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Occurrence of Vortices at an Intake of Point Sink Character†

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ABSTARCT

In this study, the occurrences of vortices entering the intake of point sink character located in a sump are explained from fluid mechanics point of view. All types of boundaries (air, solid, fluid interface and flow-dividing subsurface) cause blockage effects on the intake flow. A vortex basically originates from the boundary that has blockage effects on the intake flow. In reality, all vortices originating from the free-surface, flow-dividing surface, fluid-interface and solid boundaries are "subsurface-vortices" and they have the same nature of occurrence. Experiments indicated that a strainer-conic and a strainer-pipe type structures effectively eliminate the vortices.

Keywords: *Intake, vortex, air-entrainment, critical submergence, vortex prevention.*

1. OCCURRENCE OF FREE-SURFACE (AIR-BOUNDARY) VORTEX

Kocabaş and Yıldırım (2002) have shown that when a pipe intake of point sink character is present in a flow field, stream surfaces of spheres or spherical sink surface(s) (SSS) develop. In Fig.1(a), the SSS tangent to the free-surface (air-boundary) at its summit point A is represented by SSS_t. Continuity indicates that, among all free-surface particles, only the particle A has the largest perfectly radial velocity towards the intake.

If the fluid free-surface remains horizontal, for example; the particle B in Fig.1(a) on both the free-surface and an incomplete SSS must have only radial velocity vector towards the intake and follow the radial line of $BB_1B_2B_3$ as the incomplete SSS(s) radially shrinks to become the complete SSS_t. It requires B to go to A horizontally. But, the particle B can not simultaneously have both a radial velocity with its magnitude satisfying the continuity and a horizontal velocity towards A. Because, according to the potential solution, total velocity of B must solely be the radial velocity satisfying the continuity and it has to be the same as that of all other particles on the SSS on which B takes place. In this case, no particle can be able to replace the fastest free-surface particle A of the SSS_t once it moves radially towards the real intake. This means that the continuity at the point A of the SSS_t will fail in the potential flow assumption. As the particle A advances before all other free-surface particles towards the intake, due to viscosity-friction, it also drags the neighboring free-surface fluid particles on the adjacent incomplete SSS(s) and causes a "must" deformation (depression)

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at the free-surface [Fig.1(b)]. Hence, the particle A causes the initiation of the depression at the free-surface. The depression in SSS_t at A must be deeper than in other sections of the free-surface.

Since the intake flow evacuates the fluids inside the SSS(s), there develops suction effects within SSS(s) and SSS(s) collapse. Due to the suction effect of the intake flow and continuity, the SSS_t [also complete SSS(s) smaller than SSS_t] shrinks and the depression in it becomes deeper. The free-surface must have a slope towards the center point A of the depression so that under the effects of gravity and shear-forces, the ambient fluid at and about the free-surface can gain velocity and flow towards the point A in order to fill out the depression region in the shrinking SSS_t under the free-surface.

In addition to its radial velocity towards the intake (satisfying the continuity for the intake), the particle B has to gain another velocity towards A. The result of these two velocity vectors is tangent to the depressed free-surface. Thus, in the case of a real fluid, the particle B flows towards A by following the depressed free-surface profile of BCEA in Fig.1(b) [not $BB_1B_2B_3$ in Fig.1(a)]. In this way, B replaces A and the incomplete SSS shrinks to SSS_t. Except the free-surface particle A, all other free-surface particles can not have total velocity vectors towards the real intake and they can not directly travel towards the real intake. Instead, they have to travel at the free-surface with their total velocity vectors tangent to the depressed free-surface and wait for their turns in order to replace and gain the characteristics of the free-surface particle left the point A towards the real intake. This is the only way that the free-surface particles get a chance to reach and enter the intake. Since the free-surface particles can not have total velocity vectors towards the real intake, from the free-surface vortex point of view, the air-boundary behaves as a solid boundary not because of no-slip condition but due to the presences of SSS(s) cutting the free-surface as a result of the blockage of the air-boundary. As the particle B radially moves towards the center point A of the surface-depression, it also attains an angular velocity (it is subjected to a rotation due to the Coriolis effect and other disturbances at the free-surface). Thus, the path of B becomes a helicoidal one at the free-surface [Fig.1(c)].

As explained by Kocabaş and Yıldırım (2002), all SSS(s) rotate as they collapse. In reality, the helicoidal path of B is the chain stages of collapse of the incomplete SSS (to become SSS_t first) at the free-surface on which B takes place as shown in Fig.1(b-c). For the particles of the free-surface, the surface depression behaves as a kind of intake which is called the "depression intake" in this study. Entire free-surface flow has only one point to pass through and reach the intake. This point is A of the SSS_t [Fig.1(a-d)]. Whole free surface flow is converged to pass through the point A (or the free-surface "depression-intake"). Thus, including the Coriolis effects, any disturbance present or introduced to the free surface flow or becomes self-existent due to the instability as a result of collision of opposite velocities of the free-surface flows (particles) meeting at and about the point A is carried and passed through the point A of the SSS_t [also SSS(s) smaller than SSS_t] by the free-surface flow. The occurrence of the free-surface vortex is very sensitive to the disturbances introduced to the free-surface flow. Because all free-surface disturbances (vorticity) are accumulated and carried through the depression and reached the intake by means of the free-surface flow entering the "depression-intake". Since the sections of SSS_t or SSS(s) at and close to a solid boundary (i.e., pipe of the intake) are under the boundary-effects, these sections of SSS collapse much slower than rest of their sections where the boundary-effects are the least.

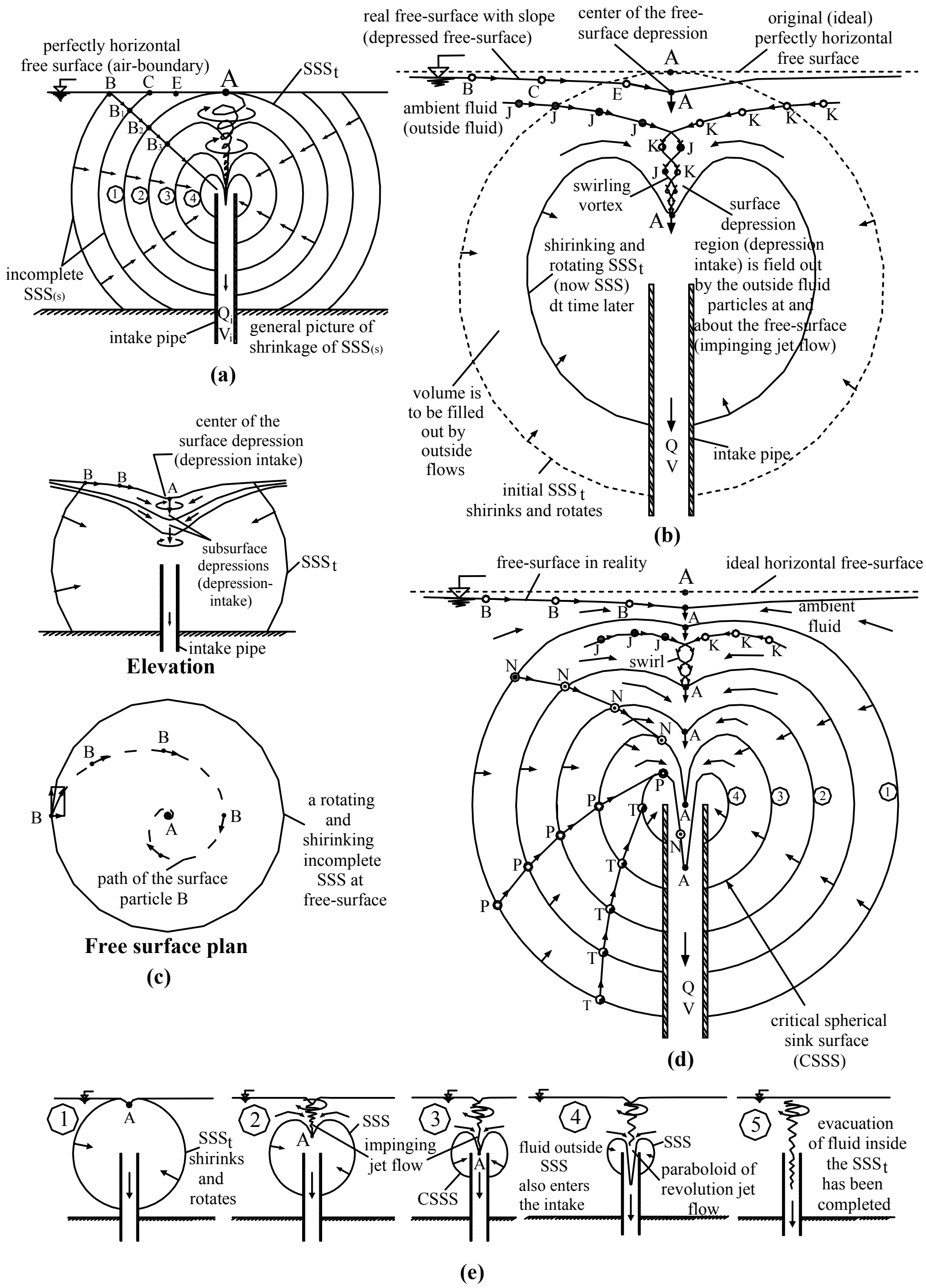

Figure 1- (a)-(e) Collapsing Stages of SSS(s) and Development of the Free-Surface Vortex Originating from the Air-Boundary.

In reality, the complete SSS(s) smaller than SSS_t are all collapsing stages of the SSS_t. As SSS_t or complete SSS(s) collapses, due to continuity, the depressions in them become deeper. Since the depression in a complete SSS behaves as a kind of intake for the subsurface ambient fluid, it is also a "depression intake" [Fig.1(b-c)]. The particles within the depression of the shrinking SSS_t have higher velocities towards the intake in comparison to the particles on other sections of same shrinking SSS_t. Therefore, the ambient fluid filling out the depression in the shrinking SSS_t advances towards the intake as an impinging jet flow. As the SSS_t and other smaller complete SSS(s) collapse, depressions in them are filled out by the ambient fluid in the form of impinging jet flows as shown in Fig.1(b-d). Flow towards a "depression" is very similar to the flow towards a real intake. The pathway of the vortex from the free surface to the real intake is made of chain-series of infinite numbers of "depression-intakes" within "depression-intakes" that have similar flow characters [Fig.1(b-d)].

Flow towards a "depression-intake" is also subjected to the effects of Coriolis force and the disturbances originating from the non-uniformities in the flow field. Due to these effects, flows towards the depressions also rotate. The sections of an SSS about its depression region where shear-deformation and rotation are very large, collapse faster than other sections of the same SSS. Due to this effect, the paths of other particles on the same SSS may also deviate from being perfectly radial towards the intake as SSS(s) collapse [as presented in Fig.1(d), all fluid particles on an SSS, i.e., A, N, P and T reach and enter the intake sooner or later by becoming a part of depression(s) in the SSS as it passes through its all collapsing stages from the very beginning to the end]. The stages of collapsing of an SSS are presented in Fig.1(d-e) which shows that collapsing stages of SSS, development of depression and the impinging jet in SSS are very similar to those occurring during the collapse of a cavitation bubble (Knapp, 1979, Figs. 8.11 and 8.12). The vacuuming action inside a cavitation bubble is created by incredibly fast condensation of water vapor. In the case of SSS(s), the vacuuming action is created by the intake flow. When SSS becomes the critical spherical sink surface (CSSS), the depression in it becomes sufficiently deep and its tip just enters the intake. If the submergence is sufficiently larger than the critical submergence, the outside ambient fluid at and close to the free-surface comfortably fills the depression out and the vortex is seen as a swirling vortex. Hence, the air-core vortex can not develop or, depending on the magnitude of the submergence, if it develops it can not reach the intake. On the other hand, if the submergence is equal to or less than the critical submergence, the ambient fluid outside the top portion of the CSSS becomes insufficient to fill the depression completely out. The depression can not be filled out solely by the fluid at and close to the free-surface. In this case air and the ambient surface fluid together fill the depression out in the SSS. The air-core vortex completely develops and air enters the intake.

The ambient fluid particles flowing into the depression(s) in the collapsing SSS(s) collide with opposite velocities at and about the path line of the particle A (center line of the depressions) and in conjunction with the Coriolis effect, cause large amount of vorticity along the path line of the particle A or within the impinging jet flow [i.e., particles J and K in Fig.1(b)]. The swirling path lines of these particles appear as a swirling vortex or swirling impinging jet flow as it is seen in the photograph in Fig.4 of Kocbaş and Yıldırım (2002). As the vorticity carrying free-surface flow proceeds through the depression and the ambient fluid outside the top portion of the SSS fills out the depression in the SSS in the form of an impinging jet-flow of paraboloid of revolution that has considerably high relative velocity with respect to the ambient fluid, a lot of vorticity is conveyed into the depression. Because of the viscosity-friction, the impinging jet drags the ambient fluid particles towards the depression and the intake. Hence, as SSS shrinks and gets smaller, the strength of the vortex increases, the depression becomes deeper (longer) and narrower [Fig.1(d-e)]. Thus, the flow filling the depression out and reaching the intake through the depression is seen as a strong fully developed swirling vortex flow.

2. OCCURRENCE OF SOLID-BOUNDARY VORTEX

Consider a solid boundary as shown in Fig.2(a). The free-surface (air-boundary) and SSS_t in Fig.1 correspond to a solid boundary and the SSS tangent to the solid boundary accordingly in Fig.2(a). Same explanations previously used for the occurrence of the free-surface vortex are also exactly valid for the occurrence of a subsurface vortex starting from a solid boundary. In the case of a real fluid, all particles [i.e. A, B and C in Fig.2(a)] on the boundary must have zero velocity. The particles on the boundary can not be removed. Thus,

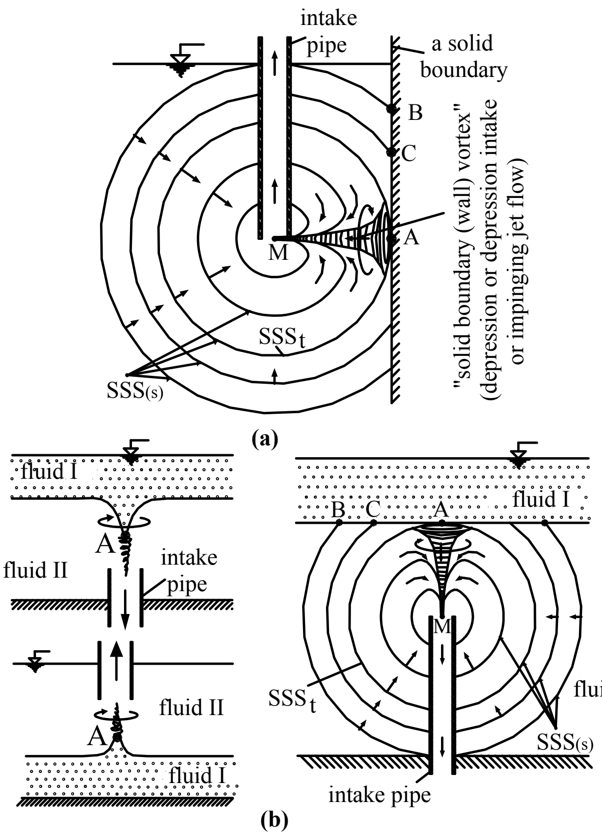

Figure.2- Development of Vortices at (a) Solid-Boundary and (b) Stratified Fluid-Interface.

the section of the SSS (larger than SSS_t) blocked by the boundary can not shrink while rest of it shrinks. Since the sections of SSS at and close to a boundary are under the boundary-effects, these sections of SSS collapse much slower than the rest of their sections where the boundary-effects are the least. The shrinkage velocities of the sections of SSS gradually increases from zero at the boundary to the maximum value in the regions far away from the boundary. This results in large velocity gradients and strong vorticity at the boundary.

While the jet flow proceeds through the depression to reach the real intake, it also carries the vorticity developed about the boundary along with it. As the SSS gets smaller, the depression becomes longer and narrower and resembles a very slender paraboloid of revolution. Whole vorticity carrying flow about the boundary is converged to pass through the point A right next to the tangent point of SSS_t on the boundary and reach the real intake by following the “depression-intake” or the pathway of the “solid boundary-vortex” [Fig.2(a)]. If the strength of the circulation (or angular velocity) sufficiently increases and pressure in the depression flow becomes less than the vapor pressure of the fluid, cavitation occurs and the subsurface vortex is seen as a “gaseous-vortex”.

3. OCCURRENCE OF VORTEX AT STRATIFIED FLUID-INTERFACE

In the case of a stratified fluid boundary, the velocity of the particle A of SSS_t where it is tangent to the fluid-interface is not zero [Fig.2(b)]. Among all fluid-interface particles, only the particle at point A has maximum radial velocity towards the intake. The collapse of SSS(s) and the development of the depression are exactly the same as those explained for an intake in a single fluid flow that has the air-boundary (free-surface) or solid boundary vortex. The layer-fluid has “negative” and “positive” effects. The “negative effect” is as follows.

Due to viscosity-friction and surface tension effects of the fluid layer not supplying flow to the intake, the approach velocity of the fluid layer supplying flow to the intake at and about the fluid-interface is decreased. Therefore, one expects that the surface depression or critical submergence is to become larger than that in the case of a free-surface (air-boundary) vortex occurring at an intake sited in a fluid with no stratification. The friction and surface tension are also the sources of the “positive effect”. The viscosity-friction and surface tension of the layer-fluid effectively dampen the disturbances and perturbations or vorticity at the fluid-interface (especially at the inner surface of the interface periphery of the vortex depression) [Fig.2(b)]. Hence, the energy and strength of the vortex and velocity of the particle A are very effectively decreased. The elongation of the vortex depression towards the intake is retarded. In over all, the positive effects of the layer-fluid on the critical submergence is much larger than its negative effects as observed by Yıldırım and Jain, 1979 and Lubin and Springer, 1967. If the submergence of the intake (clearance of the interface to the intake) is larger than its critical submergence, the stratified fluid layer not providing the intake flow fills out the depression in SSSt and no particles of the fluid layer providing the intake flow collide within the depression in SSSt in the wake of A as SSSt collapses. Therefore, no swirling occurs in the wake of A. The swirling occurring and extending between A and the intake [Fig.2(b)] is due to the collision of particles of the fluid layer (providing the intake flow) filling the depressions in SSS(s) during their collapse similar to the particles J and K in Fig.1(b). If the submergence of the intake is less than its critical submergence, the depression within SSSt behaves as a kind of axially-rotating "depression-intake" for the fluid layer not providing the intake flow. In this case, SSS(s) also develop and collapse within the stratified fluid layer, the particles of the fluid layer not providing the intake flow gain noticeable velocities towards the depression in SSSt (as they flow into the depression to fill it out) and collide in the same way as the particles J and K in Fig.1(b). Thus, a swirling and a surface depression can also occur within the stratified fluid layer not providing the intake flow. If the thickness of the top layer fluid not providing the intake flow is not sufficient to completely fill out the depression in SSSt, it will simply flow in to the air-entraining vortex depression and reach (enter) the intake by following the boundaries of the air-entraining vortex. In such a case, the effect of the stratified fluid layer on the critical submergence (air-entraining vortex) is negligible.

4. OCCURRENCE OF SUBSURFACE-VORTEX BETWEEN TWO INTAKES

Consider a group of two pipe intakes I and II with center points of M_1 and M_2 and discharges of Q_1 and Q_2 accordingly. For each intake, an infinite number of complete or incomplete SSS(s) can be drawn [Fig.3(a)]. In reality, each SSS represents a collapsing stage of a preceding larger SSS of the same intake. Let us consider any two SSS(s) intersecting each other and denote them by SSS I and SSS II for intakes I and II accordingly as presented in Fig.3(b). SSS I and SSS II can be complete or incomplete. In Fig.3(b), V_{s1} and V_{s2} are the velocities at SSS I and SSS II accordingly. The blockage effect of the flow of the intake I on the flow of the intake II is equal to the discharge of HFG.V_{s1} towards intake I. Similarly, the blockage effect of the flow of the intake II on the flow of intake I is equal to the discharge of HEG.V_{s2} towards intake II. The discharge through HEG of SSS II is reduced for an amount of HFG.V_{s1}. The net discharge through HEG towards intake II is equal to (HEG.V_{s2} – HFG.V_{s1}).

Physically, there can be three possible cases that are as follows. (HEG.V_{s2} – HFG.V_{s1}) = 0; (HEG.V_{s2} – HFG.V_{s1}) > 0 and (HEG.V_{s2} – HFG.V_{s1}) < 0. There can be an infinite number of places instantly satisfying the conditions similar to (HEG.V_{s2} – HFG.V_{s1}) = 0, (HEG.V_{s2} – HFG.V_{s1}) > 0 and (HEG.V_{s2} – HFG.V_{s1}) < 0. As an infinite numbers of SSS(s) of the intakes I and II concurrently and continuously collapsing, they cross-pass one another at an infinite number of places outside as well as inside of HEGFH with conditions similar to (HEG.V_{s2} – HFG.V_{s1}) > 0 and (HEG.V_{s2} – HFG.V_{s1}) < 0 and cause the opposite velocities to collide and create shear and irregularities within the flow field.

This self-existing endless-vorticity-feeding mechanism contributes considerable strength to the subsurface-vortex extending between the intakes I and II. There must be a flow-dividing surface [an "imaginary impervious boundary (IIB)" due to hydraulic conditions] developed in the flow field between the intakes I and II. The point A must be on both the flow-dividing surface (IIB) and the line connecting the center points of the intakes I and II at which a pair of SSS(s) [represented by SSS_{t1} and SSS_{t2} in Fig.3(b)] of both intakes are tangent to each other and velocities at them are equal in magnitude but in opposite directions at A. If the intakes are identical ($Q_1 = Q_2$) and symmetrical, the flow-dividing surface becomes a plane surface and takes place mid-way between the intakes I and II [HAG in Fig.3(b) becomes a plane IIB].

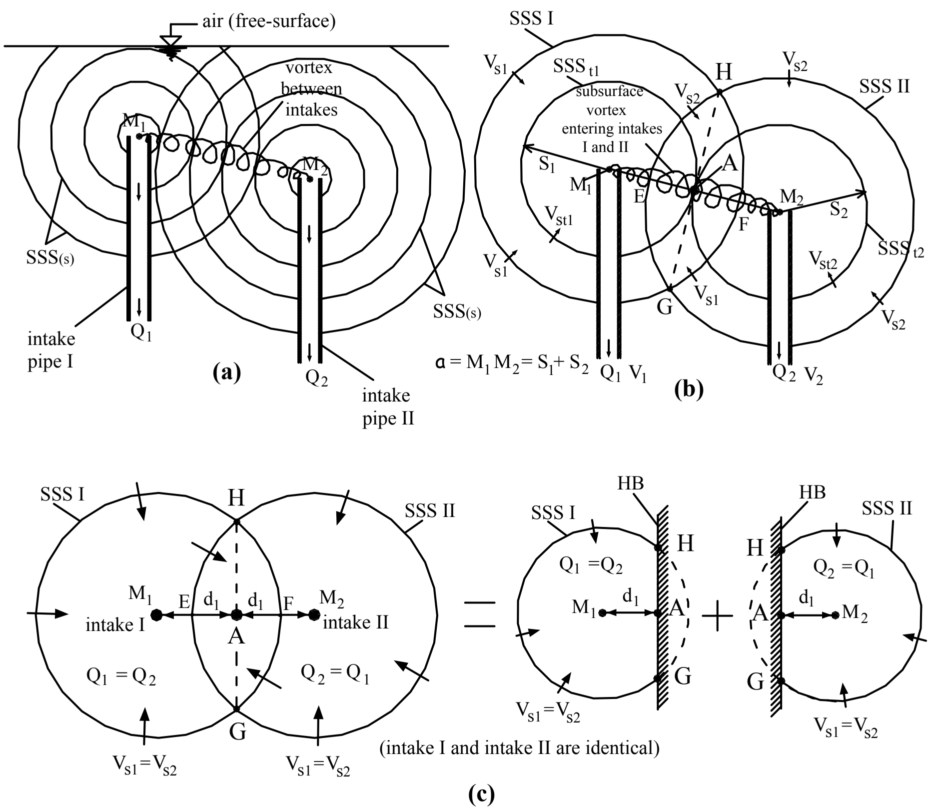

Figure 3- (a) and (b) Subsurface-Vortex Extending between the Intakes I and II and the Theoretical Location of "A" at the Flow-Dividing Surface. (c) Imaginary Impervious Boundary (IIB) Between the Identical Intakes I and II.

Theoretically, the point A should be the starting point of the subsurface-vortex extending between the intakes I and II. The occurrence of the subsurface vortex extending between two intakes is the same as that occurring at a real boundary [Figs.1, 2 and 3(a-b)]. If the subsurface-vortex is sufficiently strong, its angular velocity increases in such a way that the pressure becomes less than the vapor pressure of the fluid (cavitation occurs) and it is seen as a gaseous subsurface-vortex (cavitation vortex) extending between the intakes I and II. This phenomenon has been observed by the authors during the experiments in this study and other researchers (i.e. De Siervi et al. 1982).

Existence of the IIB [in the case of identical intakes I and II, Fig.3(c)] indicates that any type of boundary (including air) can artificially be created by means of "superposition" or "mirror image-intake" method. From the subsurface-vortex point of view, no need to know the position of the IIB. But, the location of A on IIB is needed. For general (whether or not intakes I and II are identical), the location of A is explained below.

5. LOCATION OF "A" ON THE FLOW-DIVIDING SUBSURFACE (IIB)

Conditions for the point A [Fig.3(b)].

$$S_1 + S_2 = a \;; \quad V_{st1} = V_{st2} \;; \quad Q_1 = A_{s1}.V_{st1} \;; \quad Q_2 = A_{s2}.V_{st2} \tag{1}$$

In which S_1 and S_2 are the radiuses of SSS_{t1} and SSS_{t2} respectively, a = distance between the center points M_1 and M_2 of the intakes I and II; V_{st1} = velocity at SSS_{t1}; V_{st2} = velocity at SSS_{t2}; A_{s1} = total networking surface area of SSS_{t1} and A_{s2} = total net working surface area of SSS_{t2}. Eqs.(1) gives

$$Q_1/Q_2 = A_{s1}/A_{s2} = [(A_{s1}/D_1^2)/(A_{s2}/D_2^2)](D_1/D_2)^2 \tag{2}$$

where, D_1 and D_2 are the internal diameters of the intakes I and II respectively.

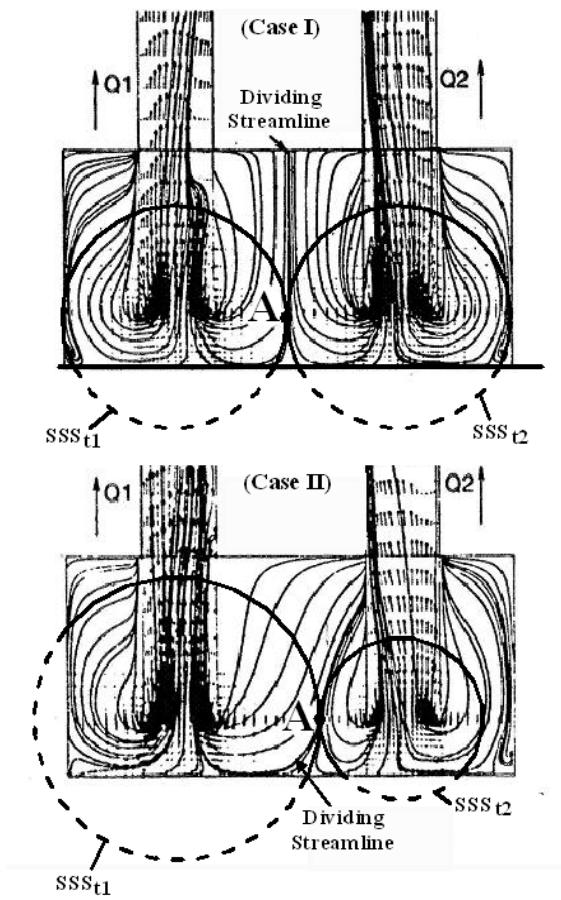

Figure 4- Comparison of Theoretical Location of the Point "A" and the Flow Dividing Line predicted by Ansar and Nakato (2002) [6].

General solution of eq.(2) in conjunction with eq.(1) requires a trial-and-error procedure that is as follows (Q_1/Q_2 is known).

i) In scale, draw the geometry of flow boundaries (intake pipes, canal walls etc.) and water surface.

ii) Choose S_1 and from eq.(1) get $S_2 = (a\text{-}S_1)$. In scale, draw SSS_{t1} and SSS_{t2} within the geometry of the flow boundaries drawn in step "i".

iii) Evaluate A_{s1} and A_{s2} of SSS_{t1} and SSS_{t2} drawn in step "ii".

iv) Check whether or not the condition in eq.(2) is satisfied.

In order to present the validity of eqs.(1) and (2), the results of Ansar et al. (2002) for the geometry and flow conditions given in their Fig.7 and Fig.9 (a) and (c) [Case I ($Q_1/Q_2 = 1$) and Case II ($Q_1/Q_2 = 7/3 = 2.33$), $D_1 = D_2 = D$ = internal diameter of the intakes] are utilized [6].

The solution results of eqs.(1) and (2) for their Case I ($Q_1/Q_2 = 1$) and Case II ($Q_1/Q_2 = 2.33$) are found to be ($S_1/D = S_2/D = 1.5$, $A_{s1}/D^2 = A_{s2}/D^2 = 17.56$) and ($S_1/D = 2.06$, $S_2/D = 0.94$, $A_{s1}/D^2 = 21.44$, $A_{s2}/D^2 = 9.20$) accordingly. The point A predicted by eqs.(1) and (2) is compared with their results in Fig.4.

6. ELIMINATION OF SUBSURFACE-VORTICES

In order to eliminate or weaken the occurrence mechanisms of the subsurface-vortex, one can utilize the following methods.

I) A "funnel-type (or a slender conical) strainer (FTS)" may be positioned in the course of the vortex filament. Thus, instead of the particles of the ambient fluid, FTS occupies the depression in SSS_t or SSS(s) as presented in Fig.5(a). The FTS has holes on its lateral surfaces connected to the central collector-cavity with an open-end at its tip through which flow is sucked by the intake. It is a closed-bottom strainer-plug-structure. FTS has plugging, friction and suction effects on the vortex.

II) In order to suck out the colliding fluid particles and swirling impinging jet flow along the course of the subsurface-vortex, a strainer-pipe (SP) with lateral holes can be located in the course of the vortex filament [Fig.5(b-c)]. SP functions similar to FTS. Flow through SP is sucked by the intake.

III) Eliminate or weaken the circulations and disturbances which stimulate the occurrence of the subsurface-vortex [i.e., radial vanes (RDV) in Fig.5(d)].

IV) Others (i.e., introducing a jet towards the boundary on the course of the vortex).

In order to check the performances of FTS, SP and RDV, experiments are conducted.

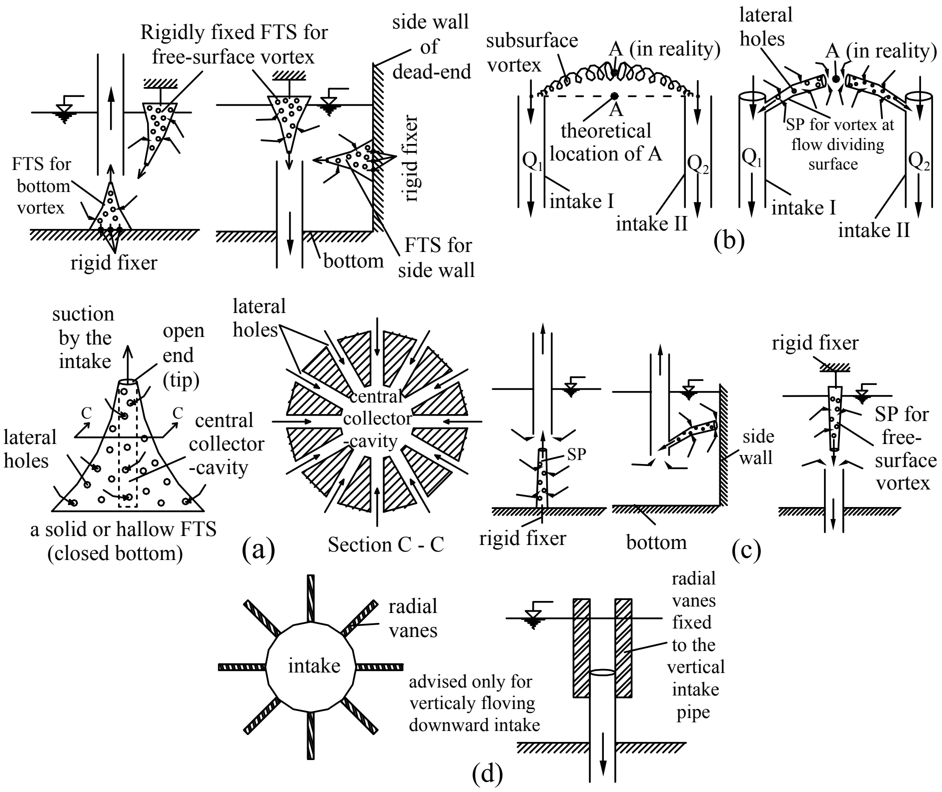

Figure 5- FTS and SP for the Elimination of Subsurface-Vortices.

7. EXPERIMENTS

Experiments are conducted on an intake (D = 5.32 cm.) placed in a rectangular canal flow. The bottom diameter of FTS and the diameter of SP used in the experiments are D and D/7 respectively.

The clearance of the tip of FTS or SP for the bottom and the free-surface vortices (boundaries against the intake) is taken as D/2. The photographs of the experiments are presented in Fig.6. As it is seen in this figure, FTS and SP effectively weaken the subsurface vortices. During the experiments it is observed that the circulatory flow about the RDV causes the separation vortices at about and between adjacent vanes.

RDV extending from the free-surface to the intake is effective for the free-surface vortex entering the intake vertically flowing downward. RDV is not effective on the vortex originating from the bottom of the sump and entering the intake vertically flowing upward. SP is effective whenever the axis of the free-surface vortex coincides with SP. But, since the diameter of SP is small, due to instabilities and irregularities in the flow, the axis and location of the free-surface vortex often alters and SP becomes ineffective. Due to its large sized-closed-end, FTS also functions as a free-surface cover and eliminates the free-surface vortex. It is clear that if flows through FTS and SP are strongly sucked out by any means other than the intake, their efficiencies increase.

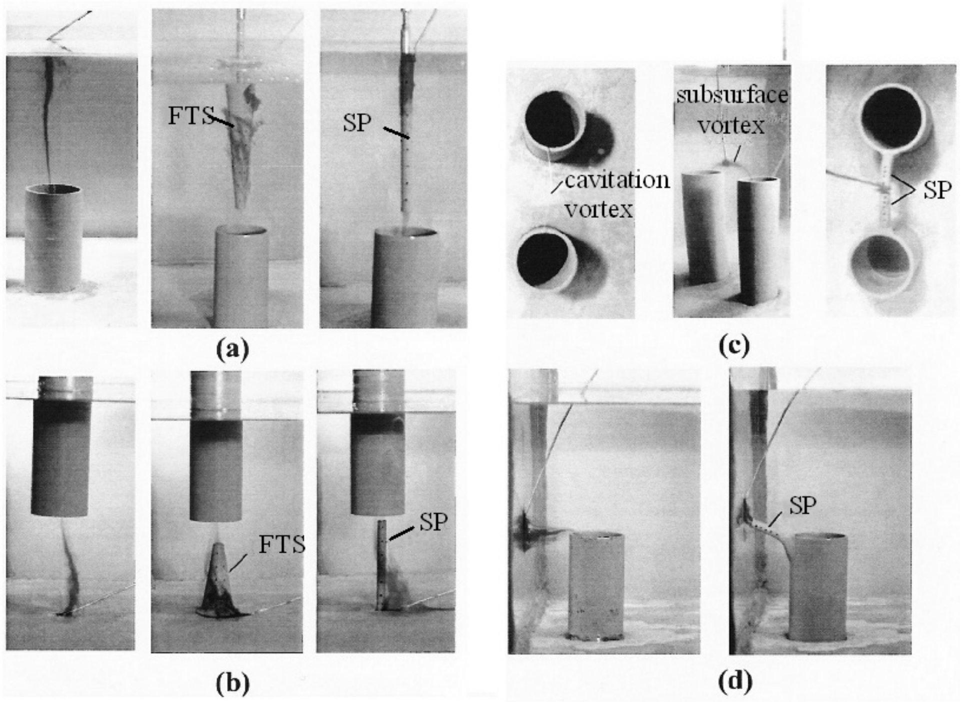

Figure 6- Photographs of FTS and SP in Action. (a) Vertically Flowing-Downward intake, (b) Vertically Flowing-Upward intake, (c) Subsurface-Vortex Between Intakes I and II and (d) Side-Wall (Boundary) Vortex.

8. CONCLUSIONS

The following conclusions are derived from this study.

- The occurrence mechanisms of the vortices entering the intake are explained from the fluid mechanics point of view. In reality, all vortices entering the intake are subsurface-vortices and they have the same nature of occurrence.
- Swirling subsurface-vortices are due to the ambient fluid filling out the depression(s) in the form of impinging jet flow(s) that develop during the collapse of SSS.
- The vortices entering the intake originate and start from the boundaries (air, solid fluid interface, flow dividing surface, etc) causing the blockage effects on the intake flow.

- A boundary from which the subsurface-vortex originates can artificially be created by means of a “mirror image-intake“ method.
- A subsurface-vortex can be eliminated by means of FTS and SP (considering the starting point of the vortex).

Symbols

The following symbols are used in this paper:

$\mathbf{A_{s1}}$ = net working surface area of SSS_{t1};

$\mathbf{A_{s2}}$ = net working surface area of SSS_{t2};

$\mathbf{D_1}$ = internal diameter of intake I;

$\mathbf{D_2}$ = internal diameter of intake II;

$\mathbf{d_1}$ = clearance of intake center to the boundary;

$\mathbf{Q_1}$ = discharge of intake I;

$\mathbf{Q_2}$ = discharge of intake II;

$\mathbf{S_{t1}}$ = radius of SSS_{t1};

$\mathbf{S_{t2}}$ = radius of $SSS_{t2;}$

$\mathbf{V_{s1}}$ = radial velocity at SSS I;

$\mathbf{V_{s2}}$ = radial velocity at SSS II.

$\mathbf{V_{st1}}$ = velocity at $SSS_{t1;}$

$\mathbf{V_{st2}}$ = velocity at $SSS_{t2;}$

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