Predicting Main Dimensions of Tug Boats Basing on Bollard Pull

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Abstract

*The pull force a tugboat can exact when tied to an immovable pie bollard is termed the bollard pull, this is the maximum pull force she is designed to exact on her towing work. This force depends on the size dimensions, hull shape and design of her propulsion machinery. This work is a correlation analysis between the main dimension variables and bollard pull is carried out to obtain useful formulas for the design of future tug boats basing on optimum bollard pull. This analysis is based on a collation of world existing tug boat parameters shown in the paper. An appraisal example computation is also presented to show the method and validity of the derived formulas.***.**

Keywords — *Tugboat, bollard pull, regression, formulas, main dimensions.*

I. INTRODUCTION

The bollard pull is the force a tug boat require to pull the ship or other marine equipment she is towing. It is classified into maximum bollard pull bpmax, steady bollard pull bps and sustained bollard pull bp, corresponding to force of the propulsion machinery running at maximum (for one minute) , nominal (five minutes), and 78 to 80 percent of nominal power of the main engine of the tug boat respectively. Measurement of the bollard pull is done by tethering the tug boat from her towing hook to a force measuring instrument and to the pier side bollard before the running of the propulsive machinery under calm sea condition see fig 1 below,

FIG 1 Bollard test arrangement

Bollard pull bp is expressed by various authorities namely [1], [2], [3], [4] show that

bp = TT(1-t) - - - - - - - - - - - - - - - - - - (1)

TT = f(Do,η_{pp},PD) - - - - - - - - - - - - - - -(2)

Where, $\eta_{pp} = \eta_O / \eta_i$ - - - - - - - - - - - -(3)

t = $t_1(\frac{B}{L}$, CB) + t_2(Hull form) + t_3(Do/L)- -(4)

Where,
TT = propeller Bollard thrust
t = Thrust deduction factor
Do = propeller nozzle diameter
ηpp = propeller pump effiency
PD = Delivered power (kw)
η_O =propeller open water efficiency
η_i = propeller ideal efficiency
B = breadth of the tugboat at midships
CB = block coefficient of tugboat
L = length of the tugboat
t_1, t_2, t_3, functions of thrust deduction fraction. These are well known.

In this work, however, the correlation analysis is on the B, D, T, P/L, P/B, P/D, LB, DT, P/T, LBD, LBT, P, and √L/B2 as independent variable and bp as independent variable.

Where:
P = Main engine Power (hp)
D = Depth
T = Design draft

So far the correlation analysis of the main dimensions and the bollard pull bp of tug boats have not been investigated for the purpose of determination of main dimensions of projected tug boat. The result of this analysis will aid the prediction of main dimensions of projected tug boats at early design stage. This will also help in the purchase or hire of tug boats for tow or push contracts as the main dimensions of the tug can be estimated knowing the total resistance of the towed vessels.

II. MATERIAL AND METHOD

The data shown in Table 1 is a short part of 365 tug boat particulars collected (the sample sizes are shown in Table 2) for each of the regression analysis. These data are obtained from the internet adverts of various companies such as in [5], [6],[7], and others.

The mathematical model for regression formulas fitted to the data were linear and none linear function. These are functions of these types

Linear, $Y = mx + c$ 1

Power, $Y = mX^{c}$. 2

Exponential, $Y = m \ln(X) + c$ 3

Polynomial $Y=aX_n+ aX_{n-1}+..+ aX_1+c$…..4

Where Y a main dimension function and,

X is the bollard pull bp of the tugboats

m, c, and n are constants determined by the regression analysis.

These are well known mathematical procedures according to reference[8], and others. The Microsoft EXCEL add in software has these program for these procedures and these are used for the regression analysis in this work.

Numerous regression correlation were made between different formulated tug parametric variables and the bollard pull but only those reliable formulas with correlation coefficient R^2 greater than 0.8 are selected and published in this paper in fig 2 to fig 14. Table 2 show the summarized formulas of the regression analysis where the number of data points N and the regression coefficients R^2 are also shown.

Table 3 and 4 show an example of the Microsoft EXCEL spread-sheet method for using these formulas to calculate the main dimensions of tug boat for a particular bollard pull described below.

III. RESULT AND DISCUSSION

The resulting formulas from this work are shown in diagrams (fig 2 to 14) and table 2. If, for example, the required sustained bollard pull for a tow is calculated to be 28mt. What will be the main dimension and power of the tug for the tow? Table 3 show the formulas entered in EXCEL work-sheet as Eq(1), Eq(2) etc for the computation of each of the main dimensions. Appropriate combinations of these formulas as shown in some cases are necessary to compute a particular dimension of the projected tug boat. Table 4 show the result of dimensions of tugs that is required to carry out the towing work effectively with the mean expected value of L = 28.08m, B = 8.58m, D = 3.69m T = 3.14m, and P = 2211hp

IV. CONCLUSIONS

Bollard pull is the major important parameter in the design and operation criteria of tug boats propulsion system. This paper focuses on the determination of the dimensional parameters length L, breadth B, depth D, Draft T in meters and power P in horse power of the tug as a function of the main bollard pull bp in metric tons. The necessary formulas for carrying out this task are derived by regression analysis from data collated from 116 world existing tug boats. The thirteen formulas derived and shown have regression coefficient R^2 greater than 0.8. This formulation is very important for the prediction of the optimum main particulars of the prospective or projected tug boat needed to tow other marine equipment (ships, barges, rigs, etc) as shown in the example stated in this paper. The formulas can also be used in a computer program for the design of tug boats.

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Table 1 A collection of the principal dimension of modern Tugboat including bollard pull bp

NAME	CLASS	BUILLT	LAO(m)	B(m)	D(m)	T(m)	bp(mt)	ME(hp)
140904 VW	TURKEYBV	2016	14.8	5.9	3	2.15	19	1660
140113 VW	SPAIN	2011	16	5.5	2.8	2.15	12.5	780
151118 VN	ITALY	1986	19	5.37	2.75	2.28	2	577
130718-VN	ISTBUL RINA	2011	19.95	7	3.2	2.2	15	1200
BEN FOSS		1980	23.71	8.00	3.34	2.95	26.4	1700
141057 vw	hollandBV	2012	24.07	12.97	4	3.8	53.4	3820
121063-VO	SPAIN RINA	1982	25	8.4	4.36	4.2	32	2030
160524-VW	SPAIN	1968	25.86	6.4	3.05	3	12	825
151228 VW	HOLLAND	2007	26	11.5	3.5	2.25	33	2400

	BV							
131028-vo	holland bv	2005	26.09	7.94	4.05	3.75	50.7	3500
ARI CRUZ - SINUK	USABS	1995	26.15	8.69	3.05	2.51	11.34	1248
ES TAURUSINDO	CHINA/NKK	1997	26.45	7.96	3.47	3.19	15	1240
151103VW	USABS	1982	27.43	9.75	3.41	2.59	23.5	2110
OLIKTOK			27.89	8.17	4.2	3.93	25	2100
9777-tg-om	SINGAPORE	1995	28.4	6.5	4.11	3.47	39.05	2800
8710-TG-OM	ITALI RINA	1985	28.55	6.56	3.82	3.14	8.7	1520
11326-TG-OM	SingporeABS	2006	29	9	4.25	3.5	40	3200
11326-TG-OM	ABS		29.1	9	4.25	3.5	30	2400
11346-TG-OM	FRANCE GL	1976	29.2	8.5	4.15	3.5	30	1500
12592-TG-OM	RUSSIA	1988	29.3	8.3	4.3	3.4	16	1604
CONTELLATION	NS	2009	30.22	9	4.38	3.68	30	2400
Island Brave	USA ABS		30.99	11.00	5.59	4.60	70	5364
11077-TG-OM	BatamIn LR	2005	31	9	4.5	3.5	40	3000
11153-OT-OM	SPAIN	2002	31.21	8.41	4.51	4	22.9	1716
T W Ocean 15	USA ABS	1998	31.52	11.28	5.49	4.27	53.8	3900
140821-VO	BV	2014	31.65	9.14	4.2	3.65	40	3200
150909 VO	USA ABS	2003	31.70	10.97	4.88	4.11	48.58	4200
TITO N SETTIMO	LR	2012	31.99	11.6	5.81	5.36	73	5364
ASD TYR	USA ABS		32.00	11.58	5.94	5.36	83.45	6834
13082 TG-OM	USA ABS	1999	32.00	10.36	5.03	4.88	62.6	4400
12985 TG OM	USA ABS	2012	32.00	11.58	5.38	5.23	60.78	4720
11163-TG-OM	turkishBV		32.5	11.7	5.6	4.3	65	5632
130643-VO	CHINA ASD	2009	33	10	4.5	4.1	50	4000
141120 VO	INDONESIA	1982	33.52	7.92	3.2	2.4	12	1273
CHEV RICHMOND	CHINA	2013	33.98	10	4.5	3.4	50	4000

Table 1. Continued

NAME	CLASS	BUILT	LAO(m)	B(m)	D(m)	T(m)	bp(mt)	ME(hp)
9547TGOM		2016	34.4	12.82	5.75	5.36	70	6303
9835-TG-OM	CHina BV	2014	34.5	9.5	4.6	3.65	40	3200
5922-TG-OM	MALAY BV	2016	35	11.5	5.62	4.8	62	5150
12885-TG-OM	china BV	2014	36	10.97	5	4.1	40	3200
140413-VO	china BV	2014	36	10.97	5	4.1	40	3200
120322-VW			36.02	10.6	4.8	3.6	64	5200
ocean Tower	CHINA BV	2009	36.1	10.6	4.9	4	40	3200
ESCORT EAGLE	LAUSABS	1970	36.58	9.45	4.54	4.11	37.5	3000
11321-TG-OM	KOREA	2012	36.9	10	4.5	3.4	59.464	4500
11143 TUG OM		2007	37	10.6	4.95	4	40.85	3200
11275-TG-OM	AFRCA/IRE	1978	37.3	10.84	4.9	4.3	40.6	3500
141137-VA	LRDAMEN	1998	37.5	9.25	4.9	3.4	69	5000

SUIATTIEUS	CCS CSA CSM	2012	37.7	10.4	4.8	3.65	65	5200
AHT	LRCHINA		37.99	11.00	5.00	3.81	60	4960
Liberty	CHINA	2014	50	15.5	7.7	5.5	105	8400
HERCULES	CHINABV	2012	58.7	14.6	5.5	4.75	66	4890
ASTERI	KEPPEL	2004	60	16	6	5	78.3	6000
150336 VA	SINGAPORE	2000	60	13.8	6.8	5.6	124	8000
9397-TG-OM	GERMANY ABS	1982	64.5	13.82	6.9	5.91	110	8160
140929	US ABS	2015	66.5	16	6.5	5.12	80	6400
9397-TG-OM			26.15	7.95	4.05	3.45	38	2720
140929-VA	DAMEN	1999	26.15	7.95	4.05	3.45	38	2720
M MORAN		2012	36.6	10.5	4.6	3.3	51	4800
Robust	SINGAPORE	2013	81	16.8	7.5	6.4	120	7000
OCEAN Wrestler	SINGAPORE	2013	81	16.8	7.5	6.4	120	7000
150632	AUTR	2013	91	22	9.6	8	240	21456
STAN2608	DAMEN		26.15	7.95	4.05	3.45	38	5440

Table 2 Tugboat design formulas as a function of bollard pull(x = bp) in metric tonnes.

N	R^2	Formula	Eq. no
116	0.900	$B = -2E\text{-}04x^2 + 0.0912x + 5.78$	**Eq1**
83	0.898	$D = -7E\text{-}05x^2 + 0.046x + 2.7135$	**Eq2**
60	0.801	$T = -6E\text{-}05x^2 + 0.0379x + 2.2631$	**Eq3**
48	0.897	$P/L = 0.0002x^3 - 0.0105x^2 + 1.9129x + 27.443$	**Eq4**
60	0.858	$P/B = 0.0003x^3 - 0.0928x^2 + 11.765x$	**Eq5**
60	0.916	$P/D = 0.0006x^3 - 0.2093x^2 + 25.759x$	**Eq6**
116	0.906	$LB = 0.0102x^2 + 5.4694x + 50$	**Eq7**
66	0.820	$DT = 0.0005x^2 + 0.4277x$	**Eq8**
60	0.836	$P/T = 0.0007x^3 - 0.2549x^2 + 31.339x$	**Eq9**
60	0.882	$LBD = 0.2457x^2 + 22.939x$	**Eq10D**
60	0.879	$LBT = 0.1953x^2 + 23.382x$	**Eq10T**
116	0.967	$P = 0.0562x^2 + 75.309x$	**Eq11**
116	0.818	$(\sqrt{L})/B^2 = 0.3725x^{-0.483}$	**Eq12**
48	0.896	$P/L = 0.0002x^3 - 0.0105x^2 + 1.9129x + 27.443$	**Eq13**
53	0.863	$bp/L = 0.0937x^{0.7037}$	**Eq14**
79	0.891	$P/D = 0.0005x^3 - 0.1657x^2 + 21.602x + 93.902$	**Eq15**
60	0.812	$DT = 0.3367x + 4.0752$	**Eq16**
60	0.836	$BT = 0.7509x + 7.8674$	**Eq17**
103	0.872	$BD = 0.0006x^2 + 0.6904x + 14.119$	**Eq 18**

Table 3 EXCEL layout for calculation of principal dimension of tugboat for bp = 28mt using.

	A	**B**	**C**	**D**	**E**	**F**
1	**LOA(m)**	**B(m)**	**D(m)**	**T(m)**	**P(t)**	**(t)**
2	bp/Eq14	Eq 1	Eq2	Eq3	Eq11	bp
3	Eq8/B2	Eq7/A3	Eq 11/EQ6	Eq11/EQ9	B2*Eq5	
4	Eq10D/(B2*C2)	Eq11/EQ5	Eq8/D3	Eq8/C2	A2*Eq4	
5	Eq10T/(B2*D2)	√**(**[(√A2)/Eq12]**)**	Eq10D/(A4*B4)	Eq9T/(A2*B2)	C2*Eq6	

6	Eq10T/(B3*D3)	Eq10T/(A2*D2)	Eq10D/(A2*B2)	Eq8/C1	D2*Eq9	
7	Eq10D/(B3*C3)	Eq10T/(A4*D5)	Eq10D/(A3*B3)	Eq8/C5	A3*Eq4	
8	$(Eq12*(B2)^2)^2$	Eq10D/(A2*C2)	Eq10D/(A8*B8)	Eq8/C6	B4*Eq5	
9	$(Eq12*(B3)^2)^2$	Eq10D/(A3*C3)	Eq10D/(A9*B9)	Eq10T/(A3*B3)	C3*Eq6	
10	$(Eq12*(B4)^2)^2$	√([(√A3)/Eq12])	Eq10D/(A5*B5)	Eq10T/(A7*B5)	D3*Eg9	
11	$(Eq12*(B5)^2)^2$	√([(√A4)/Eq12])	Eq10D/(A10*B10)	Eq10T/(A9*B9)	A4*Eq4	
12	E2/Eq13	Eq18/C2	Eq16/D2	Eq17/B2	Eq15*D3	
	FIND AVERAGE OF EACH COLUMN					

Table 4 EXCEL layout for calculation of principal dimension of tugboat for bp = 28mt using.

	A	B	C	D	E	F
1	LOA(m)	B(m)	D(m)	T(m)	P(hp)	bp(mt)
2	29.318	8.255	3.947	3.277	2152.713	28
3	25.577	8.255	2.955	3.106	2173.185	28
4	25.627	8.177	3.729	2.935	2262.252	28
5	29.859	8.525	3.984	3.338	2250.827	28
6	31.502	8.407	3.450	2.935	2271.196	28
7	34.229	9.472	3.954	2.907	1973.557	28
8	25.776	7.216	4.489	3.358	2173.185	28
9	24.818	11.048	3.045	3.826	2152.713	28
10	24.818	8.239	3.280	2.768	2751.309	28
11	29.318	8.243	4.083	2.946	1977.471	28
12	27.898	8.594	4.120	3.500	1.800.620	28
	27.945	8.594	3.730	3.174	2171.556	= MEAN

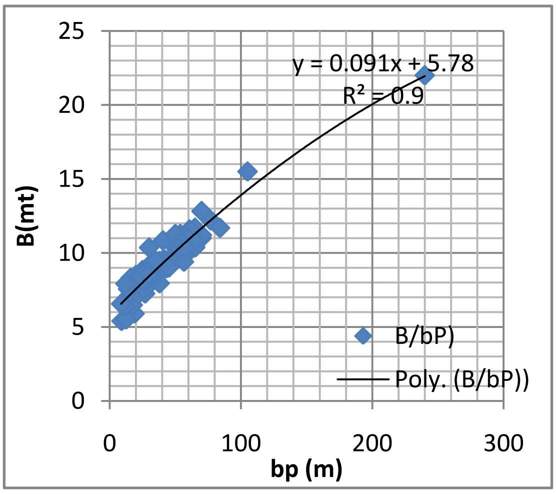

Fig 2. Breadth B of Tug boat correlation with bollard pull bp.

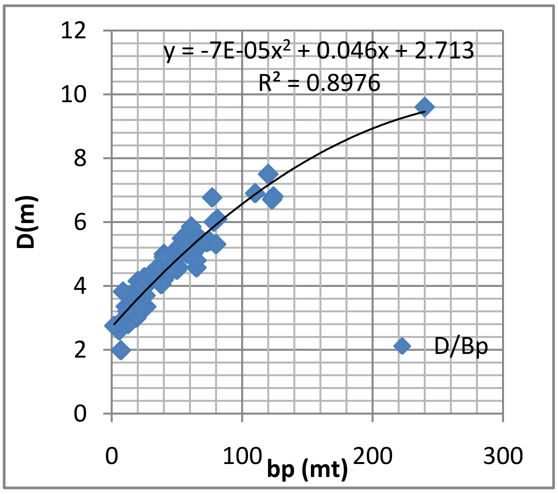

Fig 3. Depth D of Tug boat correlation with bollard pull bp

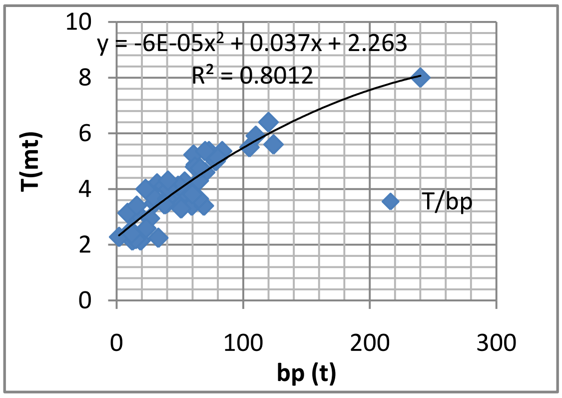

Fig 4. Draft T of Tug boat correlation with bollard pull bp.

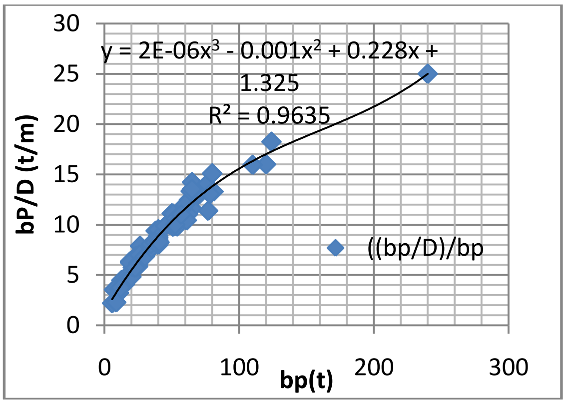

Fig 5. bp/L of Tug boat correlation with bollard pull bp

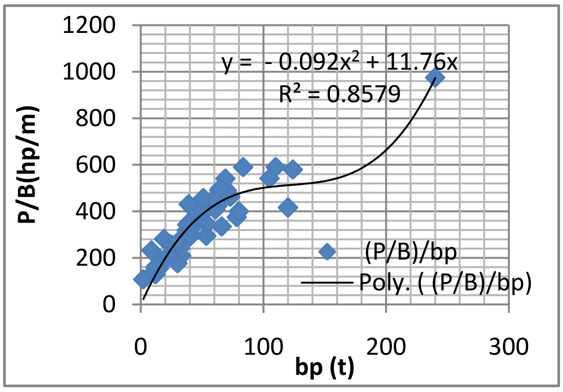

Fig 6.Power P/Breadth B ratio of Tug boat correlation with bollard pull bp.

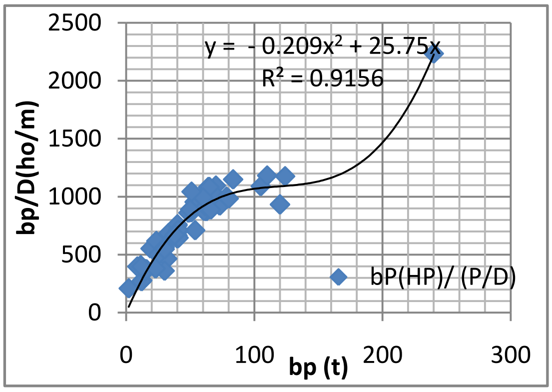

Fig 7. Power P/ Depth D ratio of Tug boat boat correlation with bollard pull bp

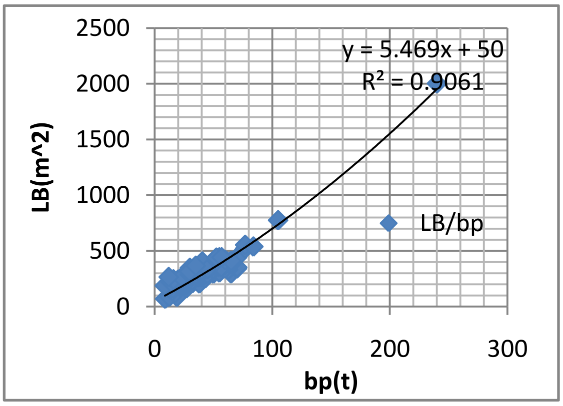

Fig 8. Length L* breadth B of Tug boat correlation with bollard pull bp

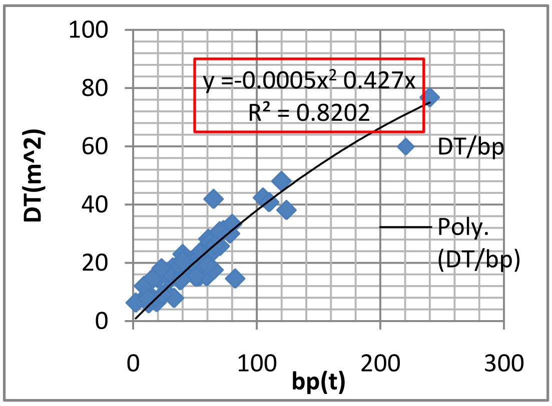

Fig 9. Depth D* draft T of Tug boat correlation with bollard pull bp

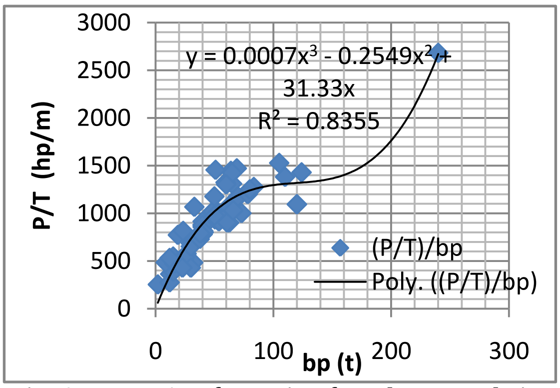

Fig 10.Power P/Draft T ratio of Tug boat correlation with bollard pull bp

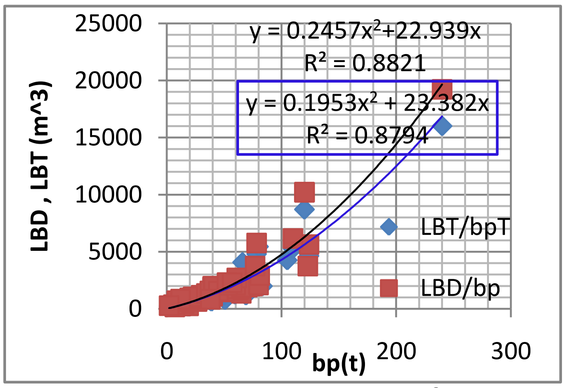

Fig 11. LBD, and LBT cubic numbers of tug boat correlation with bp

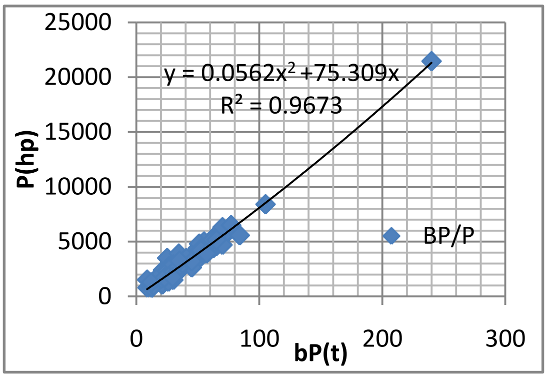

Fig 12.Power P of Tug boat correlation with bollard pull bp.

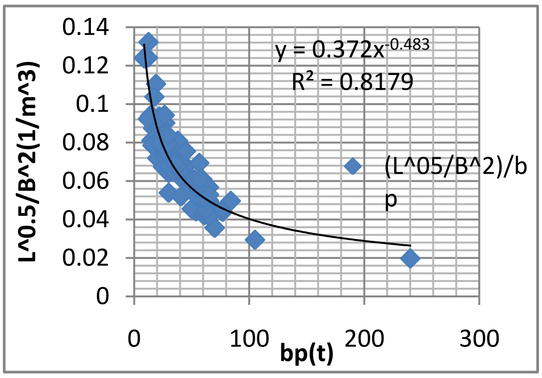

Fig 13. (√L)/B^2 ratio of Tug boat correlation with bollard pull bp

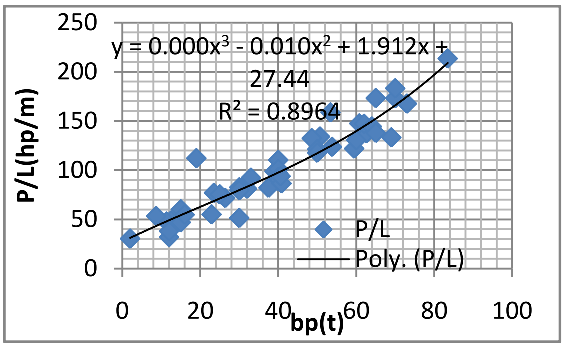

Fig 14. Power P/ Length L ratio of Tug boat Correlated with bollard pull bp

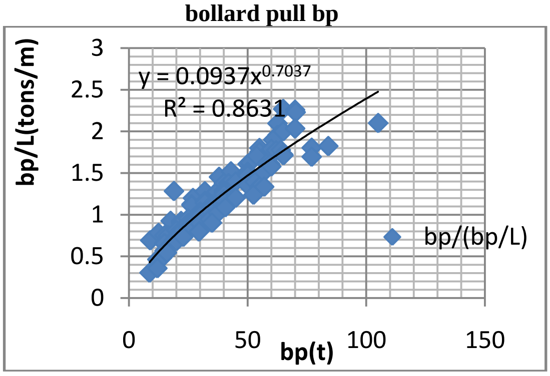

Fig 15 bp/L correlation with bollard correlated with bollard pull bp

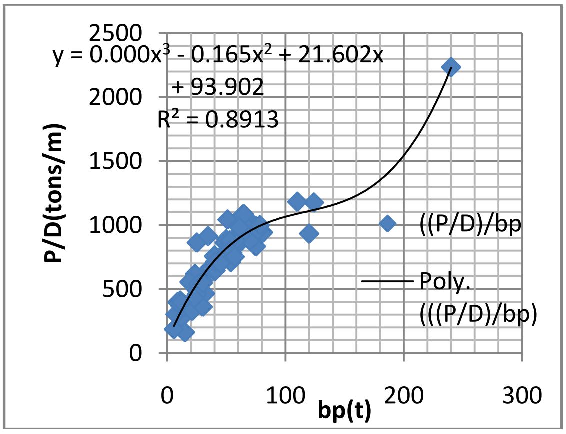

Fig 16. Power P/ Depth d ratio of Tug boat Correlated with bollard pull bp

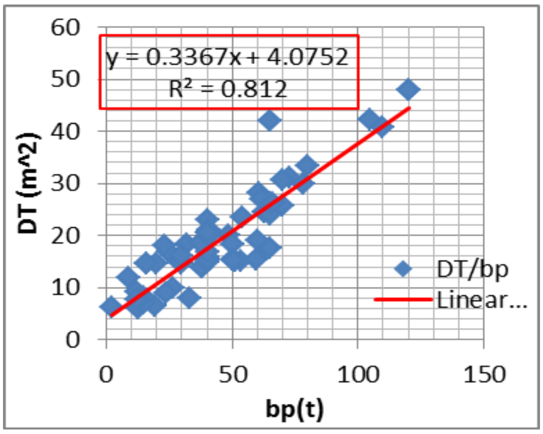

Fig 17 bp/L correlation with bollard correlated with bollard pull bp

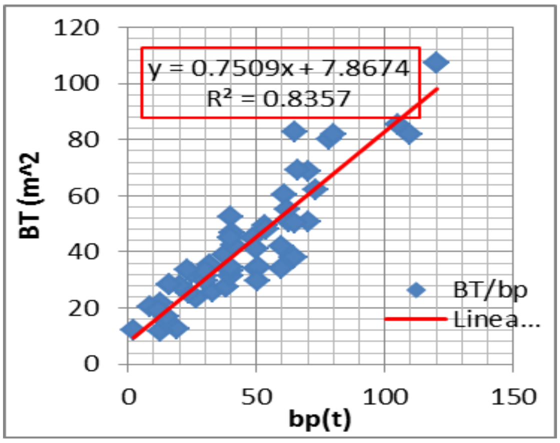

Fig 18. Power P/ Length L ratio of Tug boat Correlated with bollard pull bp

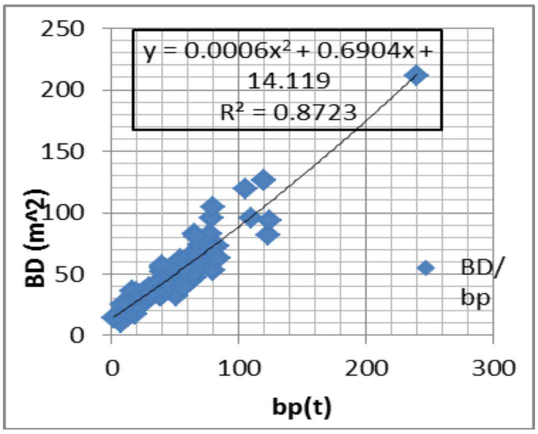

Fig 19 bp/L correlation with bollard correlated with bollard pull bp