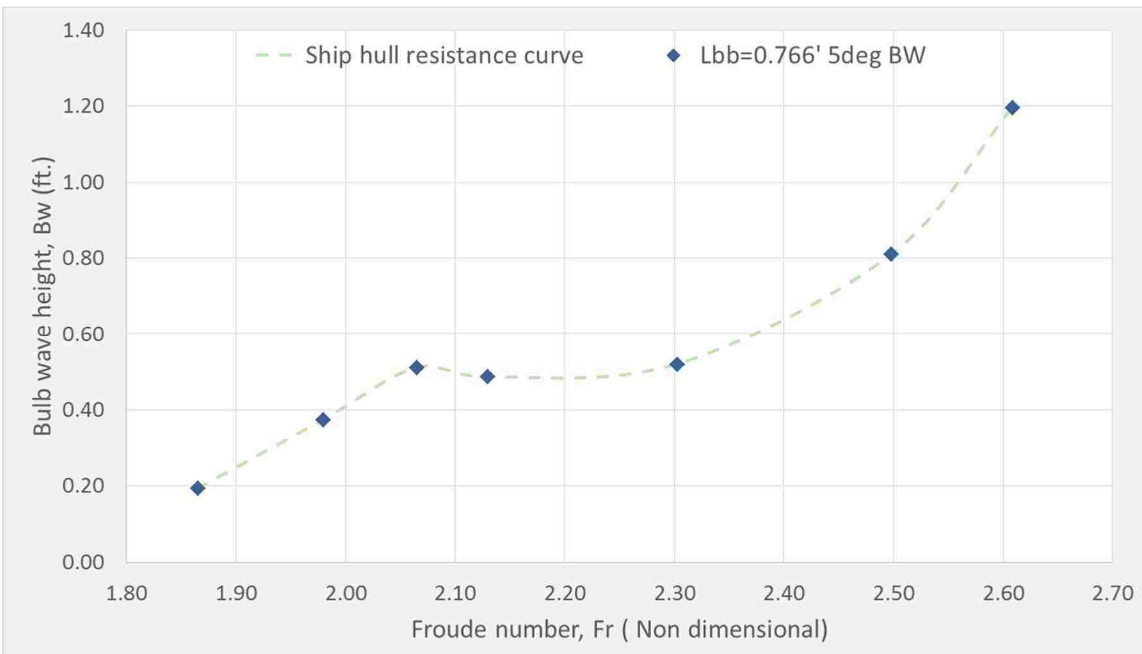


Figure 11. Experimental results bulb wave height (B_w) for range of supercritical Froude numbers(F_r)

A ship moving through water is similar of a pier in an open channel; both create waves as the water moves around them. According to the ship wave theory, the energy in a wave is proportional to the square of the wave height; therefore, if the wave height doubles, the energy required for wave-making becomes four-fold (Equation 21). This is the reason why the wave-making is the main component of the ship total resistance.

In ship designing, the wave-making resistance (R_w) becomes more important than the viscous resistance (R_v) when the ship wavelength (L_w) reaches to a value equals the ship length. The bulb wavelength (L_w) is defined by Equation 22, where v is the water velocity and g is the gravity acceleration.

$$R_w = f(C_w, \mathrm{v}^4) \qquad \text{Equation 21}$$

$$\mathrm{L_w} = \frac{2\pi \mathrm{v}^2}{\mathrm{g}} \qquad \text{Equation 22}$$

From United States Naval Academy (US Naval Academy, 2015), Equation 23 to Equation 28, are the equations used to calculate the viscous resistance in a ship, modified to account similar parameters in the bulb.

$$R_t = 0.5\rho BB_{as} C_t v^2 \qquad \text{Equation 23}$$

Where R_t is total resistance in pound force, BB_{as} is bulb area submerge in square foot, C_t is total resistance coefficient, ρ= water density (1.94 lb-s2/ft4).

$$C_t = C_v + C_w \qquad \text{Equation 24}$$

Where C_t is Total resistance coefficient, C_v is viscous resistance coefficient, and C_w is wave-making coefficient.

$$C_v = \frac{0.075}{log10(R_e - 2)^2} \qquad \text{Equation 25}$$

Where C_{vt} is the viscous resistance tangential to the bulb and R_e is Reynolds number.

$$R_e = \frac{vL_{bbs}}{k} \qquad \text{Equation 26}$$

Where L_{bbs} is bulb length submerge, k is kinematic viscosity (1.2260x10-5 ft2/s for fresh water).

$$C_v = C_{vt} + C_{vt}k_n \qquad \text{Equation 27}$$

Where k_n is viscous perpendicular resistance coefficient

$$k_n = 12\left(\frac{V_{bb}}{Y_s}\frac{B_d}{L_{bbs}}\right) \qquad \text{Equation 28}$$

Where V_{bb} is the bulb volume, B_d is bulb diameter, L_{bbs} is bulb length, Y_s is bulb submerge depth.

For the same testing conditions (flume flow and flume slope), attaching the bulb to the pier changes the water velocity. The experimental data for the pier water level non-bulb (PL_{nb}) cannot be used to calculate B_w, because the energy in the system changed. The PL_{nb}

can be calculated using Equation 29 (total energy equation). Equation 29 assumed that the water energy will be transferred to the pier wave and then into PL_{nb}.

Figure 12 show that the PL_{nb} experimental data vs. the calculated PL_{nb} values using Equation 29. The PL_{nb} experimental vales resemble the hull total resistance curve.

$$PL_{nb\ calc} = E = y_h + \frac{V^2}{2g} \qquad \text{Equation 29}$$

Where E is total energy, Y_h is hydraulic depth in ft., v is water velocity, and g is gravity acceleration.

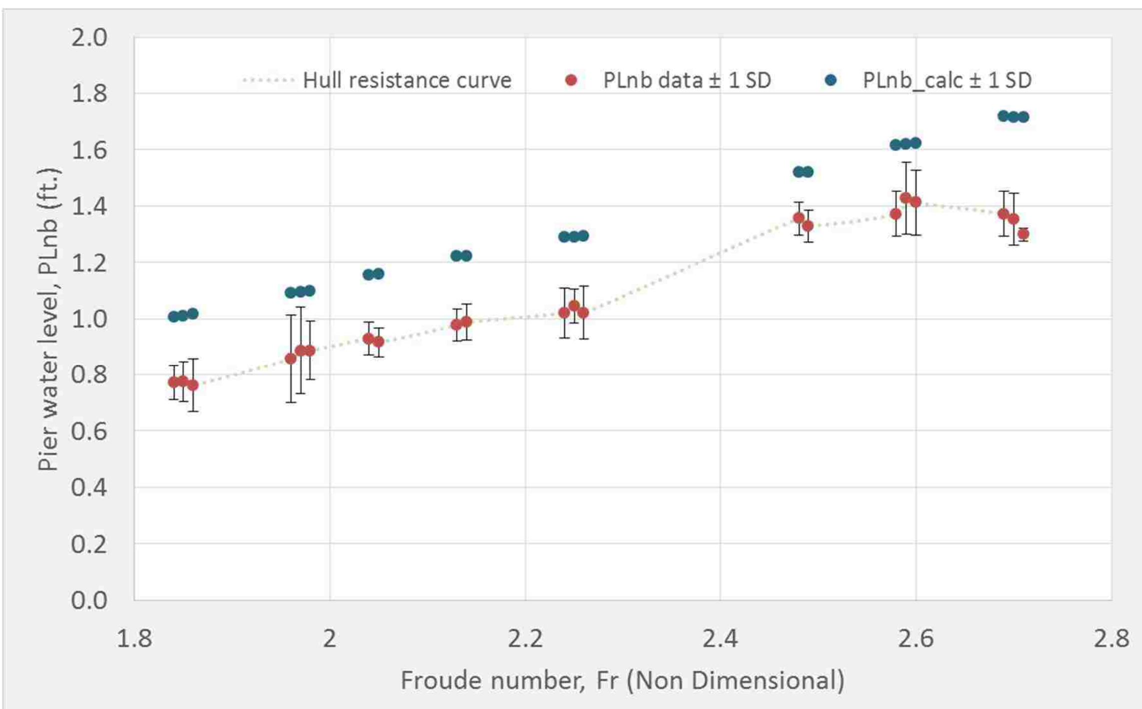


Figure 12. Pier water level non-bulb experimental data ($PL_{nb\ data}$) compared to non-bulb water level calculated ($PL_{nb\ calc}$).

If B_w is a consequence of the bulb total resistance (Equation 30 to Equation 37), an increase in the magnitude of B_w shall be directly related to a decrease of the PL_{bb} and in consequence the deck splashing.

$$\mathrm{R_t = R_v + R_w + R_A} \qquad \text{Equation 30}$$

Where R_t is total resistance, R_v is viscous resistance, R_w is wave-making resistance, and R_a is air resistance.

In piers the air resistance is not relevant, thus Equation 30 can be rewrite as Equation 31

$$R_t = R_v + R_w \qquad \text{Equation 31}$$

$$B_w = f(R_t) \qquad \text{Equation 32}$$

Where B_w is bulb wave, R_t is total resistance, R_v is total viscous resistance, and R_w= wave-making resistance.

The total bulb resistance can be calculated using the modified equation for hull total resistance:

$$R_t = 0.5\rho BB_{as}(C_v + C_w)v^2 \qquad \text{Equation 33}$$

Where R_t is total resistance wave, BB_{as} is bulb area submerges, and C_t is total resistance coefficient.

Since bulb wave is the result of the bulb total resistance, the bulb wave shall have two components, B_w component due to R_v and B_{ww} is B_w component due to R_w (Equation 34).

$$B_w = B_{wv} + B_{ww} \qquad \text{Equation 34}$$

Since the bulb takes energy from the flow, the water velocity at the end of the bulb shall be less than the channel water velocity. This reduced velocity (V_{bb}) is responsible for B_{wv} and B_{ww}. The practical bulbous lengths are not long enough to reach the bulb wavelength value, making the viscous resistance the dominant component (see Figure 13, typical); appendix A.6 contains curves for all cases. V_{bb}^2 can be calculated using Equation 35, where L_{bbs} is the bulb length submerged. Knowing V_{bb}^2, Bwv can be calculated using Equation 36. The bulb wave wave-making component cannot be calculated unless experimental values for C_w are known and according to the literature review there is not a mathematical model to calculate C_w (Equation 37and Equation 38).

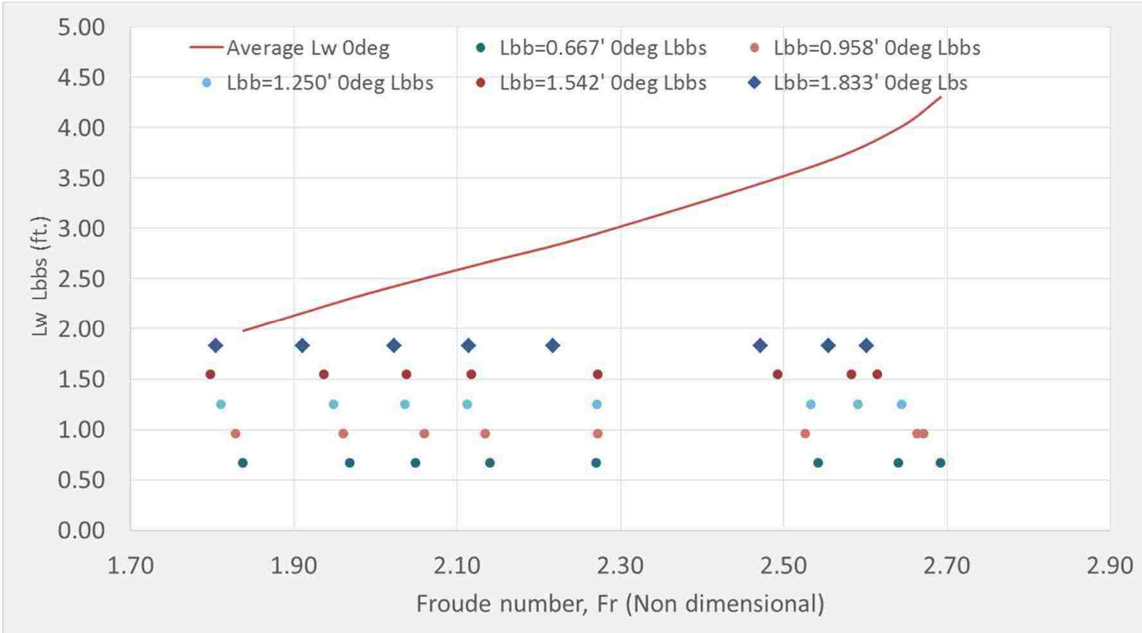


Figure 13.Bulb wavelength (L_w) and bulb submerged length (L_{bbs}), 0° pitch angle

Since bulb length is smaller than the wavelength, according to Figure 13, it is likely that the wave-making component can be discarded to facilitate the bulbous pier calculations.

$$v_{bb}^2 = v^2 - 2R_v L_{bbs}$$ Equation 35

$$B_{wv} = \frac{v_{bb}^2}{2g}$$ Equation 36

$$B_{ww} = B_w - B_{wv}$$ Equation 37

$$B_{ww} = f(BB_{as}, C_w \ , v)$$ Equation 38

$$PL_{bb\,cal} = \frac{v_{bb}^2}{2g} + Y_h$$ Equation 39

To transferee the bulbous pier model dimension into the full size bulbous pier, these two rules apply:

1. The Froude number of the model (F_{rm}) is the same as the Froude number of the pier (F_{rp}).
2. The wave-making coefficient of the bulb model (C_w) and the bulb (C_{wp}) are the same, Equation 42 and Equation 41.

$$F_{rm} = \frac{V}{\sqrt{gL_{bbs}}}$$ Equation 40

$$F_{rm} = F_{rp}$$ Equation 41

$$C_w = C_{wp}$$ Equation 42

Since the proposed model discharge the wave-making resistance, only the Froude number based on the bulb length will be used to size the full size bulbous.

3.3. VISCOUS RESISTANCE ERROR

In a ship, the use of the Froude number to scale the model to a full size bulb introduces a great deal of error duel to the fact that the water density cannot be scaled. This error is largely concentrated in the viscous resistance; several methods are proposed to deal with this error, including CFD. The theory on viscous resistance error mitigation in ships assumes the force applied to the hull is parallel to the ship waterline; this is not quite true in for the bulbous pier, the existence of the pier under the bulbous creates forces perpendicular to the bulb and in opposite direction of the flow. Until full size test are conducted, the magnitude of this error is unknown.

One of the methods used to mitigate the viscous resistance error is to increase the model surface roughness. For the bulb model, the surface roughness was increased by 3D printing the model with the layers perpendicular to the flow. The full size bulb will be build out of commercial steel pipe, a Manning's roughness coefficient of 0.012; the closest material to the 3D printed model is the metal corrugated pipe with a Manning's roughness coefficient of 0.022. This increase in the roughness shall reduce the viscous resistance error.

3.4. PIER WAVE ANALYSIS

To evaluate the bulb deck-splashing mitigation capabilities, the following method is proposed:

1. Select a bridge from the CCRFCD database with F_r in the supercritical range, similar to the bridge show in Figure 1 .
2. Use a cylindrical bulb shape similar to the Ghani & Wilson (2009) research.

3. Test pier and bulb model in a hydraulic flume and gather data to calculate B_w.
4. Propose a set of equations to calculate the B_w.
5. Calculate pier wave ratio (PWR) using Equation 43 and Equation 44, to determine the best pier bulb configuration in term of length and pitch angle.

$$PWR_{data} = \frac{PL_{nb\ cal} - PL_{bb\ data}}{PL_{nb\ cal}}$$ Equation 43

$$PWR_{cal} = \frac{PL_{nb\ cal} - PL_{bb\ cal}}{PL_{nb\ cal}}$$ Equation 44

6. Validate the proposed equation.
7. Propose design rules for pier bulb.

3.5. BRIDGE SELECTION

The Broadbent Boulevard box culvert at Duck Creek was selected to evaluate the applicability of bulbous pier concept. Figure 14, Table 3 and Table 4 show some information on the flow, pier, and channel provided by Clark County Regional Flood Control District.

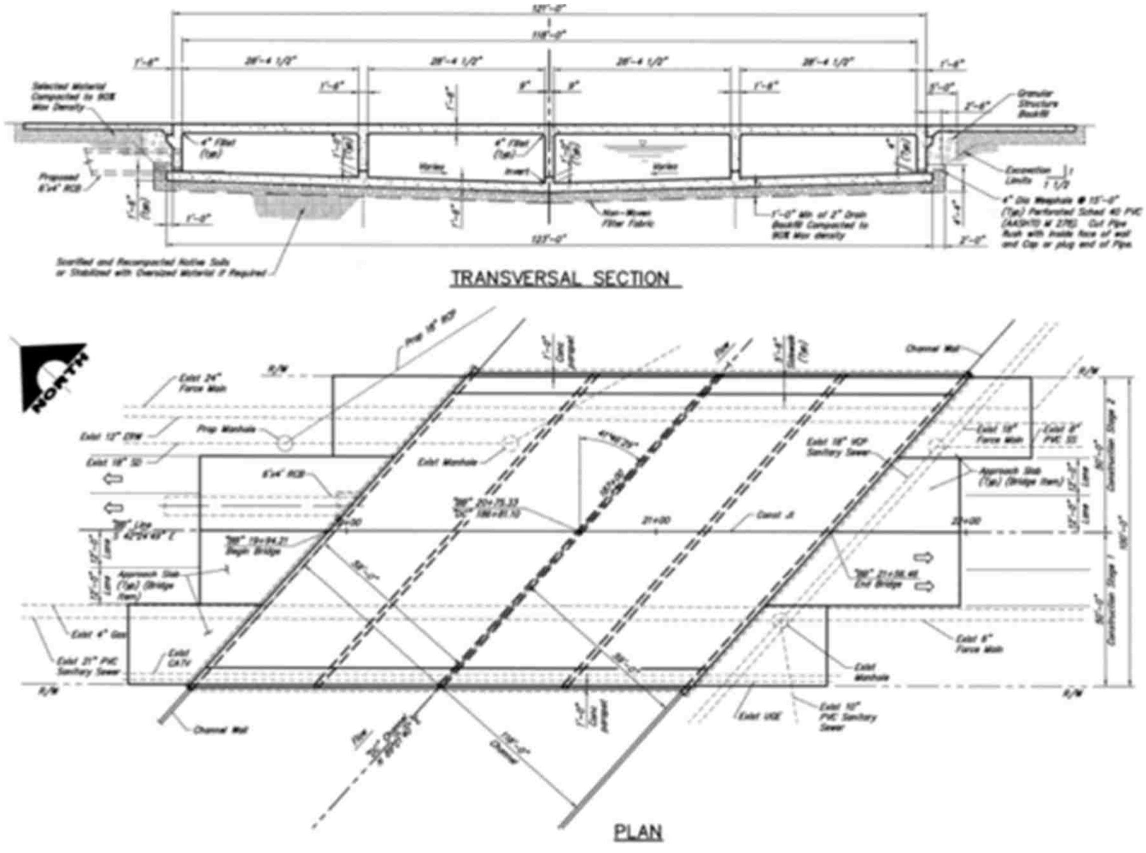


Figure 14. Broadbent Blvd. box culvert at Duck Creek

Table 3. Duck Creek channel dimensions

Dimension	Value	Unit
Width	118.00	ft.
Height	5.70	ft.
length	500.00	ft.
Flow Speed	20.14	ft./sec
Submerge Height	5.00	ft.
Hydraulic Depth	5.00	ft.
Submerge Area	590.00	ft2
Fr Channel	1.59	

Table 4. Duck Creek bridge dimensions

Dimension	Value	Unit
Pier Height	5.70	Ft
Pier Hydraulic Depth	5.00	Ft
Pier Length	152.43	Ft
Pier Width	1.50	Ft
Pier Nose radius	1.50	Ft
Submerge Pier Area	7.50	Ft
Flow Speed	20.14	ft./sec
Channel depth	11.00	Ft
Fr Pier	0.29	

3.6. FLUME CAPABILITIES

The flume flow was model by solving the Manning Equation (Equation 45) within the parameters described in Table 5. A Visual Basic Application (VBA) program was developed to solve Equation 45, under the flume automation limitations (Appendix B).

Table 5. UNLV flume characteristics

Characteristic	Values	Units
Pump Nominal Speed	1,185	RPM
Pump Nominal Flow	3,600	GPM
Flume Pump Max Speed	980	RPM
Manning Coefficient (n)	0.010	
Flume Width (w)	1.5	ft.
Flume Length (x)	58	ft.
Flume Max Slope	4.1	%
Flume Min Slope	0	%

$$A * R = \frac{nQ}{\sqrt{S}} \qquad \text{Equation 45}$$

Where A is flume wet area, R is hydraulic ratio, n is Manning number, Q is pump Flow, and S is Slope.

Figure 15 show the specific energy diagram for the UNLV flume restricted to 1.5 ft. wide.

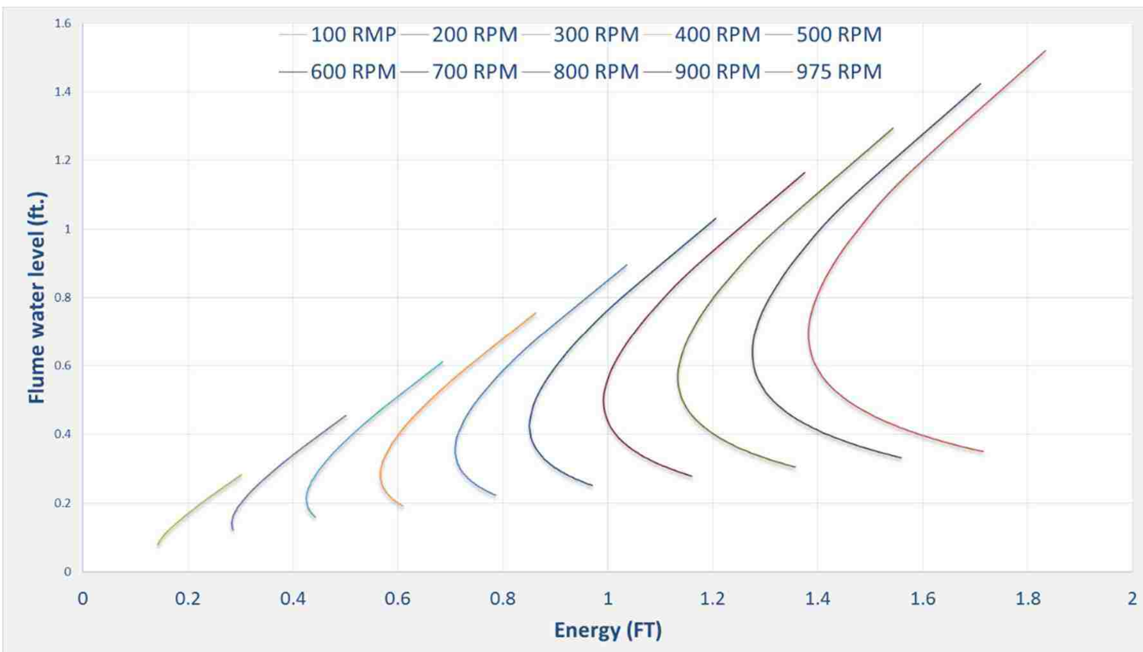


Figure 15. Specific energy diagram

For a pump equipped with variable frequency drive (VFD), the pump flow can be determine from Equation 46

$$Q = \frac{\text{Pump Nominal Flow} \times \text{Actual RPM}}{\text{Nominal RPM}} \qquad \text{Equation 46}$$

Table 6. Pump flow calculations

Condition	RPM	GPM	f^3/sec	f^3/RPM
Experimental	980	3098	6.90	0.007043
Experimental	800	2540	5.66	0.007074
Nominal	1185	3600	8.02	0.006769
Average				0.006962

3.7. DIMENSIONAL ANALYSIS

For a flume with a width restricted to 1.5 ft. and running at $F_r = 1.59$, the maximum hydraulic depth (Y_h) is equal to 0.58 ft. The model was scaled using Equation 47. Equation 48 is for an Y_h equal to 0.58 ft. In preliminary flume runs, the pier waves obtained with this model size produces waves that can be recorded with the proposed instrumentation.

$$F_r = \frac{v}{\sqrt{g y_h}} \qquad \text{Equation 47}$$

$$Model\ Scale\ Factor = \frac{0.58}{5} = 0.11667 \qquad \text{Equation 48}$$

For the experimental flume runs, an Yh equal to 0.375 ft. was selected; this will allow larger number of supercritical set points and will provide room for the expected increase in Y_h due to the introduction of the bulb (Figure 16). The result of the dimensional analysis is show in flowing tables (Table 7 and Table 8). Since the pier height does not have any significance in the equation governing the bulb design, it can be increase to 2 ft. to accommodate the necessary instrumentation

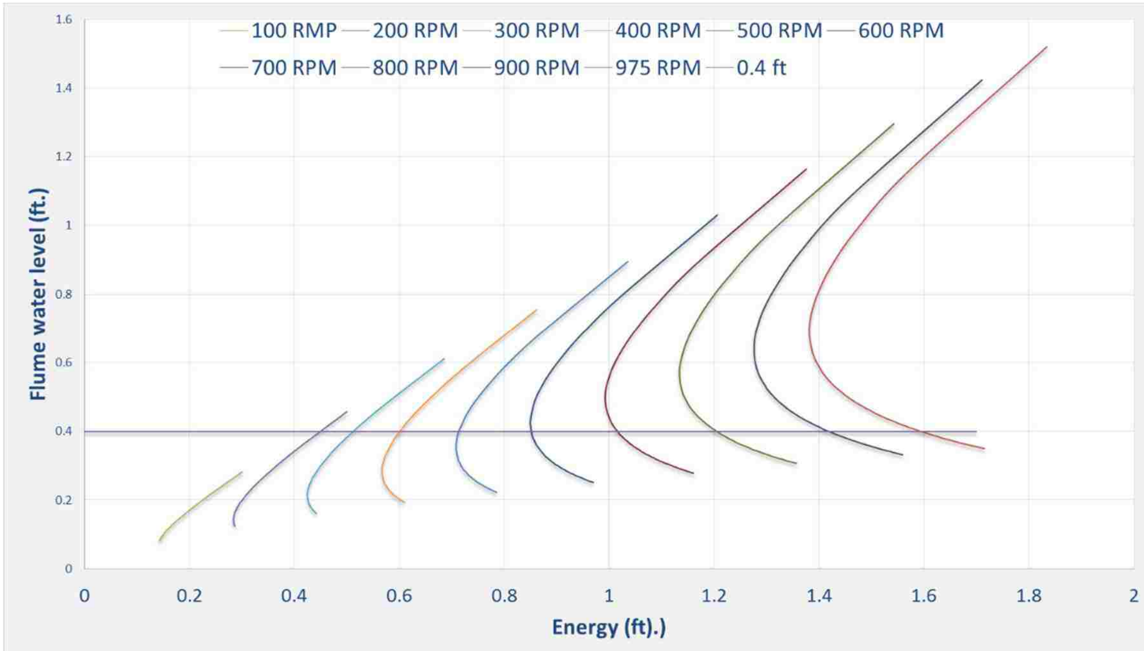


Figure 16. Specific energy diagram for hydraulic depth, $Y_h = 0.4$ ft.

Table 7. Flume dimensions

Dimension	Value	Unit
Width	1.50	ft.
Height	1.67	ft.
Length	25.00	ft.
Flow Speed	6.88	ft./sec
Submerge Height	0.58	ft.
Hydraulic Depth	0.58	ft.
Area	2.50	ft^2
Fr Flume	1.59	

Table 8. Pier model dimensions

Dimension	Value	Unit	Scale	Hoyle Parameter
Pier Height	0.67	ft.	0.12	
Pier Submerge Height	0.58	ft.	0.12	T_{FP}
Pier Length	2.00	ft.	0.12	L_{PP}
Pier Width	0.17	ft.	0.12	B_{MS}
Pier Submerge Area	0.10	ft.	0.12	A_{MS}
Pier Height	0.67	ft.	0.12	V_{WL}

3.8. PIER BULB SELECTION

The initial bulb lengths were selected using Ghani (2009) and the pier model dimensions, the results are show in Table 9 and

Table 10. The width of the bulb was set to be the same as the pier width.

Table 9. Modified bulbous pier geometry

	Min	Max	Unit	Parameter
Diameter	0.17	0.17	ft.	B_B
Length	0.03	0.13	ft.	L_{PR}
Area	0.16	0.40	ft^2	

Table 10. Ghani parameters bulbous piper

	B_B	B_{MS}	C_{BB}	L_{PR}	L_{PP}	C_{LPR}
Bulb1	0.17	0.17	1	0.03	2.00	0.013
Bulb2	0.17	0.17	1	0.06	2.00	0.028
Bulb3	0.17	0.17	1	0.09	2.00	0.044
Bulb4	0.17	0.17	1	0.13	2.00	0.063
	Z_B	T_{FP}	C_{ZB}	A_{BT}	A_{MS}	C_{ABT}
Bulb1	0.19	0.58	0.329	0.03	0.10	0.303
Bulb2	0.19	0.58	0.329	0.03	0.10	0.303
Bulb3	0.19	0.58	0.329	0.03	0.10	0.303
Bulb4	0.19	0.58	0.329	0.03	0.10	0.303
	A_{BL}	A_{MS}	C_{ABL}	V_{PR}	V_{WL}	C_{VPR}
Bulb1	0.03	0.10	0.303	0.00	0.10	0.019
Bulb2	0.03	0.10	0.303	0.03	0.10	0.32
Bulb3	0.03	0.10	0.303	0.07	0.10	0.763
Bulb4	0.03	0.10	0.303	0.00	0.10	0.019

3.9. FLUME INSTRUMENTATION

The current UNLV flume instrumentation consists of a pump RPM meter, a flume slope meter, and a magnetic flow meter; located in the pipe feeding the flume. For the bulbous pier testing, new instrumentation will be added to the flume:

1. An Endress + Hauser Liquicap capacitive level meter Liquidcap T FMI21; this equipment will measure the pier level (PL_{nb}, PL_{bb}). The level meter will be located in the plane defined by the pier nose and the flume wall (Figure 17).
2. A Greyline area velocity flow meter, model AVFM 5.0, this equipment will measure the flume flow rate (Q), Flume Water Speed (v) and the flume hydraulic depth (Yh). The instrument will be located at the bottom of the flume in front of the pier nose, few inches away from the bulb (Figure 16).

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Figure 17**.** Level meter location, UNLV flume

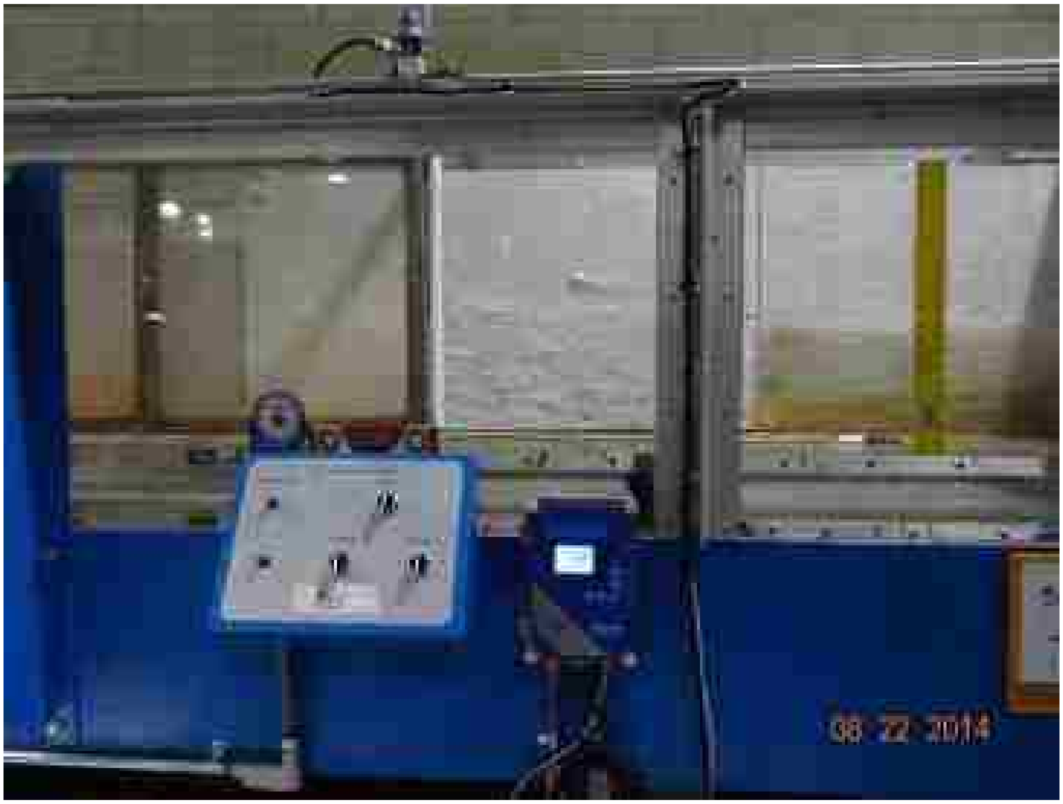

Figure 18**.** Greyline AVFM 5.0, UNLV flume

3. A Measurement Computer USB-1608G Data Logger, this data logger will collect the data coming from the pipe flow meter, level meter and the three outputs from the AVFM 5.0: flume water speed, flume water level, and flume flow rate (calculated).
4. To scale, display, and record the data collected by the data logger, the Measurement Computer DasyLab application will be installed in a laptop, the data collected will be store in Excel CSV format.
5. Froude number, bulb submerges length, bulb submerges area, and other values will be calculated in an MS Access database (APPENDIX C:).

3.10. FLUME TESTING PLAN

The test plan consists of three phases:

1. Verifying the flume Manning's roughness coefficient; this will guaranteed the accuracy of values registered by the instrumentation.
2. Obtaining the bulb optimal submerged depth
3. Testing twelve bulb models for eight steady-state conditions (slope and RPM) with Y_h = 0.375 ft.

3.10.1. VERIFYING MANNING'S ROUGHNESS COEFFICIENT

For any flow condition in the flume, the Manning's roughness coefficient shall converge to a single number (n=0.010). Solving Manning's equation for n shall provide an indication of how good is data collection. The Access database has a VBA routine calculate n based on the experimental data downloaded from the data acquisition system. Hypothesis testing for n equal to 0.010 will determine the accuracy of the collected data and the necessity of modifications to the experiment, if needed.

3.10.2. OPTIMAL BULB SUBMERGED DEPTH

From the literature review, the optimal bulb submerged depth (Y_s) can be determined by running the flume at maximum flow and changing Y_s. Preliminary tests show that optimum BSD occurs when half of the diameter of the bulb is submerge.

3.10.3. STEADY STATE TEST MATRIX

In order to evaluate the pier level reduction produced by bulb, a pier model place into a hydraulic flume and tested. Two set of data will be collected, one from the pier, and the other for pier with bulb.

The flume running at predetermine Y_h is called steady state. This is different from the actual behavior of open channels where Y_h changes as flow conditions changes. The test matrix is based on Table 11 and Table 12 values.

Table 11. Flume steady state variables

Dependent Variables	Values	Units
Flume Water Velocity		ft./s.
Hydraulic Depth		ft.
Pier Level		ft.

Independent Variables	Values	Units
Pump Speed	550 to 850	RPM
Bulb Length	0.67 to 1.58	ft.
Bulb Pitch Angle	0 to 10	°
Flume Slope	1.24 to 4	%

Table 12**.** Flume steady state parameters

Parameters	Values	Units
Y_h	0.375	ft.
Flume Width	1.5	ft.
Pier Width	0.166	ft.
Pier Length	2	ft.
Flume Gates Position	0	ft.
Bulb Submerge Depth (Y_s)	0.	ft.

The test matrix (Table 13) contains eight flume set points (RPM and slope) where Y_h = 0.375 ft. Twelve bulb models were selected for each flume set point. The bulb models are divided into four length and three angles. The bulb length is measure at the upper side of the bulb. The bulb angle is de angle between the bottom of the flume and the bottom of the bulb.

Table 13. Test matrix

Independent Variables	Value	Units	Condition
Pump Speed, Flume Slope (8 cases yh =0.375)	(550, 1.24), (601,1.59), (568, 1.99), (570,2.38), (630,2.78), (714, 3.16), (750,3.59, and (765,4.26)	RPM, %	Yh= 0.375
Bulbous Horizontal Upper Length	0.67, 0.96, 1.25, 1.54 , and 1.83	ft.	

CHAPTER 4: EXPERIMENTAL RESULTS

4.1. PIER WATER LEVEL AND BULBOUS PIER WATER LEVEL

The experimental results show that the bulb decreases pier water level. The two-sample t-test for the non-bulb pier water level (PL_{nb_T}) and the bulbous pier (PL_{bb_D}) show that the bulbous pier average water level is less that the non-bulb pier (see Table 16). Appendix A contains photographs for each point in the test matrix.

4.2. INITIAL ASSUMPTIONS

The initial bulbous L_{bb} values derived from the Ghani (2009) design parameters values proved to the insufficient to produce a significant reduction in the pier wave ratio (PWR). The short bulb with 0° pitch angle has a spray problem, water over the bulb tip detach from the flow and spray over the pier (Figure 19). To avoid this problem the bulb length (L_{bb}) shall be extended to lengths not suitable for construction, somewhere between 10 and 12 ft. The initial assumption that the bulb length (L_{bb}) is directly related to PWR was confirmed (Figure 20, typical); appendix A.5 contains figures for all cases .A higher PWR indicated that the PL_{bb} is lesser than the PL_{nb}.

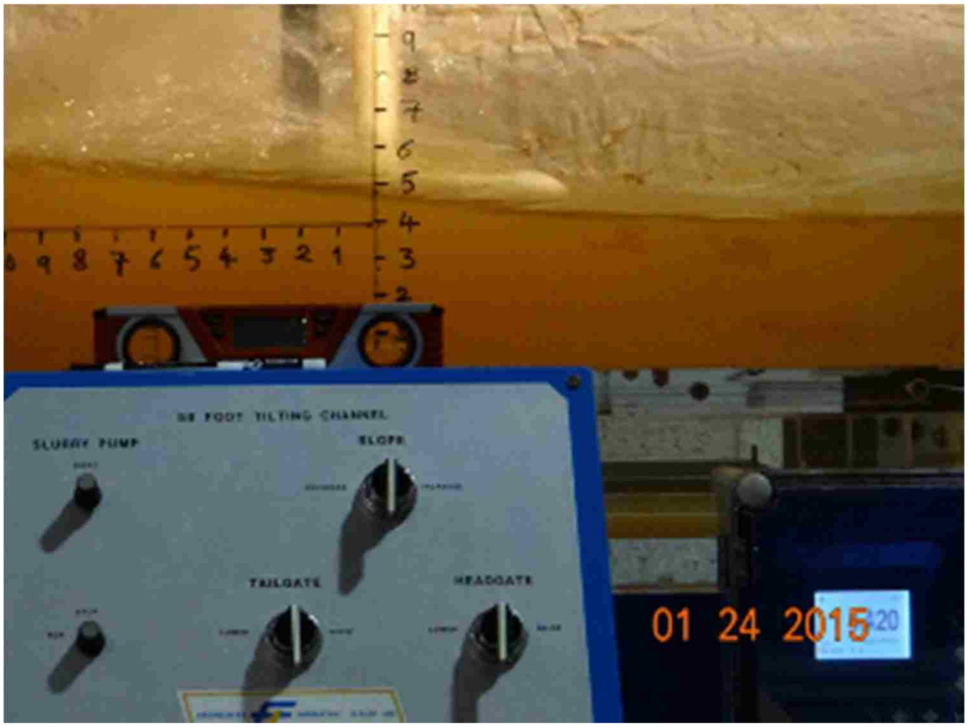

Figure 19. Bulbous pier spraying problem

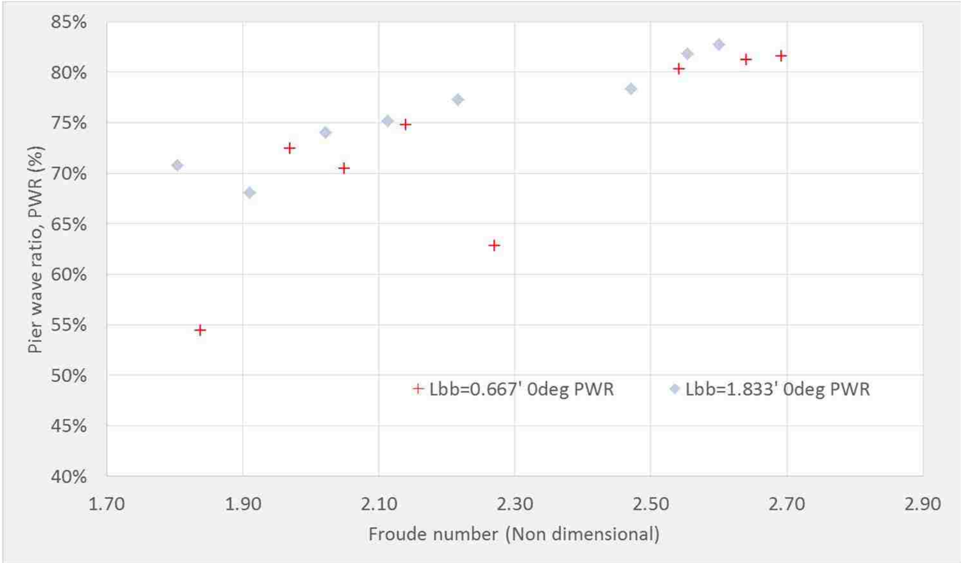

Figure 20. Pier wave ratio for 0° pitch angle bulb, bulb length (L_{bb}) = 0.667’ and 1.833’

To correct the spraying problem, the bulbous pitch angle was increased to 5° and 10°. The selection of the pitch angle was based on the value C_{ZB} used by Abdul Ghani (2006) (Figure 6 and

Table 10), a $C_{ZB} = 0.329$ is between 5° and 10° offset between the tip of the bulb and the top of the bulb (Figure 21), depending on the length of the bulb.

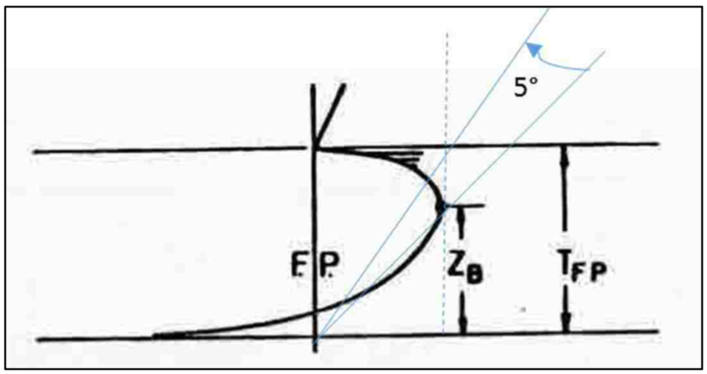

Figure 21. Bulb C_{ZB} interpretation

The increase in the pitch angle was accomplish by rotating the 0° bulb having the upper part of the bulb-pier intersection as a fix point; this approach create a series of bulbs were the upper length is the same regarding the pitch angle. Appendix A, Table 21 and Figure 60 describe different bulb families in terms of the upper bulb length.

The pitch angle is defined as the angle between the bulb horizontal axis and the bottom of the flume. The introduction of the pitch angle, corrected the spray problem and increases the PWR, for bulb with the same upper horizontal length (Figure 22). Experimental results also show that an increase in the pitch angle reduces the PL_{bb} by eliminating the flow over the bulb (Figure 23).

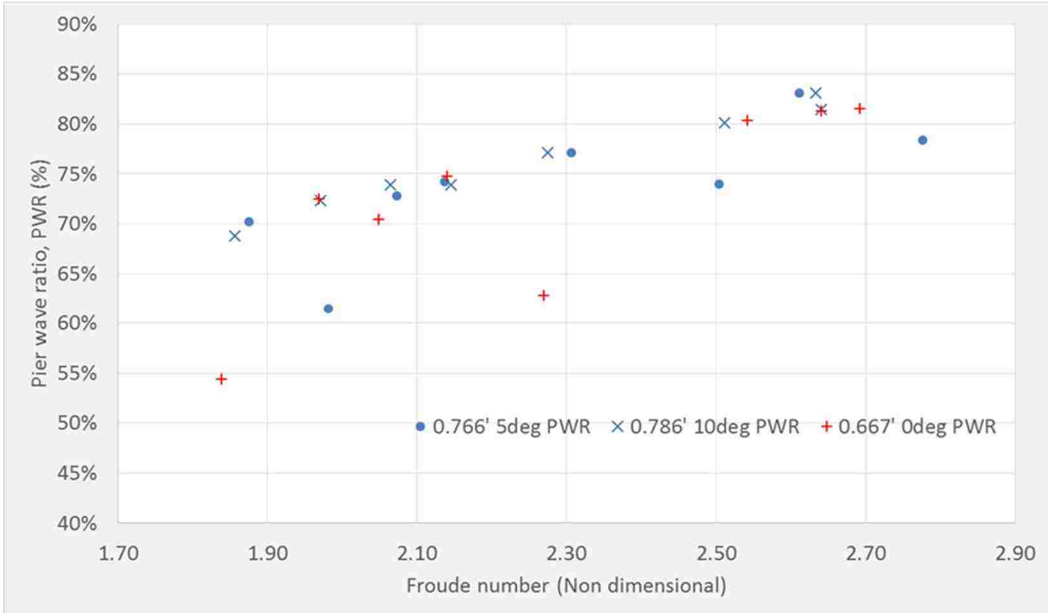

Figure 22. Pier Wave Ratio, PWR for bulbs with different pitch angles

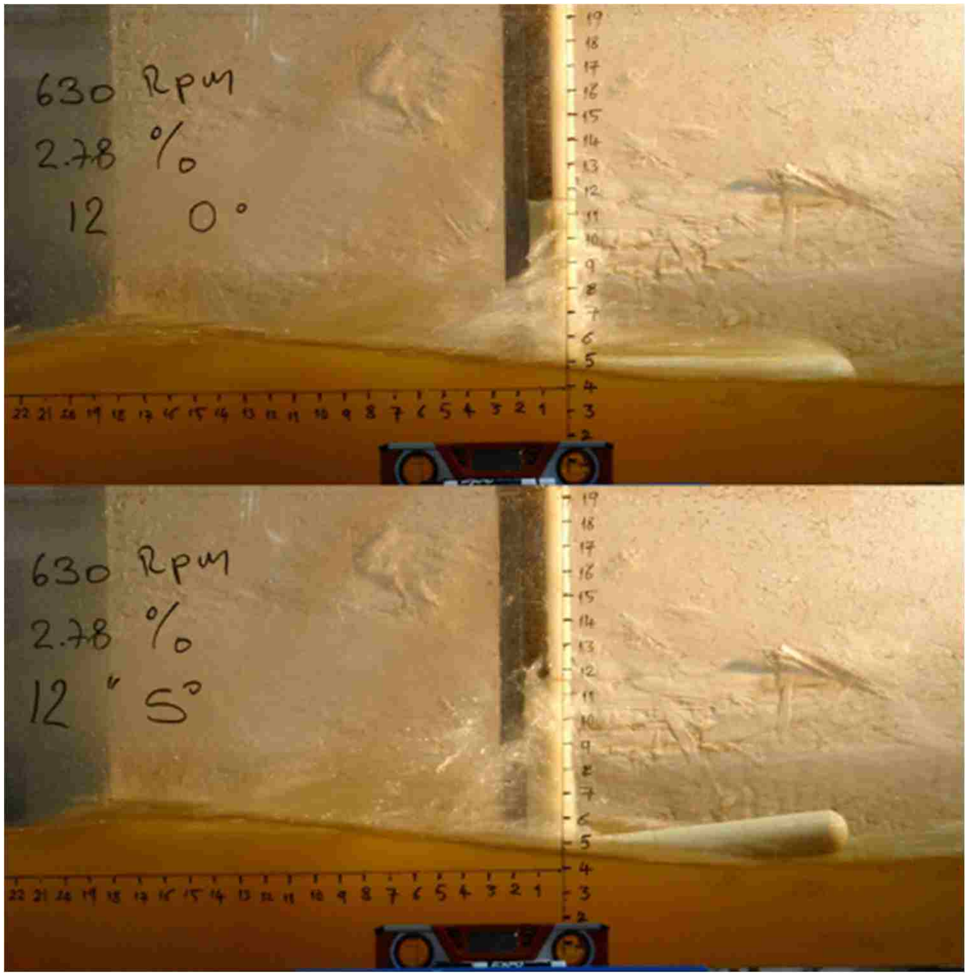

Figure 23. Bulbs spray problem, 0° and 5° pitch angle

For bulbous with 5° and 10 ° pitch, the bulbous submerge length is the bulbous length at the water line level (L_{bbs}). The reduction in L_{bbs} due to the introduction of the pitch angle, decreases PL_{bb} (see Figure 24), but provides the opportunity to brace the bulb tip to the pier once the tip clears the water line. The 0° pith angle bulb was discarded because of the large L_{bbs} required to eliminate the spraying problem.

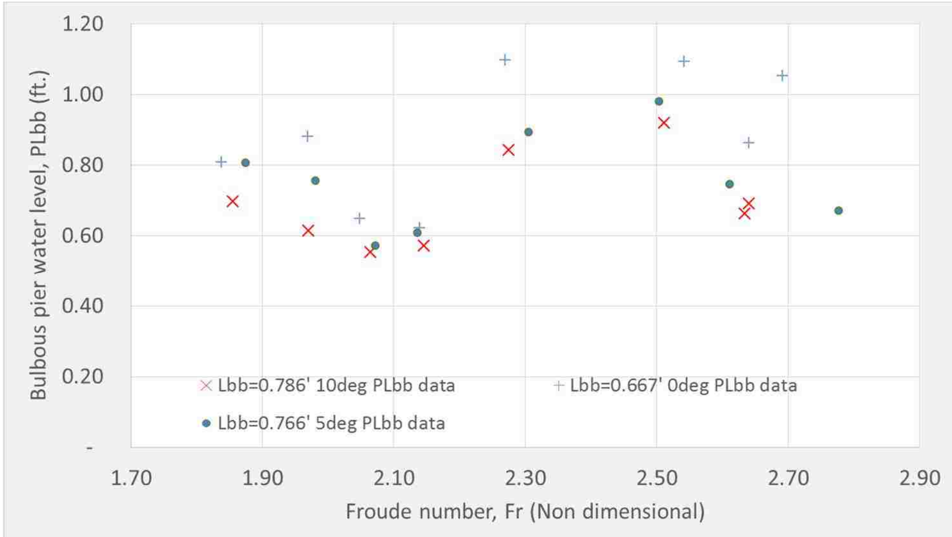

Figure 24. Bulbous pier water level for bulbs (PL_{bb}) with simmilar horizontal upper length, 0°, 5°, and 10° pitch angle

4.3. BULBOUS PIER WATER LEVEL

From Figure 25,

Figure 26, and Figure 27 (typical), the use of Equation 29 overestimate the value of the non-bulb pier water level ($PL_{nb\ calc}$) vs. the data collected for non-bulb pier water level ($PL_{nb\ data}$). This error propagates to the calculation of the theoretical bulbous pier water level ($PL_{bb\ calc}$). The overestimation is a consequence of the energy losses due to the fictional losses at the pier nose and the air-water interactions ignored by Equation 29. Appendix A, sections A1, A2, and A3 contain the experimental data and calculations for pier water level

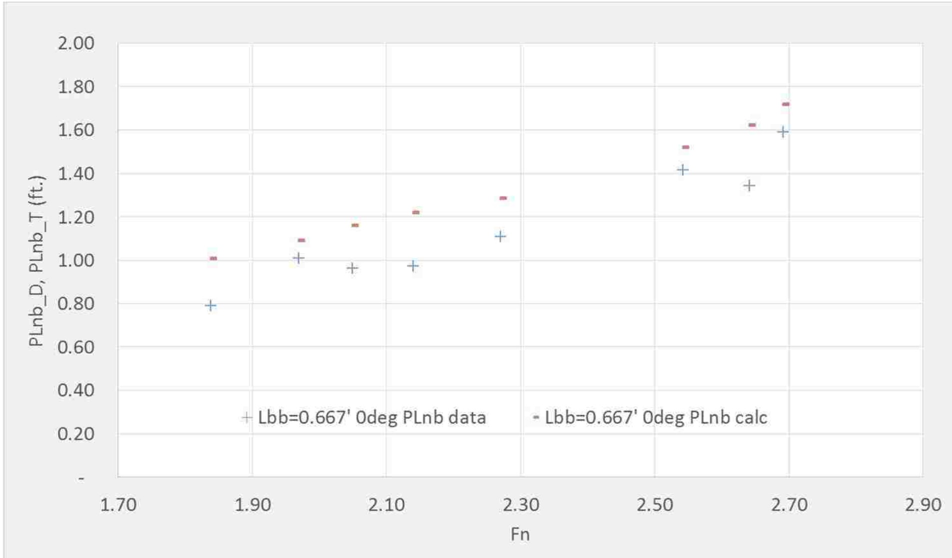

Figure 25. $PL_{nb\ data}$ and $PL_{nb\ calc}$ for bulbs with 0° pitch

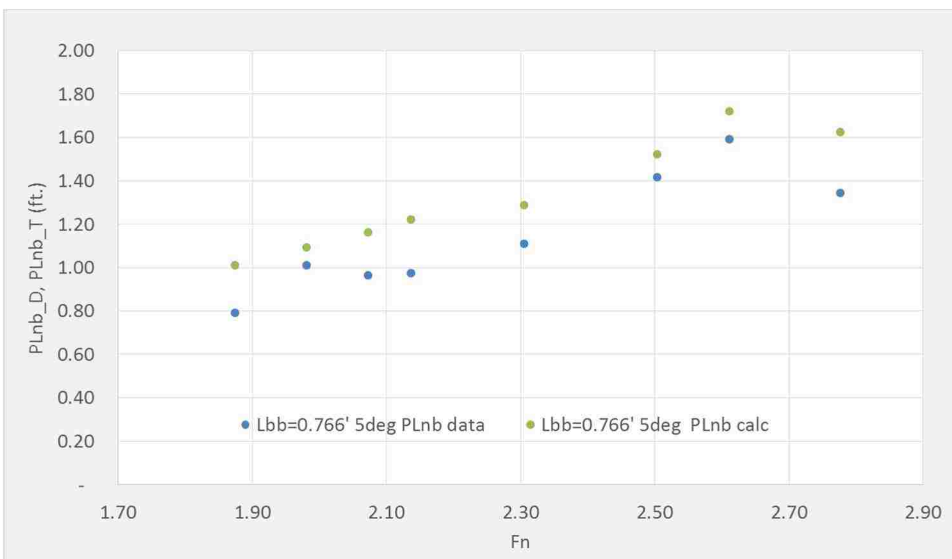

Figure 26. PL_{bb} data and PL_{bb} calc for bulbs with 5° pitch

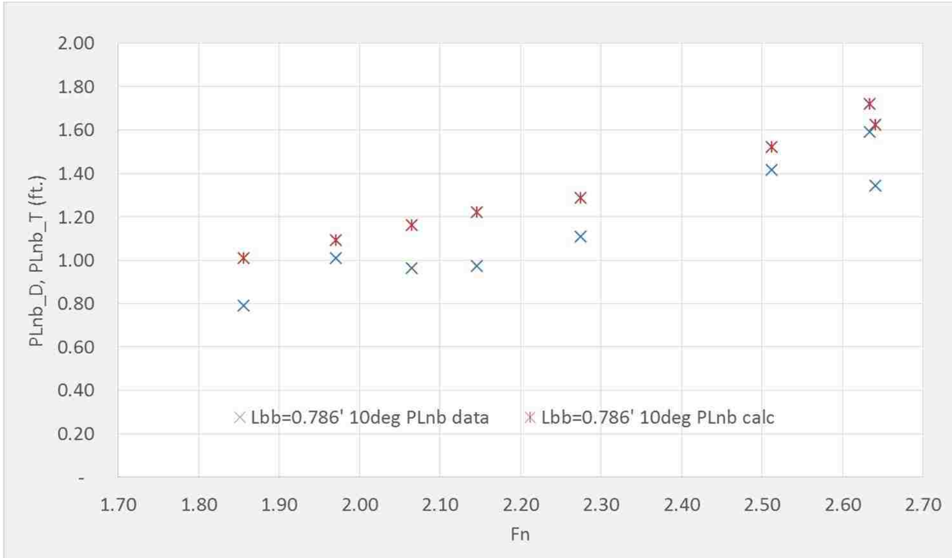

Figure 27. $PL_{bb\ data}$ and $PL_{bb\ calc}$ for bulbs with 10° pitch

4.4. BULB WAVE

The average bulb wave height (B_w) follows the form of the hull resistance curve as predicted (see Figure 28 and Figure 29, typical), in consequence, $R_{v,}$ and R_w can be calculated using the proposed set of equation for PL_{bb}. Appendix A, sections A1 and A4 contain the experimental data and calculations for bulb wave.

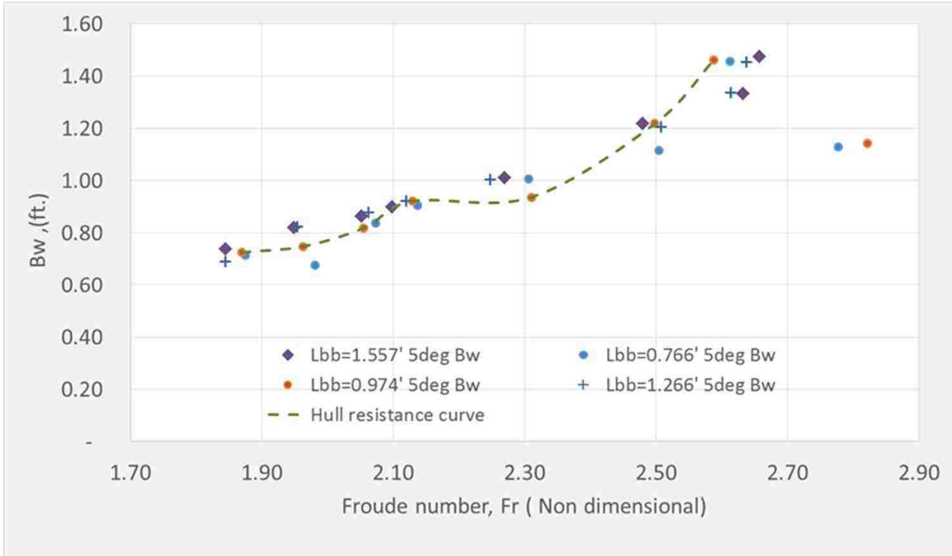

Figure 28. Bulb wave, B_w for 5° pitch angle bulb

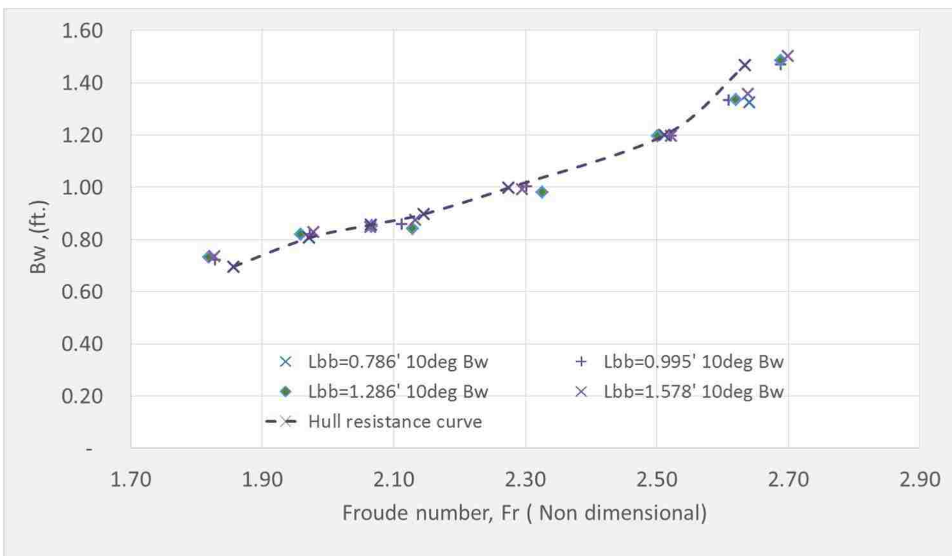

Figure 29. Bulb wave, B_w for 10° pitch angle bulb

For 10° bulbous with L_{bb} over 0.995 ft., L_{bb} is meaningless because once the bulbous tip is above the water, there no contribution to the L_{bbs}. PL_{bb} reading using the capacitive level meter have a large standard deviation; this is a consequence of the turbulent nature of the pier wave (Figure 30). To simplify the mathematical analysis, PL_{bb} maximum was selected to calculate B_w, this assumption is in line with the goal of preventing deck splashing.

Figure 30. Pier wave

4.5. BULBOUS VISCOUS AND WAVE-MAKING RESISTANCE

Appendix A, sections A1, and A contain the experimental data and calculations for the bulb wave components.

The hydraulic depth (Y_h) in the flume changes constantly due to the turbulent nature of the flow. Changes in Y_h affects the calculation of the bulbous submerge area (BB_{as}), attempts to reduce the flow turbulence while maintaining high water velocity were unsuccessful. Since the data recording system store over 3,000 points for test case (Table 13), a narrow range of Y_h ($4.4 < Yh < 4.6$ in.) was selected to get an statistical significant number of reading per test case ($n > 30$).

From Figure 31, Figure 32, and Figure 33, it is clear that the viscous resistance is the main component of the bulb wave height (Bw). According to ship hull design theory, the make-making resistance becomes dominant when the bulb-submerged length (Lbbs) is equal or greater than the bulb wavelength (Lw). For the zero degree pitch angle bulb, the submerge length is always less than the bulb wavelength, see Equation 49 and Figure 31. in consequence, Equation 34 can be modified to only include the viscous component (Equation 50). This assumption will underestimate the value of Bw at lower Fr number, were the bulb wavelength is closer to the L_{bbs}.

$$L_b = L_w = \frac{2\pi v^2}{g} \qquad \text{Equation 49}$$

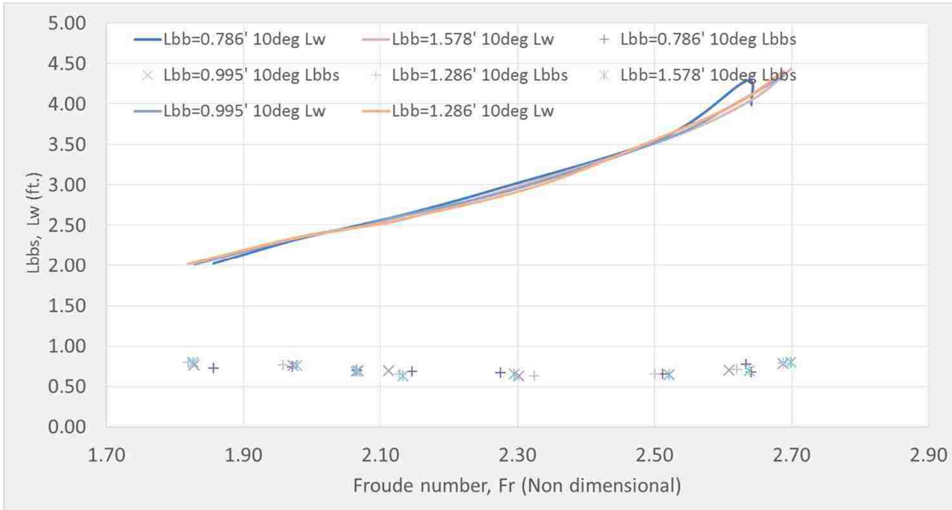

Figure 31. Bulb submerged length (L_{bbs}) and bulb wavelength (L_w), 5° pitch angle

$$B_w = B_{wv} \quad \text{Equation 50}$$

This approach will eliminate the need for a modeling each bulbous pier to obtain the B_{ww}. The cost of modeling a bulbous pier in a flume can easily exceed the cost of building a pier extension. Appendix A, section A1 and A3, contain all the experimental data for B_w, B_{wv} and B_{ww}.

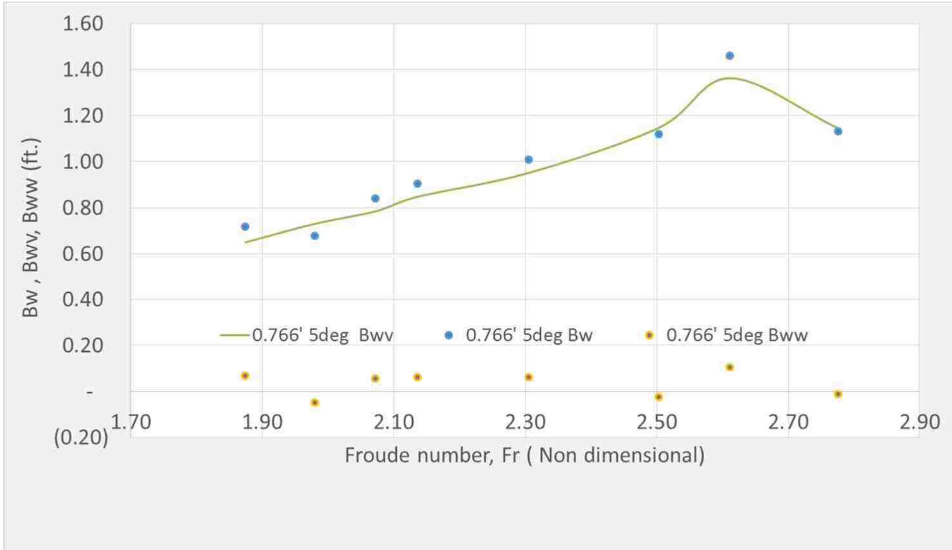

Figure 32. Bulb Wave (B_w), Viscous bulb wave, (B_{wv}) and wave-making bulb wave (B_{ww}) for bulbous pier with 5° pitch

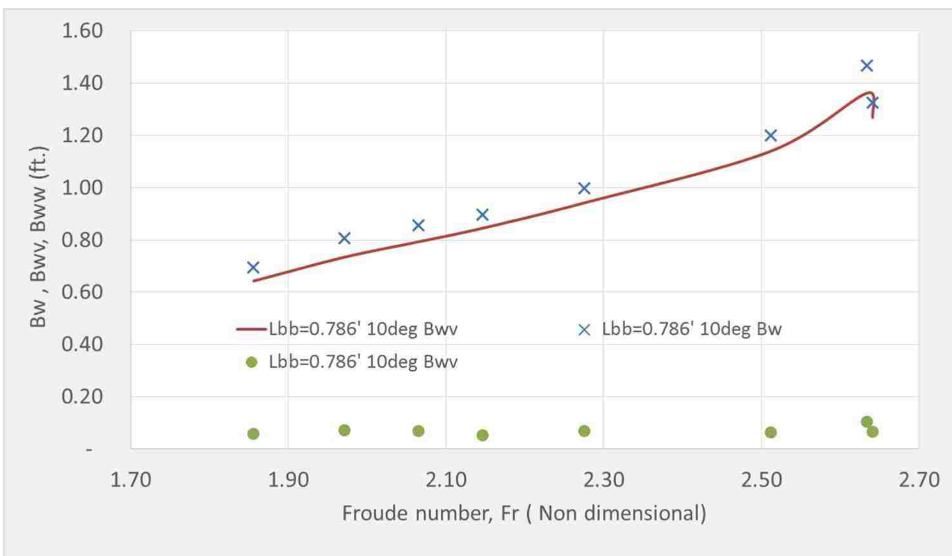

Figure 33. B_{wv} and B_{ww} for bulbous pier with 10° pitch

4.6. PIER WAVE LEVEL RATIO (PWR)

Appendix A, sections A1, A5, A6, and A7 contain the experimental data and calculations for pier wave ratio.

The propose equation to calculate pier wave ratio (PWR_{calc}) closely match the PWR experimental values (PWR_{data}). Figure 34 to Figure 35 compares the values of PWR_{data} vs. PWR_{calc}.

PWR_{cal} is more accurate for the bulbs with a pitch angle of 5˚ and 10˚; this is a consequence of the elimination of the water flowing over the bulbous for the 0˚ pitch bulb.

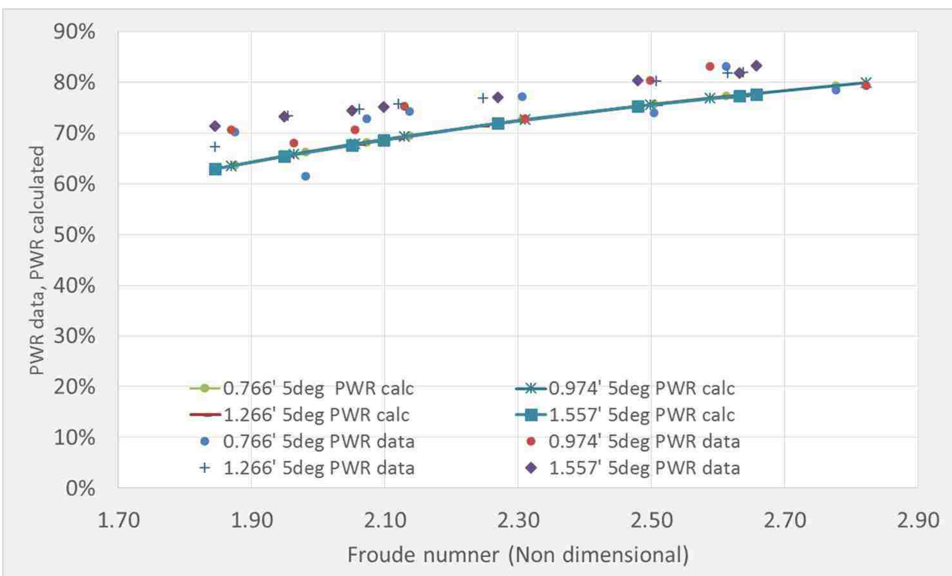

Figure 34. Pier wave ratio data (PWR_{data}) vs. pier wave ratio calculated (PWR_{calc}), bulbous pier with 5° pitch

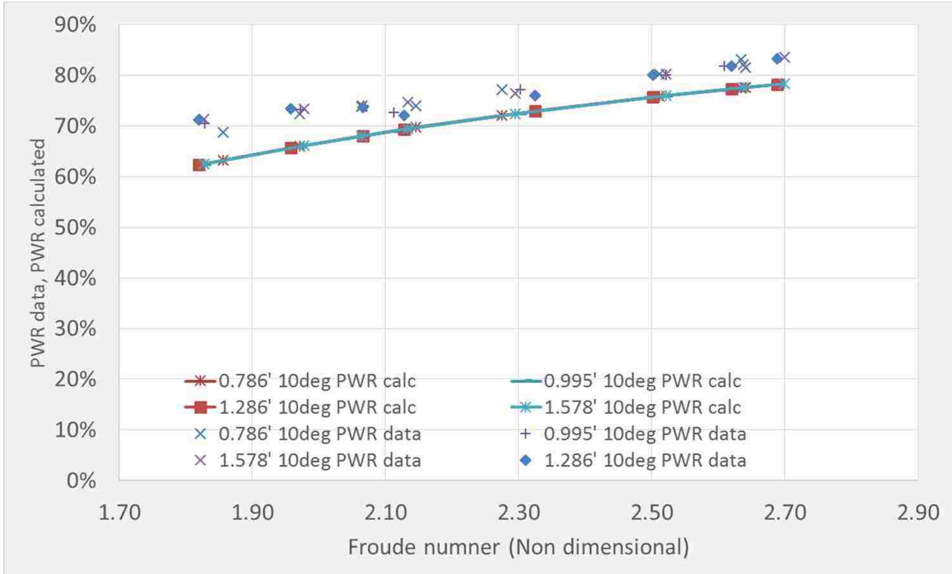

Figure 35. pier wave ratio data (PWR_{data}) and. pier wave ratio calculated ($PWR_{calculated}$) vs. Froude number (F_r), bulbous pier with 10° pitch

4.7. DESIGN CURVES FOR PIER WAVE REDUCTION

The experimental results show that that the bulb tip shall be above water to prevent deck spraying, in consequence, L_{bb} <0.9' shall be ignored.(see appendix A.7) For L_{bb}>1.2, the additional bulb length above the water do not contribute to the PWR (see appendix A.7). Only two bulbs meet these restrictions: Lbb=0.974 ft,@5deg and Lbb =0.786 ft@ 10deg. In order to translate the experimental result into full size bulb , the bulb length (L_{bb}) in the PWR vs. Froude number charts, is normalize by diving L_{bb} by the bulb submerge depth (Y_s); Figure 36 how Lbb and Y_S are measure in the bulb. The bulb submerges depth (Y_s) is base in the condition that the bulb only will submerged up to the bulb's longitudinal centerline.

The normalize values for the bulb length are described in Table 18, Table 19, and . The decision of using the 5˚ or the 10˚ bulb will require full size testing to evaluate the residual spaying problem detected in the 10˚ bulb and the deflection problem associated with a long bulbous (5˚). Figure 37and

Figure 38 show the normalize relation for the two bulbs.

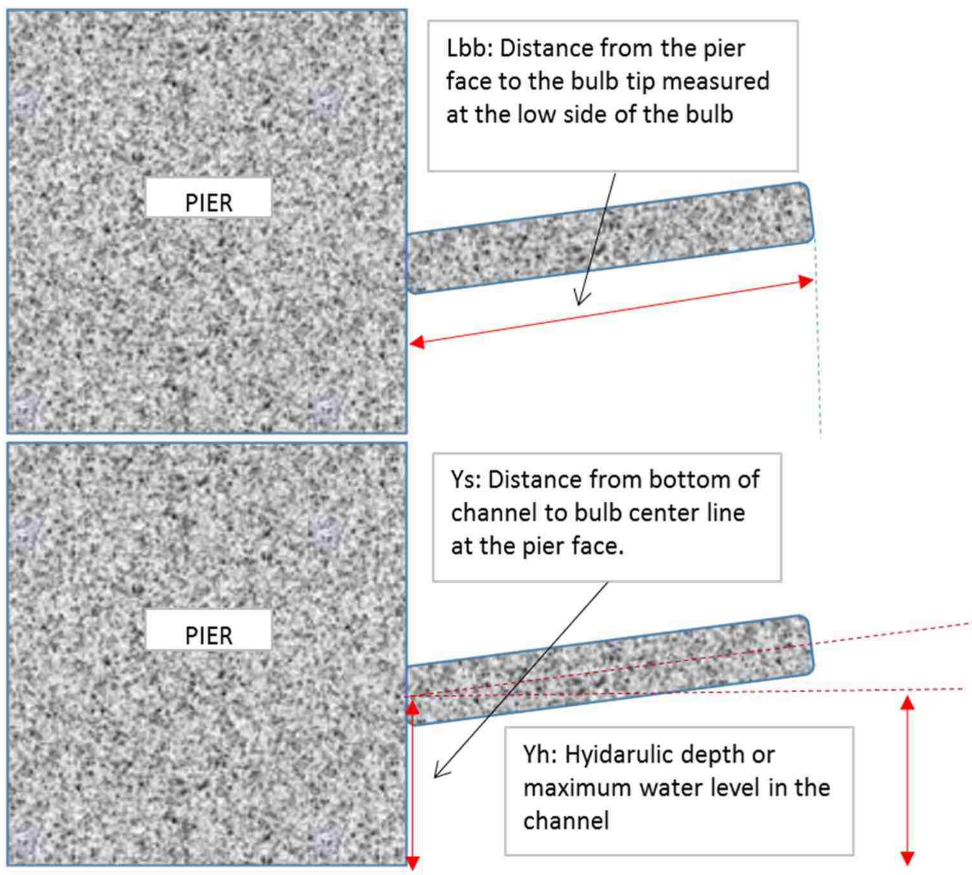

Figure 36. Normalize parameters description

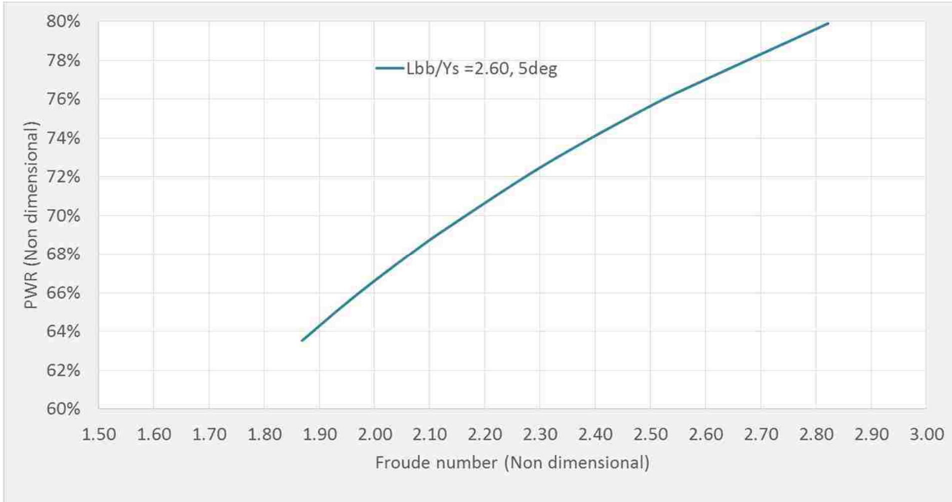

Figure 37. Proposed pier wave ratio approximation using normalize bulb length, 5˚ deg pitch angle, L_{bb}= 0.974’, Y_s= 0.375’

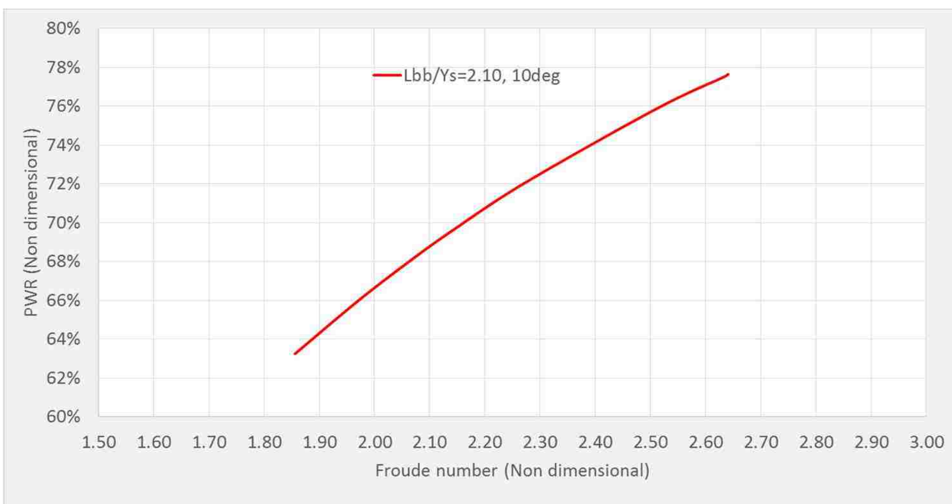

Figure 38. Proposed pier wave ratio approximation using normalize bulb length, 10˚deg pitch angle, L_{bb}= 0.786’, Y_s= 0.375

4.8. FLOW BEHAVIOR AFTER THE PIER-BULB INTERSECTION

The analysis of the water level after the bulb- pier intersection was not the subject of this research but the reduction of the water level for the bulbous pier case is a factor to consider in the selection of the bulbous pier length.

Table 14 illustrate the changes in the flume water level after the bulb, for the most cases the addition of the bulb reduces the water level for Froude numbers under 2.5 and maintain the flume water level for Froude number larger than 2.5. This can be attributed to a reduction in the water turbulence produced by the bulb (see Figure 39). The photographs in section A8 are the source for Table 14.

4.9. THE BULBOUS PIER VS. THE PIER EXTENSION

A quick cost comparison show that the cost of a 6 ft. steel pipe 12" diameter with a cap is about $700. The cost of pier extension can triple that cost.

A pier extension is designed and build for an specify range of flow conditions, if the open channel network is modified and the flow conditions change outside the original range the pier extension need to be modified, most likely to increase its length. The increase of the length in a pier extension is not a desirable outcome because every square foot of pier extension increases the energy subtracted from the flow. This energy subtraction may transform the flow from supercritical to subcritical, not desirable outcome. The bulbous pier smaller area subtracts less energy from the flow allowing a wider set of flow conditions.

Table 14. Water level after the bulb

Pump Speed (RPM)	Flume Slope (%)	Pitch angle (deg)	Bulb Length (ft.)	Froude number	Water level (in.)
550	1.24	0	-	1.85	7.0
550	1.24	0	1.25	1.80	5.5
550	1.24	5	1.27	1.84	6.0
550	1.24	10	1.29	1.81	6.0
568	1.99	0	-	2.05	5.5
568	1.99	0	1.25	2.03	5.0
568	1.99	5	1.27	2.06	5.0
568	1.99	10	1.29	2.06	5.0
570	2.38	0	-	2.13	5.1
570	2.38	0	1.25	2.10	5.2
570	2.38	5	1.27	2.11	5.0
570	2.38	10	1.29	2.12	5.0
601	1.59	0	-	1.97	8.0
601	1.59	0	1.25	1.94	7.5
601	1.59	5	1.27	1.95	7.0
601	1.59	10	1.29	1.95	6.8
630	2.78	0	-	2.25	8
630	2.78	0	1.25	2.26	6.5
630	2.78	5	1.27	2.24	6.5
630	2.78	10	1.29	2.31	6.0
714	3.16	0	-	2.49	6.0
714	3.16	0	1.25	2.52	6.0
714	3.16	5	1.27	2.50	6.0
714	3.16	10	1.29	2.49	6.0
750	3.59	0	-	2.59	5.5
750	3.59	0	1.25	2.58	5.5
750	3.59	5	1.27	2.60	5.5
750	3.59	10	1.29	2.60	5.5
765	4.26	0	-	2.70	4.5
765	4.26	0	1.25	2.63	5
765	4.26	5	1.27	2.63	4.5
765	4.26	10	1.29	2.68	4.5

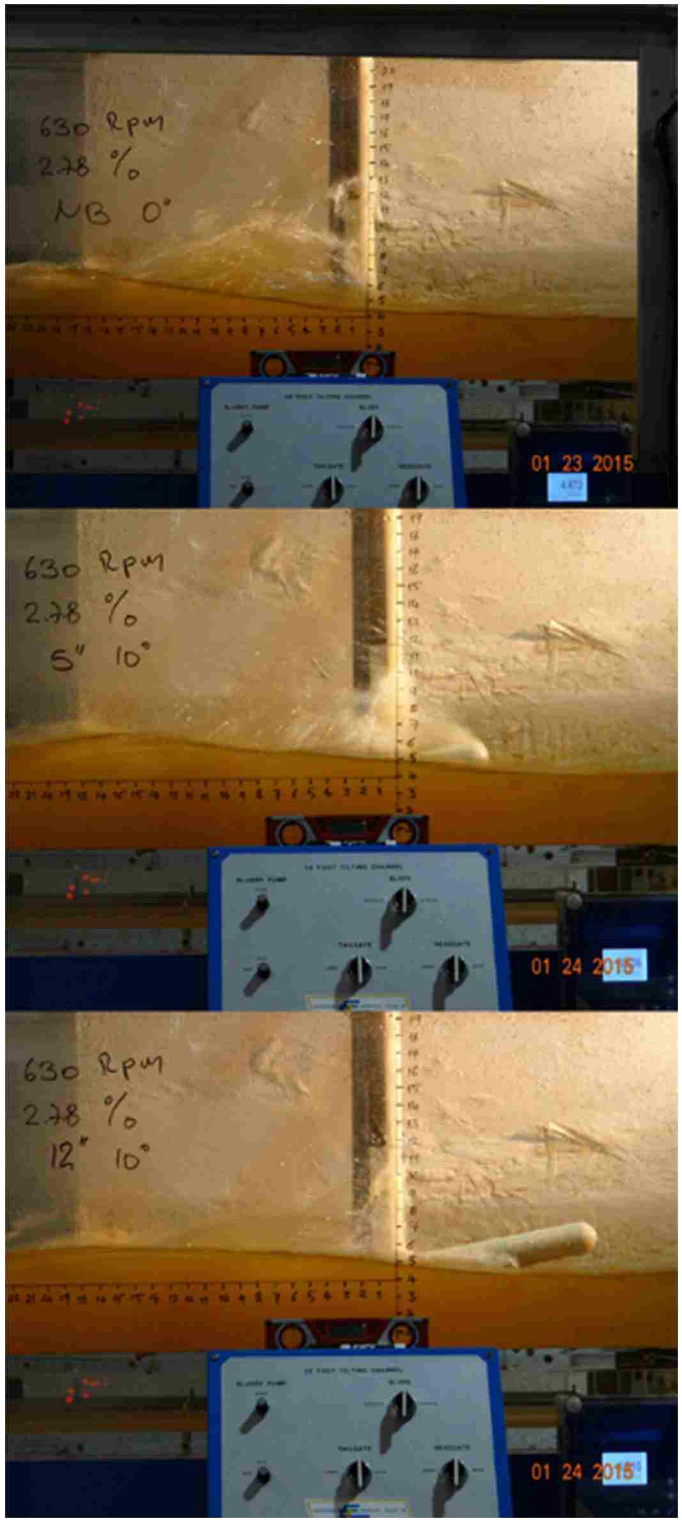

Figure 39**.** Water level after the pier-bulb intersection for a bulb with 10° pitch angle

CHAPTER 5: PROPOSED PIER BULBOUS DESIGN METHOD

For a given open channel with a pier, the following method is proposed:

5.1. GRAPHICAL METHOD

a Determine the open channel water depth (Y_h) via field data or open channel equations.

b The optimal bulb submerge depth (Y_s) is equivalent to the maximum hydraulic depth (Y_h) at bulb centerline, see Figure 40.

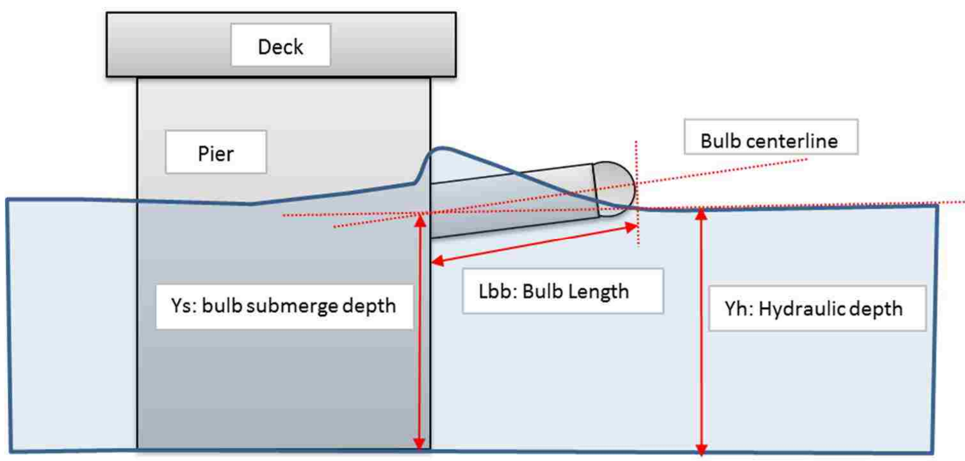

Figure 40. Definition of bulb submerge depth and bulbous length

c The bulb diameter shall be diameter shall be equal to the pier width.

d Determine the non-bulb pier wave height via Equation 51 or field value

$$PL_{nb\ calc} = E = y_h + \frac{V^2}{2g}$$ Equation 51

e Calculate the open channel Froude number (F_r).

f Using Figure 41 or Figure 42 determine L_{bb}/Y_s for the Froude number calculated in the previous step.

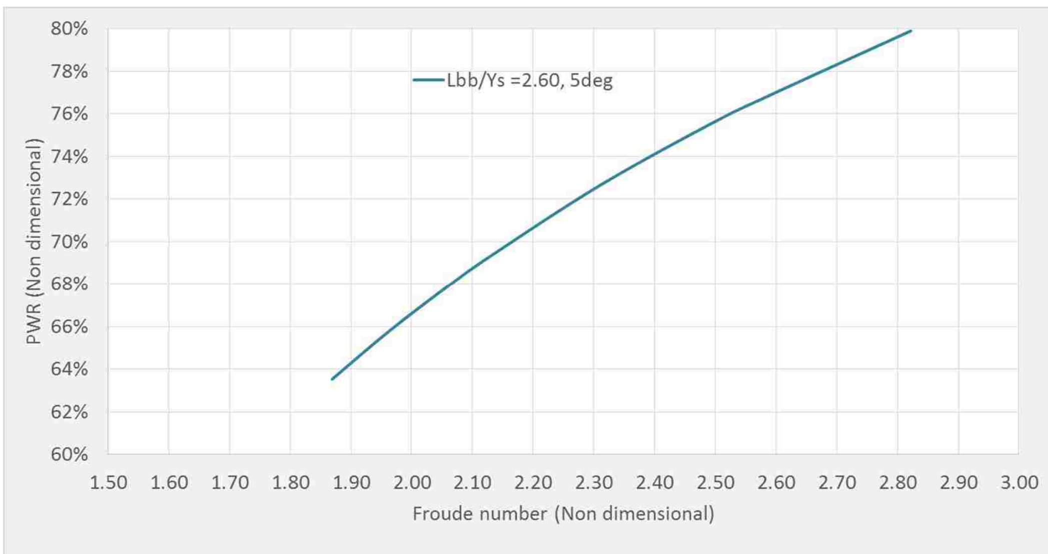

Figure 41. Proposed pier wave ratio approximation using normalize bulb length, 5˚deg pitch angle.

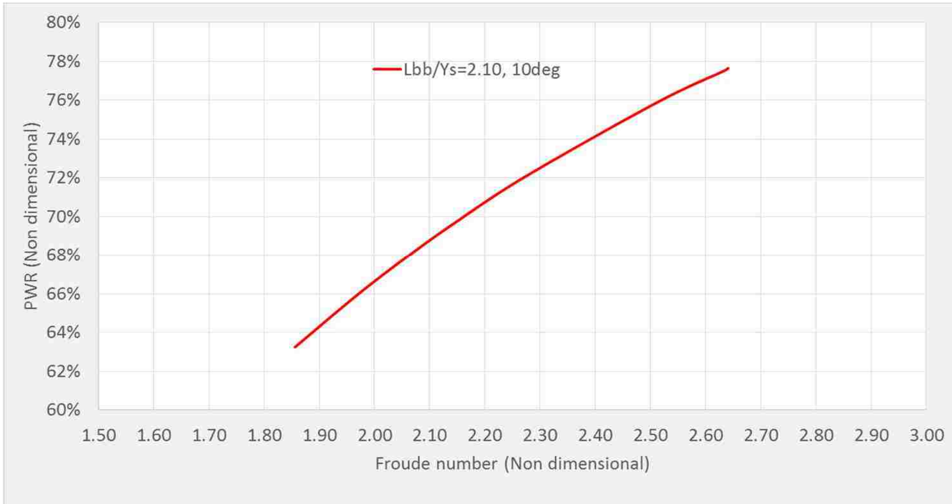

Figure 42. Proposed pier wave ratio approximation using normalize bulb length, 10˚deg pitch angle.

g Calculate the bulb length using the Y_s equal to Y_h

h Verify id the PWR reduces the pier wave to an acceptable level, if not the cylindrical bulbous is not a solution. In order to increase the PWR, the bulb submerges area need to be increased, this lead to a different bulb shape, a subject of further research.

5.2. GRAPHICAL METHOD CALCULATIONS

The calculations to generate Figure 41 and Figure 42 are as follows:

a Follow graphical method steps "a" to "e".

b Calculate Bulb length submerged (L_{bbs})

$$L_{bbs} = L_{bb}\cos(\emptyset) \qquad \text{Equation 52}$$

Where $\emptyset$ is the bulb pitch angle.

c Calculate the bulb Froude number using Equation 53.

$$F_r = \frac{v}{\sqrt{gL_{bbs}}} \qquad \text{Equation 53}$$

d Scale the bulb to experimental length by multiplying by 0.12 (the scaling factor).

e Calculate the equivalent velocity for the bulb by keeping the same bulb F_r

$$v = F_r\sqrt{g * L_{bbs}} \qquad \text{Equation 54}$$

f Determine PL_{nb} via field data or Equation 55

$$PL_{nb} = E = y_h + \frac{v^2}{2g} \qquad \text{Equation 55}$$

g Calculate PL_{bb} using the following equations:

$$R_e = \frac{vL_{bbs}}{k} \qquad \text{Equation 56}$$

Where v is the velocity, k is equal to 1.2260x10-5 ft2/s.

$$C_{vt} = \frac{0.075}{log10(R_e - 2)^2} \qquad \text{Equation 57}$$

$$V_{bb\ (cylinder)} = \frac{L_{bbs}r^2}{3Y_s}\left(\frac{3\sin(\emptyset) - 3\emptyset\cos(\emptyset) - \sin(\emptyset)^3}{1 - \cos(\emptyset)}\right) \qquad \text{Equation 58}$$

Where r is the cylinder radius.

$$k_n = 12\left(\frac{V_{bb}}{Y_s}\frac{B_d}{L_{bbs}}\right) \qquad \text{Equation 59}$$

Where B_d is the bulb diameter.

$$C_v = C_{vt} + C_{vt} \times k_n \qquad \text{Equation 60}$$

$$BB_{as\,(cylinder)} = 2L_{bbs}r\left(\frac{\sin(\emptyset) - \emptyset\cos(\emptyset)}{1 - \cos(\emptyset)}\right) \qquad \text{Equation 61}$$

$$R_v = 0.5\rho BB_{as}C_v v^2 \qquad \text{Equation 62}$$

$$v_{bb}^2 = v^2 - 2R_v L_{bbs} \qquad \text{Equation 63}$$

$$PL_{bb} = \frac{v_{bb}^2}{2g} \qquad \text{Equation 64}$$

h Calculate PWR using the following equations:

$$PWR = \frac{PL_{nb} - PL_{bb}}{PL_{nb}} \qquad \text{Equation 65}$$

i Verify id the PWR reduces the pier wave to an acceptable level, if not the cylindrical bulbous is not a solution. In order to increase the PWR, the bulb submerges area need to be increased, this lead to a different bulb shape, a subject of further research.

5.3. PROPOSED PIER BULBOUS CALCULATION EXAMPLE

Using the Duck Creek flood channel information provided Table 3 and Table 4, the following example illustrate the use graphical method (Table 15). Figure 43 show how the pier wave reduction will apply to the Duck Creek Bridge; the 63% reduction the pier wave accomplish the goal of reducing the pier wave to a level where it is minimum deck splashing.

Figure 43. Pier wave reduction example applied to the Duck Creek Bridge

Table 15. Proposed bulbous pier graphical design method.

Step	Description	Comment	Formula	Value	Units
1	Determine open channel water depth.	For the Duck Creek Case	Y_h=	5.5	ft.
2	Determine Y_s =$Y_{h,}$ for the cylindrical bulb.	For the Duck Creek Case	Y_s=	5.5	ft.
3	The bulb diameter shall be equal to the pier width.	For the Duck Creek Case, pier width =1.5 ft.	B_d =	1.5	ft.
4	Determine the non-bulb pier wave height.	For the Duck Creek Case	PL_{nb}=	7	ft.
5	Calculate the open channel Froude number (F_r).	For the Duck Creek Case, v= 22 ft/s	F_r=	1.85	
6	Using, Figure 41 or Figure 42 determine PWR.	For the Duck Creek, the 10° bulb was selected see Figure 44.	PWR=	63%	
7	Calculate the bulb length		L_{bb}= Y_s * 2.1	11.6	ft.
8	Determine PL_{bb}	PL_{bb}	PL_{bb}= PL_{nb} - PL_{nb}*PWR	2.59	ft.

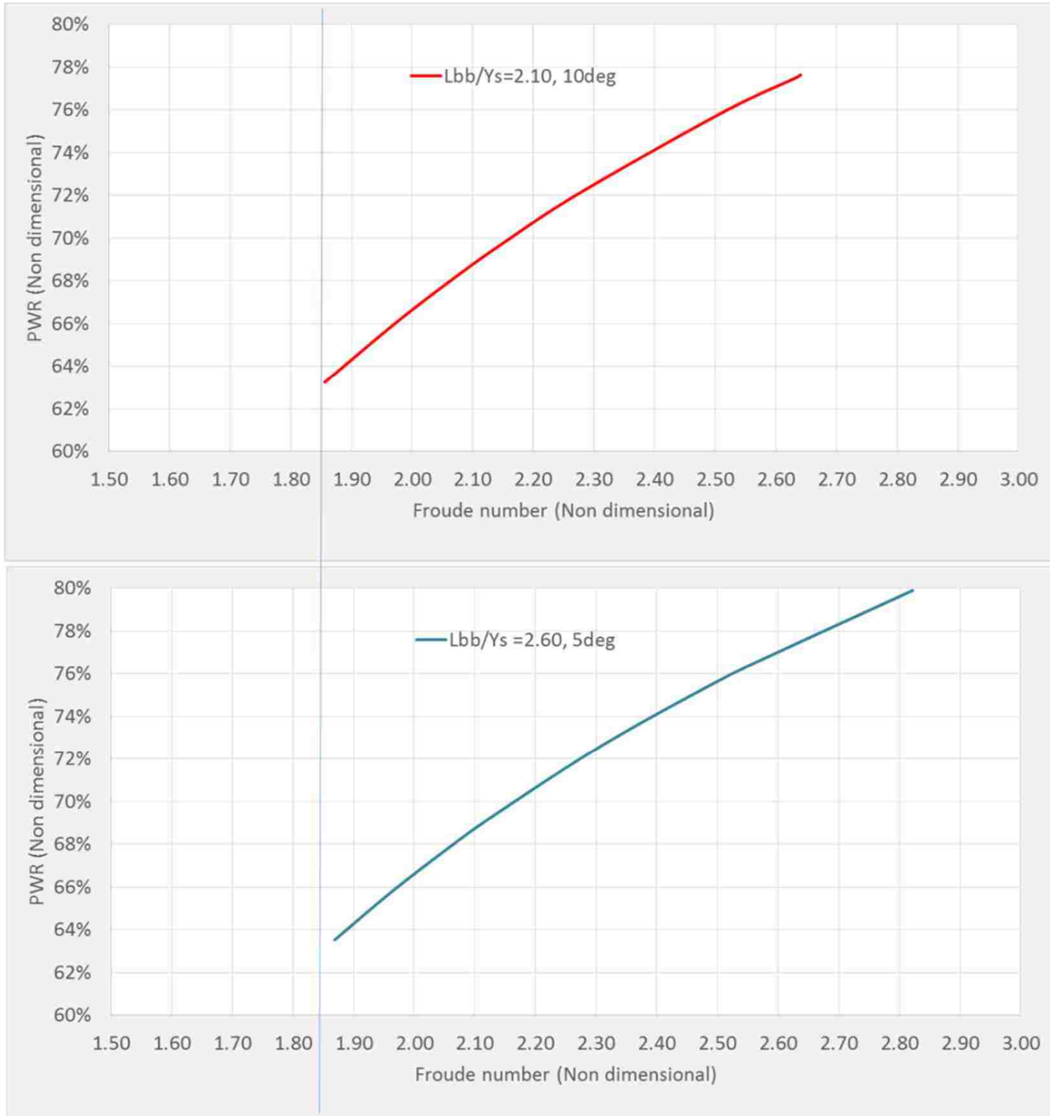

Figure 44. Graphical design method example.

CHAPTER 6: CONCLUSIONS AND RECOMMENDATIONS

6.1. CONCLUSIONS

1. Experimental values show that the bulbous pier reduces the pier wave height by subtracting energy from the water flow.
2. The viscous resistance is the main component in the pier wave height (PL_{bb}); this is due to the bulb length been less than the bulb wavelength.
3. The zero degree pitch angle bulbous pier is too long for practical application; to achieve pier reduction in the order of 0.4 the bulb length is above 10 ft.
4. The introduction of the pitch angle in the bulb reduces the length of the bulb at the water line by eliminating the flow over the bulb; this modification addresses the constructability problem of a long bulbous.
5. The non-bulbous pier water level ($PL_{nb\ calc}$) overestimates the water height in comparison with the experimental data ($PL_{nb\ data}$).
6. Making the viscous resistance the only force in the calculation of B_w underestimates it.
7. For practical application, PWR_{calc} provides a good approximation to the expected reduction in the pier wave level.

6.2. RECOMMENDATIONS

1. Full size model trials are recommended before using the pier bulbous in lieu of per extensions.

2. The cylindrical bulbous was selected based in the literature review but it is possible that other bulb shapes can outperform the cylindrical bulb; research is needed in this area.
3. The narrow channel effect documented in the literature review may be responsible for the distinct bulb wave found in the 0.958’ and 0.974’, research is needed in this area.
4. The pitch angles used in this research are extrapolation of the parameter used for bulbous bows. Finding the optimum bulb pitch angle requires additional research.

APPENDIX A: EXPERIMENTAL RESULT TABLES, FIGURES AND PICTURES

A.1. EXPERIMENTAL DATA TABLES

Table 16. Hypothesis testing: PL_{nb} vs. PL_{bb}

Two-Sample T-Test and CI: PLnb_T, PLbb_D, L_{bb} = 0.667 ft. Pitch Angle = 0°

```
Two-sample T for PLnb_T vs. PLbb_D

            N   Mean  StDev  SE Mean
PLnb_T  32000  1.323  0.239   0.0013
PLbb_D  32000  0.679  0.153  0.00085


Difference = μ (PLnb_T) - μ (PLbb_D)
Estimate for difference:  0.64407
95% lower bound for difference:  0.64146
T-Test of difference = 0.7 (vs. >): T-Value = -35.33  P-Value = 1.000  DF =
63998
Both use Pooled StDev = 0.2003
```

P-value> 0.05 DO NOT REJECT H_0
Minitab 17 report

Two-Sample T-Test and CI: PLnb_T, PLbb_D, L_{bb} = 0.958 ft. Pitch Angle = 0°

```
Two-sample T for PLnb_T vs. PLbb_D

            N   Mean  StDev  SE Mean
PLnb_T  32000  1.325  0.236   0.0013
PLbb_D  32000  0.636  0.142  0.00079


Difference = μ (PLnb_T) - μ (PLbb_D)
Estimate for difference:  0.68873
95% lower bound for difference:  0.68619
T-Test of difference = 0.7 (vs. >): T-Value = -7.31  P-Value = 1.000  DF =
63998
Both use Pooled StDev = 0.1949
```

P-value> 0.05 DO NOT REJECT H_0
Minitab 17 report

Two-Sample T-Test and CI: PLnb_T, PLbb_D, L_{bb} =1.25 ft. Pitch Angle = 0°

```
Two-sample T for PLnb_T vs. PLbb_D

            N   Mean  StDev  SE Mean
PLnb_T  32000  1.327  0.238   0.0013
PLbb_D  32000  0.617  0.132  0.00074


Difference = μ (PLnb_T) - μ (PLbb_D)
Estimate for difference:  0.71021
95% lower bound for difference:  0.70771
T-Test of difference = 0.8 (vs. >): T-Value = -58.96  P-Value = 1.000  DF =
63998
Both use Pooled StDev = 0.1926
```

P-value> 0.05 DO NOT REJECT H_0
Minitab 17 report

Two-Sample T-Test and CI: PLnb_T, PLbb_D, L_{bb} =1.542 ft. Pitch Angle = 0°

```
Two-sample T for PLnb_T vs. PLbb_D

            N   Mean  StDev  SE Mean
PLnb_T  32000  1.330  0.237   0.0013
PLbb_D  32000  0.590  0.129  0.00072


Difference = μ (PLnb_T) - μ (PLbb_D)
Estimate for difference:  0.73990
95% lower bound for difference:  0.73742
T-Test of difference = 0.8 (vs. >): T-Value = -39.86  P-Value = 1.000  DF =
49433
```

P-value> 0.05 DO NOT REJECT H_0
Minitab 17 report

Two-Sample T-Test and CI: PLnb_T, PLbb_D, L_{bb} =1.542 ft. Pitch Angle = 0°

```
Two-sample T for PLnb_T vs. PLbb_D

            N   Mean  StDev  SE Mean
PLnb_T  32000  1.330  0.236   0.0013
PLbb_D  32000  0.584  0.123  0.00069


Difference = μ (PLnb_T) - μ (PLbb_D)
Estimate for difference:  0.74570
95% lower bound for difference:  0.74326
T-Test of difference = 0.8 (vs. >): T-Value = -36.51  P-Value = 1.000  DF =
48
```

P-value> 0.05 DO NOT REJECT H_0
Minitab 17 report

Two-Sample T-Test and CI: PLnb_T, PLbb_D, L_{bb} =0.766 ft. Pitch Angle = 5°

```
Two-sample T for PLnb_T vs. PLbb_D

            N   Mean  StDev  SE Mean
PLnb_T  16000  1.311  0.228   0.0018
PLbb_D  16000  0.625  0.123  0.00097


Difference = μ (PLnb_T) - μ (PLbb_D)
Estimate for difference:  0.68658
95% lower bound for difference:  0.68321
T-Test of difference = 0.8 (vs. >): T-Value = -55.44  P-Value = 1.000  DF =
24612
```

P-value> 0.05 DO NOT REJECT H_0
Minitab 17 report

Two-Sample T-Test and CI: PLnb_T, PLbb_D, L_{bb} =0.974 ft. Pitch Angle = 5°

```
Two-sample T for PLnb_T vs. PLbb_D

            N   Mean  StDev  SE Mean
PLnb_T  16000  1.315  0.228   0.0018
PLbb_D  16000  0.569  0.125  0.00099


Difference = μ (PLnb_T) - μ (PLbb_D)
Estimate for difference:  0.74627
95% lower bound for difference:  0.74288
T-Test of difference = 0.8 (vs. >): T-Value = -26.09  P-Value = 1.000  DF =
24860
```

P-value> 0.05 DO NOT REJECT H_0
Minitab 17 report

Two-Sample T-Test and CI: PLnb_T, PLbb_D, L_{bb} =1.266 ft. Pitch Angle = 5°

```
Two-sample T for PLnb_T vs. PLbb_D

            N    Mean   StDev  SE Mean
PLnb_T  16000   1.342   0.247   0.0020
PLbb_D  16000  0.4907  0.0874  0.00069


Difference = μ (PLnb_T) - μ (PLbb_D)
Estimate for difference:  0.85145
95% lower bound for difference:  0.84805
T-Test of difference = 0.9 (vs. >): T-Value = -23.46  P-Value = 1.000  DF =
19951
```

P-value> 0.05 DO NOT REJECT H_0
Minitab 17 report

Two-Sample T-Test and CI: PLnb_T, PLbb_D, L_{bb} =1.557 ft. Pitch Angle = 5

```
Two-sample T for PLnb_T vs. PLbb_D

            N    Mean   StDev  SE Mean
PLnb_T  16000   1.340   0.246   0.0019
PLbb_D  16000  0.4778  0.0962  0.00076


Difference = μ (PLnb_T) - μ (PLbb_D)
Estimate for difference:  0.86229
95% lower bound for difference:  0.85886
T-Test of difference = 0.9 (vs. >): T-Value = -18.08  P-Value = 1.000  DF =
20790
```

P-value> 0.05 DO NOT REJECT H_0
Minitab 17 report

Two-Sample T-Test and CI: PLnb_T, PLbb_D , L_{bb} =0.787 ft. Pitch Angle = 10

```
Two-sample T for PLnb_T vs. PLbb_D

            N   Mean  StDev  SE Mean
PLnb_T  16000  1.335  0.248   0.0020
PLbb_D  16000  0.571  0.112  0.00088


Difference = μ (PLnb_T) - μ (PLbb_D)
Estimate for difference:  0.76362
95% lower bound for difference:  0.76008
T-Test of difference = 0.9 (vs. >): T-Value = -63.44  P-Value = 1.000  DF =
22258
```

P-value> 0.05 DO NOT REJECT H_0
Minitab 17 report

Two-Sample T-Test and CI: PLnb_T, PLbb_D, L_{bb} =0.995 ft. Pitch Angle = 10

```
Two-sample T for PLnb_T vs. PLbb_D

            N    Mean   StDev  SE Mean
PLnb_T  16000   1.334   0.249   0.0020
PLbb_D  16000  0.5207  0.0961  0.00076


Difference = μ (PLnb_T) - μ (PLbb_D)
Estimate for difference:  0.81298
95% lower bound for difference:  0.80951
T-Test of difference = 0.9 (vs. >): T-Value = -41.27  P-Value = 1.000  DF =
20666
```

P-value> 0.05 DO NOT REJECT H_0
Minitab 17 report

Two-Sample T-Test and CI: PLnb_T, PLbb_D, L_{bb} =1.286 ft. Pitch Angle = 10

```
Two-sample T for PLnb_T vs. PLbb_D

            N    Mean   StDev  SE Mean
PLnb_T  16000   1.336   0.255   0.0020
PLbb_D  16000  0.5211  0.0909  0.00072


Difference = μ (PLnb_T) - μ (PLbb_D)
Estimate for difference:  0.81494
95% lower bound for difference:  0.81141
T-Test of difference = 0.9 (vs. >): T-Value = -39.71  P-Value = 1.000  DF =
19993
```

P-value> 0.05 DO NOT REJECT H_0
Minitab 17 report

Two-Sample T-Test and CI: PLnb_T, PLbb_D, L_{bb} =1.578 ft. Pitch Angle = 10

```
Two-sample T for PLnb_T vs. PLbb_D

            N   Mean  StDev  SE Mean
PLnb_T  16000  1.340  0.259   0.0020
PLbb_D  16000  0.522  0.108  0.00086


Difference = μ (PLnb_T) - μ (PLbb_D)
Estimate for difference:  0.81776
95% lower bound for difference:  0.81411
T-Test of difference = 0.9 (vs. >): T-Value = -37.08  P-Value = 1.000  DF =
21448
```

P-value> 0.05 DO NOT REJECT H_0
Minitab 17 report

Pitch Angle	Slope (%)	Lbb (ft.)	Avg of Froude	Max PLnb data (ft.)	Max PLnb calc (ft.)	Yh (ft.)	Max of Velocity (ft/s)	Max of Bw (ft)	Max of Rv (lbf)	Max of BWv (ft.)	Max of BWw (ft.)	Max of Lbbs (ft.)	Max of Reynolds	Max of Bbsa (ft2)	Max of PLbb data (ft.)	Max of PLbb calc (ft.)	PWR data	PWR calc	Max of PLnb calc (ft.)	Max of PLnb data (ft.)	Lw (ft.)	Lbb/Ybs
nb	1.24	-	1.86	0.85	1.02	0.37	6.44	-	-	-	-	-	-	-	-	-	0%	0%	1.02	0.85		-
nb	1.59	-	1.98	1.02	1.10	0.37	6.85	-	-	-	-	-	-	-	-	-	0%	0%	1.10	1.02		-
nb	1.99	-	2.05	1.00	1.16	0.38	7.12	-	-	-	-	-	-	-	-	-	0%	0%	1.16	1.00		-
nb	2.38	-	2.14	1.05	1.22	0.37	7.40	-	-	-	-	-	-	-	-	-	0%	0%	1.22	1.05		-
nb	2.78	-	2.26	1.14	1.29	0.37	7.73	-	-	-	-	-	-	-	-	-	0%	0%	1.29	1.14		-
nb	3.16	-	2.49	1.54	1.52	0.37	8.61	-	-	-	-	-	-	-	-	-	0%	0%	1.52	1.54		-
nb	3.59	-	2.60	1.87	1.63	0.37	8.99	-	-	-	-	-	-	-	-	-	0%	0%	1.63	1.87		-
nb	4.26	-	2.71	1.76	1.72	0.37	9.32	-	-	-	-	-	-	-	-	-	0%	0%	1.72	1.76		-

Table 17. Non-bulb pier data

Pitch Angle	Slope (%)	Lbb (ft.)	Avg of Froude	Max PLnb data (ft.)	Max PLnb calc (ft.)	Yh (ft.)	Max of Velocity (ft/s)	Max of Bw (ft)	Max of Rv (lbf)	Max of BWv (ft.)	Max of BWw (ft.)	Max of Lbbs (ft.)	Max of Reynolds	Max of Bbsa (ft2)	Max of PLbb data (ft.)	Max of PLbb calc (ft.)	PWR data	PWR calc	Max of PLnb calc (ft.)	Max of PLnb data (ft.)	Lw (ft.)	Lbb/Ybs
-	1.24	0.667	1.84	0.81	1.00	0.38	6.37	0.54	0.01	0.63	(0.08)	0.67	346,384	0.17	0.81	0.38	54%	63%	1.01	0.79	1.98	1.78
-	1.59	0.667	1.97	0.88	1.11	0.38	6.87	0.80	0.01	0.73	0.07	0.67	373,573	0.17	0.88	0.38	72%	66%	1.09	1.01	2.30	1.78
-	1.99	0.667	2.05	0.65	1.17	0.38	7.13	0.82	0.02	0.79	0.03	0.67	387,711	0.17	0.65	0.38	70%	68%	1.16	0.96	2.48	1.78
-	2.38	0.667	2.14	0.62	1.22	0.37	7.40	0.91	0.02	0.85	0.06	0.67	402,393	0.17	0.62	0.37	75%	70%	1.22	0.97	2.67	1.78
-	2.78	0.667	2.27	1.10	1.30	0.37	7.77	0.82	0.03	0.94	(0.12)	0.67	422,512	0.17	1.10	0.37	63%	72%	1.29	1.11	2.95	1.78
-	3.16	0.667	2.54	1.09	1.52	0.36	8.63	1.21	0.04	1.16	0.06	0.67	469,277	0.17	1.09	0.36	80%	76%	1.52	1.42	3.64	1.78
-	3.59	0.667	2.64	0.86	1.64	0.37	9.05	1.33	0.05	1.27	0.06	0.67	492,115	0.17	0.86	0.37	81%	78%	1.62	1.34	4.00	1.78
-	4.26	0.667	2.69	1.05	1.75	0.38	9.39	1.42	0.06	1.37	0.06	0.67	510,604	0.17	1.05	0.38	82%	78%	1.72	1.59	4.30	1.78
-	**1.24**	**0.958**	**1.83**	**0.69**	**1.03**	**0.39**	**6.43**	**0.71**	**0.01**	**0.64**	**0.07**	**0.96**	**502,617**	**0.25**	**0.69**	**0.39**	**69%**	**63%**	**1.01**	**0.79**	**2.02**	2.56
-	**1.59**	**0.958**	**1.96**	**0.86**	**1.12**	**0.38**	**6.87**	**0.81**	**0.02**	**0.73**	**0.08**	**0.96**	**537,011**	**0.25**	**0.86**	**0.38**	**73%**	**66%**	**1.09**	**1.01**	**2.30**	2.56
-	**1.99**	**0.958**	**2.06**	**0.56**	**1.17**	**0.38**	**7.14**	**0.87**	**0.02**	**0.79**	**0.08**	**0.96**	**558,116**	**0.25**	**0.56**	**0.38**	**75%**	**68%**	**1.16**	**0.96**	**2.49**	2.56
-	**2.38**	**0.958**	**2.13**	**0.58**	**1.22**	**0.37**	**7.38**	**0.91**	**0.03**	**0.85**	**0.07**	**0.96**	**576,876**	**0.25**	**0.58**	**0.37**	**75%**	**69%**	**1.22**	**0.97**	**2.66**	2.56
-	**2.78**	**0.958**	**2.27**	**0.93**	**1.30**	**0.37**	**7.77**	**1.00**	**0.03**	**0.94**	**0.07**	**0.96**	**607,361**	**0.25**	**0.93**	**0.37**	**77%**	**72%**	**1.29**	**1.11**	**2.95**	2.56
-	**3.16**	**0.958**	**2.53**	**0.99**	**1.52**	**0.37**	**8.63**	**1.22**	**0.06**	**1.16**	**0.07**	**0.96**	**674,585**	**0.25**	**0.99**	**0.37**	**80%**	**76%**	**1.52**	**1.42**	**3.64**	2.56
-	**3.59**	**0.958**	**2.66**	**0.83**	**1.62**	**0.36**	**9.01**	**1.28**	**0.07**	**1.26**	**0.03**	**0.96**	**704,289**	**0.25**	**0.83**	**0.36**	**79%**	**78%**	**1.62**	**1.34**	**3.96**	2.56
-	**4.26**	**0.958**	**2.67**	**1.01**	**1.76**	**0.39**	**9.41**	**1.44**	**0.08**	**1.37**	**0.07**	**0.96**	**735,556**	**0.25**	**1.01**	**0.39**	**82%**	**78%**	**1.72**	**1.59**	**4.32**	2.56
-	1.24	1.250	1.81	0.63	1.03	0.39	6.42	0.68	0.02	0.64	0.05	1.25	654,568	0.33	0.63	0.39	67%	62%	1.01	0.79	2.01	3.33
-	1.59	1.250	1.95	0.81	1.12	0.39	6.88	0.82	0.02	0.73	0.09	1.25	701,468	0.33	0.81	0.39	74%	65%	1.09	1.01	2.31	3.33
-	1.99	1.250	2.04	0.52	1.16	0.38	7.11	0.85	0.03	0.78	0.06	1.25	724,918	0.33	0.52	0.38	73%	67%	1.16	0.96	2.47	3.33
-	2.38	1.250	2.11	0.53	1.22	0.38	7.37	0.91	0.03	0.84	0.08	1.25	751,427	0.33	0.53	0.38	75%	69%	1.22	0.97	2.65	3.33
-	2.78	1.250	2.27	0.84	1.31	0.37	7.80	1.00	0.04	0.94	0.07	1.25	795,269	0.33	0.84	0.37	77%	72%	1.29	1.11	2.97	3.33
-	3.16	1.250	2.53	0.84	1.53	0.37	8.67	1.22	0.07	1.17	0.06	1.25	883,972	0.33	0.84	0.37	80%	76%	1.52	1.42	3.67	3.33
-	3.59	1.250	2.59	0.84	1.64	0.38	9.02	1.34	0.08	1.26	0.08	1.25	919,658	0.33	0.84	0.38	82%	77%	1.62	1.34	3.97	3.33
-	4.26	1.250	2.65	0.99	1.76	0.39	9.39	1.46	0.10	1.37	0.10	1.25	957,382	0.33	0.99	0.40	83%	78%	1.72	1.59	4.30	3.33
-	**1.24**	**1.542**	**1.80**	**0.65**	**1.04**	**0.40**	**6.43**	**0.71**	**0.02**	**0.64**	**0.08**	**1.54**	**808,558**	**0.40**	**0.65**	**0.40**	**69%**	**62%**	**1.01**	**0.79**	**2.02**	4.11
-	**1.59**	**1.542**	**1.94**	**0.66**	**1.13**	**0.40**	**6.87**	**0.81**	**0.03**	**0.73**	**0.08**	**1.54**	**863,887**	**0.40**	**0.66**	**0.40**	**72%**	**65%**	**1.09**	**1.01**	**2.30**	4.11
-	**1.99**	**1.542**	**2.04**	**0.47**	**1.18**	**0.39**	**7.15**	**0.88**	**0.03**	**0.79**	**0.09**	**1.54**	**899,096**	**0.40**	**0.47**	**0.39**	**75%**	**67%**	**1.16**	**0.96**	**2.50**	4.11
-	**2.38**	**1.542**	**2.12**	**0.46**	**1.23**	**0.38**	**7.39**	**0.92**	**0.04**	**0.85**	**0.08**	**1.54**	**929,275**	**0.40**	**0.46**	**0.38**	**75%**	**69%**	**1.22**	**0.97**	**2.67**	4.11
-	**2.78**	**1.542**	**2.27**	**0.77**	**1.32**	**0.37**	**7.82**	**1.02**	**0.05**	**0.95**	**0.07**	**1.54**	**983,347**	**0.40**	**0.77**	**0.37**	**77%**	**72%**	**1.29**	**1.11**	**2.99**	4.11
-	**3.16**	**1.542**	**2.49**	**0.78**	**1.53**	**0.38**	**8.62**	**1.23**	**0.08**	**1.15**	**0.08**	**1.54**	**1,083,945**	**0.40**	**0.78**	**0.38**	**80%**	**75%**	**1.52**	**1.42**	**3.63**	4.11
-	**3.59**	**1.542**	**2.58**	**0.73**	**1.64**	**0.38**	**9.01**	**1.34**	**0.10**	**1.26**	**0.09**	**1.54**	**1,132,987**	**0.40**	**0.73**	**0.38**	**82%**	**77%**	**1.62**	**1.34**	**3.96**	4.11
-	**4.26**	**1.542**	**2.62**	**0.89**	**1.76**	**0.40**	**9.37**	**1.46**	**0.12**	**1.36**	**0.11**	**1.54**	**1,178,256**	**0.40**	**0.89**	**0.41**	**83%**	**77%**	**1.72**	**1.59**	**4.29**	4.11
-	1.24	1.833	1.80	0.66	1.05	0.40	6.45	0.74	0.02	0.65	0.09	1.83	964,519	0.48	0.66	0.40	71%	62%	1.01	0.79	2.03	4.89
-	1.59	1.833	1.91	0.54	1.13	0.40	6.86	0.77	0.03	0.73	0.04	1.83	1,025,829	0.48	0.54	0.40	68%	64%	1.09	1.01	2.30	4.89
-	1.99	1.833	2.02	0.46	1.18	0.39	7.13	0.87	0.04	0.79	0.08	1.83	1,066,205	0.48	0.46	0.39	74%	67%	1.16	0.96	2.48	4.89
-	2.38	1.833	2.11	0.46	1.23	0.38	7.39	0.92	0.04	0.85	0.08	1.83	1,105,084	0.48	0.46	0.38	75%	69%	1.22	0.97	2.67	4.89
-	2.78	1.833	2.22	0.80	1.32	0.38	7.76	1.01	0.05	0.93	0.09	1.83	1,160,413	0.48	0.80	0.39	77%	71%	1.29	1.11	2.94	4.89
-	3.16	1.833	2.47	0.73	1.53	0.38	8.62	1.20	0.09	1.15	0.05	1.83	1,289,016	0.48	0.73	0.38	78%	75%	1.52	1.42	3.63	4.89
-	3.59	1.833	2.55	0.64	1.64	0.39	8.97	1.33	0.11	1.24	0.09	1.83	1,341,354	0.48	0.64	0.39	82%	76%	1.62	1.34	3.93	4.89
-	4.26	1.833	2.60	0.79	1.76	0.40	9.35	1.45	0.13	1.35	0.10	1.83	1,398,179	0.48	0.79	0.41	83%	77%	1.72	1.59	4.27	4.89

Table 18. Bulbous pier data 0° pitch angle

Pitch Angle	Slope (%)	Lbb (ft.)	Avg of Froude	Max PLnb data (ft.)	Max PLnb calc (ft.)	Yh (ft.)	Max of Velocity (ft/s)	Max of Bw (ft)	Max of Rv (lbf)	Max of BWv (ft.)	Max of BWw (ft.)	Max of Lbbs (ft.)	Max of Reynolds	Max of Bbsa (ft2)	Max of PLbb data (ft.)	Max of PLbb calc (ft.)	PWR data	PWR calc	Max of PLnb calc (ft.)	Max of PLnb data (ft.)	Lw (ft.)	Lbb/Ybs
5.00	**1.24**	**0.766**	**1.88**	**0.81**	**1.02**	**0.38**	**6.47**	**0.72**	**0.01**	**0.65**	**0.07**	**0.76**	**402,508**	**0.20**	**0.81**	**0.38**	**70%**	**64%**	**1.01**	**0.79**	2.04	2.04
5.00	**1.59**	**0.766**	**1.98**	**0.76**	**1.11**	**0.37**	**6.86**	**0.68**	**0.02**	**0.73**	**(0.05)**	**0.76**	**426,770**	**0.20**	**0.76**	**0.37**	**61%**	**66%**	**1.09**	**1.01**	2.30	2.04
5.00	**1.99**	**0.766**	**2.07**	**0.57**	**1.15**	**0.37**	**7.11**	**0.84**	**0.02**	**0.79**	**0.05**	**0.76**	**442,323**	**0.20**	**0.57**	**0.37**	**73%**	**68%**	**1.16**	**0.96**	2.47	2.04
5.00	**2.38**	**0.766**	**2.14**	**0.61**	**1.22**	**0.37**	**7.39**	**0.90**	**0.02**	**0.85**	**0.06**	**0.76**	**459,742**	**0.20**	**0.61**	**0.37**	**74%**	**69%**	**1.22**	**0.97**	2.67	2.04
5.00	**2.78**	**0.766**	**2.31**	**0.89**	**1.31**	**0.36**	**7.83**	**1.01**	**0.03**	**0.95**	**0.06**	**0.76**	**487,115**	**0.20**	**0.89**	**0.36**	**77%**	**73%**	**1.29**	**1.11**	2.99	2.04
5.00	**3.16**	**0.766**	**2.50**	**0.98**	**1.52**	**0.37**	**8.60**	**1.12**	**0.05**	**1.15**	**(0.03)**	**0.76**	**535,018**	**0.20**	**0.98**	**0.37**	**74%**	**76%**	**1.52**	**1.42**	3.61	2.04
5.00	**4.26**	**0.766**	**2.61**	**0.75**	**1.76**	**0.40**	**9.37**	**1.46**	**0.08**	**1.36**	**0.10**	**0.76**	**582,921**	**0.20**	**0.75**	**0.40**	**83%**	**77%**	**1.72**	**1.59**	4.29	2.04
5.00	**3.59**	**0.766**	**2.78**	**0.67**	**1.44**	**0.30**	**8.58**	**1.13**	**0.04**	**1.14**	**(0.01)**	**0.57**	**399,493**	**0.15**	**0.67**	**0.30**	**78%**	**79%**	**1.62**	**1.34**	3.59	2.04
5.00	1.24	0.974	1.87	0.65	1.03	0.38	6.49	0.73	0.02	0.65	0.07	0.97	513,616	0.25	0.65	0.38	71%	64%	1.01	0.79	2.06	2.60
5.00	1.59	0.974	1.96	0.67	1.11	0.38	6.85	0.75	0.02	0.73	0.03	0.97	542,107	0.25	0.67	0.38	68%	66%	1.09	1.01	2.29	2.60
5.00	1.99	0.974	2.06	0.50	1.16	0.38	7.12	0.82	0.02	0.79	0.03	0.97	563,474	0.25	0.50	0.38	71%	68%	1.16	0.96	2.47	2.60
5.00	2.38	0.974	2.13	0.57	1.23	0.38	7.41	0.92	0.03	0.85	0.07	0.97	586,425	0.25	0.57	0.38	75%	69%	1.22	0.97	2.68	2.60
5.00	2.78	0.974	2.31	0.78	1.30	0.36	7.79	0.94	0.04	0.94	0.00	0.97	616,498	0.25	0.78	0.36	73%	73%	1.29	1.11	2.96	2.60
5.00	3.16	0.974	2.50	1.07	1.52	0.37	8.60	1.22	0.06	1.15	0.07	0.97	680,601	0.25	1.07	0.37	80%	76%	1.52	1.42	3.61	2.60
5.00	4.26	0.974	2.59	0.59	1.76	0.41	9.35	1.46	0.09	1.36	0.11	0.97	739,956	0.25	0.59	0.41	83%	77%	1.72	1.59	4.27	2.60
5.00	3.59	0.974	2.82	0.67	1.45	0.29	8.63	1.14	0.04	1.16	(0.01)	0.49	341,946	0.13	0.67	0.29	79%	80%	1.62	1.34	3.64	2.60
5.00	**1.24**	**1.266**	**1.85**	**0.60**	**1.03**	**0.38**	**6.45**	**0.69**	**0.02**	**0.65**	**0.05**	**1.26**	**663,313**	**0.33**	**0.60**	**0.38**	**67%**	**63%**	**1.01**	**0.79**	2.03	3.38
5.00	**1.59**	**1.266**	**1.95**	**0.54**	**1.13**	**0.39**	**6.89**	**0.83**	**0.03**	**0.74**	**0.09**	**1.26**	**708,562**	**0.33**	**0.54**	**0.39**	**73%**	**66%**	**1.09**	**1.01**	2.32	3.38
5.00	**1.99**	**1.266**	**2.06**	**0.46**	**1.17**	**0.38**	**7.17**	**0.88**	**0.03**	**0.80**	**0.08**	**1.26**	**737,357**	**0.33**	**0.46**	**0.38**	**75%**	**68%**	**1.16**	**0.96**	2.51	3.38
5.00	**2.38**	**1.266**	**2.12**	**0.48**	**1.22**	**0.38**	**7.37**	**0.92**	**0.04**	**0.84**	**0.08**	**1.26**	**757,925**	**0.33**	**0.48**	**0.38**	**76%**	**69%**	**1.22**	**0.97**	2.65	3.38
5.00	**2.78**	**1.266**	**2.25**	**0.79**	**1.31**	**0.37**	**7.77**	**1.00**	**0.05**	**0.94**	**0.07**	**1.26**	**799,061**	**0.33**	**0.79**	**0.37**	**77%**	**71%**	**1.29**	**1.11**	2.95	3.38
5.00	**3.16**	**1.266**	**2.51**	**0.63**	**1.51**	**0.37**	**8.57**	**1.21**	**0.07**	**1.14**	**0.07**	**1.26**	**881,332**	**0.33**	**0.63**	**0.37**	**80%**	**76%**	**1.52**	**1.42**	3.59	3.38
5.00	**3.59**	**1.266**	**2.61**	**0.62**	**1.64**	**0.37**	**9.02**	**1.34**	**0.09**	**1.26**	**0.08**	**1.26**	**927,610**	**0.33**	**0.62**	**0.38**	**82%**	**77%**	**1.62**	**1.34**	3.97	3.38
5.00	**4.26**	**1.266**	**2.64**	**0.56**	**1.78**	**0.40**	**9.42**	**1.45**	**0.11**	**1.37**	**0.08**	**1.26**	**968,746**	**0.33**	**0.56**	**0.41**	**82%**	**77%**	**1.72**	**1.59**	4.33	3.38
5.00	1.24	1.557	1.85	0.66	1.04	0.39	6.48	0.74	0.02	0.65	0.09	1.55	818,706	0.40	0.66	0.39	71%	63%	1.01	0.79	2.05	4.15
5.00	1.59	1.557	1.95	0.56	1.13	0.39	6.89	0.82	0.03	0.74	0.09	1.55	871,852	0.40	0.56	0.39	73%	65%	1.09	1.01	2.32	4.15
5.00	1.99	1.557	2.05	0.45	1.17	0.38	7.13	0.86	0.03	0.79	0.08	1.46	847,535	0.38	0.45	0.38	74%	68%	1.16	0.96	2.48	4.15
5.00	2.38	1.557	2.10	0.48	1.20	0.38	7.28	0.90	0.04	0.82	0.08	1.44	854,053	0.38	0.48	0.38	75%	69%	1.22	0.97	2.59	4.15
5.00	2.78	1.557	2.27	0.83	1.32	0.37	7.80	1.01	0.05	0.94	0.07	1.40	890,817	0.37	0.83	0.37	77%	72%	1.29	1.11	2.97	4.15
5.00	3.16	1.557	2.48	0.76	1.52	0.38	8.59	1.22	0.08	1.14	0.08	1.45	1,010,867	0.38	0.76	0.38	80%	75%	1.52	1.42	3.60	4.15
5.00	3.59	1.557	2.63	0.58	1.63	0.37	9.03	1.33	0.10	1.26	0.07	1.35	990,698	0.35	0.58	0.37	82%	77%	1.62	1.34	3.98	4.15
5.00	4.26	1.557	2.66	0.51	1.77	0.40	9.40	1.47	0.13	1.37	0.11	1.55	1,189,465	0.40	0.51	0.41	83%	78%	1.72	1.59	4.31	4.15

Table 19. Bulbous pier data 5˚ pitch angle

Pitch Angle	Slope (%)	Lbb (ft.)	Avg of Froude	Max PLnb data (ft.)	Max PLnb calc (ft.)	Yh (ft.)	Max of Velocity (ft/s)	Max of Bw (ft)	Max of Rv (lbf)	Max of BWv (ft.)	Max of BWw (ft.)	Max of Lbbs (ft.)	Max of Reynolds	Max of Bbsa (ft2)	Max of PLbb data (ft.)	Max of PLbb calc (ft.)	PWR data	PWR calc	Max of PLnb calc (ft.)	Max of PLnb data (ft.)	Lw (ft.)	Lbb/Ybs
10.00	**1.24**	**0.786**	**1.86**	**0.70**	**1.02**	**0.38**	**6.44**	**0.70**	**0.01**	**0.64**	**0.06**	**0.72**	**378,648**	**0.19**	**0.70**	**0.38**	**69%**	**63%**	**1.01**	**0.79**	2.02	2.10
10.00	**1.59**	**0.786**	**1.97**	**0.61**	**1.12**	**0.38**	**6.88**	**0.81**	**0.02**	**0.74**	**0.07**	**0.74**	**416,387**	**0.19**	**0.61**	**0.38**	**72%**	**66%**	**1.09**	**1.01**	2.31	2.10
10.00	**1.99**	**0.786**	**2.07**	**0.55**	**1.17**	**0.37**	**7.15**	**0.86**	**0.02**	**0.79**	**0.07**	**0.70**	**406,781**	**0.18**	**0.55**	**0.37**	**74%**	**68%**	**1.16**	**0.96**	2.50	2.10
10.00	**2.38**	**0.786**	**2.15**	**0.57**	**1.21**	**0.37**	**7.38**	**0.90**	**0.02**	**0.85**	**0.05**	**0.68**	**406,889**	**0.18**	**0.57**	**0.37**	**74%**	**70%**	**1.22**	**0.97**	2.66	2.10
10.00	**2.78**	**0.786**	**2.28**	**0.84**	**1.31**	**0.37**	**7.79**	**1.00**	**0.03**	**0.94**	**0.07**	**0.67**	**421,784**	**0.17**	**0.84**	**0.37**	**77%**	**72%**	**1.29**	**1.11**	2.96	2.10
10.00	**3.16**	**0.786**	**2.51**	**0.92**	**1.50**	**0.36**	**8.57**	**1.20**	**0.05**	**1.14**	**0.07**	**0.65**	**450,484**	**0.17**	**0.92**	**0.37**	**80%**	**76%**	**1.52**	**1.42**	3.59	2.10
10.00	**4.26**	**0.786**	**2.63**	**0.66**	**1.76**	**0.40**	**9.37**	**1.47**	**0.08**	**1.36**	**0.10**	**0.77**	**591,938**	**0.20**	**0.66**	**0.40**	**83%**	**78%**	**1.72**	**1.59**	4.29	2.10
10.00	**3.59**	**0.786**	**2.64**	**0.69**	**1.63**	**0.37**	**9.04**	**1.33**	**0.06**	**1.27**	**0.07**	**0.67**	**493,200**	**0.18**	**0.69**	**0.37**	**81%**	**78%**	**1.62**	**1.34**	3.99	2.10
10.00	1.24	0.995	1.83	0.65	1.03	0.39	6.42	**0.72**	0.01	0.64	0.08	0.77	400,922	0.20	0.65	0.39	71%	63%	1.01	0.79	2.01	2.65
10.00	1.59	0.995	1.97	0.59	1.13	0.38	6.91	**0.82**	0.02	0.74	0.08	0.76	426,194	0.20	0.59	0.38	73%	66%	1.09	1.01	2.33	2.65
10.00	1.99	0.995	2.07	0.56	1.16	0.37	7.13	**0.86**	0.02	0.79	0.07	0.69	400,721	0.18	0.56	0.37	74%	68%	1.16	0.96	2.48	2.65
10.00	2.38	0.995	2.11	0.57	1.19	0.37	7.27	**0.86**	0.02	0.82	0.05	0.69	408,038	0.18	0.57	0.37	73%	69%	1.22	0.97	2.58	2.65
10.00	2.78	0.995	2.30	0.78	1.30	0.36	7.79	**1.00**	0.03	0.94	0.06	0.62	395,880	0.16	0.78	0.36	77%	73%	1.29	1.11	2.96	2.65
10.00	3.16	0.995	2.52	0.76	1.50	0.36	8.57	**1.20**	0.05	1.14	0.07	0.64	447,720	0.17	0.76	0.36	80%	76%	1.52	1.42	3.59	2.65
10.00	3.59	0.995	2.61	0.66	1.63	0.37	9.01	**1.33**	0.06	1.26	0.08	0.69	510,566	0.18	0.66	0.37	82%	77%	1.62	1.34	3.96	2.65
10.00	4.26	0.995	2.69	0.65	1.77	0.39	9.44	**1.47**	0.09	1.38	0.09	0.78	596,163	0.20	0.65	0.39	83%	78%	1.72	1.59	4.35	2.65
10.00	**1.24**	**1.286**	**1.82**	**0.66**	**1.03**	**0.39**	**6.43**	**0.73**	**0.01**	**0.64**	**0.09**	**0.80**	**418,246**	**0.21**	**0.66**	**0.39**	**71%**	**62%**	**1.01**	**0.79**	2.02	3.43
10.00	**1.59**	**1.286**	**1.96**	**0.58**	**1.12**	**0.39**	**6.88**	**0.82**	**0.02**	**0.74**	**0.09**	**0.77**	**429,648**	**0.20**	**0.58**	**0.39**	**73%**	**66%**	**1.09**	**1.01**	2.31	3.43
10.00	**1.99**	**1.286**	**2.07**	**0.56**	**1.16**	**0.37**	**7.12**	**0.85**	**0.02**	**0.79**	**0.07**	**0.69**	**397,418**	**0.18**	**0.56**	**0.37**	**74%**	**68%**	**1.16**	**0.96**	2.47	3.43
10.00	**2.38**	**1.286**	**2.13**	**0.58**	**1.18**	**0.36**	**7.26**	**0.84**	**0.02**	**0.82**	**0.04**	**0.65**	**381,829**	**0.17**	**0.58**	**0.36**	**72%**	**69%**	**1.22**	**0.97**	2.57	3.43
10.00	**2.78**	**1.286**	**2.33**	**0.80**	**1.31**	**0.36**	**7.81**	**0.98**	**0.03**	**0.95**	**0.04**	**0.63**	**399,904**	**0.16**	**0.80**	**0.36**	**76%**	**73%**	**1.29**	**1.11**	2.98	3.43
10.00	**3.16**	**1.286**	**2.50**	**0.70**	**1.50**	**0.37**	**8.54**	**1.20**	**0.05**	**1.13**	**0.07**	**0.65**	**453,772**	**0.17**	**0.70**	**0.37**	**80%**	**76%**	**1.52**	**1.42**	3.56	3.43
10.00	**3.59**	**1.286**	**2.62**	**0.65**	**1.65**	**0.37**	**9.06**	**1.34**	**0.07**	**1.27**	**0.08**	**0.70**	**517,512**	**0.18**	**0.65**	**0.38**	**82%**	**77%**	**1.62**	**1.34**	4.01	3.43
10.00	**4.26**	**1.286**	**2.69**	**0.61**	**1.79**	**0.39**	**9.50**	**1.49**	**0.09**	**1.40**	**0.09**	**0.79**	**611,575**	**0.21**	**0.61**	**0.39**	**83%**	**78%**	**1.72**	**1.59**	4.41	3.43
10.00	1.24	1.578	1.83	0.67	1.04	0.39	6.45	**0.74**	0.01	0.65	0.09	0.80	419,548	0.21	0.67	0.39	71%	62%	1.01	0.79	2.03	4.21
10.00	1.59	1.578	1.98	0.57	1.13	0.38	6.94	**0.83**	0.02	0.75	0.09	0.76	428,045	0.20	0.57	0.38	73%	66%	1.09	1.01	2.35	4.21
10.00	1.99	1.578	2.06	0.55	1.16	0.37	7.12	**0.85**	0.02	0.79	0.07	0.68	395,232	0.18	0.55	0.37	74%	68%	1.16	0.96	2.47	4.21
10.00	2.38	1.578	2.13	0.57	1.18	0.36	7.26	**0.88**	0.02	0.82	0.06	0.63	372,218	0.16	0.57	0.36	75%	69%	1.22	0.97	2.57	4.21
10.00	2.78	1.578	2.30	0.79	1.31	0.36	7.80	**0.99**	0.03	0.94	0.05	0.65	408,763	0.17	0.79	0.36	76%	72%	1.29	1.11	2.97	4.21
10.00	3.16	1.578	2.52	0.74	1.50	0.36	8.56	**1.20**	0.05	1.14	0.06	0.64	444,948	0.17	0.74	0.36	80%	76%	1.52	1.42	3.58	4.21
10.00	3.59	1.578	2.64	0.65	1.66	0.37	9.09	**1.36**	0.07	1.28	0.08	0.69	511,595	0.18	0.65	0.37	82%	78%	1.62	1.34	4.03	4.21
10.00	4.26	1.578	2.70	0.58	1.80	0.39	9.53	**1.50**	0.09	1.41	0.10	0.79	616,532	0.21	0.58	0.39	84%	78%	1.72	1.59	4.43	4.21

`Table 20. Bulbous pier data 10˚ pitch angle

A.2. EXPERIMENTAL DATA FIGURES: PL_{nb}

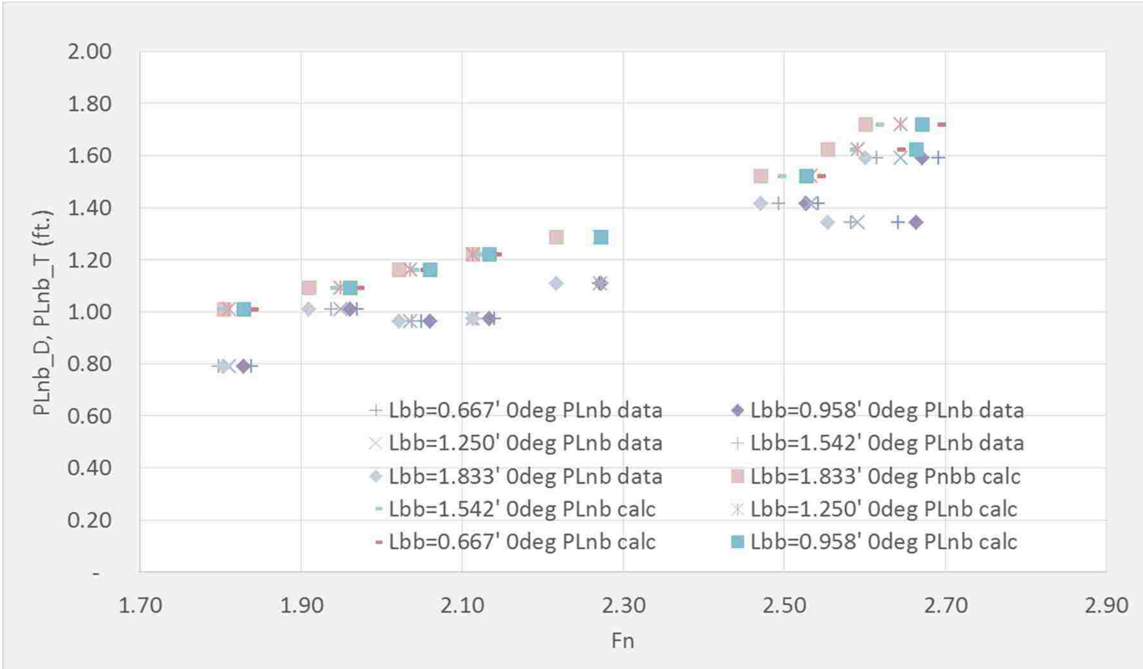

Figure 45. Non-bulb pier water level (PL_{nb}), 0° pitch angle

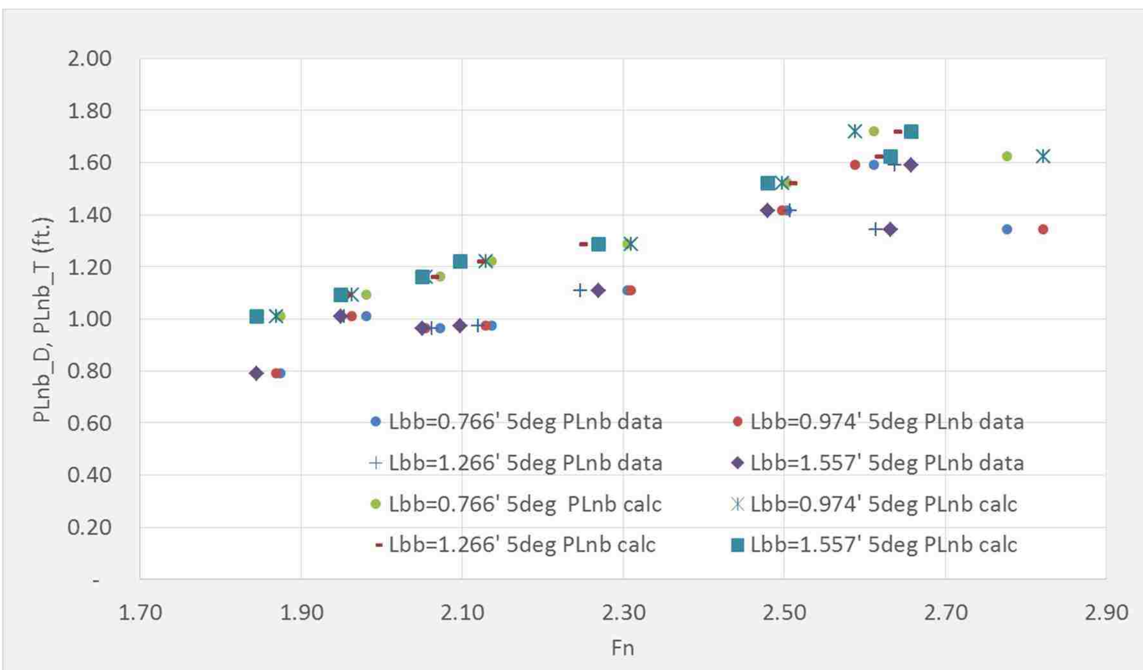

Figure 46. Non-bulb pier water level (PL_{nb}), 5° pitch angle

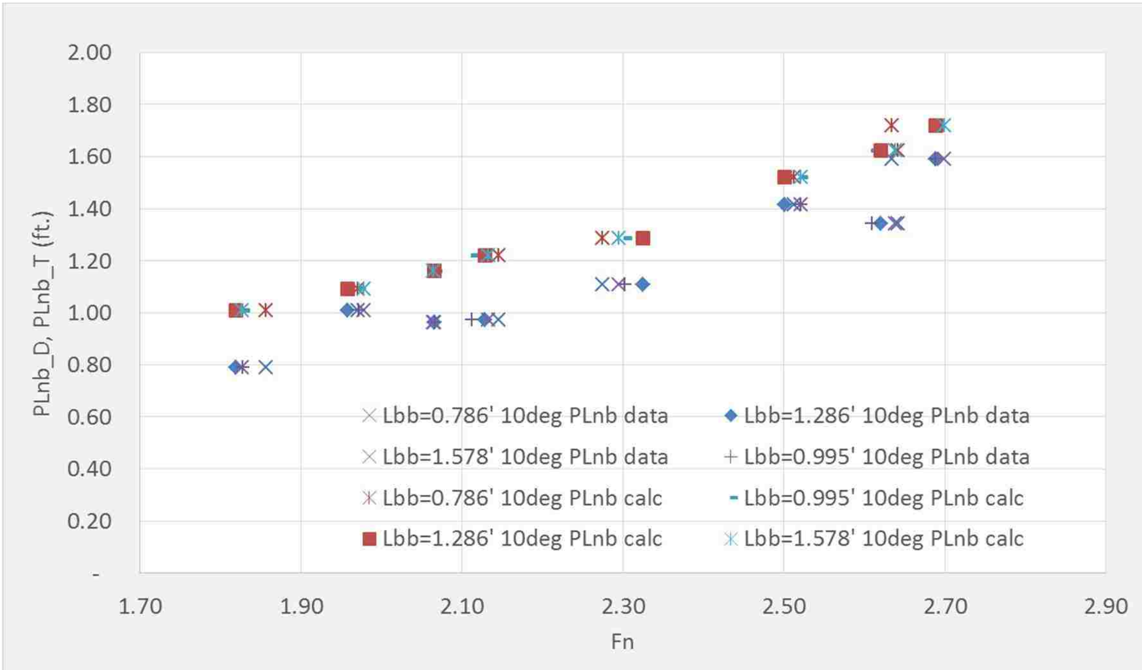

Figure 47. Non-bulb pier water level (PL_{nb}), 10° pitch angle

A.3. EXPERIMENTAL DATA FIGURES: PL_{bb}

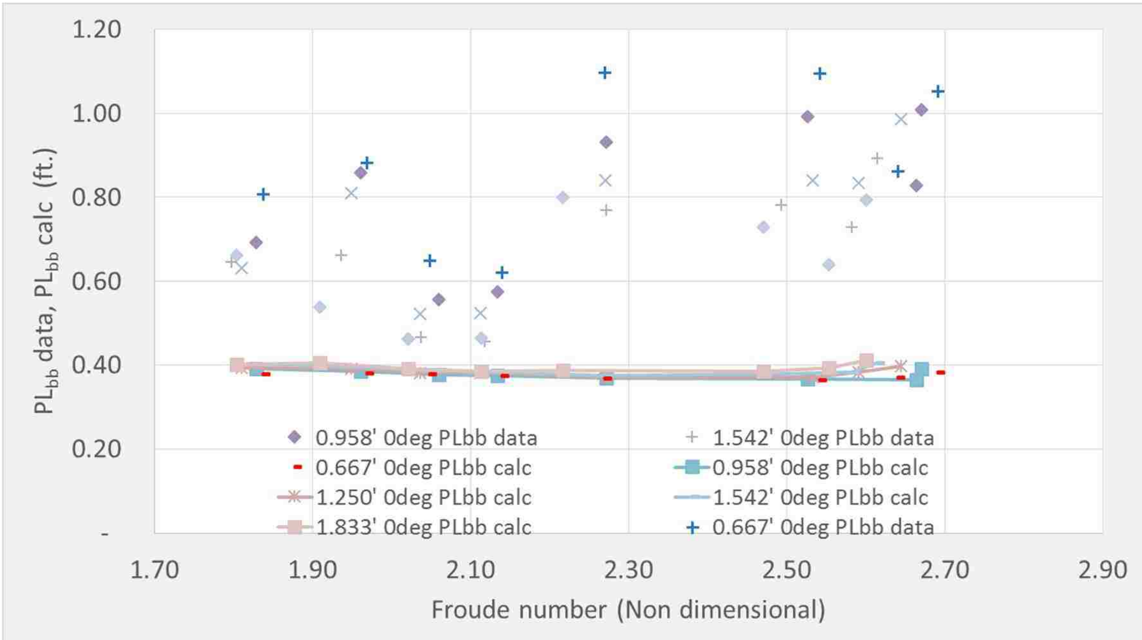

Figure 48. Bulbous pier wave level (PL_{bb}), 0° pitch angle

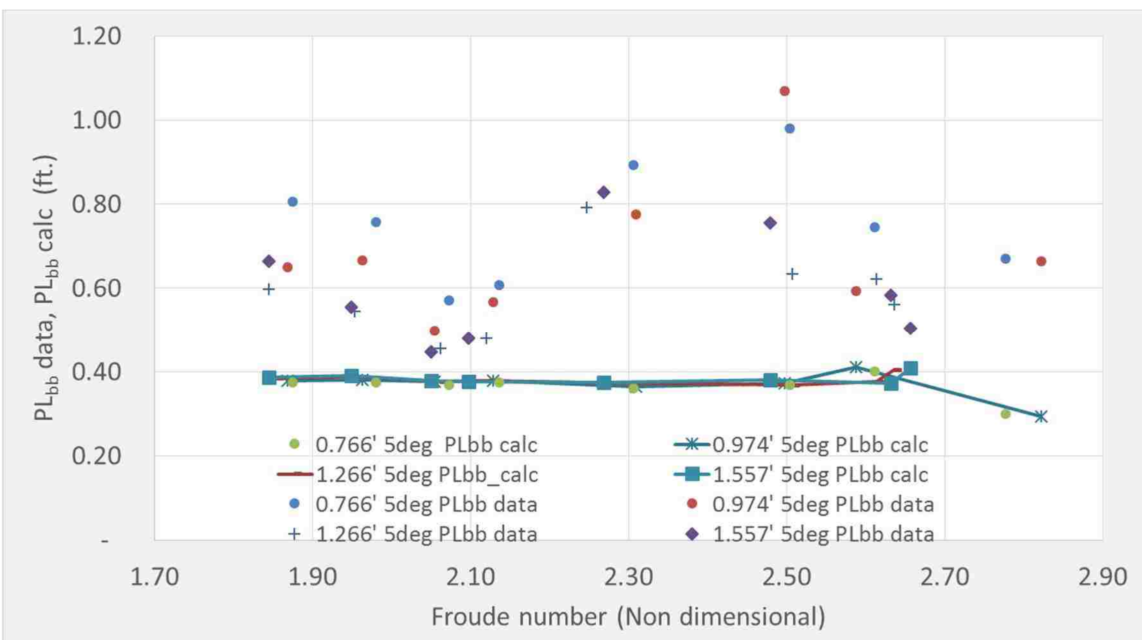

Figure 49. Bulbous pier wave level (PL_{bb}), 5° pitch angle

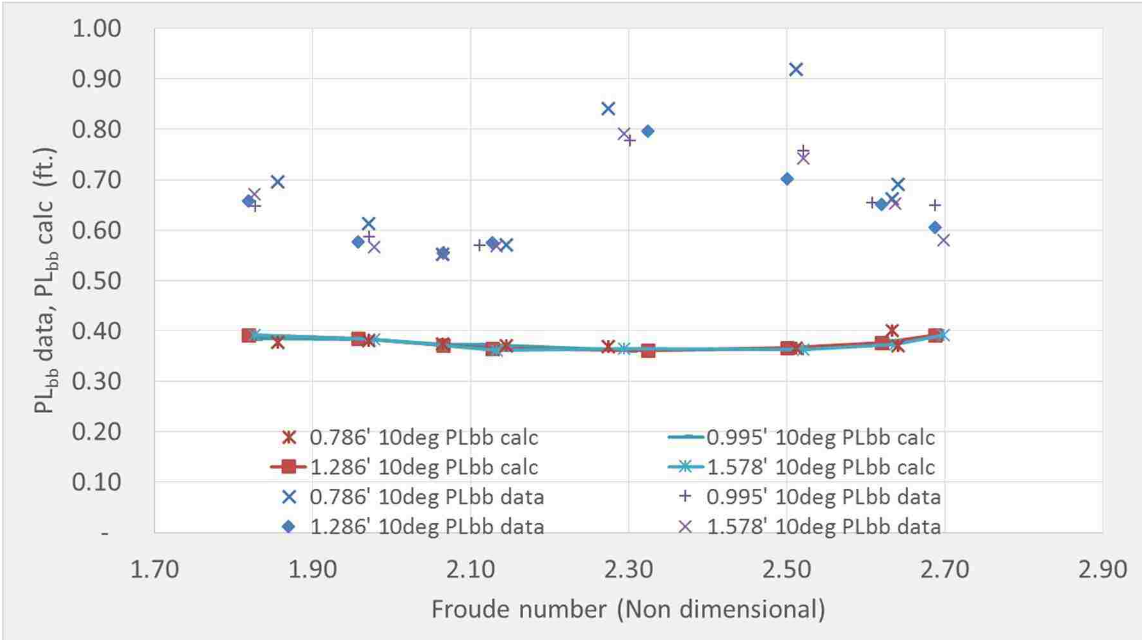

Figure 50. Bulbous pier wave level (PL_{bb}), 10° pitch angle

A.4. EXPERIMENTAL DATA FIGURES: B_w, B_{wv} AND B_{ww}

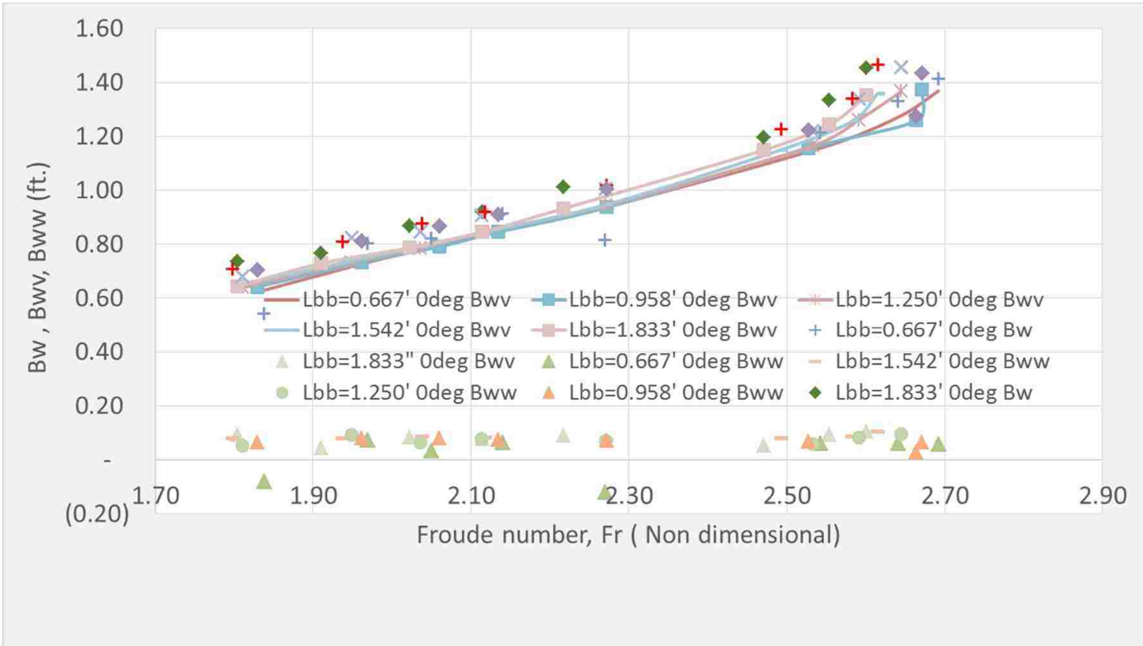

Figure 51. Bulbous wave (B_w), viscous bulbous wave (B_{wv}) and wave-making bulbous wave (B_{ww}), 0° pitch angle

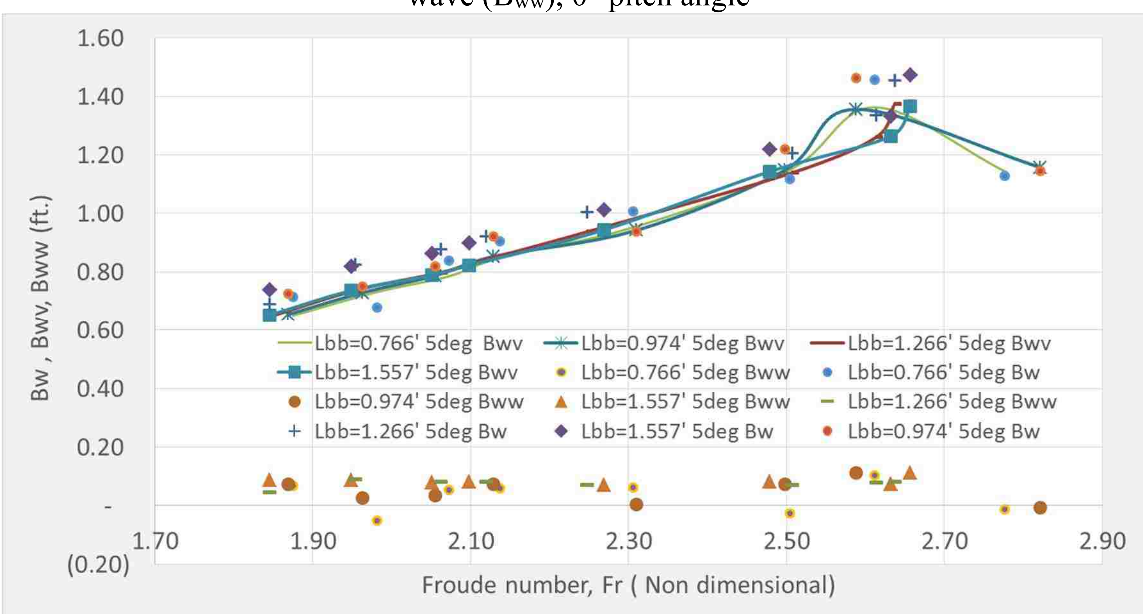

Figure 52. Bulbous wave (B_w), viscous bulbous wave (B_{wv}) and wave-making bulbous wave (B_{ww}), 5° pitch angle

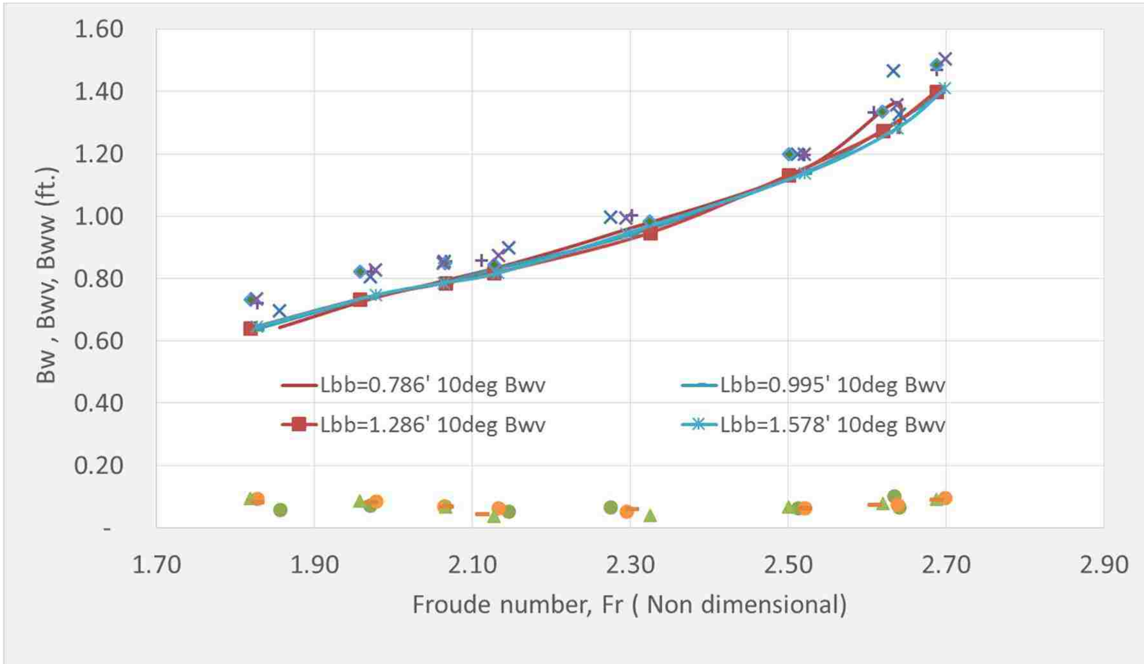

Figure 53. Bulbous wave (B_w), viscous bulbous wave (B_{wv}) and wave-making bulbous wave (B_{ww}), 10° pitch angle

A.5. EXPERIMENTAL DATA FIGURES: PWR

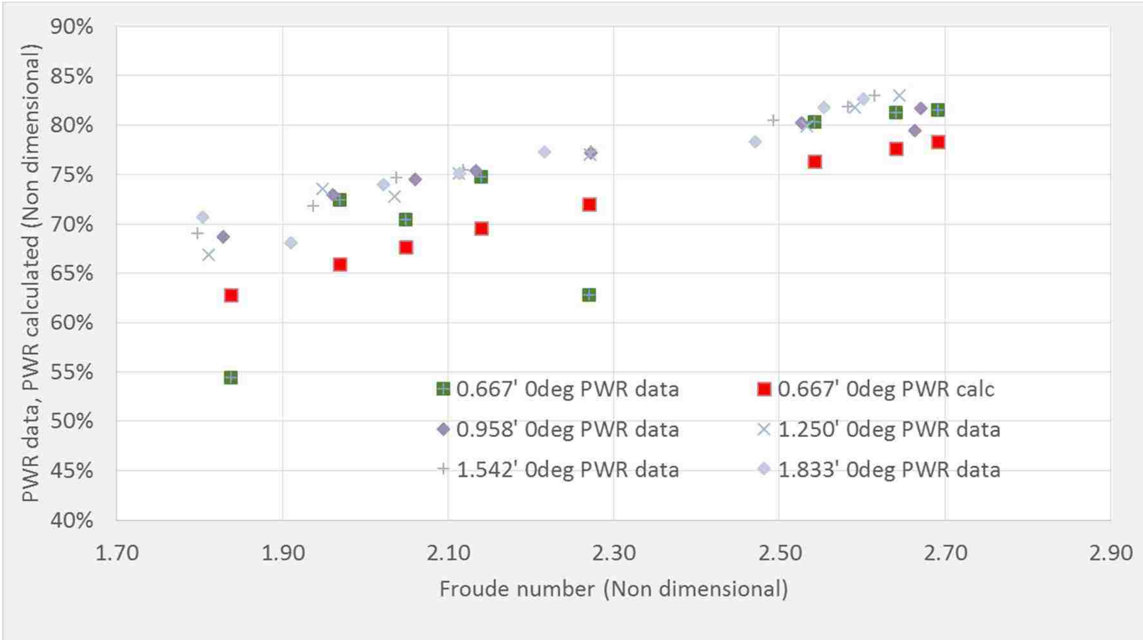

Figure 54. Pier water level ratio (PWR), 0° pitch angle

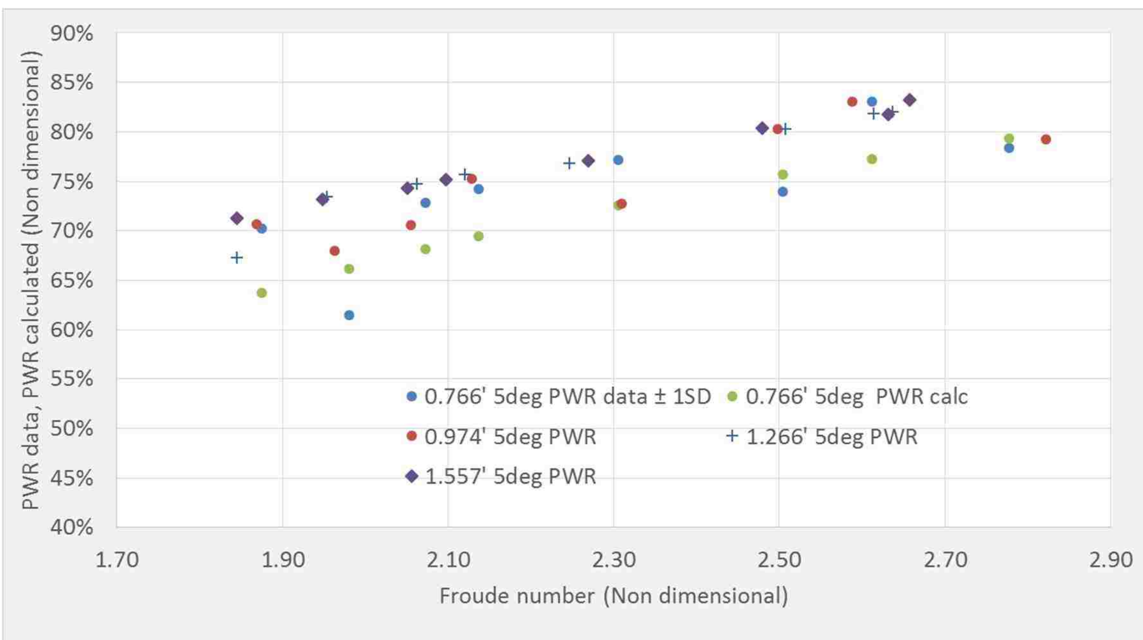

Figure 55. Pier water level ratio (PWR), 5° pitch angle

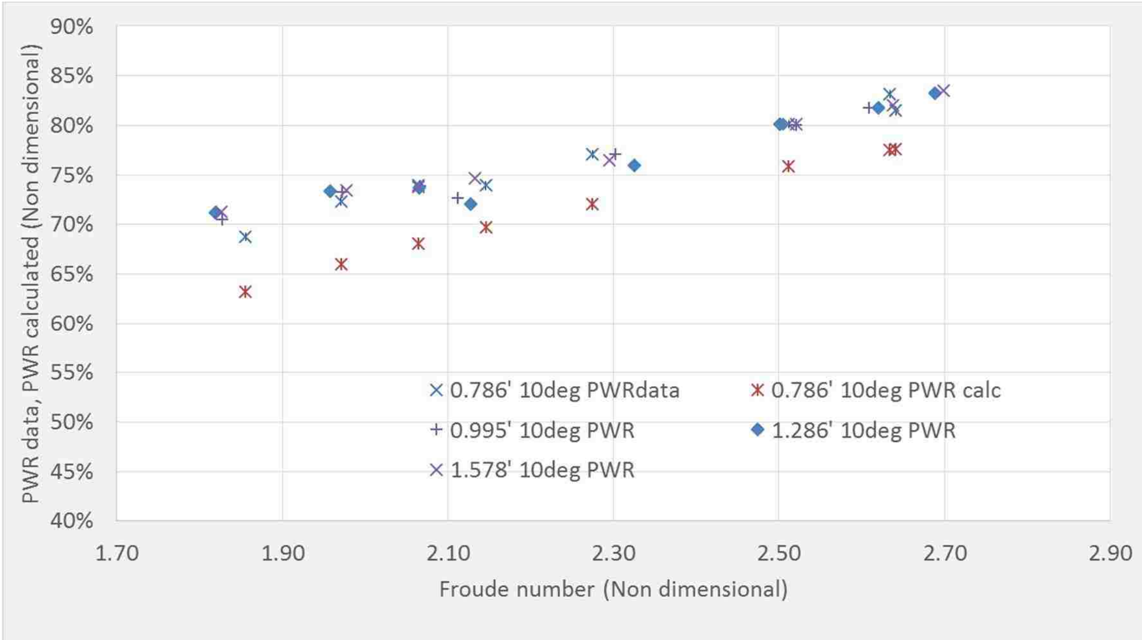

Figure 56. Pier water level ratio (PWR), 10° pitch angle

A.6. EXPERIMENTAL DATA FIGURES: L_w VS. L_{bbs}

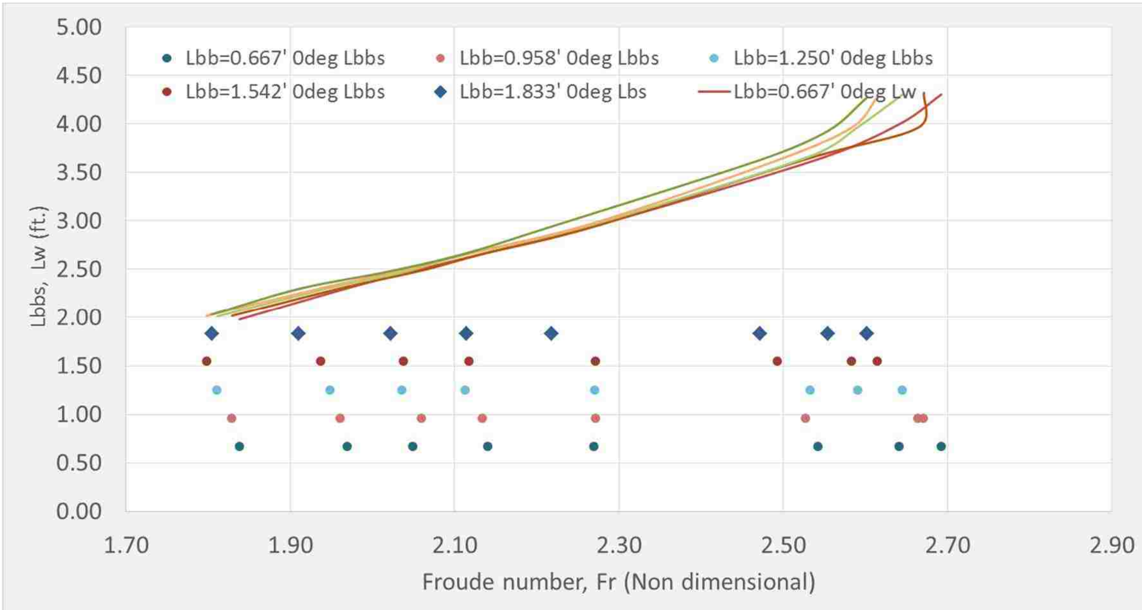

Figure 57. Bulb wavelength (L_w) vs. bulb submerge length (L_{bbs}), 0° pitch angle

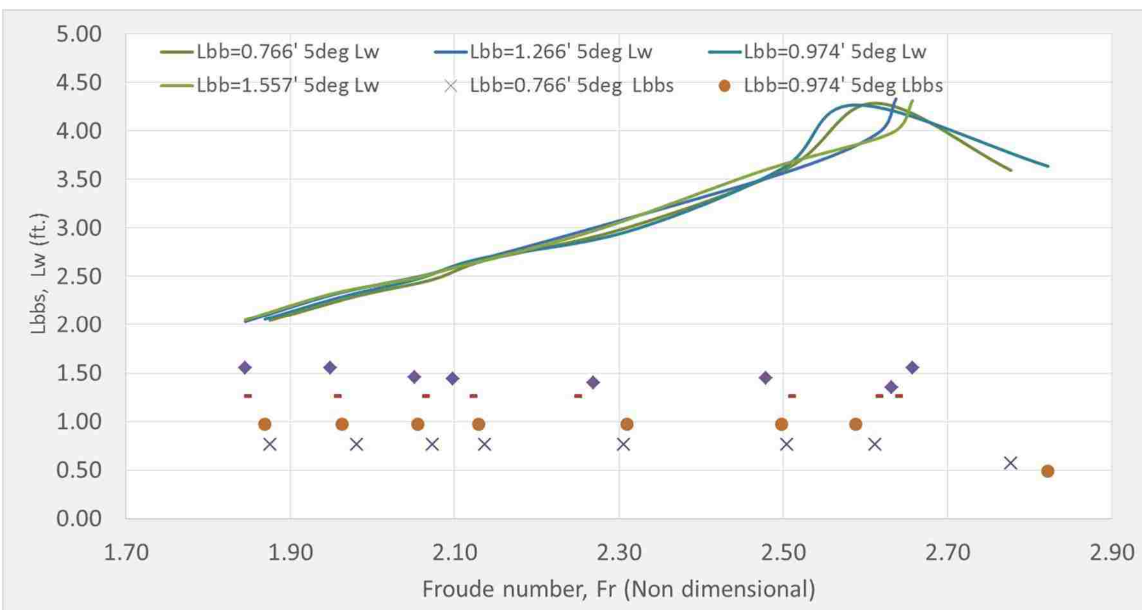

Figure 58. Bulb wavelength (L_w) vs. bulb submerge length (L_{bbs}), 5° pitch angle

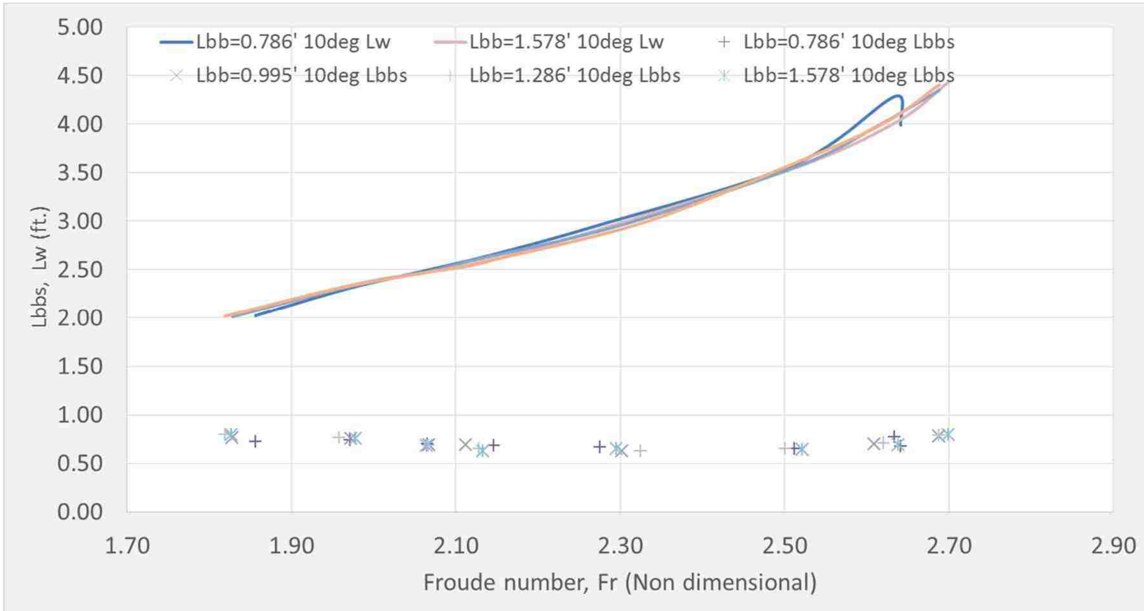

Figure 59. Bulb wavelength (L_w) vs. bulb submerge length (L_{bbs}), 10° pitch angle

A.7. EXPERIMENTAL DATA FIGURES: PICTURES

Table 21. Bulb lengths experimental size families

Pitch Angle (deg)	L_{bb} (ft.)	L_{bbu} (in)
-	0.667	8.5
-	0.958	12
-	1.250	15.5
-	1.542	19
-	1.833	22
5.00	0.766	8.5
5.00	0.974	12
5.00	1.266	15.5
5.00	1.557	19
10.00	0.786	8.5
10.00	0.995	12
10.00	1.286	15.5
10.00	1.578	19

Where L_{bb} is the bottom bulb length along the bulb axis and L_{bbu} is the upper bulb length along the bulb axis.

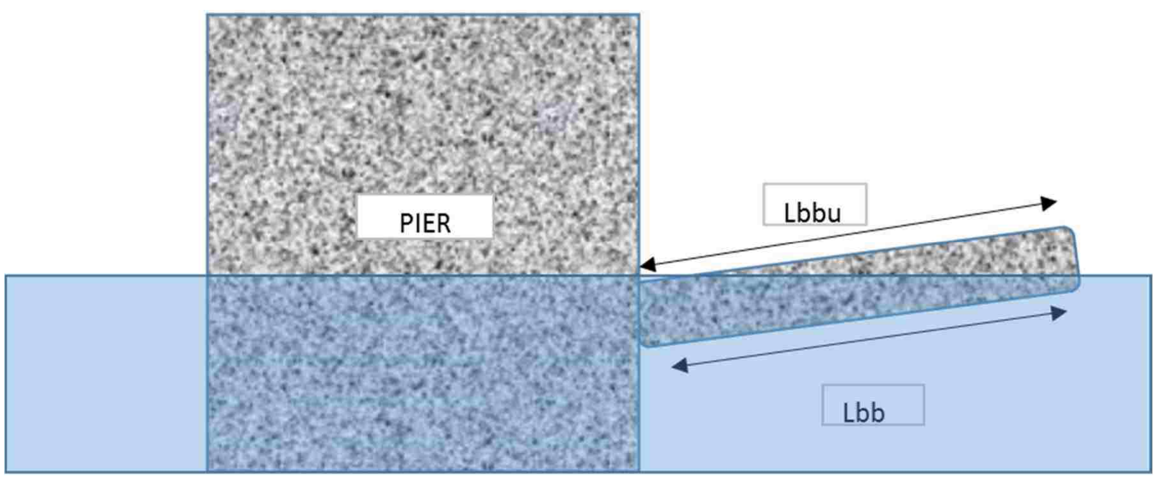

Figure 60. Bulb bottom and upper length

Figure 61. 550 RPM, slope: 1.24%, L_{bb}= 0”, pitch angle = 0°

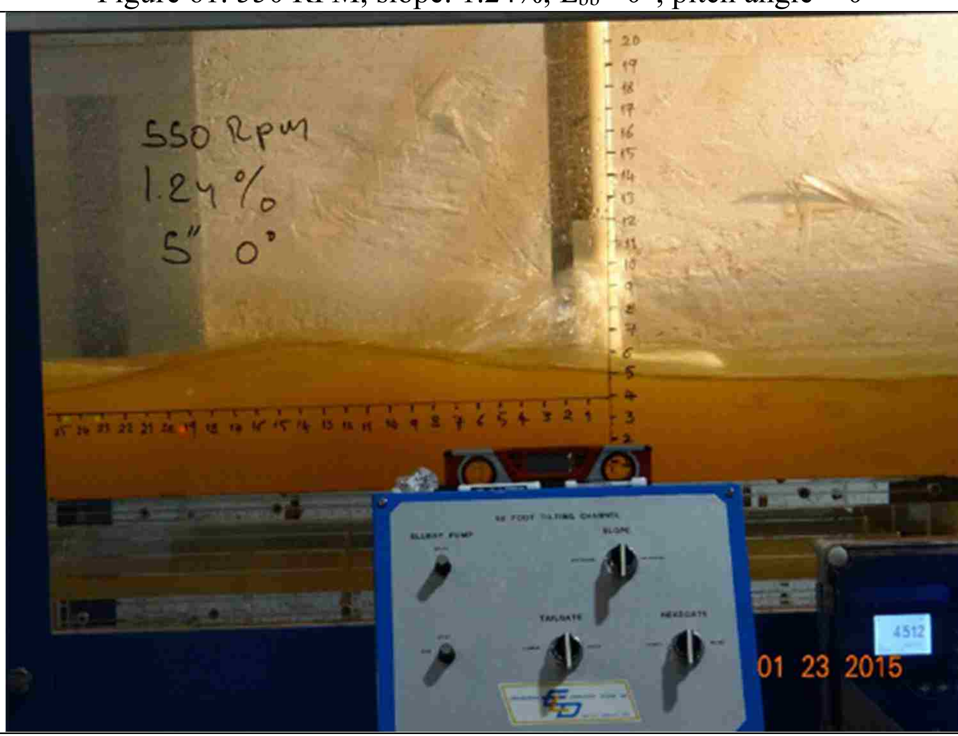

Figure 62. 550 RPM, slope: 1.24%, L_{bb}= 5”, pitch angle = 0°

Figure 63. 550 RPM, slope: 1.24%, L_{bb}= 8.5”, pitch angle = 0°

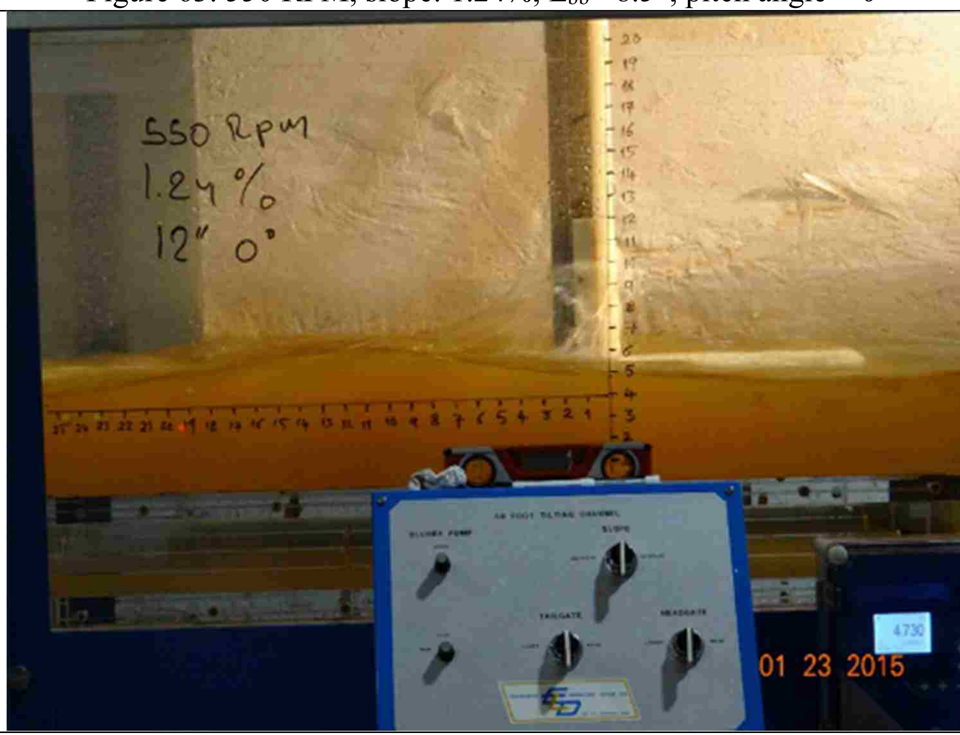

Figure 64. 550 RPM, slope: 1.24%, L_{bb}= 12”, pitch angle = 0°

Figure 65. 550 RPM, slope: 1.24%, L_{bb}= 15.5”, pitch angle = 0°

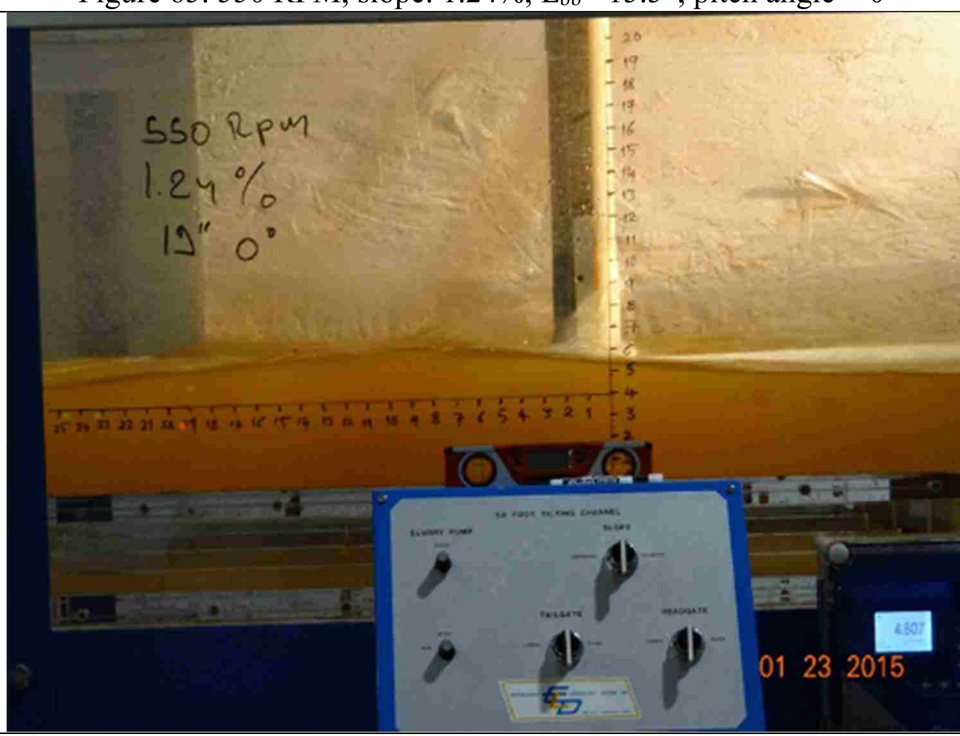

Figure 66. 550 RPM, slope: 1.24%, L_{bb}= 19”, pitch angle = 0°

Figure 67. 550 RPM, slope: 1.24%, L_{bb}= 5”, pitch angle = 5°

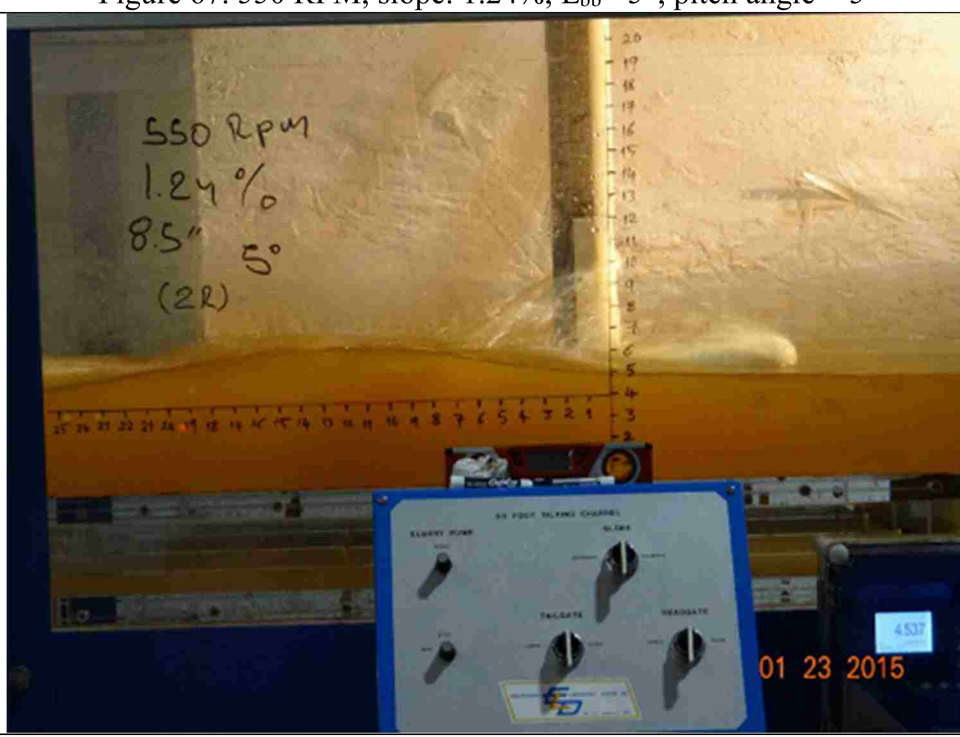

Figure 68. 550 RPM, slope: 1.24%, L_{bb}= 8.5”, pitch angle = 5°

Figure 69. 550 RPM, slope: 1.24%, L_{bb}= 12", pitch angle = 5°

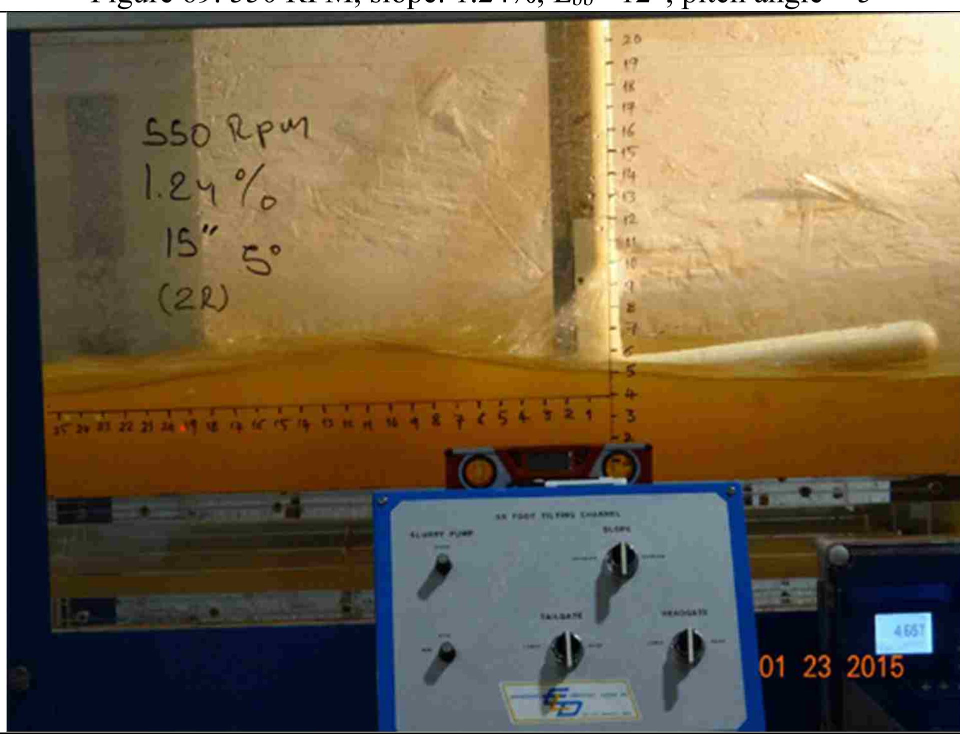

Figure 70. 550 RPM, slope: 1.24%, L_{bb}= 15", pitch angle = 5°

Figure 71. 550 RPM, slope: 1.24%, L_{bb}= 5”, pitch angle = 10°

Figure 72. 550 RPM, slope: 1.24%, L_{bb}= 8.5”, pitch angle = 10°

Figure 73. 550 RPM, slope: 1.24%, L_{bb}= 12”, pitch angle = 10°

Figure 74. 550 RPM, slope: 1.24%, L_{bb}= 15.5”, pitch angle = 10°

Figure 75. 601 RPM, slope: 1.59%, L_{bb}= 0”, pitch angle = 0°

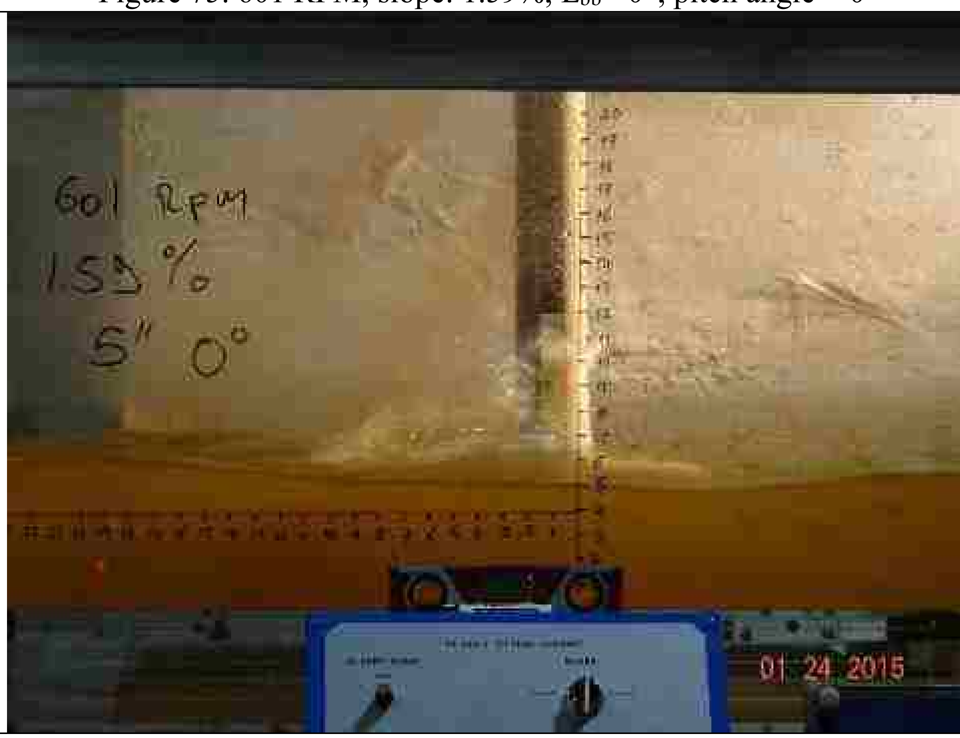

Figure 76. 601 RPM, slope: 1.59%, L_{bb}= 5”, pitch angle = 0°

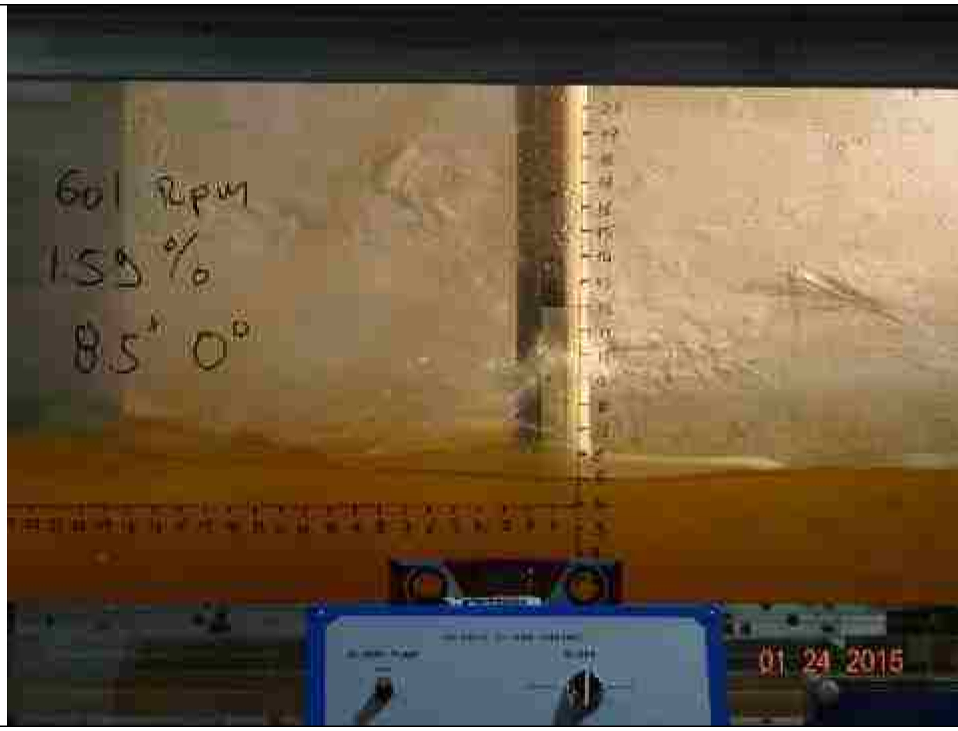

Figure 77. 601 RPM, slope: 1.59%, L_{bb}= 8.5”, pitch angle = 0°

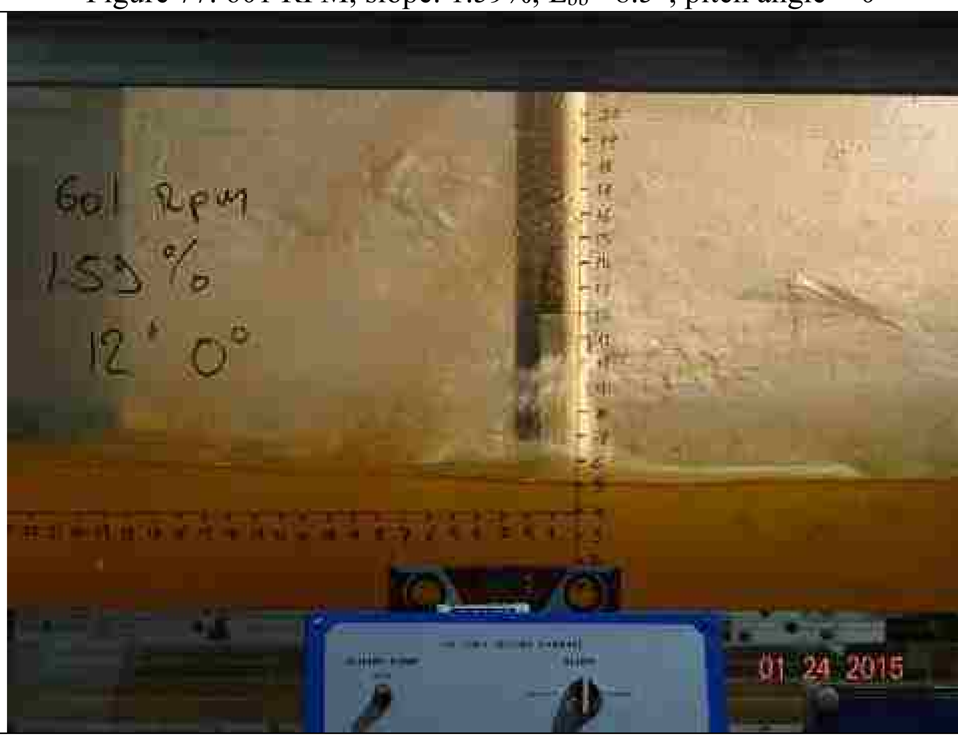

Figure 78. 601 RPM, slope: 1.59%, L_{bb}= 12”, pitch angle = 0°

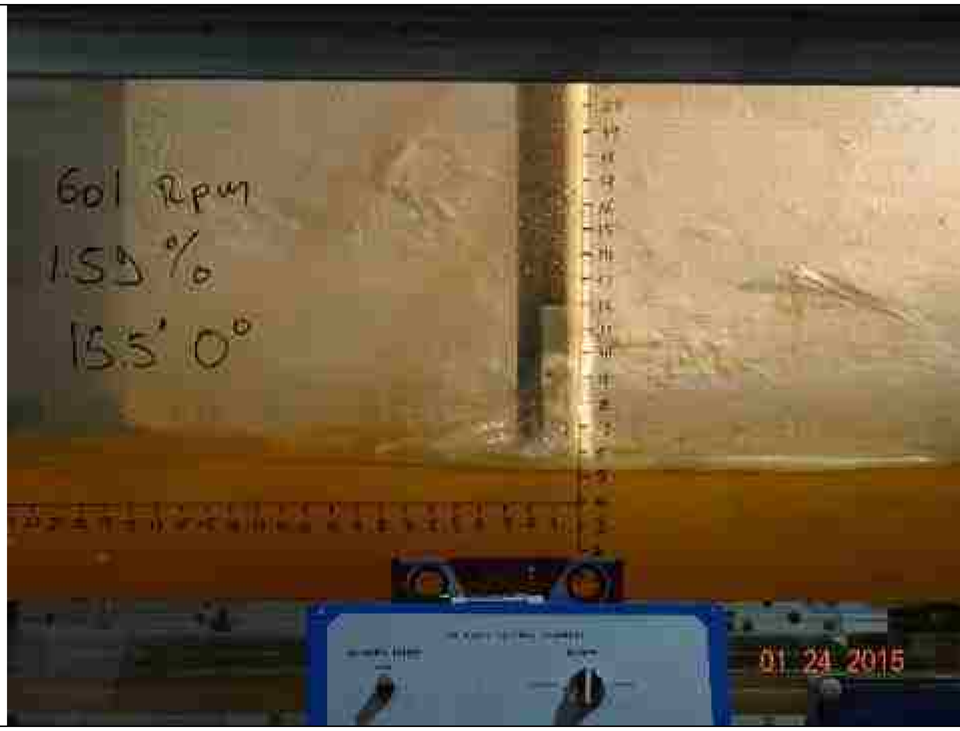

Figure 79. 601 RPM, slope: 1.59%, L_{bb}= 15.5”, pitch angle = 0°

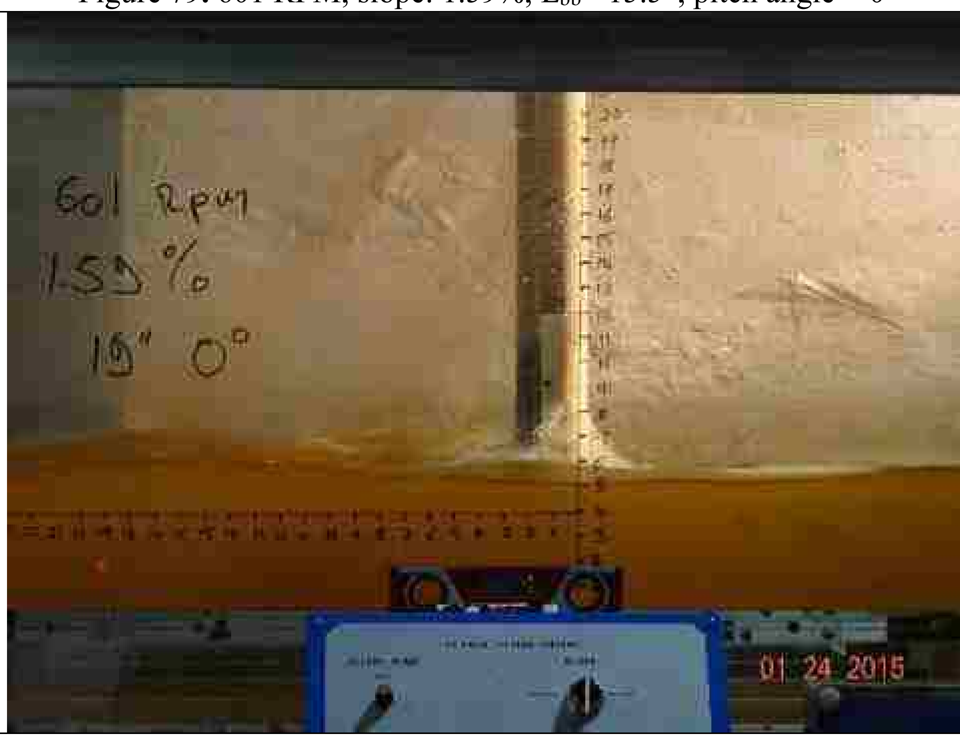

Figure 80. 601 RPM, slope: 1.59%, L_{bb}= 19”, pitch angle = 0°

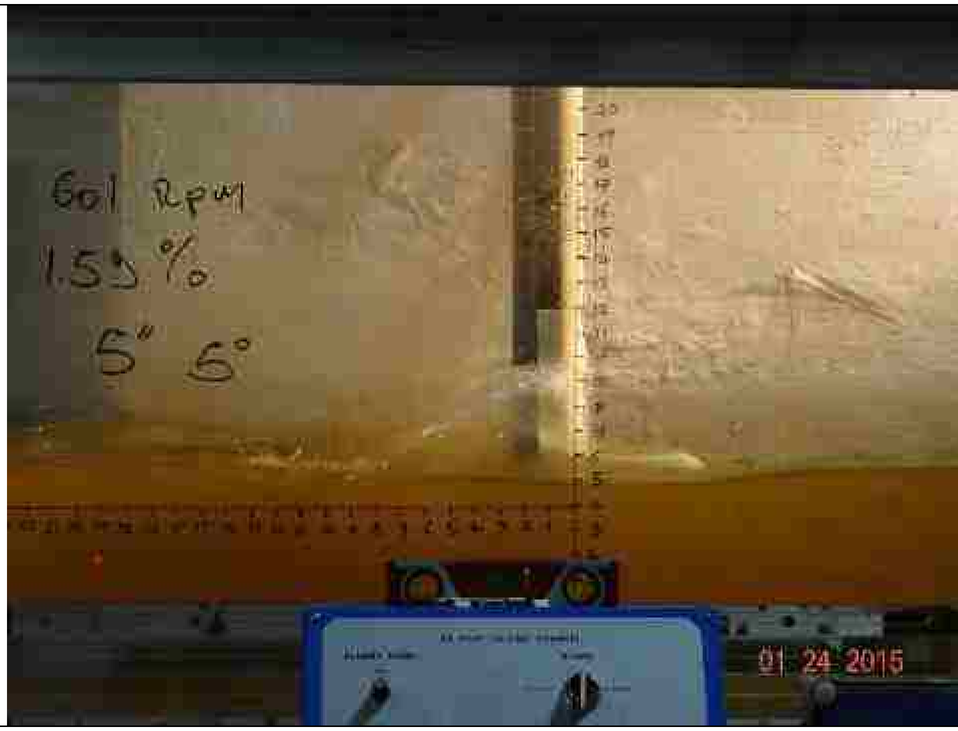

Figure 81. 601 RPM, slope: 1.59%, L_{bb}= 5”, pitch angle = 5°

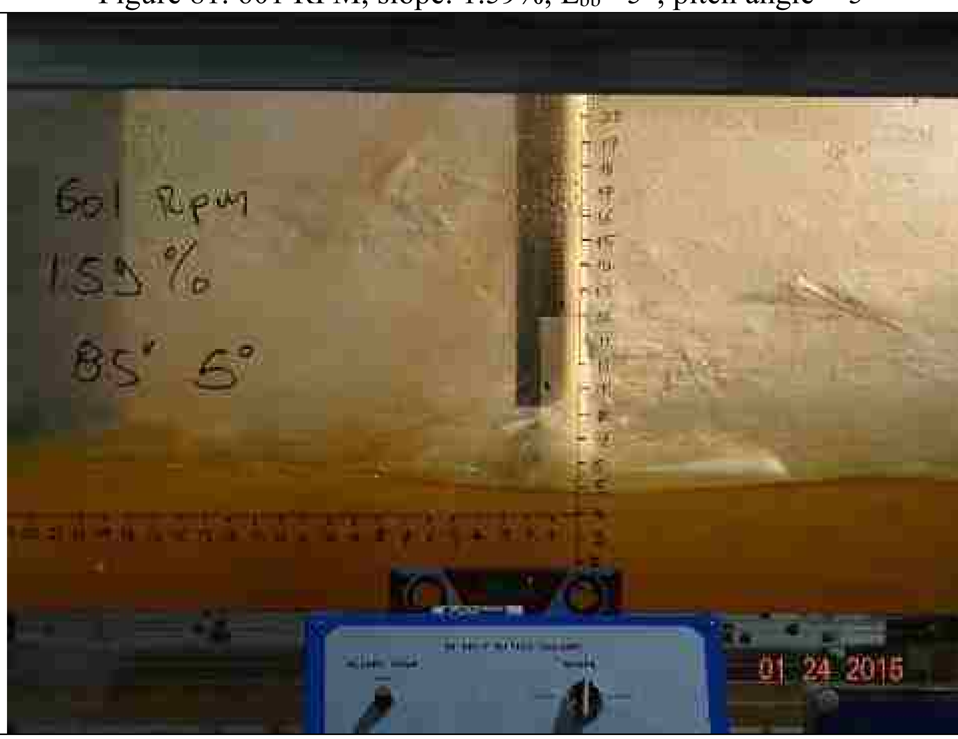

Figure 82. 601 RPM, slope: 1.59%, L_{bb}= 8.5”, pitch angle = 5°

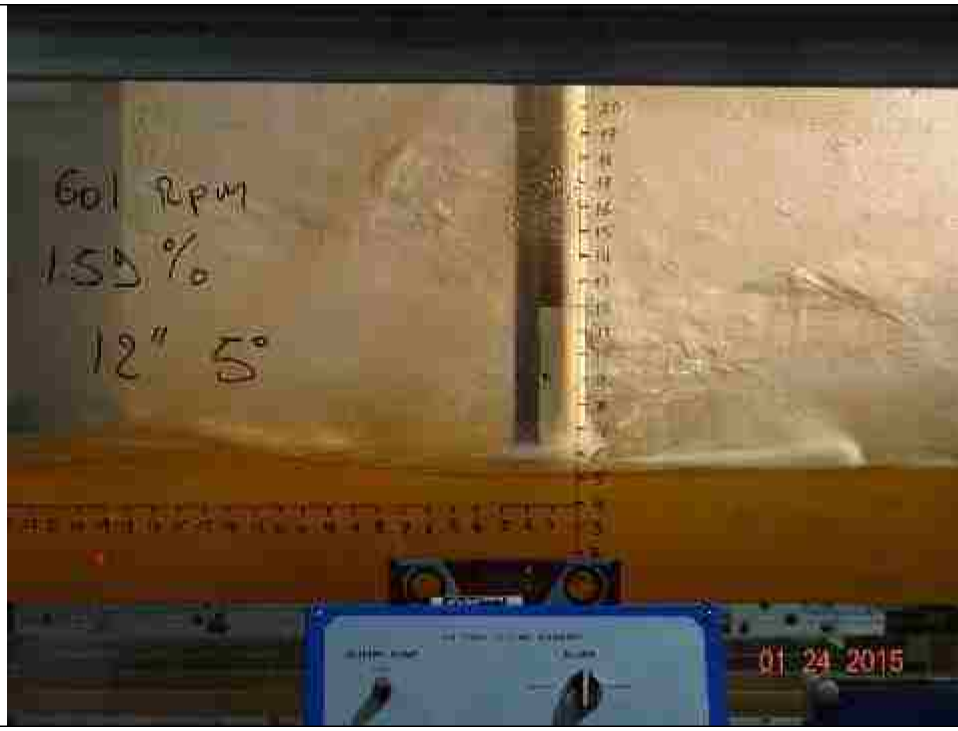

Figure 83. 601 RPM, slope: 1.59%, L_{bb}= 12”, pitch angle = 5°

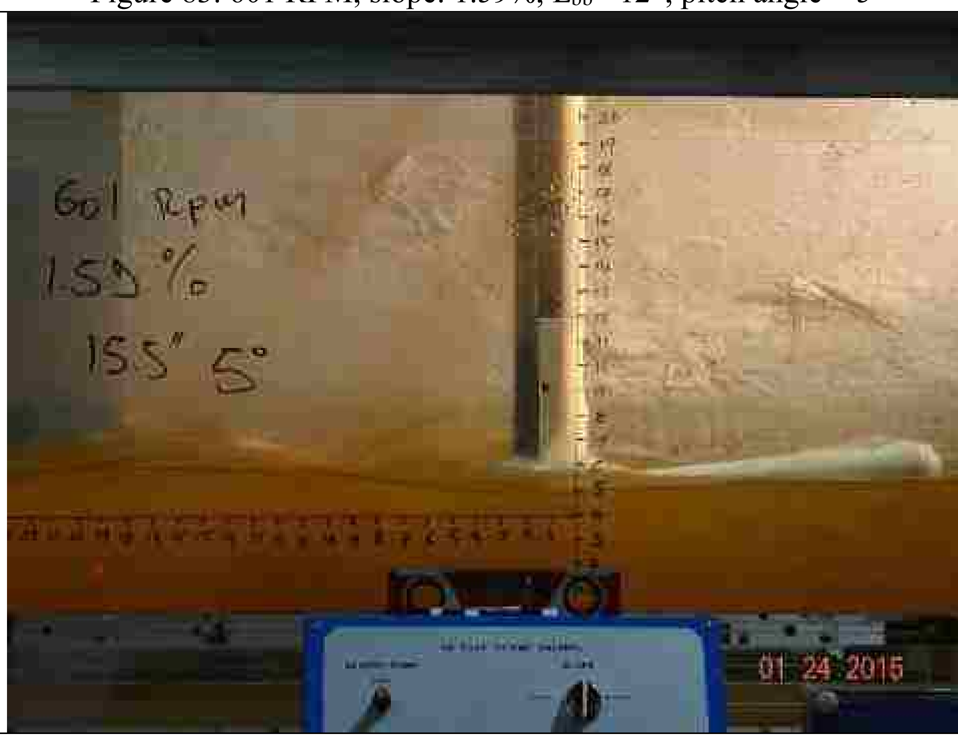

Figure 84. 601 RPM, slope: 1.59%, L_{bb}= 15.5”, pitch angle = 5°

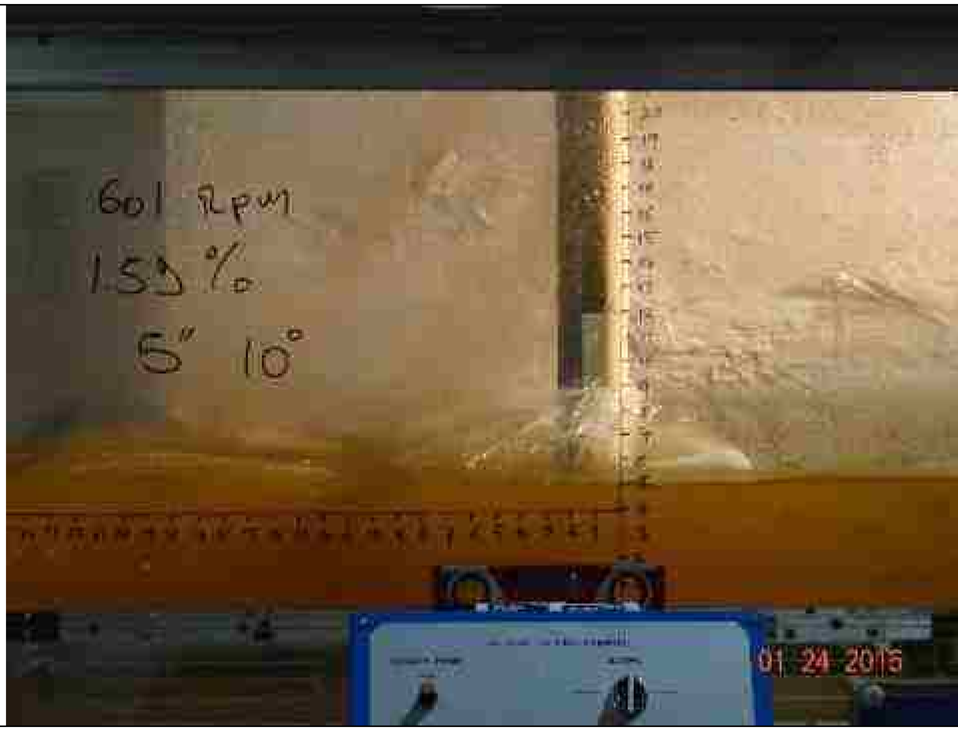

Figure 85. 601 RPM, slope: 1.59%, L_{bb}= 5”, pitch angle = 10°

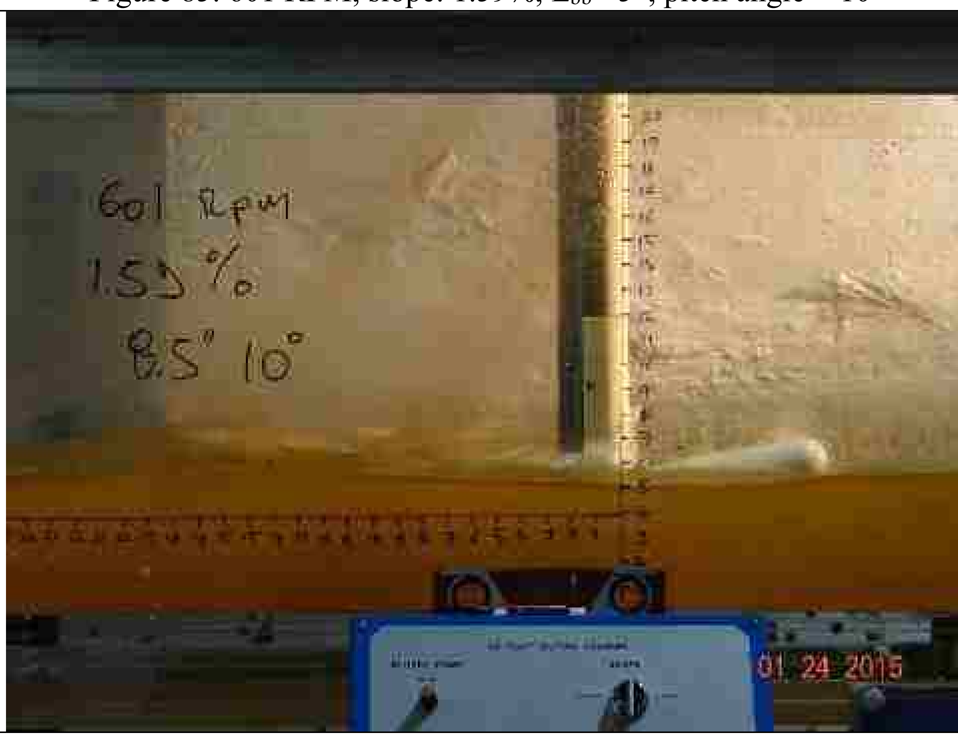

Figure 86. 601 RPM, slope: 1.59%, L_{bb}= 8.5”, pitch angle = 10°

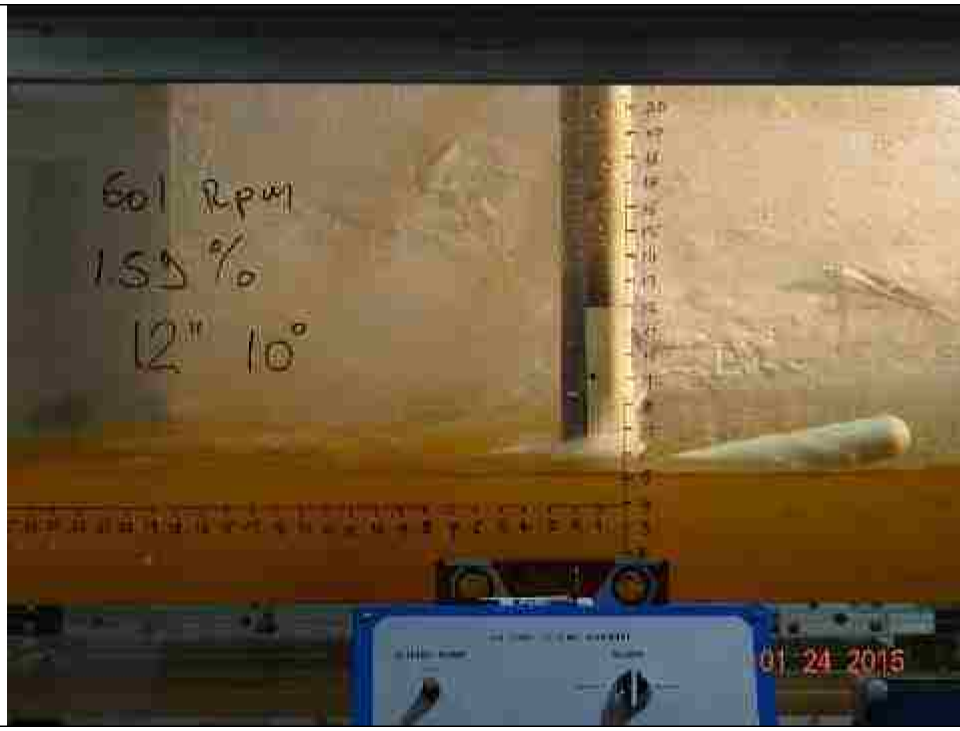

Figure 87. 601 RPM, slope: 1.59%, L_{bb}= 12”, pitch angle = 10°

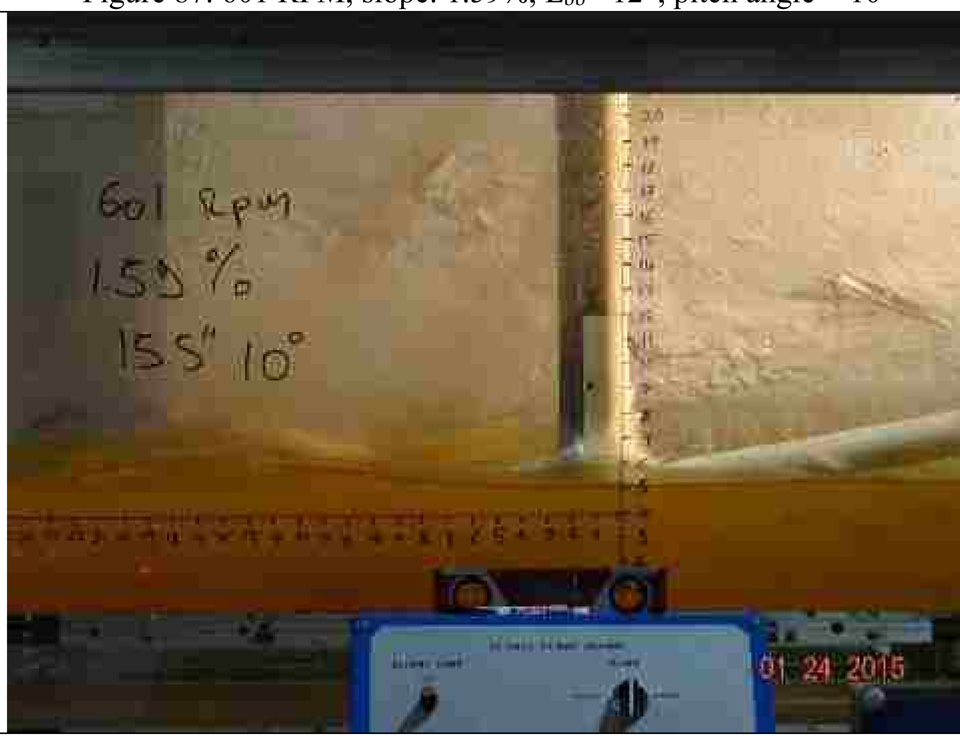

Figure 88. 601 RPM, slope: 1.59%, L_{bb}= 15.5”, pitch angle = 10°

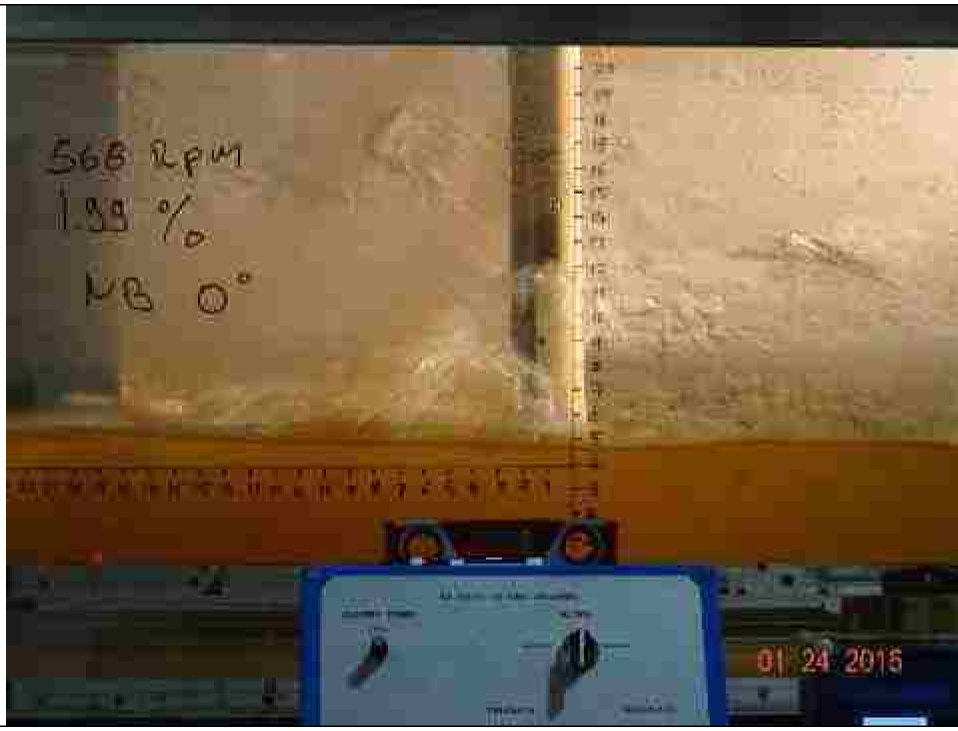

Figure 89. 568 RPM, slope: 1.99%, L_{bb}= 0”, pitch angle = 0°

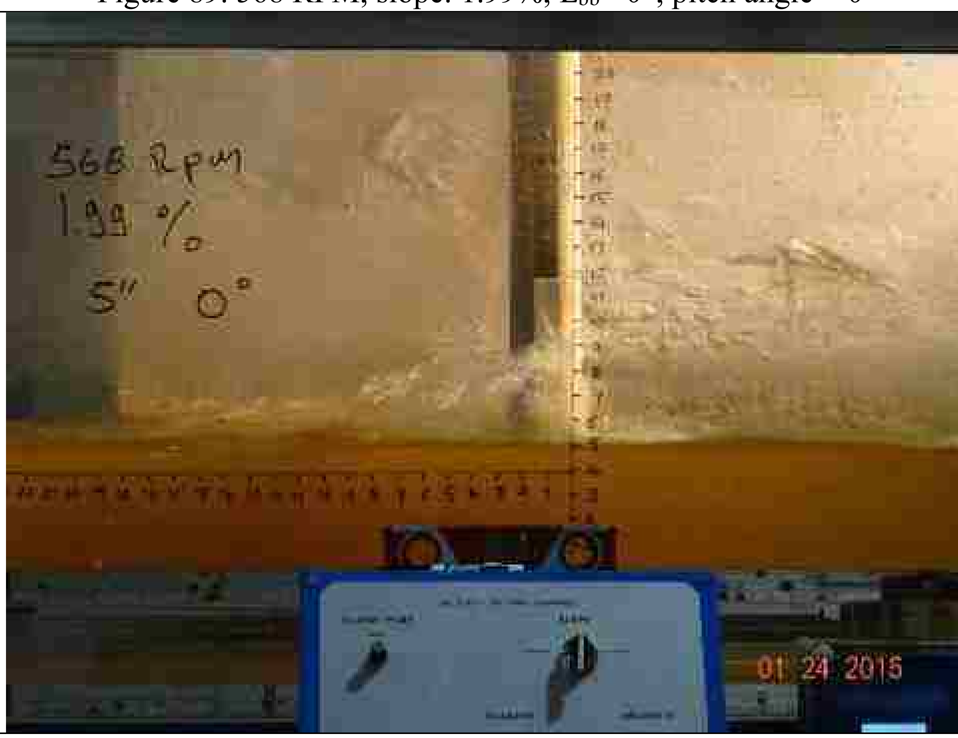

Figure 90. 568 RPM, slope: 1.99%, L_{bb}= 5”, pitch angle = 0°

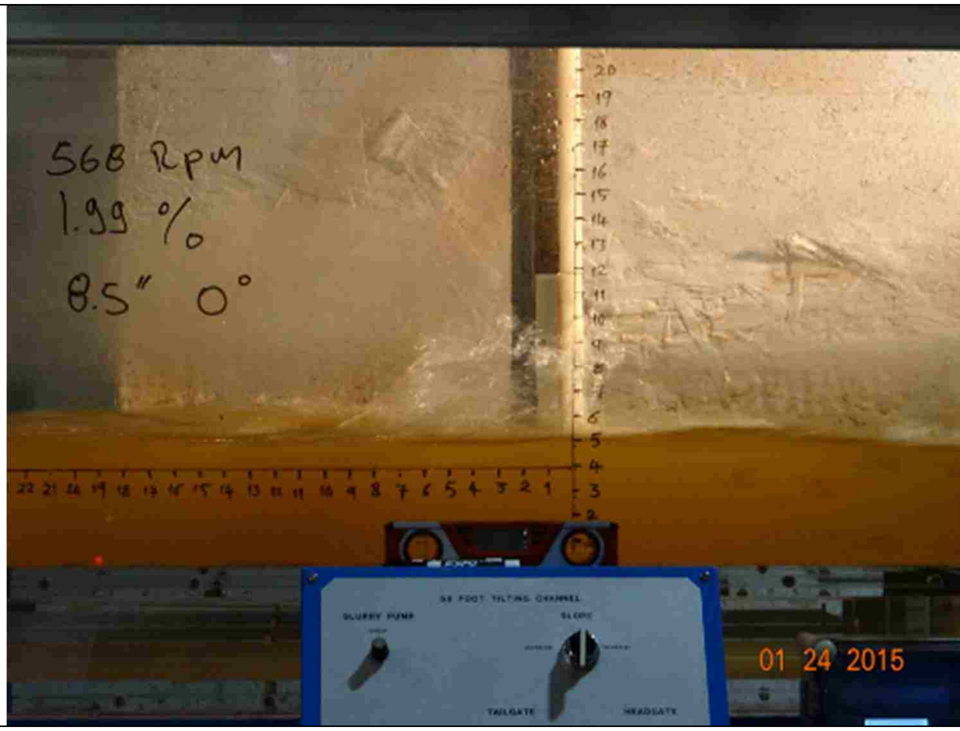

Figure 91. 568 RPM, slope: 1.99%, L_{bb}= 8.5”, pitch angle = 0°

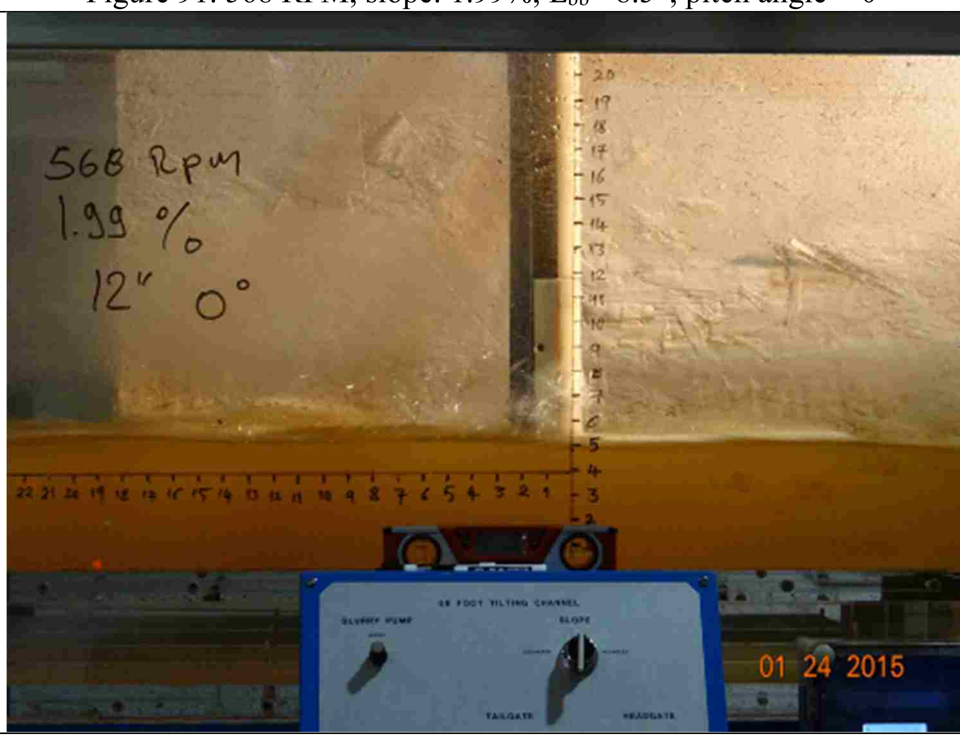

Figure 92. 568 RPM, slope: 1.99%, L_{bb}= 12”, pitch angle = 0°

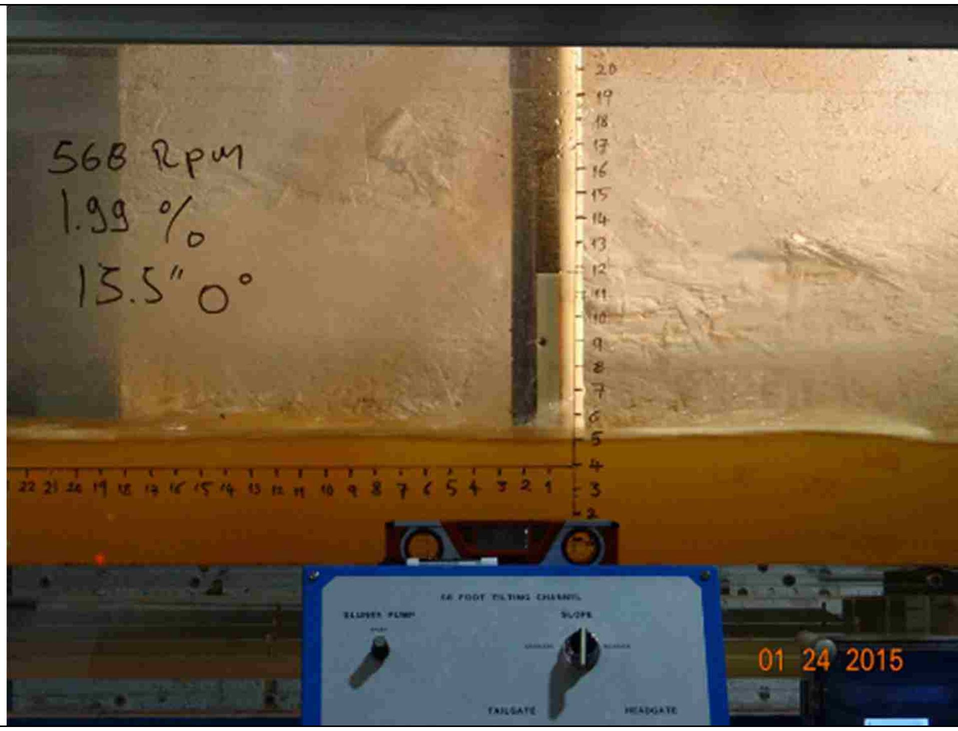

Figure 93. 568 RPM, slope: 1.99%, L_{bb}= 15.5", pitch angle = 0°

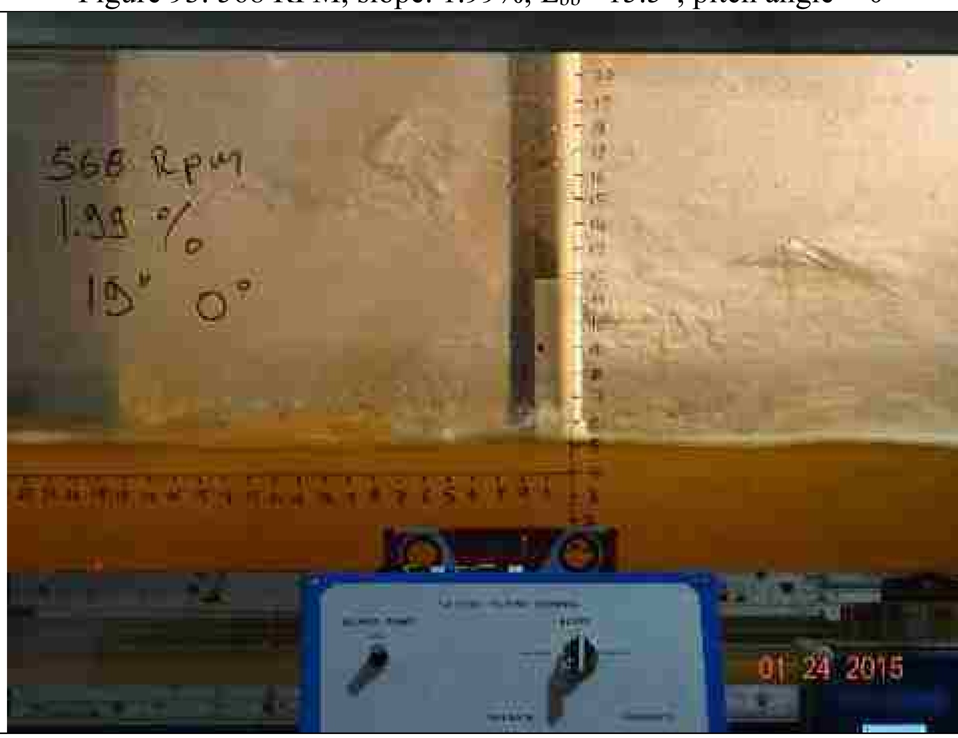

Figure 94. 568 RPM, slope: 1.99%, L_{bb}= 19", pitch angle = 0°

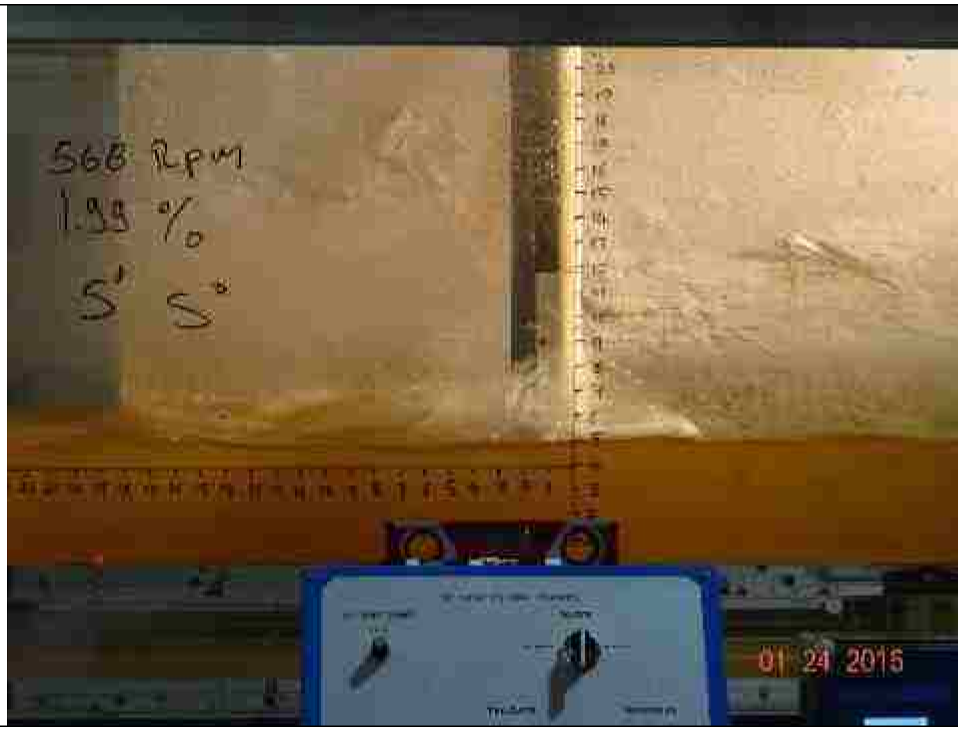

Figure 95. 568 RPM, slope: 1.99%, L_{bb}= 5”, pitch angle = 5°

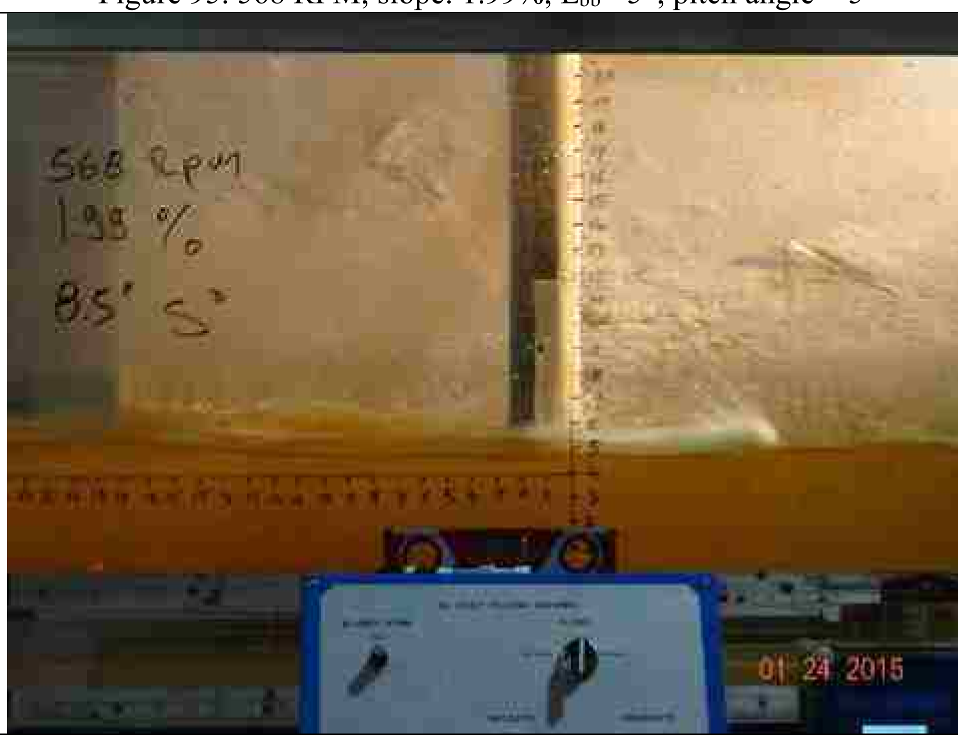

Figure 96. 568 RPM, slope: 1.99%, L_{bb}= 8.5”, pitch angle = 5°

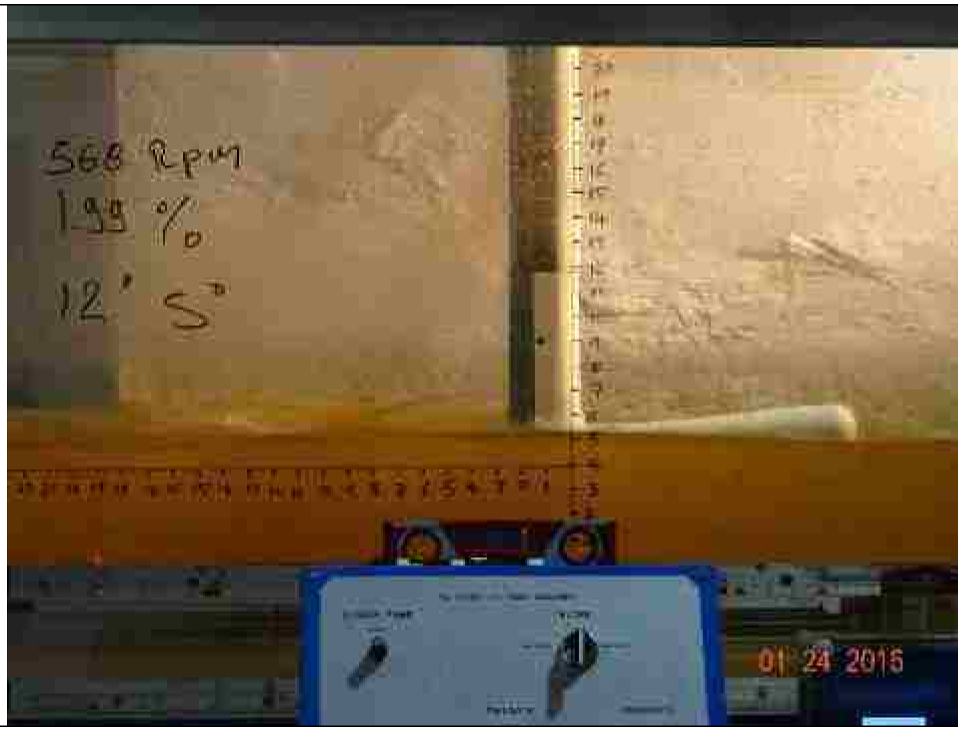

Figure 97. 568 RPM, slope: 1.99%, L_{bb}= 12”, pitch angle = 5°

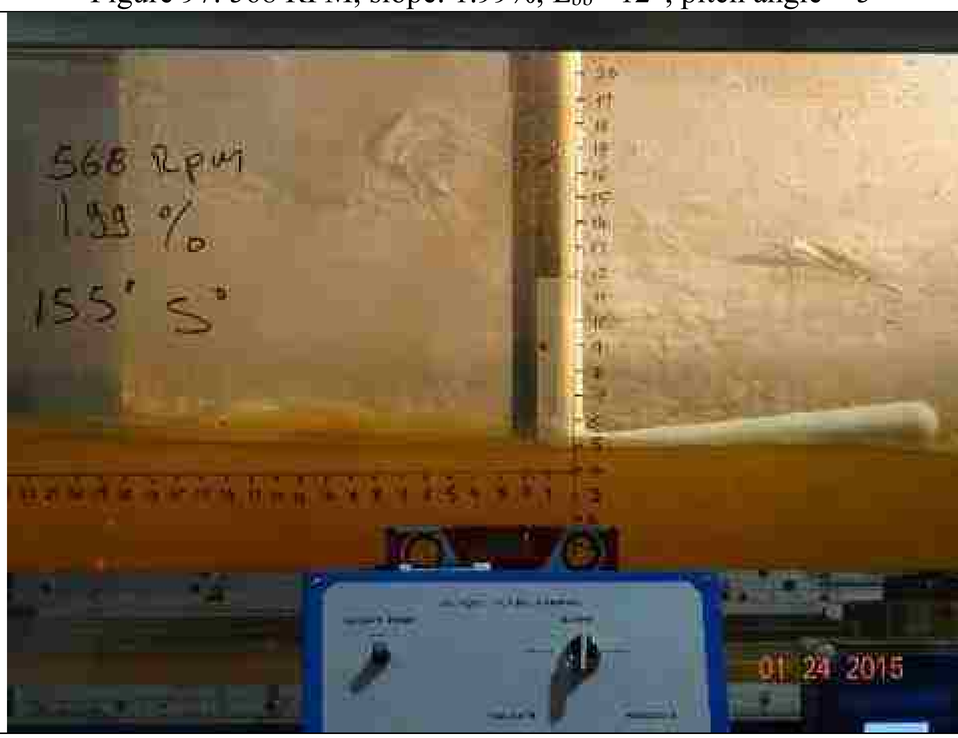

Figure 98**.** 568 RPM, slope: 1.99%, L_{bb}= 15.5”, pitch angle = 5°

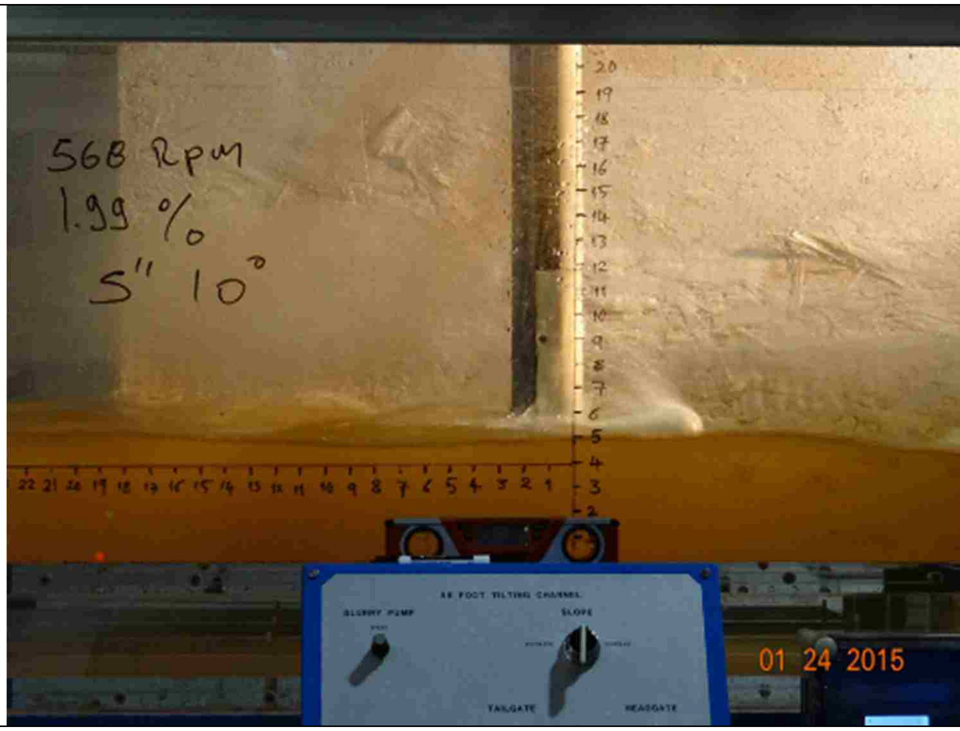

Figure 99. 568 RPM, slope: 1.99%, L_{bb}= 5”, pitch angle = 10°

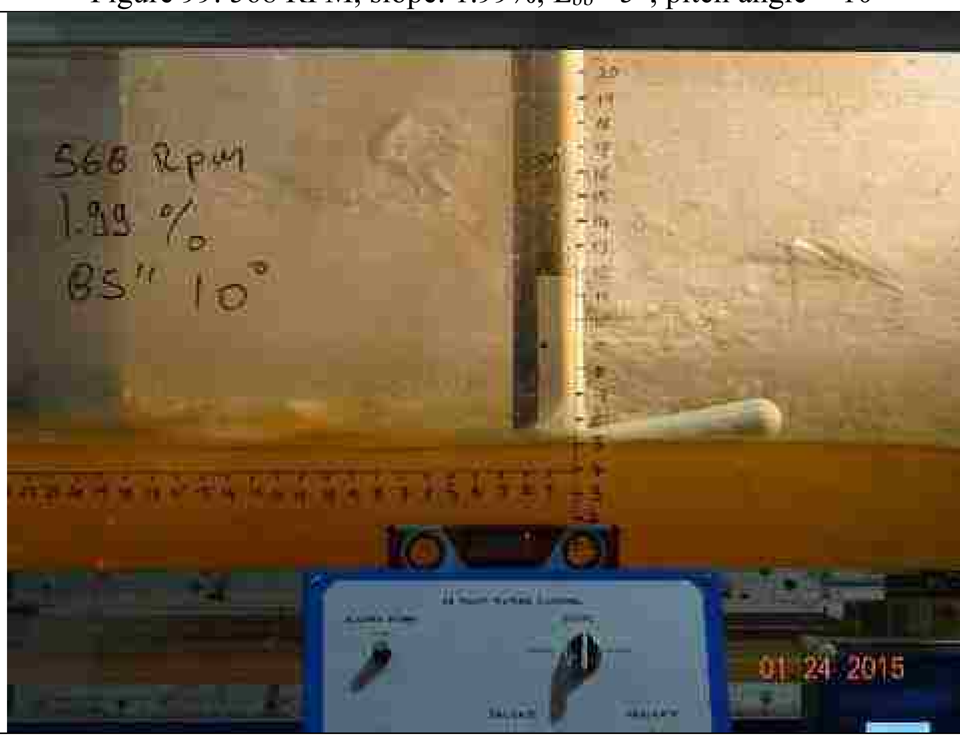

Figure 100. 568 RPM, slope: 1.99%, L_{bb}= 8.5”, pitch angle = 10°

Figure 101. 568 RPM, slope: 1.99%, L_{bb}= 12, pitch angle = 10°

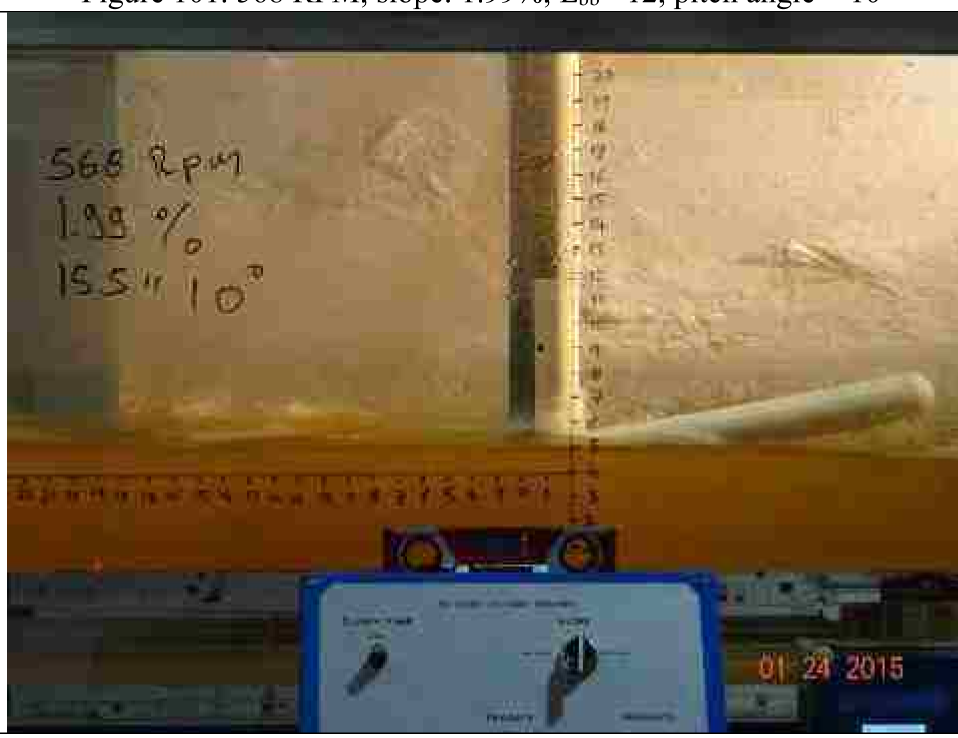

Figure 102. 568 RPM, slope: 1.99%, L_{bb}= 15.5", pitch angle = 10°

Figure 103. 570 RPM, slope: 2.38%, L_{bb}= 0”, pitch angle = 0°

Figure 104. 570 RPM, slope: 2.38%, L_{bb}= 5”, pitch angle = 0°

Figure 105. 570 RPM, slope: 2.38%, L_{bb}= 8.5", pitch angle = 0°

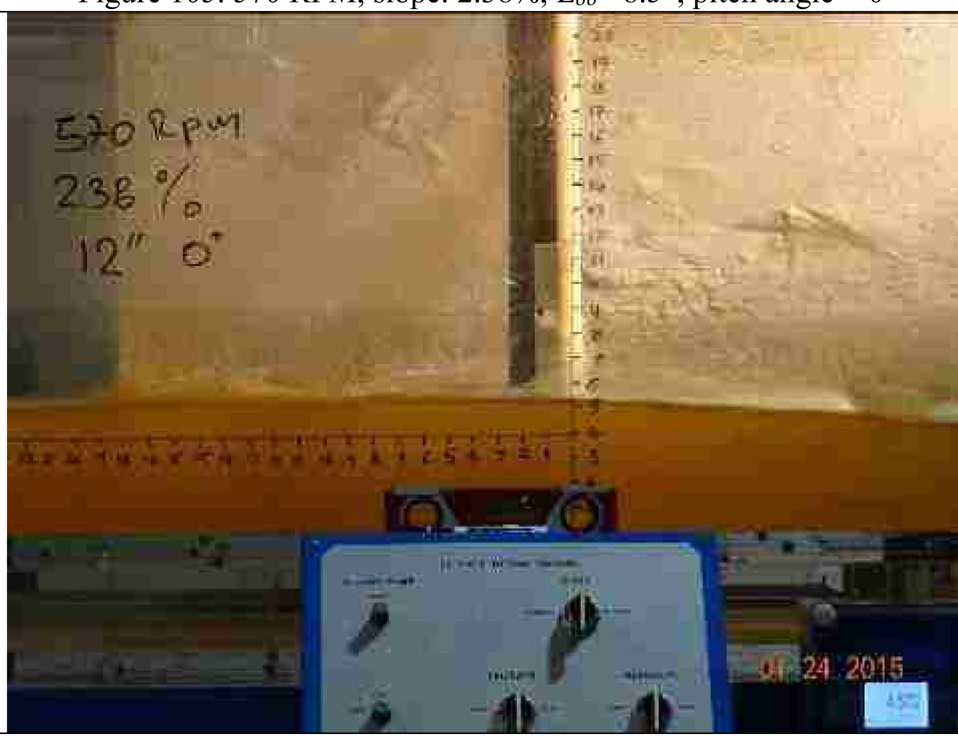

Figure 106**.** 570 RPM, slope: 2.38%, L_{bb}= 12", pitch angle = 0°

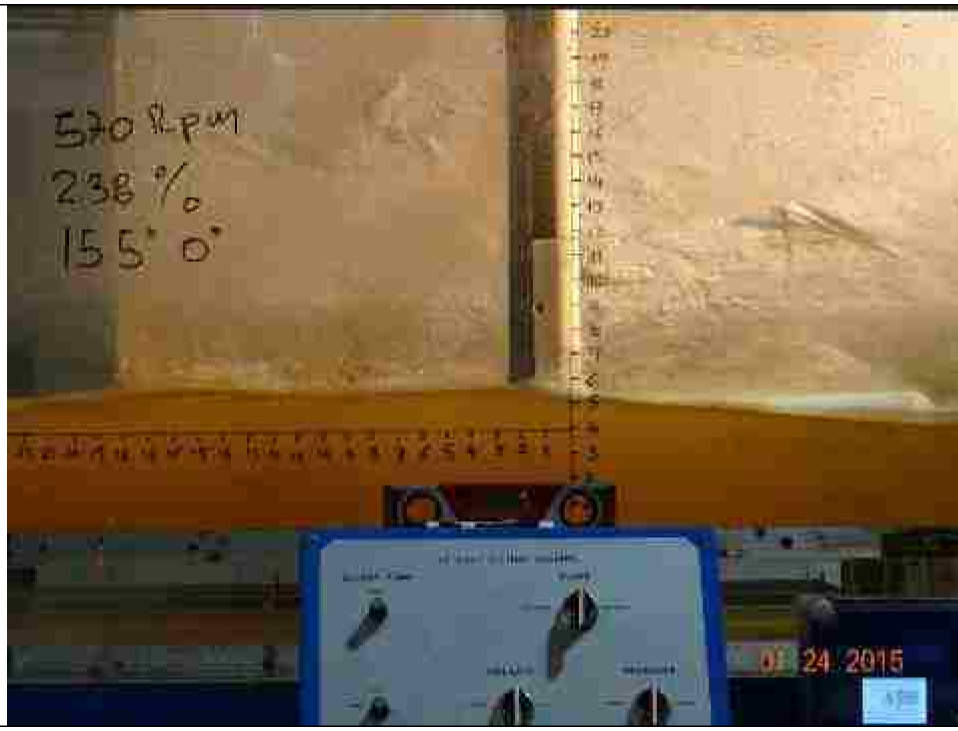

Figure 107. 570 RPM, slope: 2.38%, L_{bb}= 15.5”, pitch angle = 0°

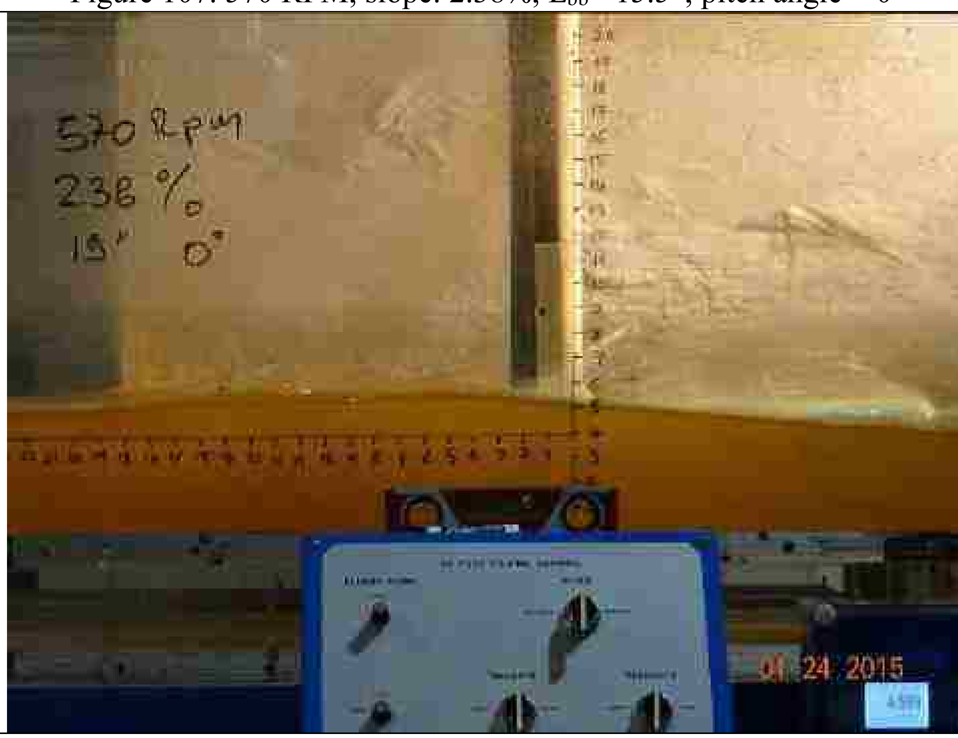

Figure 108. 570 RPM, slope: 2.38%, L_{bb}= 19”, pitch angle = 0°

Figure 109. 570 RPM, slope: 2.38%, L_{bb}= 5”, pitch angle = 5°

Figure 110. 570 RPM, slope: 2.38%, L_{bb}= 8.5”, pitch angle = 5°

Figure 111. 570 RPM, slope: 2.38%, L_{bb}= 12”, pitch angle = 5°

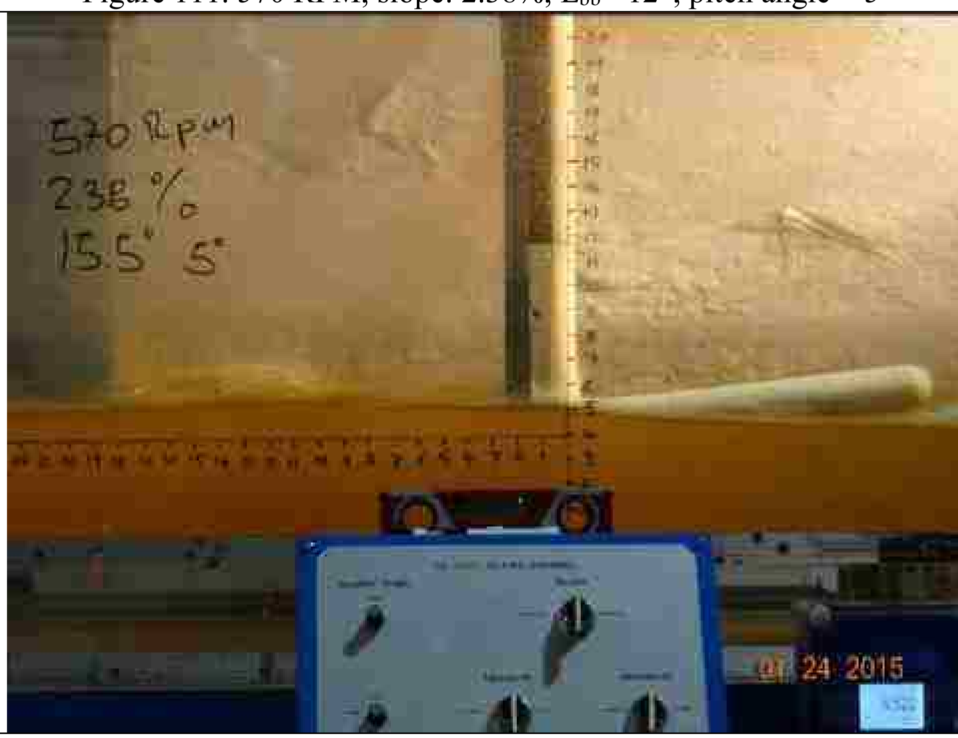

Figure 112. 570 RPM, slope: 2.38%, L_{bb}= 15.5”, pitch angle = 5°

Figure 113. 570 RPM, slope: 2.38%, L_{bb}= 5”, pitch angle = 10°

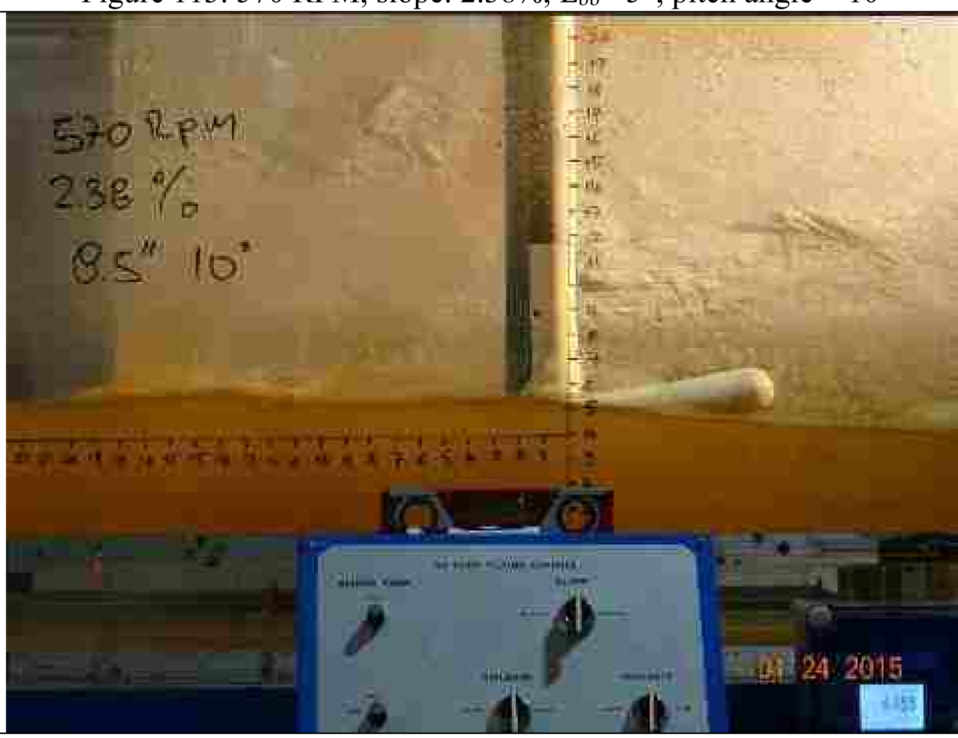

Figure 114. 570 RPM, slope: 2.38%, L_{bb}= 8.5”, pitch angle = 10°

Figure 115. 570 RPM, slope: 2.38%, L_{bb}= 12”, pitch angle = 10°

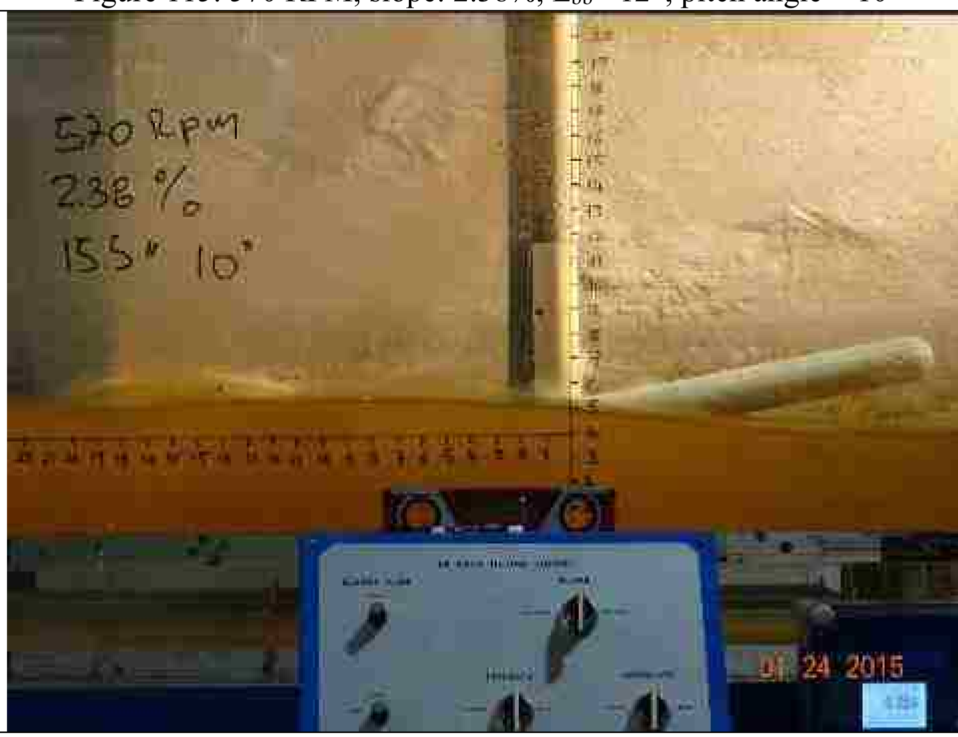

Figure 116. 570 RPM, slope: 2.38%, L_{bb}= 15.5”, pitch angle = 10°

Figure 117. 630 RPM, slope: 2.78%, L_{bb}= 0”, pitch angle = 0°

Figure 118. 630 RPM, slope: 2.78%, L_{bb}= 5”, pitch angle = 0°

Figure 119. 630 RPM, slope: 2.78%, L_{bb}= 8.5", pitch angle = 0°

Figure 120. 630 RPM, slope: 2.78%, L_{bb}= 12", pitch angle = 0°

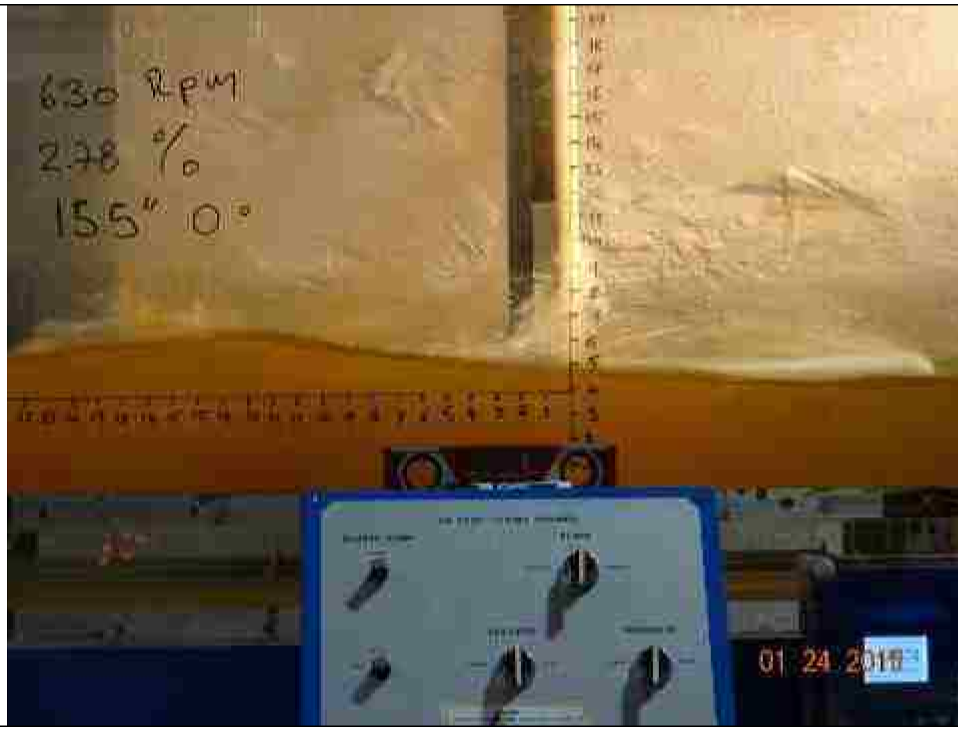

Figure 121. 630 RPM, slope: 2.78%, L_{bb}= 15.5", pitch angle = 0°

Figure 122. 630 RPM, slope: 2.78%, L_{bb}= 19", pitch angle = 0°

Figure 123. 630 RPM, slope: 2.78%, L_{bb}= 5”, pitch angle = 5°

Figure 124. 630 RPM, slope: 2.78%, L_{bb}= 8.5”, pitch angle = 5°

Figure 125. 630 RPM, slope: 2.78%, L_{bb}= 12”, pitch angle = 5°

Figure 126. 630 RPM, slope: 2.78%, L_{bb}= 15.5”, pitch angle = 5°

Figure 127. 630 RPM, slope: 2.78%, L_{bb}= 5”, pitch angle = 10°

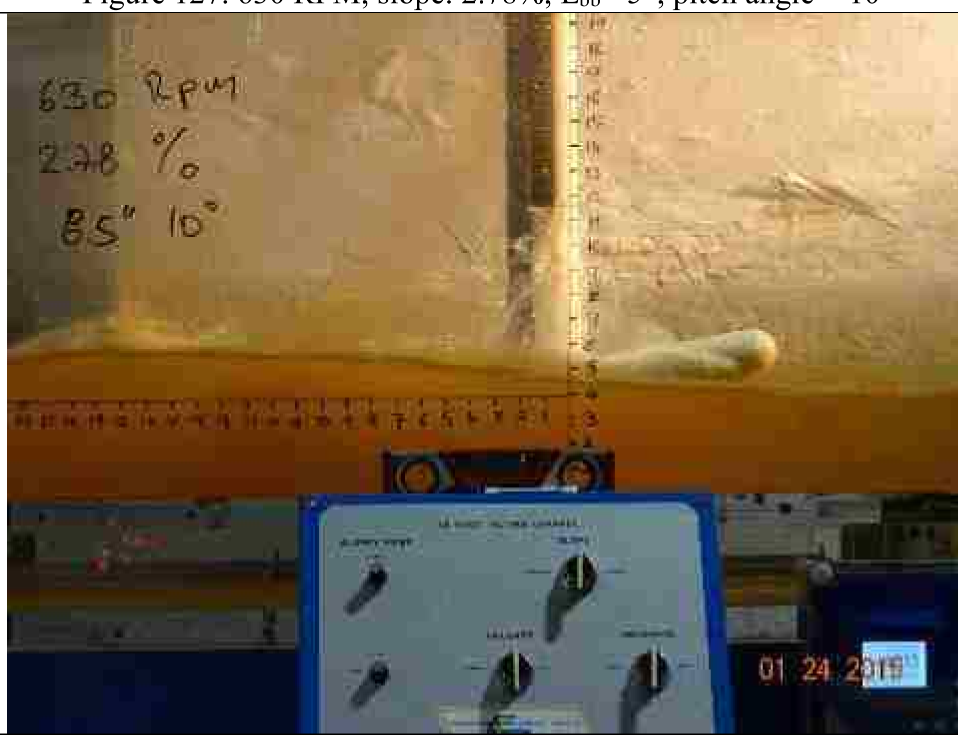

Figure 128. 630 RPM, slope: 2.78%, L_{bb}= 8.5”, pitch angle = 10°

Figure 129. 630 RPM, slope: 2.78%, L_{bb}= 12”, pitch angle = 10°

Figure 130. 630 RPM, slope: 2.78%, L_{bb}= 15.5”, pitch angle = 10°

Figure 131. 714 RPM, slope: 3.16%, L_{bb}= 0”, pitch angle = 0°

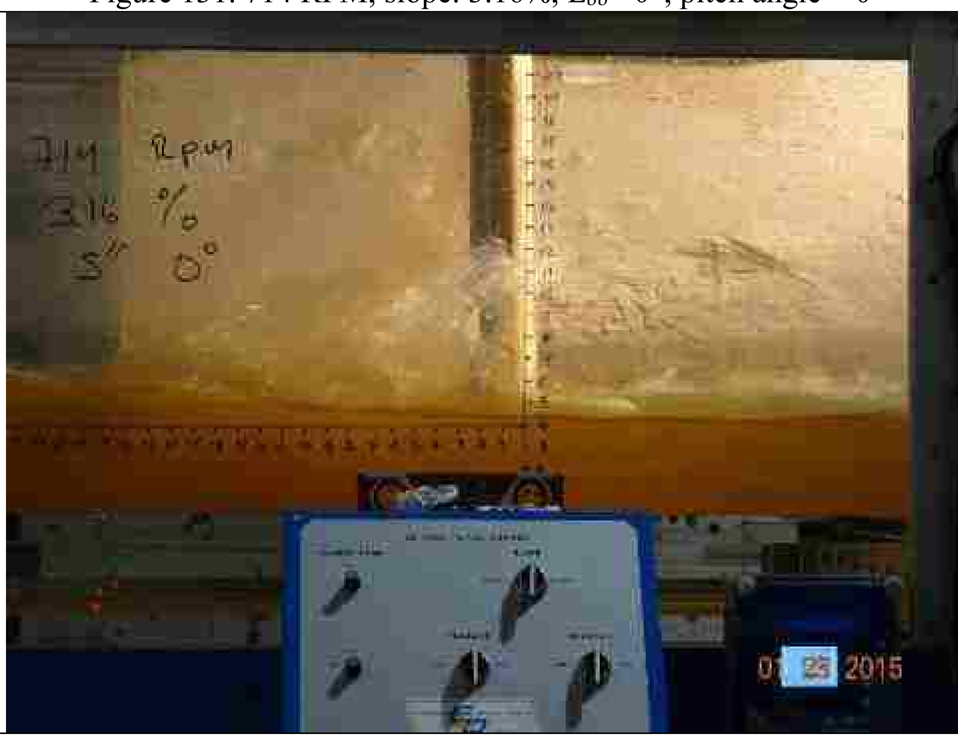

Figure 132. 714 RPM, slope: 3.16%, L_{bb}= 5”, pitch angle = 0°

Figure 133. 714 RPM, slope: 3.16%, L_{bb}= 8.5”, pitch angle = 0°

Figure 134. 714 RPM, slope: 3.16%, L_{bb}= 12”, pitch angle = 0°

Figure 135. 714 RPM, slope: 3.16%, L_{bb}= 15.5”, pitch angle = 0°

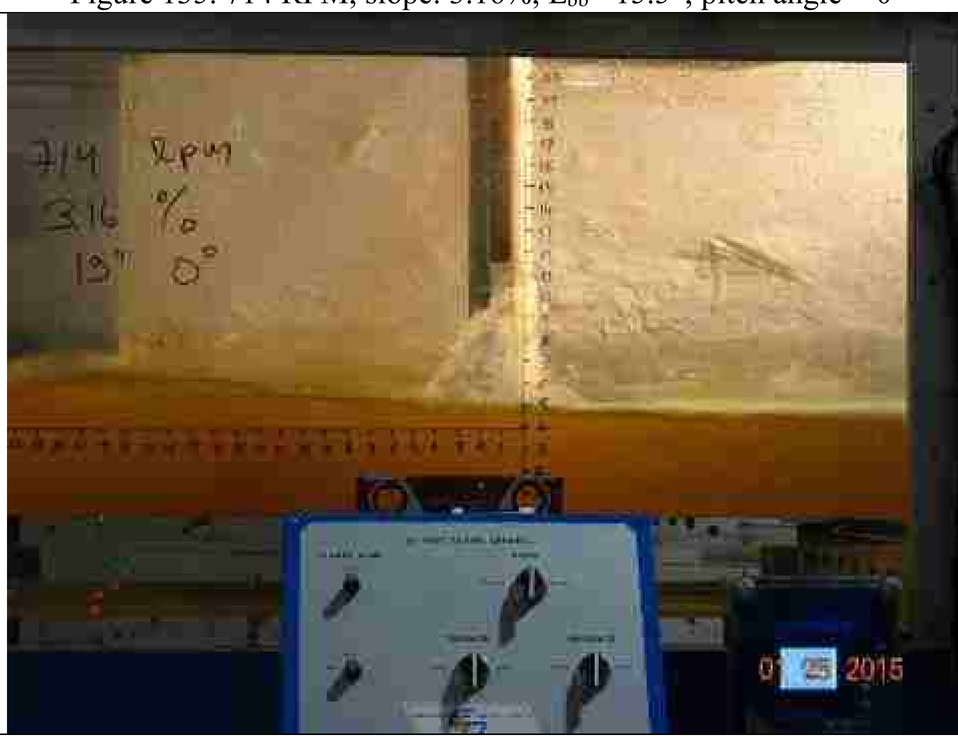

Figure 136. 714 RPM, slope: 3.16%, L_{bb}= 19”, pitch angle = 0°

Figure 137. 714 RPM, slope: 3.16%, L_{bb}= 5”, pitch angle = 5°

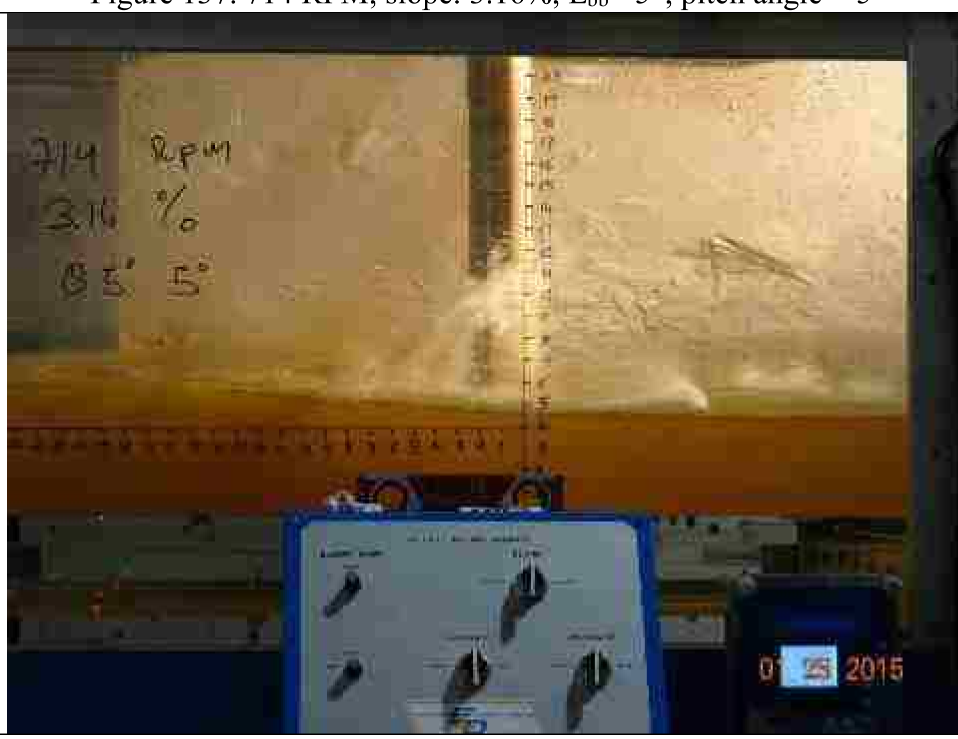

Figure 138. 714 RPM, slope: 3.16%, L_{bb}= 0”, pitch angle = 5°

Figure 139. 714 RPM, slope: 3.16%, L_{bb}= 12”, pitch angle = 5°

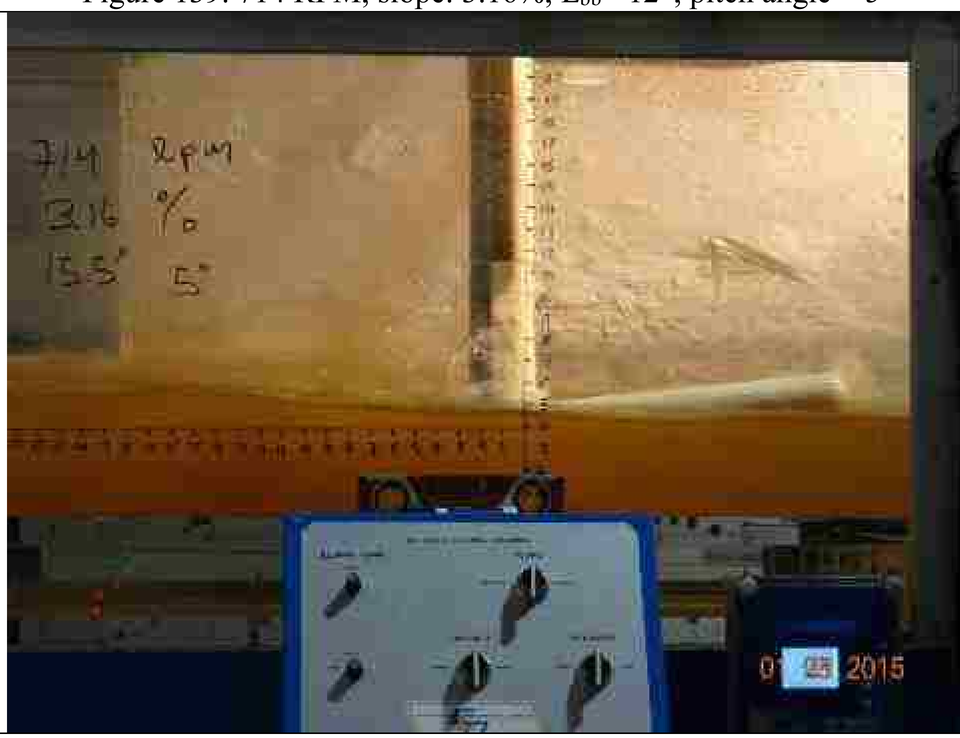

Figure 140. 714 RPM, slope: 3.16%, L_{bb}= 15.5”, pitch angle = 5°

Figure 141. 714 RPM, slope: 3.16%, L_{bb}= 5”, pitch angle = 10°

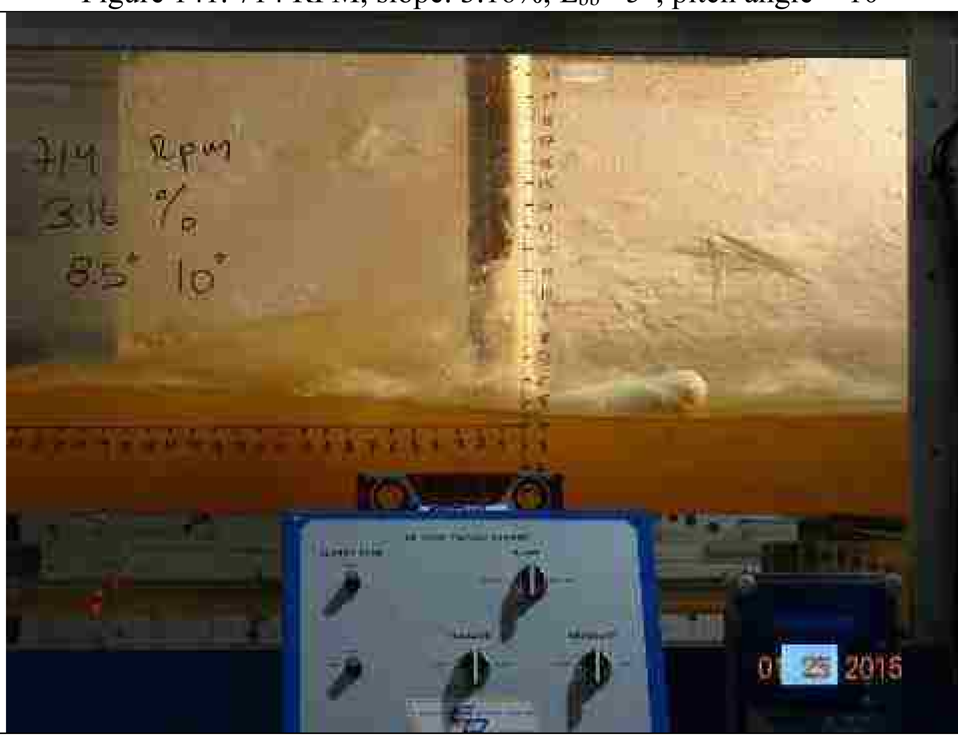

Figure 142. 714 RPM, slope: 3.16%, L_{bb}= 8.5”, pitch angle = 10°

Figure 143. 714 RPM, slope: 3.16%, L_{bb}= 12”, pitch angle = 10°

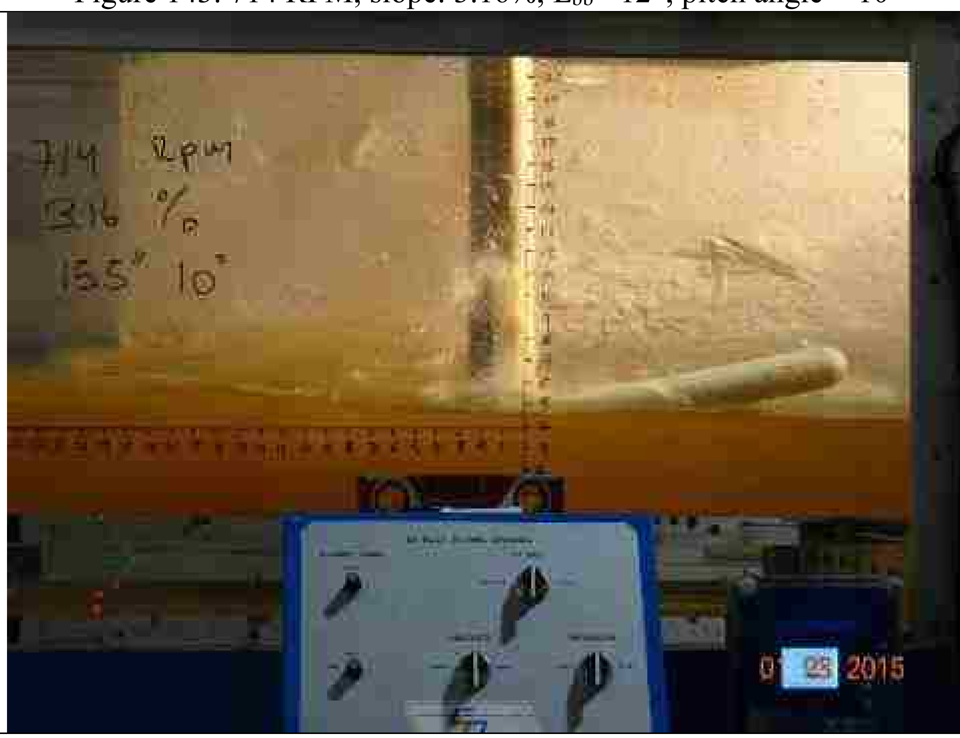

Figure 144. 714 RPM, slope: 3.16%, L_{bb}= 15.5”, pitch angle = 10°

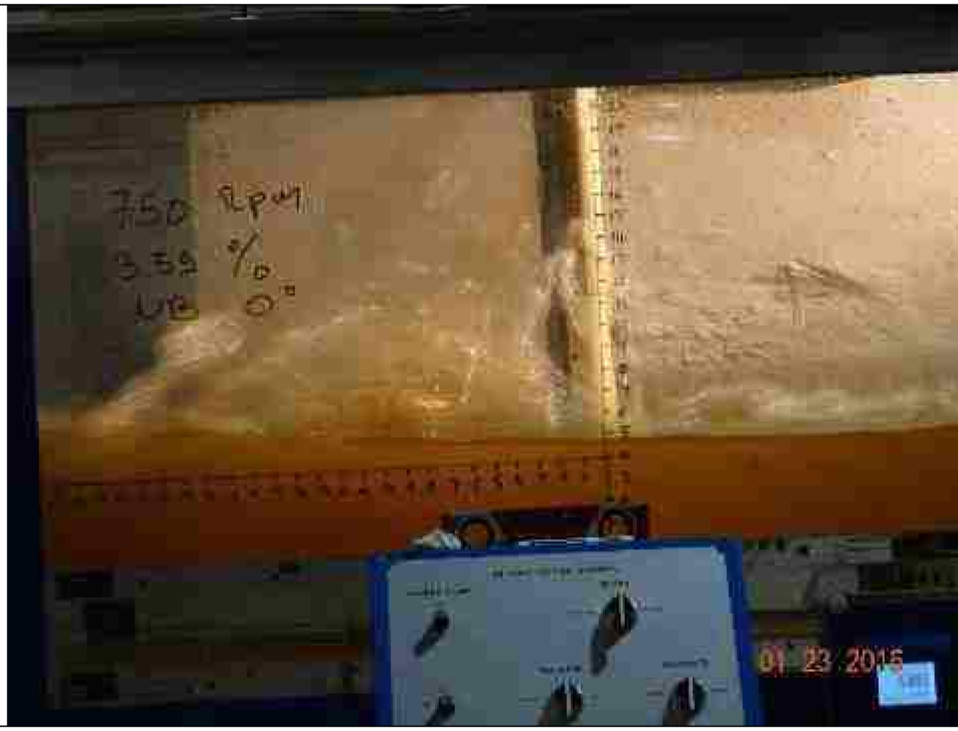

Figure 145. 750 RPM, slope: 3.59%, L_{bb}= 0”, pitch angle = 0°

Figure 146. 750 RPM, slope: 3.59%, L_{bb}= 5”, pitch angle = 0°

Figure 147. 750 RPM, slope: 3.59%, L_{bb}= 8.5”, pitch angle = 0°

Figure 148. 750 RPM, slope: 3.59%, L_{bb}= 12”, pitch angle = 0°

Figure 149. 750 RPM, slope: 3.59%, L_{bb}= 15.5”, pitch angle = 0°

Figure 150. 750 RPM, slope: 3.59%, L_{bb}= 19”, pitch angle = 0°

Figure 151. 750 RPM, slope: 3.59%, L_{bb}= 5”, pitch angle = 5°

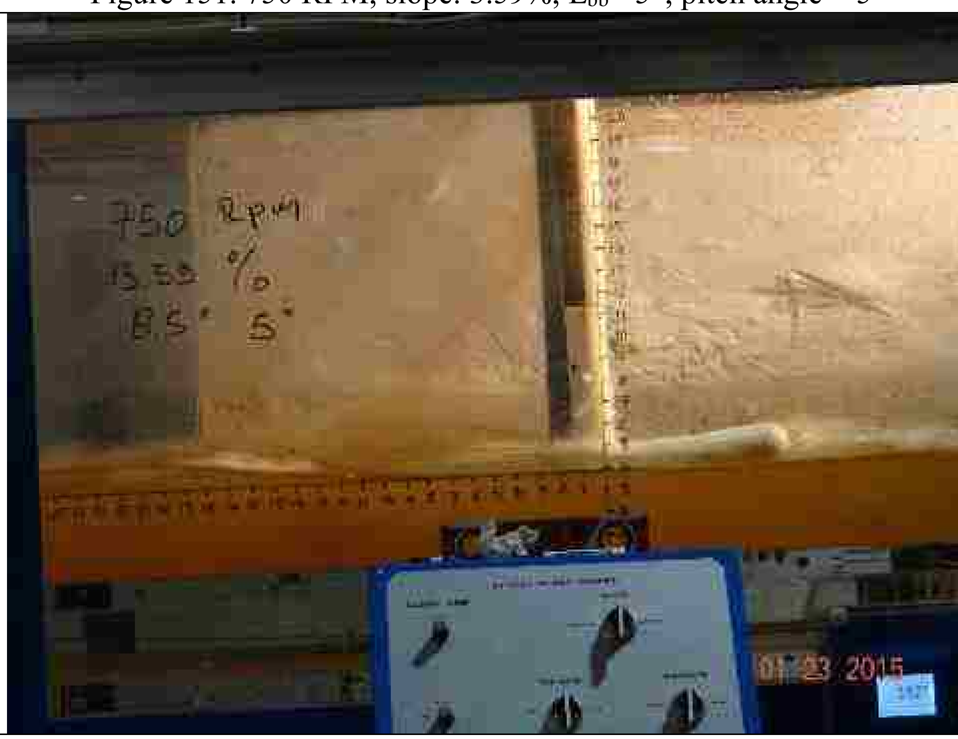

Figure 152. 750 RPM, slope: 3.59%, L_{bb}= 8.5”, pitch angle = 5°

Figure 153. 750 RPM, slope: 3.59%, L_{bb}= 12”, pitch angle = 5°

Figure 154. 750 RPM, slope: 3.59%, L_{bb}= 15.5”, pitch angle = 5°

Figure 155. 750 RPM, slope: 3.59%, L_{bb}= 5”, pitch angle = 10°

Figure 156. 750 RPM, slope: 3.59%, L_{bb}= 8.5”, pitch angle = 10°

Figure 157. 750 RPM, slope: 3.59%, L_{bb}= 12”, pitch angle = 10°

Figure 158. 750 RPM, slope: 3.59%, L_{bb}= 15.5”, pitch angle = 10°

Figure 159. 765 RPM, slope: 4.26%, L_{bb}= 0”, pitch angle = 0°

Figure 160. 765 RPM, slope: 4.26%, L_{bb}= 5”, pitch angle = 0°

Figure 161. 765 RPM, slope: 4.26%, L_{bb}= 8.5”, pitch angle = 0°

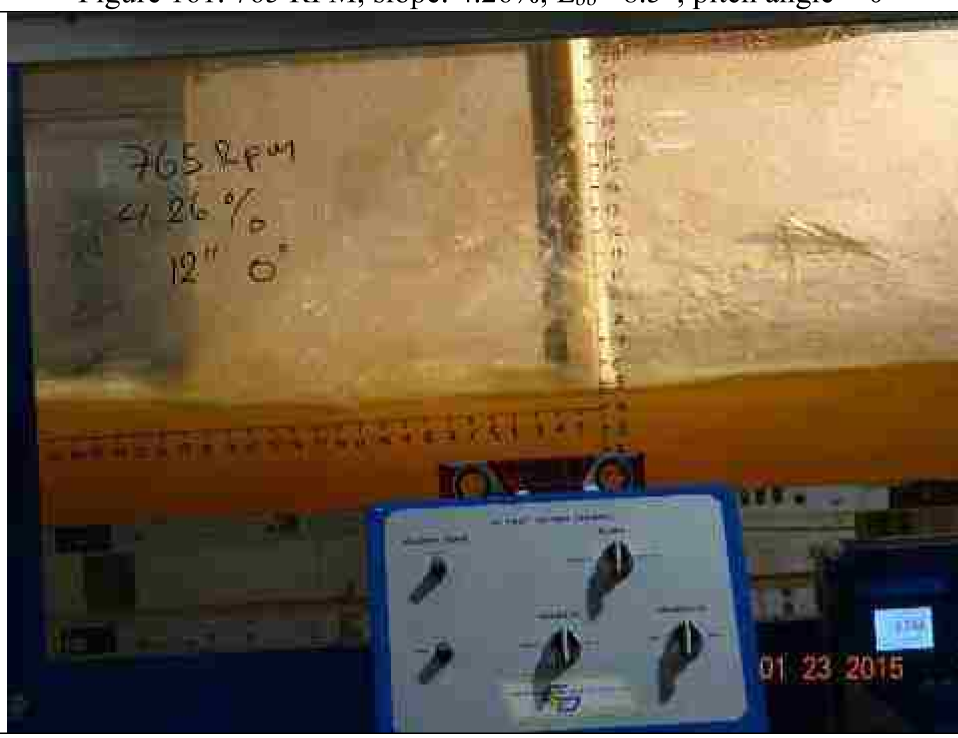

Figure 162. 765 RPM, slope: 4.26%, L_{bb}= 12”, pitch angle = 0°

Figure 163. 765 RPM, slope: 4.26%, L_{bb}= 15.5”, pitch angle = 0°

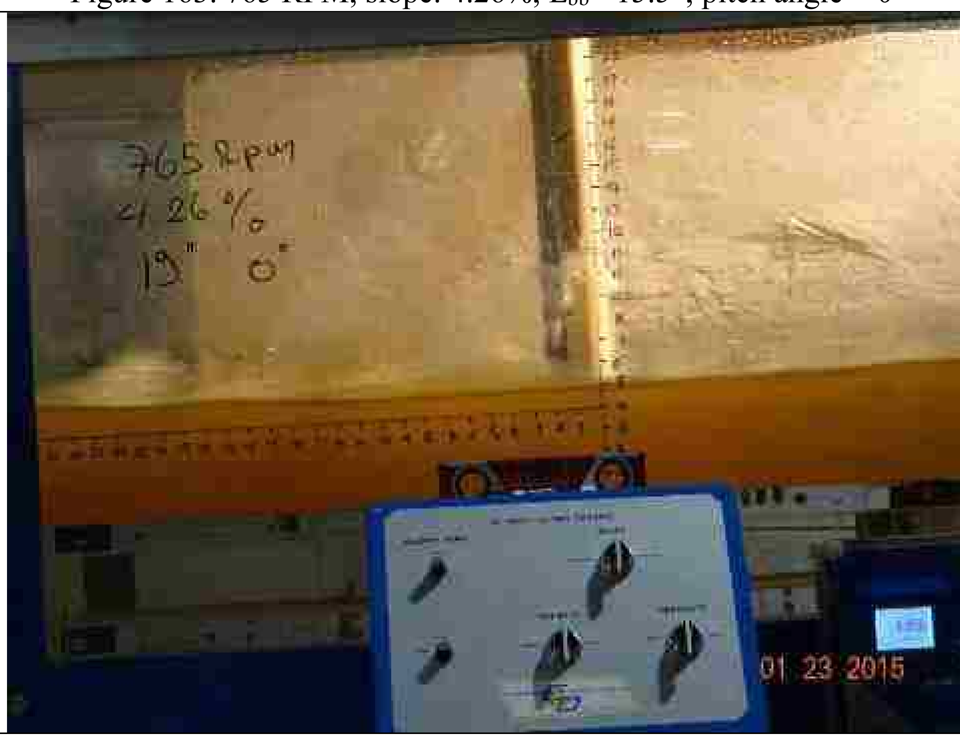

Figure 164. 765 RPM, slope: 4.26%, L_{bb}= 19”, pitch angle = 0°

Figure 165. 765 RPM, slope: 4.26%, L_{bb}= 5”, pitch angle = 5°

Figure 166. 765 RPM, slope: 4.26%, L_{bb}= 8.5”, pitch angle = 5°

Figure 167. 765 RPM, slope: 4.26%, L_{bb}=12", pitch angle = 5°

Figure 168. 765 RPM, slope: 4.26%, L_{bb}= 15.5", pitch angle = 5°

Figure 169. 765 RPM, slope: 4.26%, L_{bb}= 5", pitch angle = 10°

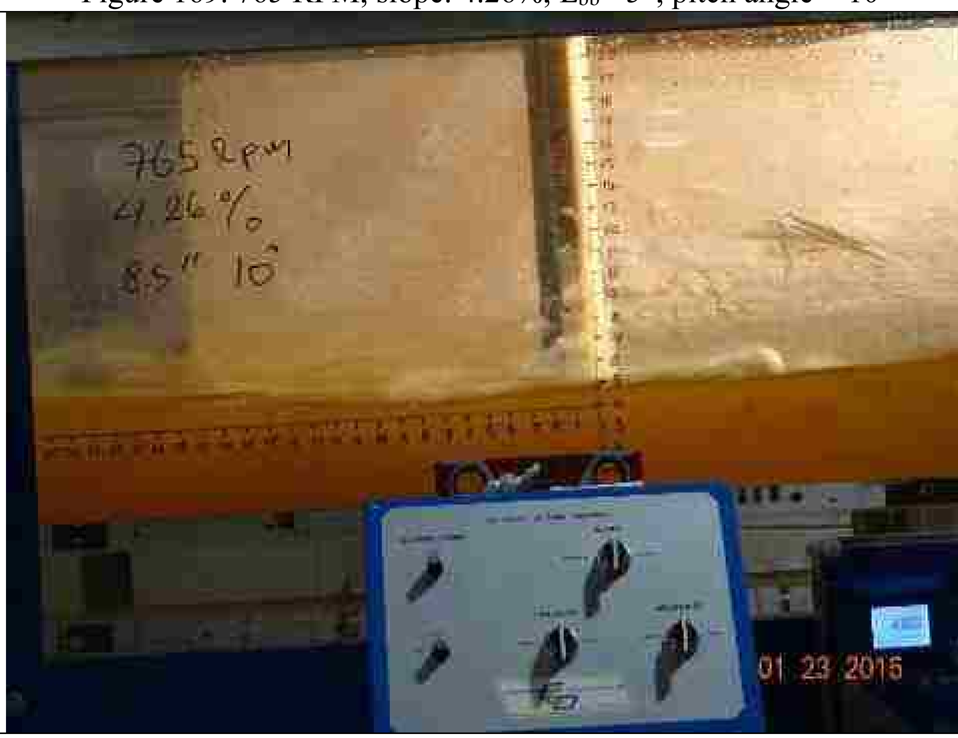

Figure 170. 765 RPM, slope: 4.26%, L_{bb}= 8.5", pitch angle = 10°

Figure 171. 765 RPM, slope: 4.26%, L_{bb}= 12”, pitch angle = 10°

Figure 172. 765 RPM, slope: 4.26%, L_{bb}= 15.5”, pitch angle = 10°

APPENDIX B: VBA CODE FOR MANNING EQUATION

```
Option Compare Database

 Sub table(Table_Name, Manning)
 'subroutine working don't delete

 Dim dbs As Database, tbl As TableDef, fld As Field
 Dim Flume_Width As Double
 Dim Flume_length As Double
 Dim Pump_N_Speed As Double
 Dim Pump_N_Flow As Double
 Dim Min_Slope As Double
 Dim Max_Slope As Double
 Dim Min_RPM As Double
 Dim Max_RPM As Double
 Dim Step_RPM As Double
 Dim Flume_Speed As Double
 Dim Froude As Double
 Dim Energy As Double
 Dim Culver_Elevation As Double
 Dim Pier_submerge As Double
 Dim iReply As Integer
 Dim Slope As Double
 Dim Pump_Speed As Double
 Dim Pump_Flow As Double
 Dim Water_Wepth As Double
 Dim L As Double ' Left side of manning equation
 Dim R As Double ' Right side of manning equation
 Dim Y As Double
 Dim i As Integer



If Not IsNull(DLookup("Name", "MSysObjects", "Name=Table_Name")) Then
    'Table Exists

 iReply = MsgBox(Prompt:="Table Exist, Do you want to delete table? ", _
         Buttons:=vbYesNoCancel, Title:="Create Table")

   If iReply = vbYes Then
   DoCmd.Close acTable, Table_Name, acSaveYes

   DoCmd.DeleteObject acTable, Table_Name
```

```
    Else 'They cancelled (VbCancel)

        Exit Sub

    End If

End If


Set dbs = CurrentDb
If Len(Table_Name) = 0 Then
Table_Name = "test"
End If

Set tbl = dbs.CreateTableDef(Table_Name)
Set fld = tbl.CreateField("Pump_Speed_T", dbLong)
tbl.Fields.Append fld
Set fld = tbl.CreateField("Pump_Flow_T", dbDouble)
tbl.Fields.Append fld
Set fld = tbl.CreateField("Slope_T", dbDouble)
tbl.Fields.Append fld
Set fld = tbl.CreateField("Water_Depth_T", dbDouble)
tbl.Fields.Append fld
Set fld = tbl.CreateField("Area_T", dbDouble)
tbl.Fields.Append fld
Set fld = tbl.CreateField("Wet_Perimeter_T", dbDouble)
tbl.Fields.Append fld
Set fld = tbl.CreateField("Hydraulic_Ratio_T", dbDouble)
tbl.Fields.Append fld
Set fld = tbl.CreateField("Flume_Speed_T", dbDouble)
tbl.Fields.Append fld
Set fld = tbl.CreateField("Froude_T", dbDouble)
tbl.Fields.Append fld
Set fld = tbl.CreateField("Energy_T", dbDouble)
tbl.Fields.Append fld
Set fld = tbl.CreateField("L", dbDouble)
tbl.Fields.Append fld
Set fld = tbl.CreateField("R", dbDouble)
tbl.Fields.Append fld

dbs.TableDefs.Append tbl
dbs.TableDefs.Refresh
RefreshDatabaseWindow
```

```
MsgBox Table_Name & "  Table Created."

Slope = 0

Do
Slope = Slope + 0.1
Y = 0.0001
 'All dimesion in ft
Flume_Width = 1.5
Flume_length = 58
Pump_N_Speed = 1850
Pump_N_Flow = 8.02

Min_RPM = 10
Max_RPM = 1000
Step_RPM = 1
Pump_Speed = Min_RPM

Do
Pump_Flow = Pump_Speed * 0.006961934
L = (Pump_Flow * Manning) / (1.49 * Sqr(Slope / 100))

Do
 Area = Y * Flume_Width
 Wet_Perimeter = 2 * Y + Flume_Width
 Hydraulic_Ratio = Area / Wet_Perimeter
 R = Area * Hydraulic_Ratio ^ (2 / 3)
Y = Y + 0.0001
 Loop Until L - R < 0

Water_Depth = Y
Flume_Speed = Pump_Flow / Area
Froude = Flume_Speed / (Sqr(32.174 * Water_Depth))
Energy = Y + ((Pump_Flow) ^ (2) / (2 * 32.17 * Y * 1.5))

Call addrecord(Table_Name, Pump_Speed, Pump_Flow, Slope, Water_Depth,
Hydraulic_Ratio, Area, Wet_Perimeter, R, L, Flume_Speed, Froude, Energy)
Pump_Speed = Pump_Speed + Step_RPM
Loop Until Pump_Speed = Max_RPM + Step_RPM



 Loop Until Slope > 5
```

```
MsgBox Table_Name & "  Records Created."


 End Sub

Private Sub addrecord(Table_Name, Pump_Speed, Pump_Flow, Slope,
Water_Depth, Hydraulic_Ratio, Area, Wet_Perimeter, R, L, Flume_Speed, Froude,
Energy)
'subroutine working don't delete

  Dim dbcurrent As DAO.Database
  Dim Ctables As DAO.Recordset

  Set dbcurrent = CurrentDb
  Set Ctables = dbcurrent.OpenRecordset(Table_Name)

  Ctables.AddNew
  Ctables("Pump_Speed_T").Value = Pump_Speed
  Ctables("Pump_Flow_T").Value = Round(Pump_Flow, 3)
  Ctables("Slope_T").Value = Slope
  Ctables("Water_Depth_T").Value = Round(Water_Depth, 3)
  Ctables("Hydraulic_Ratio_T").Value = Round(Hydraulic_Ratio, 3)
  Ctables("Area_T").Value = Round(Area, 3)
  Ctables("Wet_Perimeter_T").Value = Round(Wet_Perimeter, 3)
  Ctables("L").Value = Round(L, 3)
  Ctables("R").Value = Round(R, 3)
  Ctables("Flume_Speed_T").Value = Round(Flume_Speed, 3)
  Ctables("Froude_T").Value = Round(Froude, 3)
  Ctables("Energy_T").Value = Round(Energy, 3)

  Ctables.Update



End Sub
```

APPENDIX C: VBA CODE FOR BULBOUS PIER EQUATION

```
Option Compare Database


Sub linear_A()
 Dim Table_Time As String
 Dim myRS As DAO.Recordset
 Dim myRS1 As DAO.Recordset
 Dim fso
 Dim strSQL, strSQL1 As String
 Dim Dbs As Database, tbl As TableDef, fld As Field
 Dim ID As Long
 Dim time As Single
 Dim Flume_Flow As Single
 Dim Flume_Level As Single
 Dim Velocity As Single
 Dim Pier_Level As Single
 Dim Pipe_Flow As Single
 Dim Slope As Single
 Dim RPM As Single
 Dim BB_Length As Single
 Dim BB_Length_E As Single
 Dim BB_Length_Y As Single
 Dim BB_Length_S As Single
 Dim BB_Depth As Single
 Dim BB_Angle As Single
 Dim BB_Volume As Single
 Dim BB_Volume_S As Single
 Dim BB_Area_S As Single
 Dim Froude As Single
 Dim BB_SR As Single
 Dim BBLE_BBSR As Single
 Dim Pier_SB As Single
 Dim BBVS_PVS As Single
 Dim BB_Radian As Double
 Dim Serie As String
 Dim NCserie As String
 Dim KCserie As String
 Dim S_124_550, S_159_601, S_199_568, S_238_570, S_278_630, S_316_714,
S_359_750, S_426_765 As String
 Dim S_124_550_M, S_159_601_M, S_199_568_M, S_238_570_M, S_278_630_M,
S_316_714_M, S_359_750_M, S_426_765_M As Single
 Dim pi As Double
```

```
Dim R As Single  'Bulbous radius
Dim Q As Double ' grouping  equation incline pipe vol
Dim LL As Double ' grouping  equation incline pipe vol
Dim aa As Double ' grouping  equation incline pipe vol
Dim h0 As Single ' grouping  equation incline pipe vol
Dim K As Double ' grouping  equation incline pipe vol
Dim h1, h2 As Single
Dim L, h   As Single
Dim CounterStop As Boolean
Dim t1, t2 As String
Dim a, b As Double
Dim xx, n, CC1, RR, CounterMax As Integer
Dim BBVNS As Single ' Bulbous volume not submerge
Dim BBPS As Single ' Bulbous vertical submerge
'Dim BW_T As Double
'Dim BW_R As Double
Dim RFlume_Level As Single
Dim alpha As Single ' bulbous submerger area calculation parameter
Dim beta As Single ' bulbous submerger area calculation parameter
'Dim a, b As Single ' bulbous submerger area calculation parameter
Dim sigma As Single ' bulbous submerger area calculation parameter
Dim op As Single ' bulbous submerger area calculation parameter
Dim y As Single ' bulbous submerger area calculation parameter
Dim hh As Single ' bulbous submerger area calculation parameter
Dim Lbbes As Single ' bulbous length effective submerge parameter
Dim Energy As Single ' flume energy equation
Dim Z As Single ' slope elevation
Dim Pier_Level_Energy As Single
Dim RN As Double ' Reynolds number
Dim CF As Double ' Viscous Friction coefficient
Dim BW As Single ' Bulbous Wave
Dim BW_T As Single ' Bulbous Wave theorical
Dim BW_Error As Single ' Bulbous Wave theorical
Dim Kn As Single ' viscous normal constant
Dim Rv As Single ' vicous resistance
Dim Vbb2 As Single ' wave-making resistance
Dim BWv As Single ' Bulb wave viscous component
Dim BWw As Single ' Bulb wave wave-making component
Dim PWR As Single ' pier wave ratio
Dim PWR_T As Single
Dim PWR_TC As Single
Dim PWR_err As Single
Dim PLbb_T As Single ' pier bulbous pier level theorical
Dim PLbb_D As Single ' pier bulbous pier level data
```

```
Dim PLbb_err As Single

'--------------------------------

Table_Name = "01_23_2015_cals"

Call Table_Exist(Table_Name)

Set Dbs = CurrentDb

Set tbl = Dbs.CreateTableDef(Table_Name)

Set fld = tbl.CreateField("ID", dbLong)
tbl.Fields.Append fld

Set fld = tbl.CreateField("Time", dbSingle)
tbl.Fields.Append fld

Set fld = tbl.CreateField("Flume_Flow", dbSingle)
tbl.Fields.Append fld

Set fld = tbl.CreateField("Flume_Level", dbSingle)
tbl.Fields.Append fld

Set fld = tbl.CreateField("Velocity", dbSingle)
tbl.Fields.Append fld

Set fld = tbl.CreateField("Pier_Level", dbSingle)
tbl.Fields.Append fld

Set fld = tbl.CreateField("Pier_Level_Energy", dbSingle)
tbl.Fields.Append fld

Set fld = tbl.CreateField("Pipe_Flow", dbSingle)
tbl.Fields.Append fld

Set fld = tbl.CreateField("Slope", dbSingle)
tbl.Fields.Append fld

Set fld = tbl.CreateField("RPM", dbSingle)
tbl.Fields.Append fld

Set fld = tbl.CreateField("BB_Length", dbSingle)
```

```
tbl.Fields.Append fld

Set fld = tbl.CreateField("BB_Length_S", dbSingle)
tbl.Fields.Append fld

Set fld = tbl.CreateField("BB_Depth", dbSingle)
tbl.Fields.Append fld

Set fld = tbl.CreateField("BB_Angle", dbSingle)
tbl.Fields.Append fld

Set fld = tbl.CreateField("BB_Volume", dbSingle)
tbl.Fields.Append fld

Set fld = tbl.CreateField("BB_Volume_S", dbSingle)
tbl.Fields.Append fld

Set fld = tbl.CreateField("BB_Area_S", dbSingle)
tbl.Fields.Append fld

Set fld = tbl.CreateField("BB_Radian", dbDouble)
tbl.Fields.Append fld

Set fld = tbl.CreateField("BBLE_BBSR", dbSingle)
tbl.Fields.Append fld

Set fld = tbl.CreateField("Froude", dbSingle)
tbl.Fields.Append fld

Set fld = tbl.CreateField("Pier_VS", dbSingle)
tbl.Fields.Append fld

Set fld = tbl.CreateField("BBVS_PVS", dbSingle)
tbl.Fields.Append fld

Set fld = tbl.CreateField("RFlume_Level", dbSingle)
tbl.Fields.Append fld

Set fld = tbl.CreateField("Serie", dbText)
tbl.Fields.Append fld

Set fld = tbl.CreateField("CSerie", dbText)
tbl.Fields.Append fld
```

```
Set fld = tbl.CreateField("Energy", dbSingle)
tbl.Fields.Append fld

Set fld = tbl.CreateField("Reynolds", dbSingle)
tbl.Fields.Append fld

Set fld = tbl.CreateField("Coeff_Friction", dbDouble)
tbl.Fields.Append fld

Set fld = tbl.CreateField("BW", dbSingle)
tbl.Fields.Append fld

Set fld = tbl.CreateField("Rv", dbSingle)
tbl.Fields.Append fld

Set fld = tbl.CreateField("Vbb2", dbSingle)
tbl.Fields.Append fld

Set fld = tbl.CreateField("BWv", dbSingle)
tbl.Fields.Append fld

Set fld = tbl.CreateField("BWw", dbSingle)
tbl.Fields.Append fld

Set fld = tbl.CreateField("PWR", dbSingle)
tbl.Fields.Append fld

Set fld = tbl.CreateField("PWR_T", dbSingle)
tbl.Fields.Append fld


Set fld = tbl.CreateField("PWR_TC", dbSingle)
tbl.Fields.Append fld
Set fld = tbl.CreateField("PWR_err", dbSingle)
tbl.Fields.Append fld

Set fld = tbl.CreateField("PLbb_T", dbSingle)
tbl.Fields.Append fld

Set fld = tbl.CreateField("PLbb_D", dbSingle)
tbl.Fields.Append fld

Set fld = tbl.CreateField("PLbb_err", dbSingle)
tbl.Fields.Append fld
```

```
Dbs.TableDefs.Append tbl
Dbs.TableDefs.Refresh
RefreshDatabaseWindow
MsgBox Table_Time & "  Table Created."


'------------------------------------------


S_124_550_M = 9.4
S_159_601_M = 10.8
S_199_568_M = 11.07
S_238_570_M = 11.35
S_278_630_M = 12.19
S_316_714_M = 16.22
S_359_750_M = 16.35
S_426_765_M = 16.17
g = 32.174
pi = 3.1415926535
R = 1 / 12 ' Bulbous radio
RR = 0
n = 0
CounterMax = 2000
'&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&
&&&&&&&&&&&&&&&&&

strSQL1 = " SELECT Series.CSerie FROM Series ORDER BY Series.CSerie;"
Set myRS1 = Dbs.OpenRecordset(strSQL1)
myRS1.MoveFirst

'&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&
&&&&&&&&&&&&&&&&&&


Do While Not myRS1.EOF
CC1 = 0
'RR = RR + 1

KCserie = myRS1![Cserie]

'&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&
&&&&&&&&&&&&&&&&&&
strSQL = "SELECT [01-23-2015-2].* FROM [01-23-2015-2]ORDER BY [01-23-2015-
2].CSerie;"
```

```
Set myRS = Dbs.OpenRecordset(strSQL)
myRS.MoveFirst
'&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&&
&&&&&&&&&&&&&&&&&&



Do While Not myRS.EOF
'n = n + 1

   NCserie = myRS![Cserie]

   t1 = CStr(NCserie)
   t2 = CStr(KCserie)
   xx = CInt(StrComp([t1], [t2]))

   If xx = 0 Then
   CounterStop = False
   Else
   CounterStop = True
   End If


 If CC1 = CounterMax Then
 CounterStop = True
 End If

If CounterStop = False Then

CC1 = CC1 + 1

ID = myRS![ID]
time = myRS![time]
Flume_Flow = myRS![Flume_Flow]
Flume_Level = myRS![Flume_Level] / 12
RFlume_Level = Round(Flume_Level, 1)
Velocity = myRS![Velocity]
Pier_Level = myRS![Pier_Level] / 12
Pipe_Flow = myRS![Pipe_Flow]
Slope = myRS![Slope]
RPM = myRS![RPM]
BB_Angle = myRS![BB_Angle]
```

```
BB_Radian = ((BB_Angle * pi) / 180)
BB_Depth = myRS![BB_Depth] / 12
Froude = myRS![Froude]
Serie = myRS![Serie]

Select Case True

Case BB_Angle = 0
Select Case True

   Case myRS![BB_Length] = 0
   BB_Length = 0
   Case myRS![BB_Length] = 5
   BB_Length = 8 / 12
   Case myRS![BB_Length] = 8.5
   BB_Length = 11.5 / 12
   Case myRS![BB_Length] = 12
   BB_Length = 15 / 12
   Case myRS![BB_Length] = 15.5
   BB_Length = 18.5 / 12
   Case myRS![BB_Length] = 19
   BB_Length = 22 / 12

End Select

Case BB_Angle = 5
Select Case True

   Case myRS![BB_Length] = 0
   BB_Length = 0
   Case myRS![BB_Length] = 5
   BB_Length = 9.1875 / 12
   Case myRS![BB_Length] = 8.5
   BB_Length = 11.6875 / 12
   Case myRS![BB_Length] = 12
   BB_Length = 15.1875 / 12
   Case myRS![BB_Length] = 15.5
   BB_Length = 18.6875 / 12
   Case myRS![BB_Length] = 19
   BB_Length = 22.1875 / 12

End Select
Case BB_Angle = 10
Select Case True
```

```
   Case myRS![BB_Length] = 0
   BB_Length = 0
   Case myRS![BB_Length] = 5
   BB_Length = 9.4375 / 12
   Case myRS![BB_Length] = 8.5
   BB_Length = 11.9375 / 12
   Case myRS![BB_Length] = 12
   BB_Length = 15.4375 / 12
   Case myRS![BB_Length] = 15.5
   BB_Length = 18.9375 / 12
   Case myRS![BB_Length] = 19
   BB_Length = 22.4375 / 12


End Select

End Select
'-------------------------------------------------------

Select Case True

Case BB_Length = 0
   BB_Length_E = 0
   BB_Depth = 0
   BB_SR = 0
   BBPS = 0
   Pier_VS = 0
   BBVS_PVS = 0
   BBLE_BBSR = 0
   BB_Volume_S = 0
   BB_Volume = 0

Case BB_Length > 0

   Select Case True

      Case BB_Angle = 0
      BB_Length_E = BB_Length
      BB_Length_Y = 0

      Case BB_Angle > 0
      BB_Length_E = BB_Length * Cos(BB_Radian)
      BB_Length_Y = BB_Length * Sin(BB_Radian)
```

```
End Select

BBPS = Flume_Level - (3 / 12)

  Select Case True

   Case BB_Angle = 0
   BB_Volume_S = (((R ^ 2) * ArcCos((R - BBPS) / R)) - (R - BBPS) * Sqr(2 * R *
BBPS - BBPS ^ 2)) * BB_Length

   Case Flume_Level <= 5

   If BBPS <= BB_Length_Y Then
   h0 = 0
   LL = BBPS / Sin(BB_Radian)

   Else
   h0 = BBPS - BB_Length_Y
   LL = BB_Length
   End If

   K = 1 - (h0 / R)
   Q = K - (LL * Tan(BB_Radian) / R)
   aa = BB_Radian

   If h0 > 1 Then

   BB_Volume_S = (R ^ 3 / Tan(aa)) * (K * ArcCos(K) - (1 / 3) * Sqr(1 - K ^ 2) * (K ^
2 + 2) - Q * ArcCos(Q) + (1 / 3) * Sqr(1 - Q ^ 2) * (Q ^ 2 + 2))
   Else

   BB_Volume_S = (R ^ 3 / Tan(aa)) * (-Q * ArcCos(Q) + (1 / 3) * Sqr(1 - Q ^ 2) * (Q
^ 2 + 2))

   End If



   Case Flume_Level > 5


   h1 = (Flume_Level - (3 / 12)) / Sin(BB_Radian)
```

```
      h1 = (Flume_Level - (5 / 12)) / Sin(BB_Radian)
      BB_Volume_S = pi * (R ^ 2) * ((h1 + h2) / 2)


    End Select

    BB_Volume = pi * (R ^ 2) * BB_Length
    BB_SR = BB_Depth / Flume_Level
    Pier_VS = (Flume_Level * 2 * BB_Length_E) - BB_Volume_S
    BBVS_PVS = BB_Volume_S / Pier_VS
    BBLE_BBSR = BB_Length_E / BB_SR
    BBVNS = BB_Volume - BB_Volume_S

End Select



'*****************************************************************

 If BB_Length > 0 Then
   alpha = Atn(Flume_Level - (4 / 12))
   beta = pi - 2 * alpha
   a = 2 * Cos(alpha)
   b = BBPS
   sigma = 0.5 * pi + Atn((a - 1) / b)
   op = BB_Length * Sin(BB_Radian)
   y = BBPS

      If op < y Then
      hh = BB_Length_E
      Else
      hh = y / Tan(BB_Radian)
      End If

    BB_Area_S = 2 * hh * R * (Sin(sigma) - sigma * Cos(sigma)) / (1 - Cos(sigma))
    BB_Length_S = hh
 Else
    BB_Area_S = 0
    BB_Length_S = 0
 End If

'*****************************************************************

 Z = (Slope / 100) * (525.5 / 12)
```

```
Energy = Flume_Level + (Velocity ^ 2) / (2 * g)

Pier_Level_Energy = Energy

Pier_Level_Losses = 0



If BB_Length > 0 Then

RN = Velocity * BB_Length_S / 0.00001226


Kn = 12 * (BB_Volume_S) * (2 / 12) / ((BB_Length_S ^ 2) * (Flume_Level - 3))


CF = 0.075 / (Log10(RN - 2) ^ 2)

BW = Pier_Level_Energy - Pier_Level


Rv = ((1 / 2) * 1.94 * BB_Area_S * CF * (Velocity ^ 5) * (1 + Tan(BB_Radian))) * CF
* (1 + Kn) ' viscous resistance

Vbb2 = Velocity ^ 2 - 2 * Rv * BB_Length_S ' velocity at the bulbous base

BWv = (Vbb2 / (2 * g))  ' Bulbous wave viscous component

BWw = BW - BWv ' Bulbous wave wave-making component

PLbb_T = Pier_Level_Energy - BWv
PLbb_D = Pier_Level
PLbb_err = (PLbb_D - PLbb_T) / PLbb_D

PWR = Pier_Level / Pier_Level_Energy ' Pier wave ratio

PWR_T = PLbb_T / Pier_Level_Energy

PWR_TC = PWR_T * 2
PWR_err = (PWR - PWR_T) / PWR

Else
```

```
 RN = 0
 CF = 0
 BW = 0
 Rv = 0
 Vbb2 = 0
 BWv = 0
 BWw = 0
 Kn = 0
 PLbb_T = 0
 PLbb_D = 0
 PLbb_err = 0
 PWR = 0
 PWR_T = 0
 PWR_err = 0

 End If

'*********************************************************************

Call addrecord(ID, Table_Name, time, Flume_Flow, Flume_Level, Velocity, Pier_Level,
Pipe_Flow, Slope, RPM, BB_Length, BB_Length_S, BB_Depth, Froude, Serie,
BB_Angle, BB_Volume, BB_Volume_S, BB_Area_S, BBLE_BBSR, BB_Radian,
Pier_VS, BBVS_PVS, NCserie, RFlume_Level, Energy, Pier_Level_Energy, RN, BW,
Rv, Vbb2, CF, BWv, BWw, PWR, PWR_T, PWR_err, PLbb_D, PLbb_T, PWR_TC,
PLbb_err)

End If

myRS.MoveNext
Loop

myRS1.MoveNext
Loop



'---------------------------------------------

MsgBox Table_Time & " Finish!!  Records Created."


 End Sub
```

```
Private Sub addrecord(ID, Table_Name, time, Flume_Flow, Flume_Level, Velocity,
Pier_Level, Pipe_Flow, Slope, RPM, BB_Length, BB_Length_S, BB_Depth, Froude,
Serie, BB_Angle, BB_Volume, BB_Volume_S, BB_Area_S, BBLE_BBSR, BB_Radian,
Pier_VS, BBVS_PVS, NCserie, RFlume_Level, Energy, Pier_Level_Energy, RN, BW,
Rv, Vbb2, CF, BWv, BWw, PWR, PWR_T, PWR_err, PLbb_D, PLbb_T, PWR_TC,
PLbb_err)
'subroutine working don't delete

  Dim dbcurrent As DAO.Database
  Dim Ctables As DAO.Recordset

  Set dbcurrent = CurrentDb
  Set Ctables = dbcurrent.OpenRecordset(Table_Name)

  Ctables.AddNew

  Ctables("ID").Value = ID
  Ctables("Time").Value = time
  Ctables("Flume_Flow").Value = Flume_Flow
  Ctables("Flume_Level").Value = Flume_Level
  Ctables("Velocity").Value = Velocity
  Ctables("Pier_Level").Value = Pier_Level
  Ctables("Pipe_Flow").Value = Pipe_Flow
  Ctables("Slope").Value = Slope
  Ctables("RPM").Value = RPM
  Ctables("BB_Length").Value = BB_Length
  Ctables("BB_Length_S").Value = BB_Length_S
  Ctables("BB_Depth").Value = BB_Depth
  Ctables("BB_Angle").Value = BB_Angle
  Ctables("BB_Volume").Value = BB_Volume
  Ctables("BB_Volume_S").Value = BB_Volume_S
  Ctables("BB_Area_S").Value = BB_Area_S
  Ctables("BBLE_BBSR").Value = BBLE_BBSR
  Ctables("Froude").Value = Froude
  Ctables("Serie").Value = Serie
  Ctables("CSerie").Value = NCserie
  Ctables("Pier_VS").Value = Pier_VS
  Ctables("BB_Radian").Value = BB_Radian
  Ctables("BBVS_PVS").Value = BBVS_PVS
  Ctables("RFlume_Level").Value = RFlume_Level
  Ctables("Energy").Value = Energy
  Ctables("Pier_Level_Energy").Value = Pier_Level_Energy
  Ctables("Reynolds").Value = RN
  Ctables("BW").Value = BW
```

```
  Ctables("Rv").Value = Rv
  Ctables("Vbb2").Value = Vbb2
  Ctables("BWv").Value = BWv
  Ctables("BWw").Value = BWw
  Ctables("PLbb_D").Value = PLbb_D
  Ctables("PLbb_T").Value = PLbb_T
  Ctables("PLbb_err").Value = PLbb_err
  Ctables("Coeff_Friction").Value = CF
  Ctables("PWR").Value = PWR
  Ctables("PWR_T").Value = PWR_T
 Ctables("PWR_TC").Value = PWR_TC
  Ctables("PWR_err").Value = PWR_err


  Ctables.Update


End Sub


Function ReportFileStatus(filespec)
  Dim fso, msg
  Set fso = CreateObject("Scripting.FileSystemObject")
  If (fso.FileExists(filespec)) Then
    msg = 1 'filespec & " exists."
  Else
    msg = 0 'filespec & " doesn't exist."
  End If
  ReportFileStatus = msg
End Function
```

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CURRICULUM VITAE

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PROFESSIONAL EXPERIENCE

PROJECT MANAGER **2010 – Present**
Acting Supervisor of Electrical engineering (3 moths)
Bureau of Reclamation, Hoover Dam.

As a Project Manager for several project at LCDO, I developed detailed project plans to include project scope, objectives, priorities, work activities and assignments, milestones, deliverables, schedule, and cost estimates, overseeing and tracking activity progress, preparing budget reports, progress reports, program schedules, and cost estimates.

Projects List:

- Hoover N6 generator stator repairs
- Hoover CO2 system control modernization
- Replace underrated generator breakers at Hoover
- 480v distribution panel replacement Hoover Dam
- Elevator modernization for Hoover and Parker Dams
- EDraw deployment (the new drawings management system) for Hoover, Davis and Parker Dams.
- Construction and commissioning of the generator control modernization for Davis Dam (partial) and Parker.
- Replacement of the 128KA SC generator breakers for Hoover Dam.
- $30 million in the 10-year plan for projects including electrical, mechanical, NERC/WECC compliance and civil work.

As acting Engineering Supervisor for Hoover, I supervise, provided guidance, and direction to the subordinate staff, maintenance and operation personnel in matters of: government regulations, maintenance, operations, engineering, customer service, budgeting, scheduling, technical procedures, permits required for construction, issues associated with environmental regulations and assessments.

ENGINEERING & MAINTENANCE MANAGER **11/2006 – 10/2010**
CertainTeed- Saint-Gobain Corporation, Las Vegas, Nevada

As Engineering and Maintenance Manager For CertainTeed, I developed detailed project plans to include project scope, objectives, priorities, work activities and assignments, milestones, deliverables, schedule, and cost estimates, overseeing and tracking activity progress, preparing budget reports, progress reports, program schedules, and cost estimates.

Projects List:

- Mechanical, electrical and controls, upgrades to the Claudius Peter Mill; a 3 year Projects aim to increase energy efficiency.
- Developed and commissioned the energy management system, including EPA compliance program.
- Integration of the quality control system into the process control. All the quality data and quality reports are generated in real time, countermeasure for quality defect can be implemented with minimum process loses.
- Mechanical, electrical and controls, upgrades to the Gypsum board dryer; a 4 year Projects aim to increase energy efficiency by recirculation part of the exhaust gases back into the dryer. This project required a permanent engagement with the stakeholder due to the complexity and financial risk involved.
- Recycle gypsum board Project, CertainTeed was interest in obtain green credits for using large quantities for wasted gypsum board from construction sites into the manufacturing of new gypsum board. This project required partnership with several private and public entities to redirect the wasted gypsum board form the construction sites to the CertainTeed plant.
-

Responsibilities:

- Managed a staff of four engineers, two technicians and 14 hourly employees, providing guidance, and direction to the subordinate staff in matters of: government regulations, maintenance, operations, engineering, customer service, budgeting schedules, and procedures, issues associated with environmental regulations and assessments.
- Responsible for budgeting and budget control for maintenance and capital projects, including IT.
- Responsible, as a part of the North America team, for auditing other plant's energy budgets and preparing recommendation to correct variances.
- Hosted and participated as an instructor at two energy technical conferences for North America. These conferences provide training for process, production, and engineering managers.
- Successfully presented to the CertainTeed Board of Directors 3 projects for process modifications aimed at increasing quality and reducing cost. These projects were selected for funding over other 35 competing projects.
- Wrote, in conjunction with European energy team, the standard for design energy management system worldwide.

PROJECT MANAGER **3/2004 – 11/2006**

C.S. Consulting Engineers, Las Vegas, Nevad**a** **http://www.csconsultingengineers.com**

As a Project Manager at CS Consulting Engineers, I lead over the design of more than 50 projects; developed detailed project plans to include project scope, objectives, priorities, work activities and assignments, milestones, deliverables, schedule, and cost estimates, overseeing and tracking activity progress, preparing budget reports, progress reports, program schedules, and cost estimates. Experience should also demonstrate the ability to provide supervision, leadership, guidance, and direction to subordinate staff on project management and administrative activities and function.

Other responsibilities:

- Represented the company at county and city designs reviews, addressing code compliance issues.
- Managed the development of the inspection division, a new business unit.

ESTIMATOR & ENGINEERING SUPERVISOR **11/2003 – 3/2004**

The Truss Company, Las Vegas, Nevada **http://www.ttclv.com** (Operation closed)

- Responsible for ensuring designs complied with all pertinent construction codes.

INSTRUMENTATION CONSTRUCTION & ENGINEERING MANAGER 1/2001 – 11/2003
JANTESA, Engineering Company, Venezuela, http://www.jantesa.com.ve

As Engineering and Maintenance Manager For JANTESA, I developed detailed project plans to include project scope, objectives, priorities, work activities and assignments, milestones, deliverables, schedule, and cost estimates, overseeing and tracking activity progress, preparing budget reports, progress reports, program schedules, and cost estimates.

Projects List:

- VALCOR oil refinery, a $600 million contract in conjunction with CITGO. This project included:
    - Installation of a new control system and migration of the existing control system.
    - Interconnection between the existing refinery and new process units.
    - Design and construction of all the instrumentation and controls.
- Managed the design and construction of CERRO NEGRO oil refinery, an $800 million contract in conjunction with EXXON-MOBIL. The major production units at the CERRO NEGRO project started commissioning activities without additional delays or contract penalties. This project included:
    - Design and installation of the control system.
    - All the instrumentation and control.
    - Nuclear (gamma rays) level and flow instrumentation.
    - Process analyzers.

Managed a staff of 10 engineers, providing guidance, and direction to the subordinate staff, maintenance and operation personnel in matters of: government regulations, maintenance, operations, engineering, customer service, budgeting, scheduling, technical procedures, permits required for construction, issues associated with environmental regulations and assessments.

CONSTRUCTION SUPERINTENDENT 1/2000 – 1/2001
PROGESI, General Contracting Company, Venezuela,
http://www.gasandoil.com/goc/company/cnl01957.htm

- Managed final construction works that previous contractor was unable to complete at PETROZUATA oil refinery, an $800 million contract in conjunction with CONOCO.
- Completed all pending construction work on schedule, a task not ever accomplished by any of my predecessors.
- Successfully organized and restructured the company's operation to increase profits by $1.3 million.
- Directly managed 20 engineers with oversight over 700 employees; providing guidance, and direction to the subordinate staff, maintenance and operation personnel in matters of: government regulations, engineering, budgeting, scheduling, technical procedures, permits required for construction, issues associated with environmental regulations and assessments.

GENERAL MANAGER & OWNER 7/1995 – 1/2000
MANTENIMIENTO UNIVERSAL, Contractor Company, Venezuela

- Managed company's construction and design team. Some of my main clients included: Coca-Cola Bottling, Toyota and several tuna canning manufacturers.
- Maintained and upgrade the sewer pumping station system and sewer treatment plant for the City of Cumana (800,000 inhabitants).
- Continuously generating new clients was the key to building a successful company for five years.
- Managed 13 technicians.

REGIONAL MAINTENANCE MANAGER **5/1987-7/1995**
CADAFE, Electrical Power Company, Venezuela http://www.cadafe.com.ve

- Managed maintenance programs for the 230/115kV system.
- Responsible for the engineering and construction of the instrumentation and electrical works.
- Restructured the maintenance and construction operation, which lead to first place in zero fail transmission lines (115 and 230 kV), during the first semester of 1992.
- Responsible for over 2300 miles of transmission lines and 50 miles of high voltage underwater cable.
- Managed 30 employees within 3 districts and 15 power stations.

EDUCATION

UNIVERSITY OF NEVADA, LAS VEGAS, Las Vegas, NV
Currently conducting the research's toward attaining my PhD in Civil and Environmental Engineering with a minor in Engineering Management.
Dissertation: "The Bulbous Principle Applied to Pier in Supercritical Flow"

UNIVERSITY OF NEVADA, LAS VEGAS, Las Vegas, NV
Graduated with a Master of Science in Engineering (MSE) Civil and Environmental Engineering

UNIVERSIDAD DE ORIENTE, VENEZUELA
Graduated with a Bachelor of Science (BSE) in Electrical Engineering
Graduated with Honors, Top 1% of class

SKILLS

MANAGERIAL

- Knowledge of the budget process and planning, programming and budgeting system in order to assist with the development of long-range (multi-year) budgetary plans to support development and execution of projects.
- Skill in representing the organization's viewpoint in formal meetings and in dealing with stakeholders, the general public and individuals.
- Conducted statistical analysis and developed operational research models.
- Restructured deficient operations to achieve maximum efficiency at minimum cost.
- Developed Annual Operating Plans for production, maintenance, and engineering.
- Prepared and evaluated detailed engineering packages and evaluated financial viability and constructability.
- Prepared and evaluated Construction Bid Packages.
- Prepared, implemented, and modified construction schedules.
- Managed multicultural and union environments.
- Managed the retrofit of obsolete systems without production interruption.
- Used financial software such as People soft and SAP.
- Development and implementation of cost deployment.
- Ensured compliance with safety, environmental and labor regulations.

ENGINEERING/TECHNICAL

Systems/Software

- Various CMMS systems such as Infor and other SQL database systems.
- Various scheduling and planning software such as MS Project and Primavera.
- Various estimating software packages such as Win Estimator and Timberline.
- SQL database.
- SharePoint.
- AutoCAD and Visio.
- MSVB and C++

Structural/Civil Engineering

- Various structural engineering software packages such as RISA AND ENERCAL.
- Various Geotechnical modeling software.

Automation and Controls

- PLC such as A-B, ABB, SIEMENS, MODICON, TELEMECANIQUE and others.
- ESD such as TRICONEX.
- DCS such as FOXBORO I/A SERIES and ABB IT series.
- HMI such as Wonderware.
- Control elements such as valve, transmitter, and analyzers.

Electrical

- Design and construction of industrial and commercial power installations.
- Design and operation of power substations, transmission lines, and underwater cables.
- Billing models for industrial and high demand consumers.
- Industrial inverters.
- Electrical protection coordination.

Energy Efficiency and Energy Conservation

- Developed electrical and fossil fuel consumption model to calculate energy efficiency.
- Developed alternative operations models to reduce energy consumption.

OTHER

Bilingual in English/Spanish

Advanced skills in Microsoft Excel, Word, Power Point