

THE EFFECTS OF WEIGHT CHANGES ON SHIP'S STABILITY

ABSTRACT

Over the years, there had been increase in the use of offshore structures. This might not be unconnected with the awareness of the importance of the maritime sector as well as the rise in energy demand. Consequently, the construction, transportation of offshore structures has drastically increased. The loading of offshore structures such as barges requires thorough and careful planning so as to ensure that the barge is stable. This is achieved where following the loading and offloading of the vessel, the position of the centre of gravity, trim and heel are always in acceptable level. This research therefore, employed a rectangular barge on which ballasting procedures were carried out aimed at eliminating trim and heel. This is done by pumping into the barge 1802.84 tonnes of water which was distributed to tanks 2S and 4S. At the end trim and heel are taken to be corrected when $LCG = 33.53m$ and $TCG = 0$ where the reference point was the body system orientation (taken from the bow). However, owing to the little quantity of water to be distributed compared to the size of the given tanks, the result showed that trim and heel are taken to be corrected when $X_{CG}(LCG) = 28.49m$ and $Y_{CG}(TCG) = 0.12m$.

Key Words: *Stability, Loading and Offloading, Ballasting, Trim and Heel.*

NOMENCLATURE: h_1 = Excess height to correct (m), T = Tidal reading (m), H_q = Water level below quay (m), L = Quay elevation (above LLW) (m), D_1 = Barge draft (m), LLW = Low Low Water, H = Barge depth (m), S = Starboard, P = Port.

1. INTRODUCTION

Loading and offloading are two very essential operations in offshore structures that could either be carried out by phase 0 (crane loading) or rolling and skidding. Either means could lead to stability problem. Ship stability is a term used to describe the tendency of a ship to return back to her equilibrium when she is inclined from an upright position (Kobyliński and Kastner, 2003). Ship stability performance depends on two main factors which are the shape of the hull and distribution of weights. The first one is a constant value and in moderate term and can be changed very rarely during rebuilding of a vessel (Lester, 2000). (Krata, 2013) studied the impact of sloshing liquids on ship stability for various dimensions of partly filled tanks that showed that the weight distribution changes in every port due to cargo operations, bunkering and related operations such as ballasting. These changes in the weight distribution play a very prominent role in determining the stability of the ship (Samson et al, 2003).

The stability of ships in terms of the movement of the ships' center of gravity can also be seen when ships move through water of different densities (Barrass and Derrett, 2006). Simple explanation for this is the mass, volume and density relation. As the ship moves from water of lower density to that of higher density, volume of water displaced is lower and therefore, the draught of the submerged part of the vessel reduces. (Krata et al, 2012) studied the influence of liquid sloshing phenomenon taking place in ships' tanks on ship transverse stability.

In the study, a review of several existing ships specifications was made. Effort specifically was made on ballast tanks, their shapes and dimensions. The data collected in the course of the study covered items such as general specification of a ship; total number of ballast tanks; number of ballast tanks in every listed group that is, double bottom tanks, side deep-tanks, wing tanks, fore and after peaks; possibility of ballasting of cargo holds; tanks dimensions (breadth, height and length of each tank); location of tanks in ship's hull; shape of each tank; free surface correction values according to ships stability booklet provided on-board; recommended algorithms of computation of a free surface effect for partly filled tanks. Location and function of ships' tanks on the basis of collected data describing the most significant characteristics of ships' tanks and the classification of tanks were prepared. The very first criteria for distinguishing groups of tanks are their location and shape as well as their use which were strictly defined. According to such assumption, several groups of tanks can be placed starboard and portside and labeled according to their functions.

Ballasting operations could result to two types of stability situations, transverse (rolling) and longitudinal (pitching) stabilities. In applying phase 0 (crane loading), (Koumako, 2000) demonstrated the ballasting requirements for loadout operations in varying tidal conditions. The results showed that zero trim and zero lists could be achieved as Y_{CG} and X_{CG} equal to zero where the point of reference is taken at the center. Study of stability is very important as stability of any loaded ship depends on its main dimensions, shape of the submerged hull and on the actual location of her centre of gravity KG (Babics, 2011). Therefore, in investigating the link between ballasting and stability, this research seeks to study the effects of loading and distribution of the loads in a rectangular barge on its centre of gravity where the reference points X_{CG} , Y_{CG} and Z_{CG} axes are made from the bow.

2. MATERIALS AND METHODS

Since the ballasting operation was done in a jetty, a hydrographical surveyor was employed to conduct the survey (sounding) of the location so as to ascertain the depth of the waterway. The reference datum is the "Low Low Water" (LLW). The values of the centre of gravity longitudinally and transversely were considered from the body system orientation. This is done when the reference points, X_{CG} , Y_{CG} and Z_{CG} are taken from the bow.

Tables with hydrostatic properties that gave the values of the different loads against the reference points were employed for the calculations. Of the 10 tanks available, only tanks 2S and 4S were used to correct the existing trim and heel. For a better understanding of the calculation process, a flowchart is drawn and Java program was used for the computation of the water needed. The calculated ballast water was then distributed to the tanks to correct the heel and trim.

Presented in fig.1 and fig. 2 are the side and plan views of the barge respectively. The X, Y and Z plane are taken positive when considered in the direction as shown but if is in the reverse direction, they are negative.

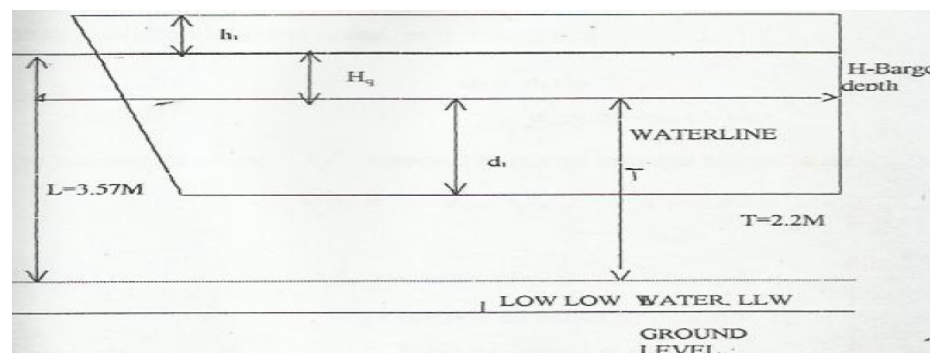


Fig.1: Side view of the barge

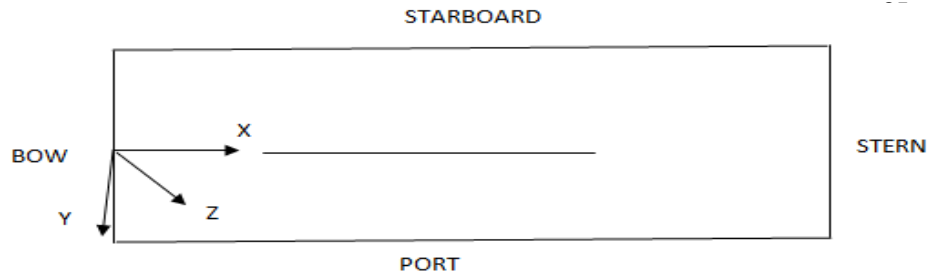


Fig.2: Plan view of the barge showing the reference point and the directions of X, Y and Z

Also, tables 1 and 2 show the tanks and the barge particulars respectively. In table 1, P is taken as port while S is starboard.

Table 1: Tanks with dimensions, capacities and their functions

S/No.	Tank	Length (m)	Breadth (m)	Depth (m)	Capacity/Vol. (m ³)	Function	Capacity/Weight (kg)
1	1S	30	36	15	16200	Not Used	16605
2	1P	30	36	15	16200	Not Used	16605
3	2S	30	36	15	16200	Ballast Tank	16605
4	2P	56	36	15	30240	Ballast Tank	30996
5	3S	52	36	15	28080	Tide Control	28782
6	3P	52	36	15	28080	Tide Control	28782
7	4S	52	36	15	28080	Ballast Tank	28782
8	4P	52	36	15	28080	Ballast Tank	28782
9	5S	30	36	15	16200	Not Used	16605
10	5P	30	36	15	16200	Not Used	16605

Table 2: Parameters of the Rectangular Barge

Lightweight of the barge	905.29 tonnes
Center of gravity of the barge without weight	$X_G = 33.53\text{m}$, $Y_G = 0.00\text{m}$, $Z_G = 2.74\text{m}$
Weight of load (piles) altogether	578.74tonnes
The piles are placed at center of gravity	$X_G = 30.01\text{m}$, $Y_G = -1.29\text{m}$, $Z_G = 5.64\text{m}$
GM_t	11.20m
GM_l	127.10m
H	4.57m
Lov	67.06m
Beam of barge	21.95m
Lpp	64.37m
Quay Elevation (above LLW), L	3.57m
Tidal Reading, T	2.2m
Load Draught, d_2	3.2m
Block coefficient, Cb	0.92

LEVELING OF THE BARGE WITH THE QUAY

It is required to pump in certain quantity of water into the barge for ballasting purpose, but before then, the value of h_1 which is the excess height to correct is known. From calculation if the excess height to correct is negative (deficit), loadout cannot be carried out but if it is positive, (excess) then water can be pumped into the barge to level the barge with the quay.

116 **DETERMINATION OF EXCESS HEIGHT TO CORRECT, h_1 AND VOLUME OF**
117 **WATER NEEDED FOR BALLASTING**

$$h_1 = H - d_1 - H_q \text{ (Koumako and Uyo, 2000)} \quad 1$$

118 And $H_q = L - T \quad 2$

119 If the value of h_1 comes out to be positive, the elevation of the barge deck can now be align
120 with the quay at a draught of:

$$d_2 = d_1 + h_1 \quad 3$$

121 The volume of water, V needed to pump into the barge is:

$$V = V_2 - V_1 \quad 4$$

122 Where:

123 $V_1 = L \times B \times d_1 \times C_b = \text{Volume of water at draught } d_1;$

124 $V_2 = L \times B \times d_2 \times C_b = \text{Volume of water at draught } d_2$

125 **HEEL AND TRIM CORRECTION**

126 Tanks 2p, 2s, 4p and 4s are used for both heel and trim correction. The heel correction is
127 effected by employing the moment required to change heel per one unit. This is determined
128 as:

$$MCT = \frac{\Delta \times GM_l}{L_{pp}} \text{ (American Bureau of Shipping, 1980)} \quad 5$$

129 Where:

130 GM_l : Transverse metacentric height; L_{pp} : Length between perpendiculars

131 Δ : Mass displacement and it can be determined from:

$$\Delta = L \times B \times d_2 \times C_b \times \rho_{\text{salt water}} \text{ (Douglas, 2002)} \quad 6$$

132 The total trim is estimated as:

$$T_T = \frac{([LCG - LCB] \times \Delta)}{MCT} \quad 7$$

133 Where:

134 LCB : Longitudinal center of buoyancy; LCG :longitudinal center of gravity

135 A positive value of T_T means trim by bow. To obtain trim a desirable trim value, certain
136 quantity of water is needed to be pumped into the trim control tank and this amount of water
137 can be expressed as:

$$W_T = \left(\frac{GG_1 \times \Delta}{GG_1 - d_T} \right) \quad (Lewis, 1988) \quad 8$$

138 d_T : Trimming distance is the center of gravity of the barge in the longitudinal direction when
 139 there is no external load on the barge less the center of gravity of the barge in the longitudinal
 140 direction when the piles are loaded and it is given as:

$$d_T = 33.53m - 29.99 = 3.54m$$

141 GG_1 : Trimming lever and it is calculated thus:

142 **Table 3: Table showing the ship's light weight, piles weight and their centre of gravity from centre**

Weight, W (t)	KG (m)	Moment (tones*m)	CG from centerline	Moment starboard	Moment Portside (Mp)
905.29	2.74	2480.49	0.00	0	Nil
578.47	5.64	3262.57	-1.29	Nil	746.23
$\Sigma W=1483.76$		5743.06			$\Sigma M_p=746.23P$

143 Table 3 shows the light weight (W) of the barge and its centre of gravity (KG), the weight of
 144 the piles loaded and the KG is also shown. Negative sign indicates portside and then the
 145 trimming lever is calculated thus:
 146

$$GG_1 = \frac{\Sigma W}{\Sigma M_p} \quad (Lester, \quad 1985)$$

147 The total heel likewise is expressed as:

$$H_T = \frac{([TCG - TCB] \times \Delta)}{MCT} \quad 9$$

148 Where TCG: Transverse Centre of Gravity (m)

149 TCB: Transverse Centre of Buoyancy (m)

150 If the H_T value is negative, the list is by the portside and where it becomes positive, the list is
 151 starboard. However, to achieve zero list the quantity of water needed to be pumped into the
 152 list control tank is obtained as:

$$W_H = \frac{GG_1 \times \Delta}{GG_1 - d_T} \quad 10$$

153 Where:

154 d_T : The center of gravity of the barge in the transverse direction when there is no external
 155 load on it less the center of gravity of the barge in the transverse direction when the piles are
 156 loaded.

157 That is, $d_T = 0.00m - (-1.29m) = 1.29m$

158 The total quantity of water required for both the list and trim correction is given as:

$$W_{TH} = W_T + W_H \quad 11$$

159 **COMPUTER MODEL**

A flowchart showing the sequential flow of the methods followed in arriving at the total quantity of water needed for the correction of heel and trim is shown in fig. 3. The Java program that flows from the flowchart aided the step by step computation of equations 1 – 11. The program displayed an output result of 1802.84 tonnes which is then distributed to the ballast tanks.

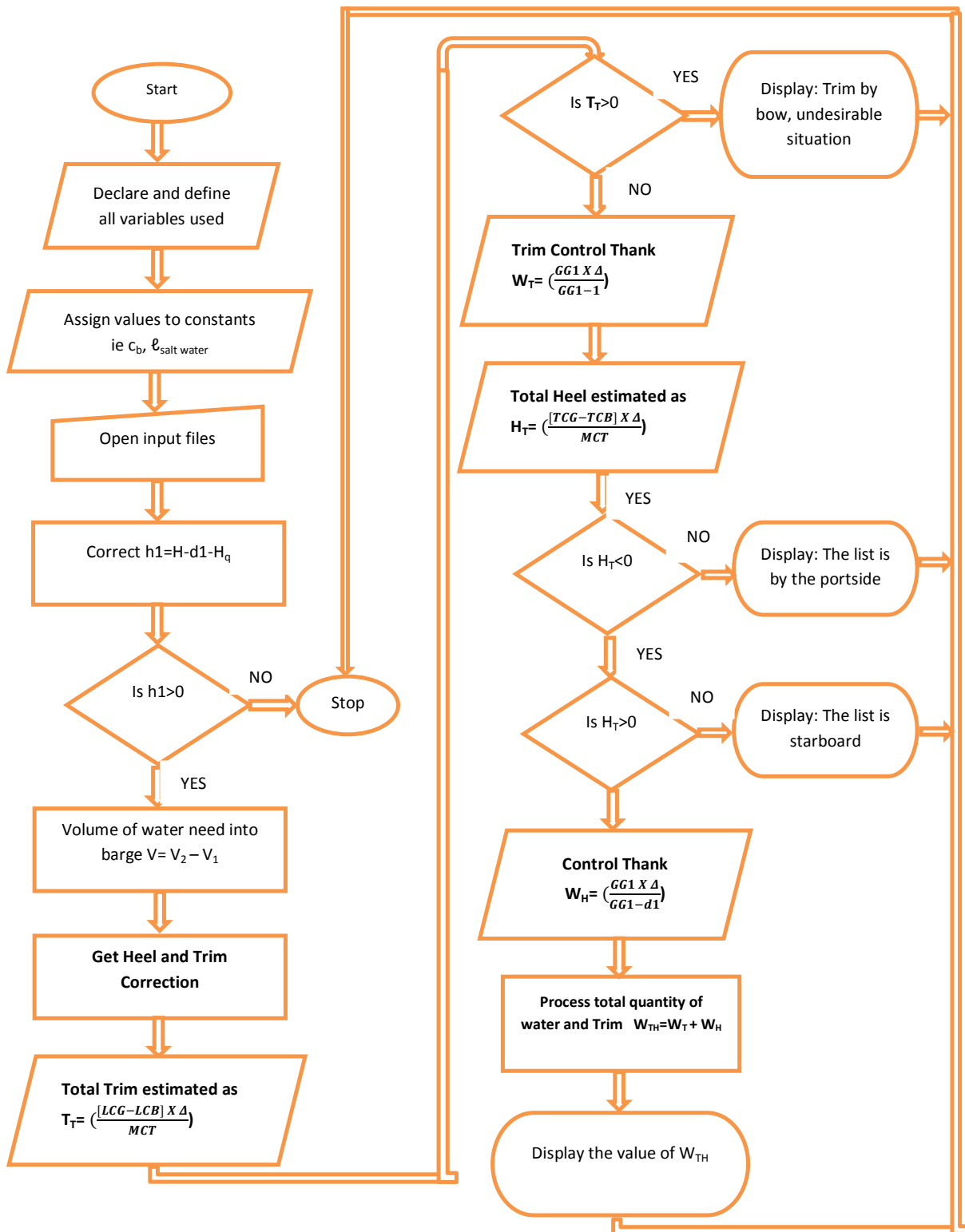


Fig. 3: Flowchart illustrating the computation process of the water needed for the ballasting operation

3. RESULT AND DISCUSSION

Although tanks 2S, 2P, 4S and 4P are all meant for the ballast purpose however, only tanks 2S and 4S are used. The quantity of ballast needed is 1802.84 tones. Table 4 shows the tanks, percentage utilization and the centre of gravities of the corresponding weights from the keel. The 2.50% represents the water and mud that could not be pumped out and left behind in the tank. It is an allowance that was taken into consideration for any unused tank. Trim and heel are corrected where LCG (X_{CG}) gives 28.49m and TCG (Y_{CG}) gives 0.12m.

Table 4: Table of the ballast water distribution to the tanks and their centre of gravities

	Ballast Data								Weight Calculations		
	Full Capacity	% Used	Weight	KG	Wt*KG	X_{CG}	Y_{CG}	Z_{CG}	MX	MY	MZ
Barge Weight	t	%	t	m	t*m	m	m	m	t*m	t*m	t*m
Lightship			905.29	2.74	2480.49	33.53	0.00	2.74	30354.37	0.00	2480.49
Loaded Piles			578.74	5.64	3264.09	30.01	-1.29	5.64	17359.88	-746.23	3262.57
Subtotal			1484.03	3.87	5744.58	32.16	-0.50	3.87	47714.25	-746.23	5743.06
Ballast											
1S	16605	2.50	415.13	1.01	419.28	17.68	5.49	1.01	7339.50	2279.06	419.28
1P	16605	2.50	415.13	1.01	419.28	17.68	-5.49	1.01	7339.50	-2279.06	419.28
2S	16605	5.61	931.66	2.18	2031.02	17.68	5.49	2.18	16471.75	5114.81	2031.02
2P	30996	2.50	774.90	1.89	1464.56	17.68	-5.49	1.89	13700.23	-4254.20	1464.56
3S	28782	2.50	719.55	1.88	1352.75	34.14	5.49	1.88	24565.44	3950.33	1352.75
3P	28782	2.50	719.55	1.88	1352.75	34.14	-5.49	1.88	24565.44	-3950.33	1352.75
4S	28782	3.03	871.17	2.29	1994.66	49.99	5.49	2.29	43549.79	4782.72	1994.66
4P	28782	2.50	719.55	1.88	1352.75	49.99	-5.49	1.88	24565.44	-3950.33	1352.75
5S	16605	2.50	415.13	1.01	419.28	17.68	5.49	1.01	7339.50	2279.06	419.28
5P	16605	2.50	415.13	1.01	419.28	17.68	-5.49	1.01	7339.50	-2279.06	419.28
Subtotal			6396.90	1.75	11225.61	27.63	0.265	1.75	176776.09	1693	11225.61
	Total		7880.66	2.15	16968.67	28.49	0.12	2.15	224490.34	946.77	16968.67

The capacity (weight) utilization of the tanks on board the barge is presented in fig. 4. This is done after the water pumped into the tanks for the ballasting purposes has been distributed and it showed from the shape of curve that tanks 2S and 4S all situated at the starboard which are the only tanks used for the ballasting contains the largest quantity of water in terms of weight.

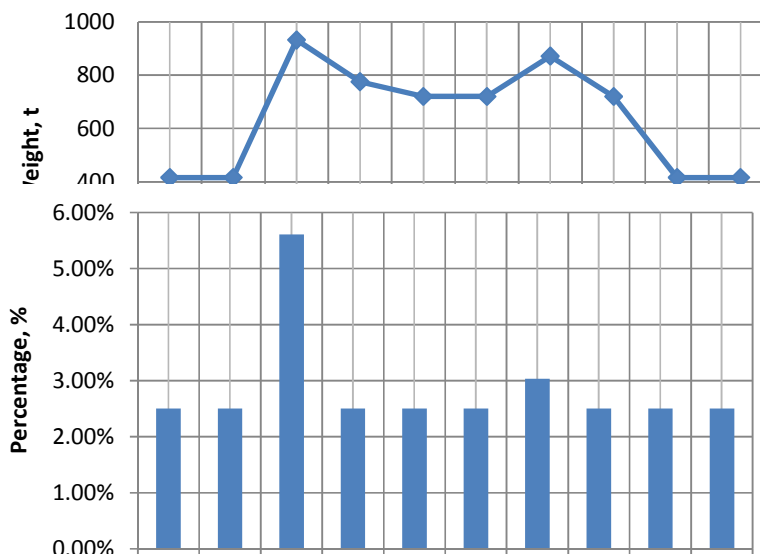


Fig.

the
this

5 shows the capacity (percentage) utilization of the tanks on board barge. Again, is done after the

water pumped into the tanks for the ballasting purposes has been distributed. The bars showed that tank 2S correspond to the highest percentage and then followed by tank 4S which again showed they contain the largest quantity of water.

4. CONCLUSION AND RECOMMENDATION

Having considered the importance of offshore vessels as well as the effects of loading and offloading on the stability of the vessels, a research on the effects of ballasting operation and subsequent distribution of the ballast water into ballast tanks 2S and 4S on a rectangular barge were carried out with the aim of eliminating trim and heel. This is done by sending in 1802.84 metric tons of water and distributing same into the tanks with regards to X_{CG} , Y_{CG} . The results of the study showed that at $X_{CG} = 28.49$, $Y_{CG} = 0.12$, trim and heel are corrected.

From the findings of this work, the recommendation is that prior to the deployment of any offshore structures, proper attention should be given to the loading and offloading operations with regards to the changes on the centre of gravity of the structures.

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