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Anti-Limb Entrapment Insert

by Ralph L. Barnett

ABSTRACT

Access to the suction pipe in a main drain can occur whenever the sump cover is unfastened, broken, or missing. An arm or leg can be placed, sucked, or propelled into the pipe where the limb can be trapped by various mechanisms including suction, wedging, and tissue swelling. Although their success rate is unimpressive, there are a number of mitigation strategies for limb entrapment that are based on reduced pressure differential. These strategies are thoroughly examined in this paper. None of these compare however to the classic notion of preventing entrapment in the first instance. Restricting the pipe opening to small apertures through the use of permanent cross-members eliminates the limb entrapment hazard. Unfortunately, the cross-member solution used, for example, in tubs and slop sinks introduces new hazards that were not present in the open pipe; hair entrapment, finger entrapment, and mechanical entrapment (e.g. swimwear). This paper introduces a pipe insert at the entrance to the pipe that uses permanent fins to provide anti-limb entrapment. The fins are designed with an iso-friction profile to shed hair that may be entrained into the pipe. The equation for the profile is obtained in polar coordinates. The geometry of the fins minimizes finger and mechanical entrapment. Scallops are included around the edge of the pipe that inhibits body entrapment which can restrain a child with a suction force of 50 to 100 lbf (222 to 445 N). The use of an anti-limb entrapment insert together with a retrofittable anti-evisceration ring will achieve the same entrapment protection with or without a sump cover.

INTRODUCTION

With the exception of swimming, the top categories of traumatic injury and death all deal with activities that are necessities in a modern world. A subset of swimming and bathing accidents is attributable to suction fittings used for drains or circulation systems in pools and spas. There are five hazards associated with such fittings, to wit,

Hair Entrapment/Entanglement:

"Hair becomes knotted or snagged in an outlet cover." [1]. Every known case of entrapment has occurred because of tangling and not because of strong suction forces [2]. Between January 1990 and August 2004, the Consumer Product Safety Commission (CPSC) reports 43 incidents of hair entrapment which resulted in twelve drowning deaths.

Body Suction Entrapment:

"Suction applied to a large portion of the body or limbs resulting in an entrapment." [1] The CPSC has identified 74 cases of body entrapment between January 1990 and August 2004 including 13 confirmed deaths.

Limb Entrapment:

"A limb sucked or inserted into an opening of a circulation outlet with a broken or missing cover in the pool resulting in a mechanical bind or swelling." [1] The focus of this paper is the prevention of limb entrapment without introducing other hazards.

Evisceration/Disembowelment:

"Suction applied directly to the intestines through an unprotected sump or suction outlet with a missing or broken cover." [1] The scenario leading to evisceration typically involves young children who sit on uncovered suction outlets in the bottom of public wading pools. When the child's buttocks seal the drain opening the resulting suction disembowels the child in about 1/4 second at low differential pressures.

Mechanical Entrapment:

"Potential for jewelry, swimsuit, hair decorations, finger, toe, or knuckle to be caught in an opening of an outlet or cover." [1] The CPSC reports an incident involving a 43 year old woman

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whose necklace was caught in a cover; another case involved a 21 year old man's swim trunks [2].

After defining the five different entrapment hazards the American National Standard for Suction Entrapment Avoidance in Swimming Pools, Wading Pools, Spas, Hot Tubs, and Catch Basins, ANSI/APSP-7 2006, advocates a safety system point of view; e.g.;

- "Complication arises from conflicting solutions for these different forms of entrapment. For example, the suction outlet cover that prevents limb entrapment can cause hair entrapment."
- "…safety devices and/or piping configurations are often perceived as complete entrapment solutions when in fact, they may address one or more, but not all, of the hazards."
- "It must be noted that there is one overriding conclusion that is inescapable; there is no 'back up' for a missing suction outlet cover."

This last observation also appears as a warning in Section 4.3,

> **4.3 DANGER. There is no backup for a missing or damaged suction outlet cover/grate. If any cover/grate is found to be damaged or missing, the pool or spa shall be immediately closed to bathers.**

The anti-limb entrapment insert discussed in this paper represents one step in providing "missing cover protection."

ENTRAPMENT REMEDIATION CONCEPTS

This section summarizes most of the safety systems that have been proposed or developed for each of the five entrapment hazards.

A. Hair Entrapment Safeguards

Children and adults use swimming pools and hot tubs for exercise, relaxation, competition, exhibition, romance, exhilaration and therapy. When swimmers and bathers frolic underwater they risk exposing their hair to active pool drains. For example, swimming a circuit to and from a drain is a common aquatic exercise that brings the head into the vicinity of the drain where strands of hair may be entrained into the drainage flow and pass through the apertures in conventional drain gratings.

When hair strands are drawn through drain gratings hair entanglement may proceed by the knotting or wrapping mechanisms illustrated in Figs. 1a and 1b respectively. Both mechanisms are sufficiently aggressive that a bather may be trapped even in the face of heroic intervention. Drain covers can be designed to avoid hair entanglement or to allow escape. Some of the physical and mechanical properties of hair have been collected in Table 1 to assist our understanding of hair entrapment.

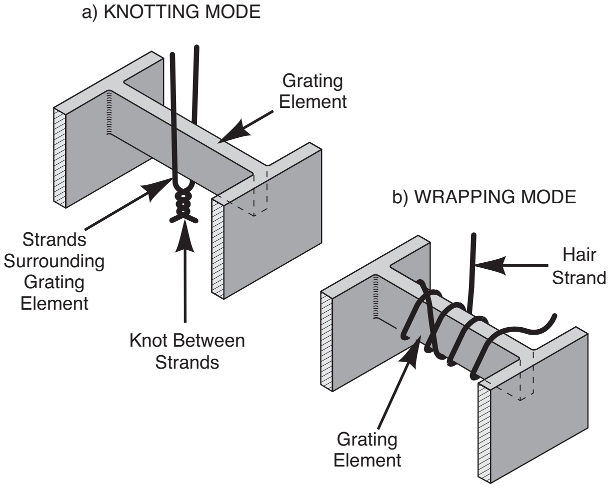


Figure 1. Hair Entanglement Models

1. Collimated Gratings

By extending the vertical dimensions of most conventional drain gratings, one obtains a series of prismatic tubes such as shown in Fig. 2. If these tubes are longer than the critical hair length shown in Fig. 3, there are no mechanical elements for the hair strands to snag or lasso. "Between – Tube Knotting" is only possible when hair strands exceed the critical length which is currently set at 16 in. (406 mm) in the U.S. [7].

The elongated tube concept was fully described by Barnett in a Triodyne Safety Alert in February 1998 [8]. Figure 2b from that publication was patented by Barnett on May 18, 1999 [9]. A utility patent [10] was granted to Nelson on November 9, 1999 for the same concept. The idea of an elongated tube for controlling hair entanglement was incorporated into Patent 6,230,337 B1 [11] by Barnett on May 15, 2001 and into Patent 6,738,994 B2 [12] by Barnett and Poczynok on May 25, 2004. The latter two patents address all of the entrapment hazards including hair entanglement. Note that the spherical profile illustrated in Fig. 2b mitigates body entrapment and evisceration hazards.

2. Cantilevered Grating Elements

Conventional grating elements, such as shown in Fig. 1, consist of horizontal prismatic beams supported at both ends. As indicated in Fig. 1a, no escape geometry is provided in the knotting mode. Furthermore, a single wrap around a straight element can entrap a strand of hair. On the other hand, cantilevered elements always provide escape geometry as illustrated in Fig. 4a. Indeed, the steep angle on the bottom surface of the element leads to shedding of the hair lasso. The effect of the tapered cantilever

Table I. Follicle Facts

1. Number of Hairs on an Average Human Head

   Brunette: 100,000 hairs
   Blonde: 120,000 to 150,000 hairs
   Red Head: 80,000 to 90,000 hairs

2. Hair Strength (Strand)

   Caucasian: 0.49N to 0.98N (0.11 lb_f to 0.22 lb_f)
   Asian: 0.98N (0.22 lb_f)
   Folicle Anchoring Strength: 0.69N ± 0.16 N (0.16 lb_f ± 0.036 lb_f)

3. Hair Diameter:

   - Micron: 1/1000 x mm; symbol µm
   - Europeans: 50-90 µm (0.0020 in. to 0.0035 in.)
   - Asians: 120 µm (0.0047 in.)

4. Failure Stress

   12 kg/mm^2 = 17.042 psi

5. Normal Hair Growth:

   1 cm/month (0.39 in./month) for up to 7 years

6. Strain:

   Elastic Limit Strain: 2%
   Fracture Strain (Dry): 25-30%
   Fracture Strain (Wet): 50%

7. Normal Hair Loss:

   50 to 100 hairs per day

8. Density (Covering Scalp)

   615 $hairs/cm^2$ (3,968 $hairs/in^2$) 20-30 yr. men
   435 $hairs/cm^2$ (2,806 $hairs/in^2$) 80 yr. men

9. Specific Gravity: 12

10. Implications:

    - 79.4 g_f hair strength: 2.8 oz_f/strand
    - A 176 lb_f (783 N) person can hang from a 1000 hairs
    - Hair on an average male can support 100 men (100,000 hairs)
    - 5 lb_f (22 N) is developed by only 29 hair strands

Ref: 3, 4, 5, 6

profile illustrated in Fig. 4b also precludes wrapping entanglement by the same shedding mechanism [13].

Figure 5 depicts various drain grating designs which incorporate only cantilevered elements. The domed profile illustrated in Fig. 5c makes it very difficult to fully cover the drain with the human body. This safety feature attenuates the development of a dangerous vacuum.

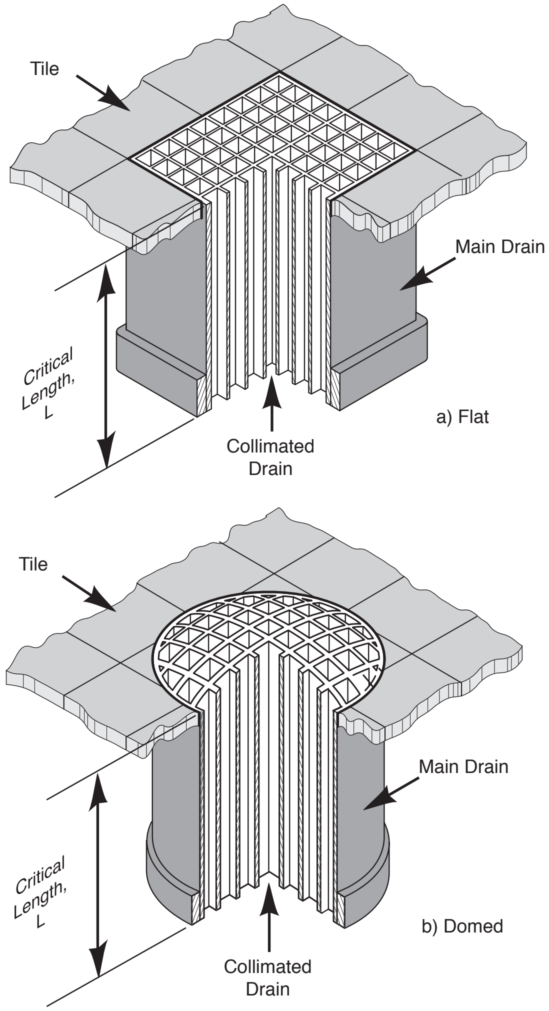


Figure 2. Collimated Grating

3. Cutting Edge Grating Elements

Disengagement of entangled hair from drain gratings is restricted by forces developed at the bottom surface of the grating elements. If these surfaces are fashioned into a cutting edge as shown in Fig. 6, hair strands may be severed to release a bather. The edges may incorporate some of the modern "stay sharp" profiles. Grating materials must be selected to sustain the integrity of the cutting edges in the face of harsh pool and hot tub chemistry. Furthermore, the grating apertures must be designed to preclude finger contact with the sharp edges at the bottom of the grating

4. Liftable Gratings

Unsecured gratings will not hold down a swimmer whose hair has become ensnared. Most conventional gratings are secured to pool surfaces or main drains using fastening systems that cannot be breached by human strength. Conceptually, it is a straight forward problem to design covers with detents or breakaway fasteners that will release them at modest force levels (see Fig. 7). As a practical

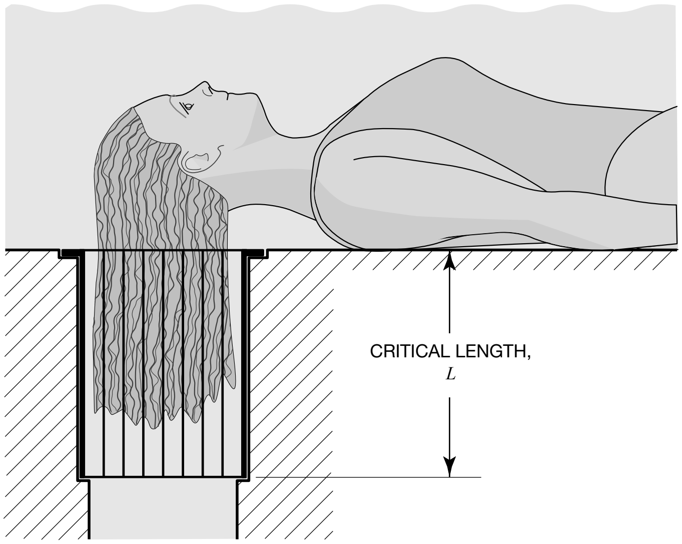


Figure 3. Critical Length

matter, there are many design constraints;

- Currently (2012) hair pull is limited to 5 lb_f (22 N).
- Hair entrapment may occur anywhere on the grate.
- Hair pull may be applied in any direction.
- Vandal resistance.
- UV and chemical resistant (10 year exposure).
- High reliability.
- The bather may defeat the concept by pushing against or standing on the grate while attempting to extricate their hair.
- The bather must be able to swim to the surface with the grating entangled in their hair.
- A missing grating may expose swimmers to tripping hazards, limb entrapment, body entrapment, and evisceration.

A safety grating was invented and marketed by Zars in January 2001 [14] which addressed many of the foregoing design constraints.

5. 1.5 Feet/Second Rule

By fiat the pool industry has adopted a rule-of-thumb masquerading as a theorem; "Hair entanglement will not occur in grate/covers when the water flow speed is kept below 1.5 ft/sec [457 mm/sec]." The most current national safety standard, ANSI/APSP-16 2011 [7], specifies that

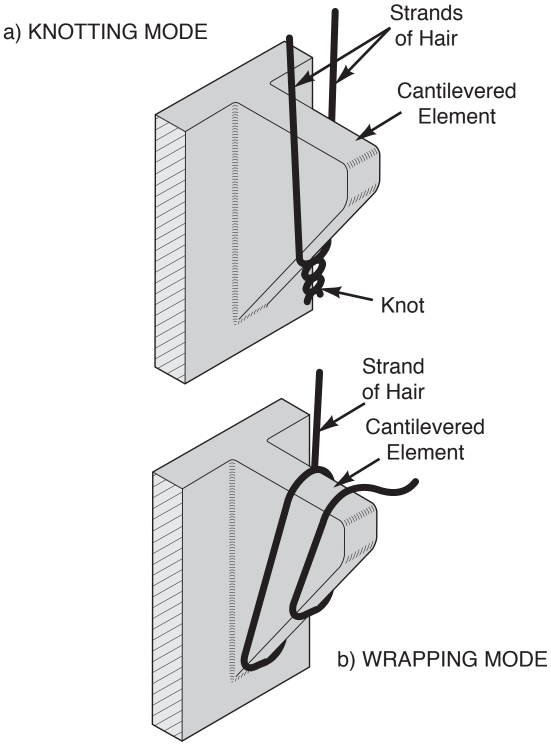


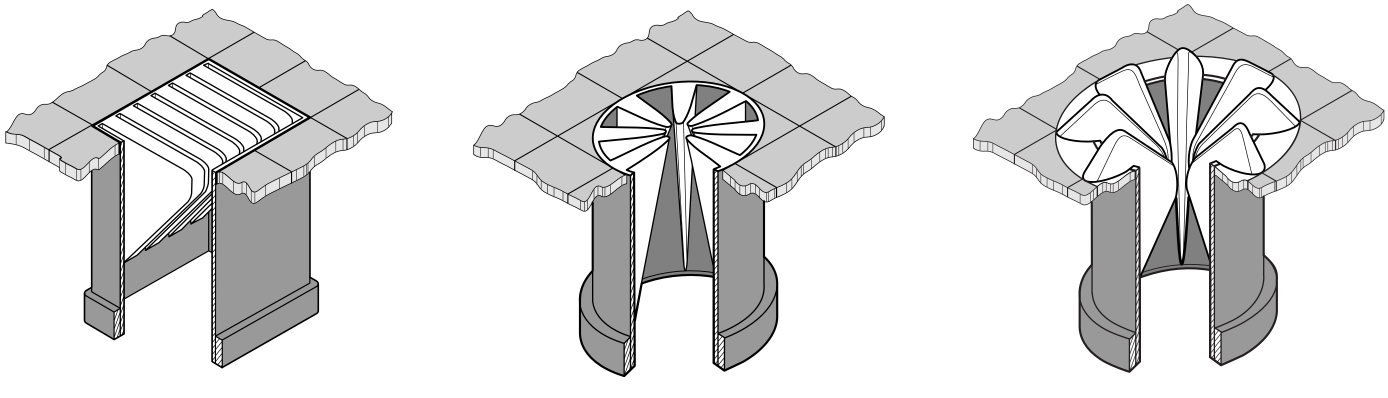
Figure 4. Cantilevered Grating Elements

> 4.1.4 Field Fabricated Outlets. For field fabricated outlets, hair entrapment tests are not required, but velocity through cover/grate openings shall not exceed 1.5 ft/sec (4.675 gpm/in.^{2}) [457 mm/sec (2.73 Lpm/cm^2)] of open area.

At the state level, New York's Codes, Rules and Regulations, 2007 states the following [15]:

> NYCRR §6-1.29 (2007) 9.6.2
>
> - 9.6.2 Grating. The main drain suction outlet shall be protected by anti-vortex covers <u>or</u> gratings.
> - The open area shall be large enough to assure the velocity does not exceed 1.5 feet per second through the grating. Openings in grates shall not be over one-half inch wide.
> - Gratings or drain covers shall not be removable without the use of tools.

In 2009, on behalf of Hayward Pool Products, Gary Ortiz and Robert Rung provided a comprehensive discussion of the 1.5 ft/sec rule in their presentation entitled "Prescriptive and Performance



(a) Rectangular Array (b) Circular Array (c) Domed Array

Figure 5. Cantilevered Grating Assemblies

Standards: Flow Ratings of Suction Outlet Fittings (Main Drains)" [16]. Among their observations are the following:

- Earliest citation found – 1958 "National Spa and Pool Institute (NSPI) Recommended Standard;"

"The outlet grate clear area shall be such that when the maximum flow of water is being pumped through the floor outlet, the velocity through the clear area of the grate shall not be greater than 1 1/2 ft. per second…."

- No known scientific or technical basis for the 1.5 ft/sec. rule.

- Hair tests performed by "Nationally Recognized Testing Laboratories" have demonstrated entrapment in accordance with ASME A112.19.8-2007 [17] at flow velocities as low as 1.3 ft/sec. This disproves the 1.5 ft/sec. rule.

- In some cases a flow velocity of 1.5 ft/sec. exceeds cover manufacturer's flow rating

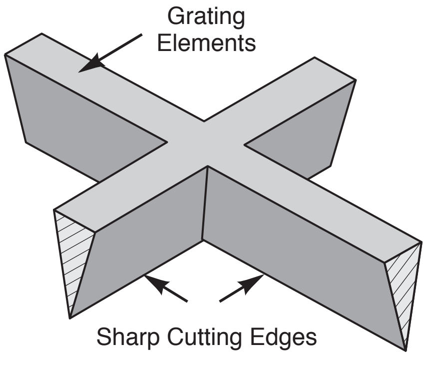


Figure 6. Intersecting Sharp Edged Grating Elements

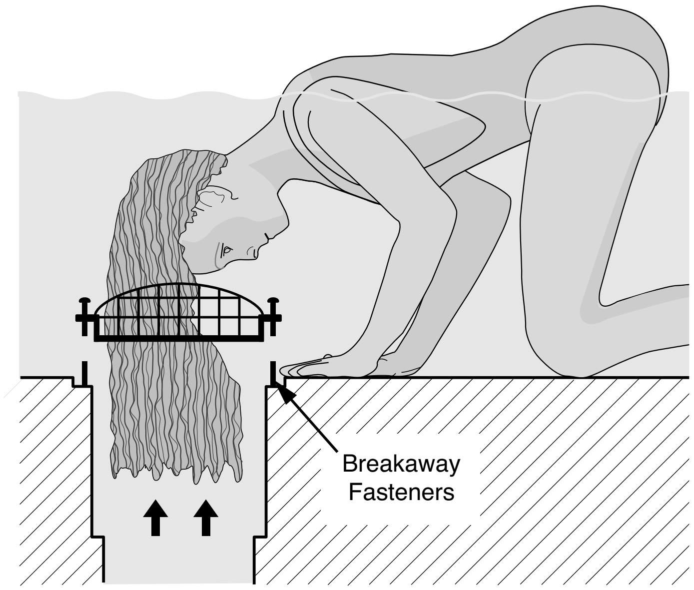


Figure 7. Breakaway Grating Concepts

6. Performance Criteria (Conventional Covers)

A statistical performance standard has been promulgated by standard ANSI/APSP-16 2011 that will decrease but not eliminate hair entrapment by entanglement. Under standardized conditions that tend to simulate hair entanglement scenarios, manufactured (as opposed to field fabricated) grates/covers are tested with respect to the forces required to extricate hair samples at various flow rates. The hair entrapment forces are generated by hydrodynamic drag on the hair strands, by friction resistance of strands rubbing against grating elements, and by interference caused by entanglement. Eighty percent of the flow rate associated with an extraction force of 5 lb_f (22 N) becomes the rating of the candidate grate/cover.

Several rules-of-thumb guide designers of conventional outlet covers;

- Small apertures reduce the entrainment of strands into the grate/cover elements. (Recall: 29 hair loops break at 5 lb_f (22 N))
- Friction resistance is lowered by passageways that are not circuitous.
- Small flow velocities decrease hydrodynamic drag.
- Small flow velocities reduce turbulence that entangles hair strands. (Recall: All known hair entrapment accidents have been caused by entanglement).

The hair entrapment standard contains a number of relevant passages;

- Hair Samples

  Type 1. A full head of natural, fine, straight, blond European, human hair with cuticle on hair stems, 16 in. (406 mm) in length, 5.5 oz ± 0.5 oz (155g ± 15g), and affixed to a Professional Wig Display Mannequin.

  Type 2. Natural, medium to fine, straight, light brown colored human hair weighing 2 oz ± 0.11 oz (57 g ± 3g) and having a length of 16 in. (406 mm) affixed to a 1 inch [25 mm] diameter wood dowel of length 12 in [305 mm]. Notes: No research has established that these hair samples are the most tangle-prone The full head sample always governs the flow rating.

- Five pounds is specified in the standard because it is speculated to be the pain threshold of children. Note: No research has been performed to establish a proper hair pull criterion.
- Before a force test is executed, the test dowel or test skull is manipulated for 60 sec. and then held against the outlet fitting for another 30 sec. to feed hair into the fitting.
- Ten tests are conducted with each sample type at various resistance levels approaching 5 lb_f (22 N).
- Hair exposure to a grating during testing is of the order of one hour. This may be compared to the typical exposure of swimmers to a given style grate/cover. For example, 250,000 covers that are "life rated" for seven years may be exposed to swimmers for a 180 hr/year. The outlet cover spends almost 1/3 of a billion hours in the company of swimmers.

B. Suction Entrapment Safeguards

Suction gives rise to body and limb entrapment and evisceration. Two approaches are used to mitigate these dangers; reduced suction and timely termination of suction. The basis suction entrapment problem is framed in Fig. 8a where a perfect pump creates a full vacuum (absolute pressure = zero). If a body seals the sump it is subjected to a hold-down pressure p where p = 14.7 psi + H (0.4333 psi/ft) [p= 101 kPa + H(9.801 kPa/m)] where H is the head of water above the sump in feet (meters for SI units). Hold-down forces of 400 to 600 lb_f (1780 to 2669 N) are developed in circular sumps and frames; two to three inch (51-76 mm) PVC pipes develop between 50 and 100 lb_f (222 and 445 N) respectively.

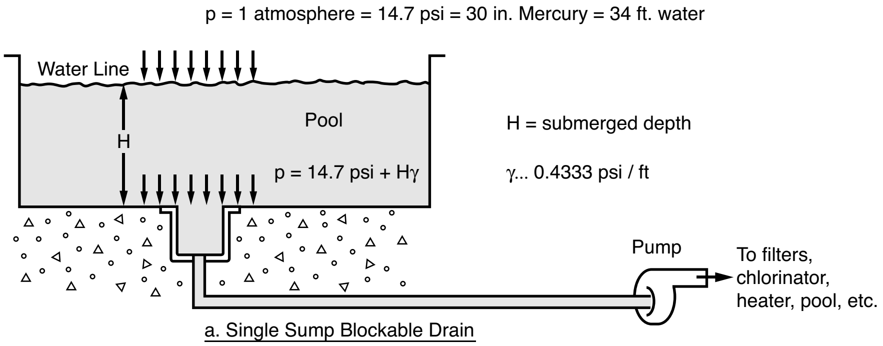
When an immersed body does not completely seal a sump or a suction outlet pipe, the water flowing past the body produces a pressure drag related to the pressure difference between the upstream and downstream surfaces. The water flow also creates a viscous shear called skin friction at the body/fluid boundaries. The total drag on a body or limb is sensitive to flow velocity which in turn depends on the pressure differential created by the pump.

For uncovered sumps Fig. 8 displays the current schemes for controlling the pressure differential. Because the dual drain, Fig. 8b, and the unblockable sump, Fig. 8c, allow water to continuously flow into the pump, a full vacuum cannot be developed. For the vent system, Fig. 8d, and the gravity feed system, Fig. 8e, the maximum vacuum cannot exceed $H\gamma$. When the water column in the vent line or collector tank is drawn down completely, air is entrained into the pump which loses its prime. With respect to the single blockable sump in Fig. 8a, drain covers are designed with unblockable ports for water to bypass partially obstructed covers. For suction outlet pipes, a scalloped end precludes sealing. For perfectly sealed suction outlet devices, even the smallest pumps, given sufficient time, can pull a near perfect vacuum. On the other hand, for a partially sealed sump, pipe, or drain cover the hold-down force increases with pump size and capability.

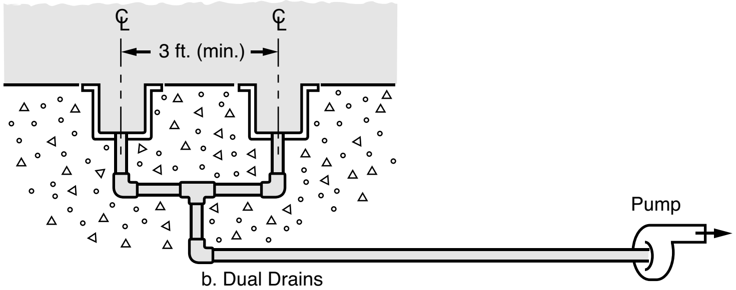
Another approach for protecting bathers from suction dangers is to shut down or reverse the motor/pump system whenever the vacuum level is too high. This is accomplished with so called Safety Vacuum Relief Systems (SVRS). These systems may monitor line pressure, flow, or electrical load. At harmful levels they introduce various combinations of protocols,

- Shut off pump motor
- Reverse flow direction
- Incapacitate pump (introduce air to kill the prime)
- Reduce pressure to atmospheric

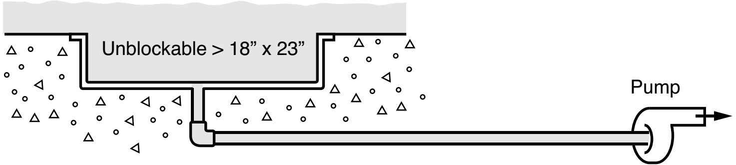
It is generally accepted that the SVRS devices do not act rapidly enough to prevent evisceration. On the other hand, some restrict the vacuum levels such that evisceration will not take place.



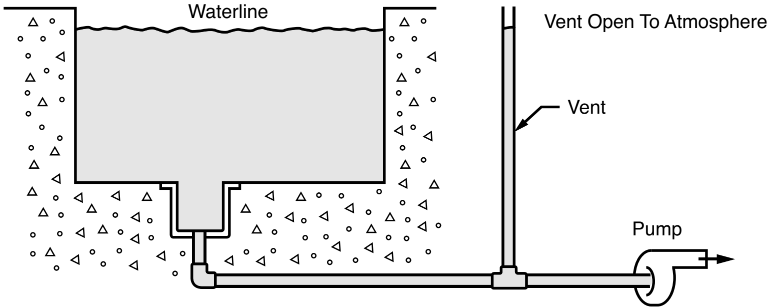
a. Single Sump Blockable Drain



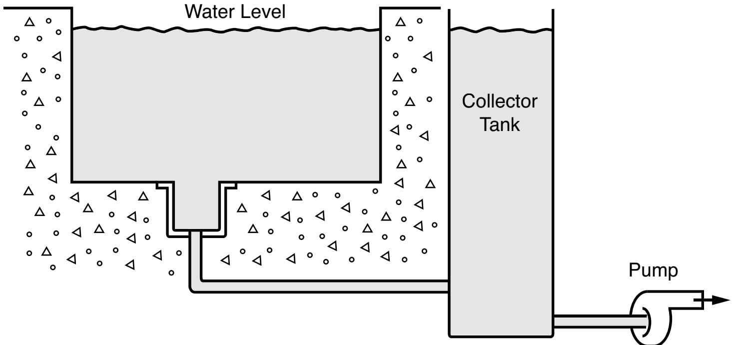
b. Dual Drains



c. Unblockable Drain and Sump



d. Vent System



e. Gravity Feed System

Figure 8. Entrapment Avoidance Systems

C. Mechanical Entrapment Safeguards

Suction outlet covers are strainers fashioned with one or more holes of various geometries. Ideally, they should allow maximum water flow with minimum throughput of solids such as fingers or apparel. The New Zealand Swimming Pool Design Standard NZS 4441:2008 requires that grate opening either preclude the passage of a 0.3 in. (8mm) diameter rod or allow the passage of a 1 in. (25 mm) diameter rod [18]. Infants cannot pass their fingers through an 8mm circular hole [19]. In the U.S. a finger probe designed by Underwriters Laboratories [20] provides the anti-finger entrapment criteria. Suction fittings shall not allow the passage of the 25mm diameter cylindrical end of the UL Articulated Probe. On the other end with the articulated finge, penetration is limited for small aperture opening and for large aperture openings.

ANTI-LIMB ENTRAPMENT INSERT

Manufactured or field built sumps, used in swimming pools are generally serviced by 1 1/2 to 3” (38 to 76 mm) PVC pipes oriented perpendicular or parallel to the bottom surface of the pool. The entrance to the pipe may be unencumbered, it may be cemented into a socket that is built into a manufactured sump, or it may be cemented into the socket end of a fitting that has a threaded pipe end that screws into a receptacle built into the sump. The associated passageways into the pipe all provide a limb entrapment hazard. The safety objective is to design a device that eliminates this hazard without significantly compromising the water flow. Further, the safety device must not introduce new dangers with respect to hair or finger entrapment

A. Anti-Limb Entrapment

Figure 9a shows a photograph of a candidate pipe insert for a 2” PVC pipe. This safety device incorporates scallops around its leading edge to prevent bathers from sealing the pipe or sump outlet and developing a hold-down force as high as 64 lb_f (O.D. x 14.7 psi) [285]. Using the test set-up illustrated in Fig. 10, the withdrawal forces associated with an adult anthropometric hand are presented in Table 2. Various blocking strategies were tested using a 2” PVC pipe insert with three scallops. Ten trials were conducted per strategy.

To set up each trial, the chosen blocking material was attached to a hanging load cell in the desired position by a flexible nylon cord and an eyebolt. The load cell was fastened to an Acme screw jack. During testing, the wheel of the jack was manipulated to raise and lower the set-up into and out of 18” of water. The 2 hp (1.5kW) STA-RITE pump was powered on prior to the lowering of the blockage item. Of the strategies tested, three included setting a blockage item above the pipe insert and one blocked the pipe without the insert. For control purposes, an aluminum contact disk was used to seal the pipe without the insert. All of the attachments were negatively buoyant, and their forces were deducted from data averages to produce corrected averages.

Turning to the results, observe from Table 2 that a flat body contact produces a withdrawal force of only 6.5 lb_f (29 N); a karate chop (edge of hand) across two scallop valleys can be withdrawn with 13.7 lb_f (60.9 N). A three year old, according to Reference 7, can develop a removal force of 15 lb_f (67 N). When an adult palms the 2” pipe insert, the withdrawal force is 20.7 lb_f (92.1 N) or 43.5% of the full blocking removal force. The smaller hand of a child cannot develop such high resisting forces.

Referring to Figs. 9c and 9d, the pipe remains a single hole (simply connected) with a cross-section that will not admit a 25mm diameter rod. When infants reduce their hands to the narrowest configuration as shown in Fig. 11, the smallest 2 – 3.5 year old cannot reach through a circular hole smaller than 1.5 in. (38.1mm) [19]. Clearly, the three fin insert cannot be breached. When the insert wall thickness is 1/16 in. (1.6 mm), the cross-sectional area is reduced by 18.94%.

B. Anti-Hair Snare Design

In general, hair can become ensnared on fins or scallops. The two worst case scenarios for these contingencies are depicted in Fig. 12a. Observe that at any point on the fin, the contact angle of a hair loop may be sufficiently shallow that the hair strands will slide. The contact angle that will guarantee such slipping is related to the coefficient of friction of the hair/fin couple. If the entire edge of the fin makes the same contact angle with all hair strands, the shape of the fin forms an iso-friction surface that will always shed hair.

The shape of the fin can be obtained using the polar coordinates shown in Fig. 12b. At any point (r,θ) the angle α is fixed, thus,

$$\frac{dr}{r d\theta} = \tan\alpha = constant \qquad \text{Eq. 1}$$

At the initial point on the fin

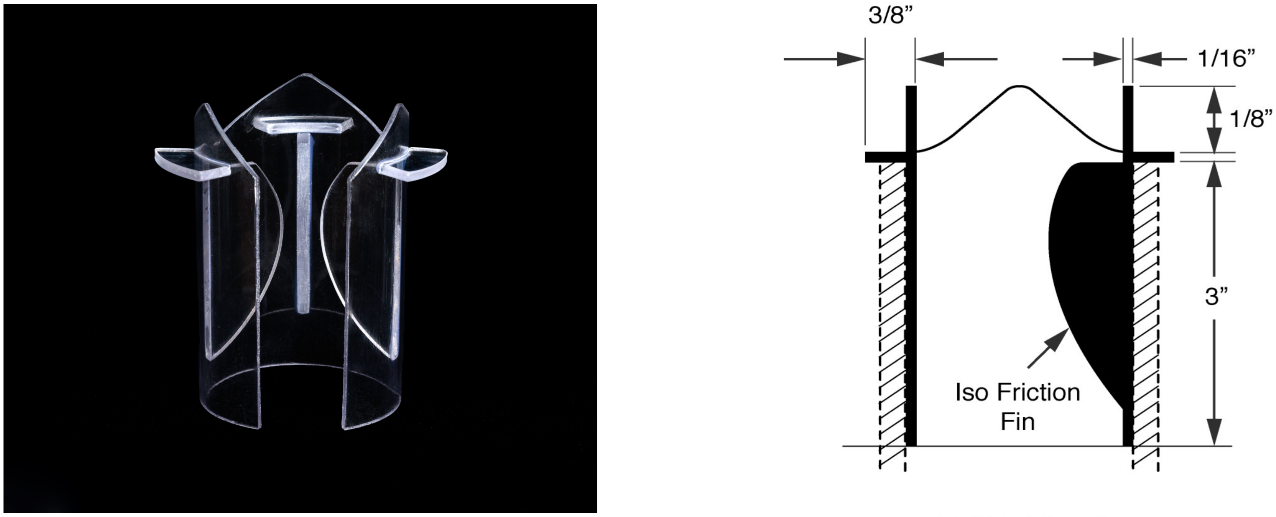
$$r = R_0 \;\; at \;\; \theta = \theta_0$$

Using separation of variables we obtain the equation defining the edge of the fin

$$r = R_0 e^{(\theta - \theta_0)\tan\alpha} \qquad \text{Eq. 2}$$

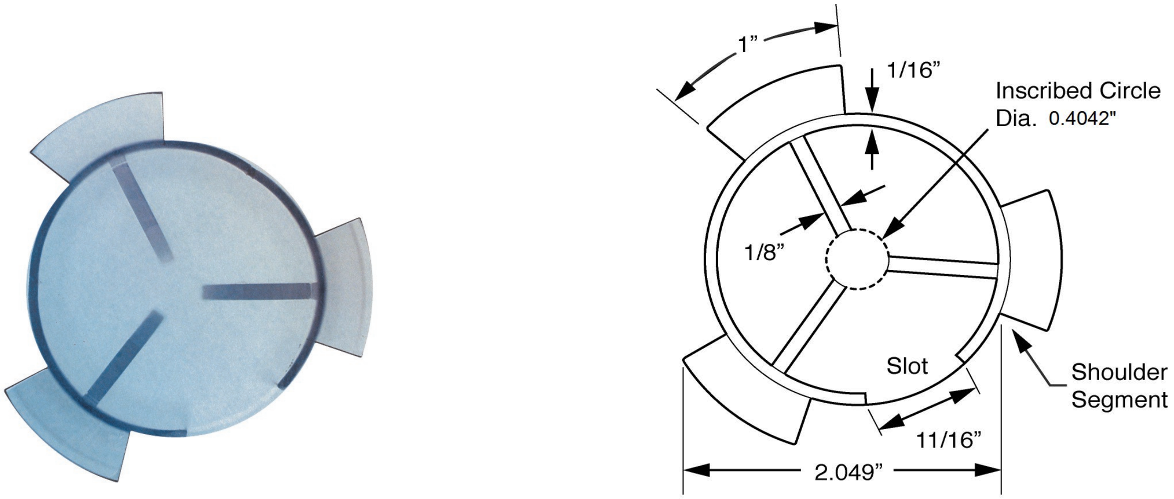
The length of the fin, x_{max}, is the radius associated with the largest possible θ, θ = π/2; thus,

$$\text{Fin Length} \quad x_{\max} \equiv r(\pi / 2)$$



a) Side Elevation - Photograph

b) Side Elevation



c) Top View - Inserted in 2" PVC Pipe - Photograph

d) Top View - Inserted in 2” PVC Pipe

Figure 9. Two Inch Anti-Limb Entrapment Insert - Three Scallops Three Fins

$$X_{\max} = R_0 e^{(\pi/2-\theta_0)\tan\alpha} \qquad \text{Eq. 3}$$

The width of the fin y at any point (r, θ) is given by y = r cos θ or

$$y = R_0 \cos\theta \; e^{(\theta-\theta_0)\tan\alpha} \qquad \text{Eq. 4}$$

The maximum fin width $y_{\max}$ is obtained in the usual way by setting the derivative of y equal to zero; thus,

$$\left.\frac{dy}{d\theta}\right|_{\theta=\theta_{opt}} = 0 \Rightarrow \tan\theta_{opt} = \tan\alpha \qquad \text{Eq. 5}$$

Hence,

$$\theta_{opt} = \tan^{-1}(\tan\alpha) \qquad \text{Eq. 6}$$

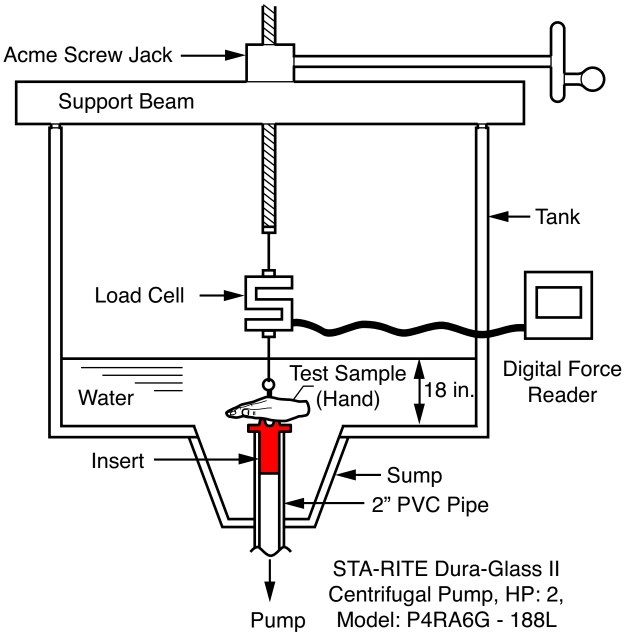


Figure 10. Schematic -Test Set-Up For Measuring Withdrawl Forces

Table II. Withdrawal Forces - Blocked 2" PVC Pipe Insert, Three Scallops and Three Fins

Number of Trials	Pipe Blocking Strategies			
	Fully Sealed Pipe	Flat Contact (Disk)	Palming the Pipe	Karate Chop-Block Two Scallop Valleys
1	49 lb$_f$	7 lb$_f$	22 lb$_f$	16 lb$_f$
2	49 lb$_f$	7 lb$_f$	21 lb$_f$	15 lb$_f$
3	49 lb$_f$	7 lb$_f$	23 lb$_f$	15 lb$_f$
4	49 lb$_f$	7 lb$_f$	21 lb$_f$	13 lb$_f$
5	49 lb$_f$	7 lb$_f$	23 lb$_f$	12 lb$_f$
6	49 lb$_f$	7 lb$_f$	20 lb$_f$	16 lb$_f$
7	49 lb$_f$	7 lb$_f$	20 lb$_f$	14 lb$_f$
8	49 lb$_f$	7 lb$_f$	21 lb$_f$	13 lb$_f$
9	49 lb$_f$	7 lb$_f$	21 lb$_f$	16 lb$_f$
10	49 lb$_f$	7 lb$_f$	21 lb$_f$	15 lb$_f$
Avg.	49 lb$_f$	7 lb$_f$	21.3 lb$_f$	14.5 lb$_f$
St'd Dev.	zero	zero	1.06 lb$_f$	1.43 lb$_f$
Buoy. Corr.	1.4 lb$_f$	0.5 lb$_f$	0.6 lb$_f$	0.8 lb$_f$
Corrected Average	47.6 lb$_f$ (212 N)	6.5 lb$_f$ (73 N)	20.7 lb$_f$ (92 N)	13.7 lb$_f$ (61 N)

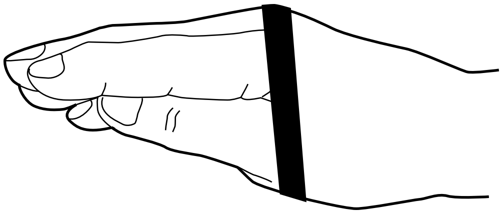
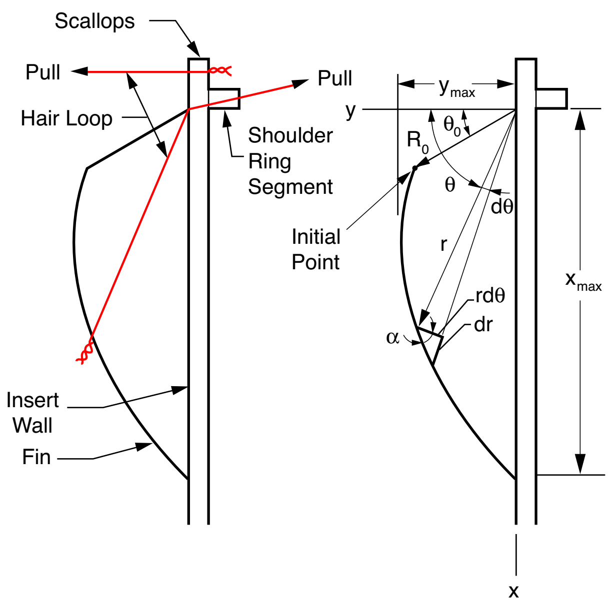


Figure 11. Minimum Hand Clearance



a. Snag Scenarios

b. Iso-Friction Fin

Figure 12. Anti-Hair Snare Geometry

$$y_{\max} = y(\theta_{opt}) = R_0 \cos[\tan^{-1}(\tan\alpha)] e^{[\tan^{-1}(\tan\alpha)-\theta_0]\tan\alpha} \qquad \text{Eq. 7}$$

The relationship between the constant angle α and hair friction can be obtained by examining a tangent to the fin curve, Fig. 13. The free body diagram of the hair/fin contact point shows that the external tangential component force F cos β is opposed by the friction force μ F sin β. The hair strand will slip if

$$\mu F \sin\beta < F \cos\beta \qquad \text{Eq. 8}$$

Hence,

$$\beta < \tan^{-1}(1/\mu) \ldots \textit{slip criterion} \qquad \text{Eq. 9}$$

In terms of the complimentary angle α,

$$\alpha > \pi/2 - \tan^{-1}(1/\mu) \ldots \textit{shedding criterion} \qquad \text{Eq. 10}$$

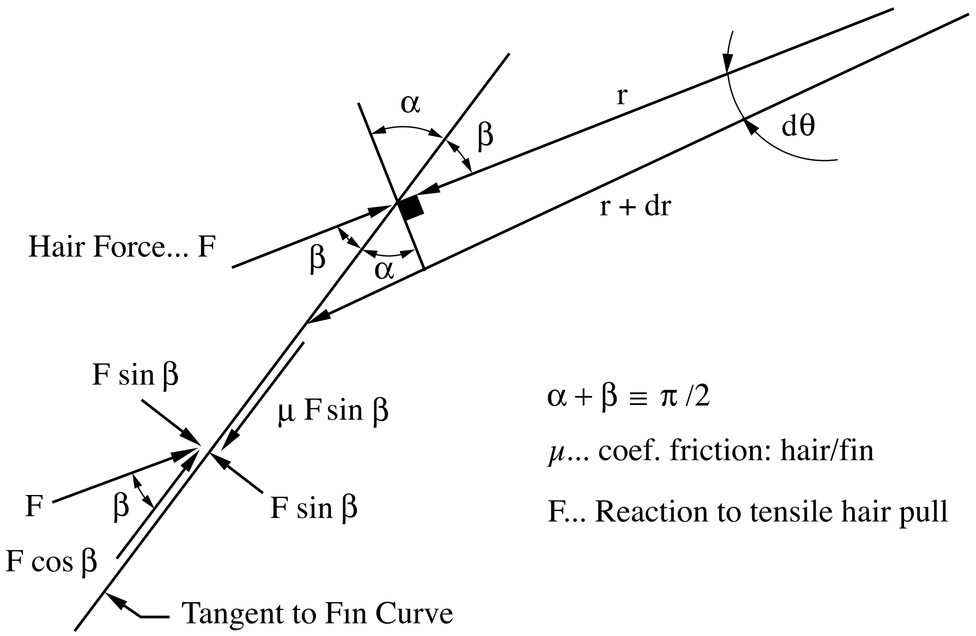


Figure 13. Friction Relationships

Example: $R_0 = 0.49$ in. (12 mm), $\theta_0 = 0$, $\mu = 1$

Shedding Angle: $\alpha = \pi / 2 - \tan^{-1}(1/\mu)$ Eq. 10

$$= \pi / 2 - \tan^{-1}(1/1)$$

$$\alpha = \pi / 4 ... (45^{\circ})$$

Iso-Friction Fin: $r = R_0 e^{(\theta - \theta_0)\tan\alpha}$ Eq. 2

$$= 0.49 \ e^{(\theta - 0)\tan \pi/4}$$

$$r = 0.49 e^{\theta}$$

Fin Length: $x_{\max} = R_0 e^{(\pi/2 - \theta_0)\tan\alpha}$ Eq. 3

$$= 0.49 \ e^{(\pi/2 - 0)\tan \pi/4}$$

$$= 0.49 \ e^{\pi/2} = 2.3571 \ in.$$

Max Fin Width:

$$y_{\max} = R_0 \cos[\tan^{-1}(1/\mu)] e^{[\tan^{-1}(\tan\alpha) - \theta_0]\tan\alpha}$$

$$= 0.49 \cos[\tan^{-1}(1/1)] e^{[\tan^{-1}(\tan \pi/4) - 0]\tan \pi/4}$$

$$= 0.49 \cos \ (\pi / 4) e^{[\pi/4](1)} = 0.7599 \ in.$$

Referring back to Fig. 12 a, a horizontal loop of hair is shown straddling the top of a scallop. As the hair is withdrawn, planar forces act on the scallop as depicted in Fig. 14. An upward component of the hair force urges the hair strand off of the scallop. In addition to shedding, the hair loop may be lifted off of the scallop or it may unravel.

C. Mechanical Entrapment Mitigation

The cross section of a typical pipe insert is shown in Fig. 9c and 9d. Roughly, the single (simply connected) hole is divided by symmetrically located fins that define an inscribed central circle surrounded by sectors. The sectors provide prismatic passageways that admit the articulated finger of the UL Articulated Probe without resistance. On the other hand, they preclude any penetration of the 1 in. (25mm) cylindrical end of the probe.

The central passageway to the phantom inscribed circle is like a funnel leading to a pinch point. A pinch point is defined as "Any location inside the assembled suction fitting where an aperture enlarges upstream and downstream." The maximum width of the fins, $y_{\max}$, was designed to prevent the second

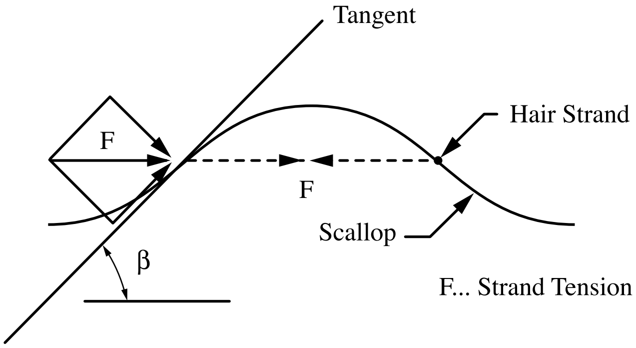


Figure 14. Free Body Diagram: Hair Strand On Scallop

articulated joint of the UL Probe from passing beyond the pinch point. Observe from the example that y_{max} = 0.7599 in. (19.30 mm) when R_0 = 0.49 in. (12 mm). The diameter of the inscribed circle for an insert that fits tightly inside a 2” PVC Schedule 40 pipe (I.D. = 2.049 in. [52.04 mm]) with a wall thickness of 1/16 in.(1.6 mm) is given by,

Inscribed Circle Diameter = I.D. – 2 (Wall Thickness – 2 y_{max}
= 2.049 – 2 (1/16) – 2 (0.7599)
= 0.4042 in. (10.27 mm)

The smaller dimension of the second joint of the UL Probe is 0.460 in. (11.7 mm); therefore, there is no penetration as required by ANSI/APSP-16 2011 [7].

OBSERVATIONS

A. The proposed retrofit insert is designed to be cemented into a specific size pipe. The cement may be placed on the cylindrical surface of the insert and/or on the bottom surface of the shoulder segments shown in Figs. 9 and 12. The cement only resists human efforts to remove the insert; otherwise, very small forces interact with the insert. Removal of a cemented insert is easier if only the shoulder segments are bonded to the outlet.

B. The insert is designed to fit not only a specific size pipe; but, all of its fittings and sump terminations as well. Unfortunately, the fittings are often smaller than the pipe I.D. To accommodate this situation with a single size insert, a slot has been incorporated into the insert sidewall as shown in Figs. 9a and 9d. In the case of the 2” PVC pipe insert, squeezing the walls allows it to fit both the original pipe, I.D. = 2.049 in. (52.04 mm), and the male/female adapter with an I.D. = 1.900 in. (48.26 mm).

C. The sidewall slot has an additional property that greatly facilitates the cementing process. The slot allows an oversize insert diameter that spring loads itself against the I.D. of the pipe or pipe fitting. This holds the insert in position while the cement is setting.

D. The anti-limb entrapment insert prevents limb entrapment without any significant compromise to the flow.

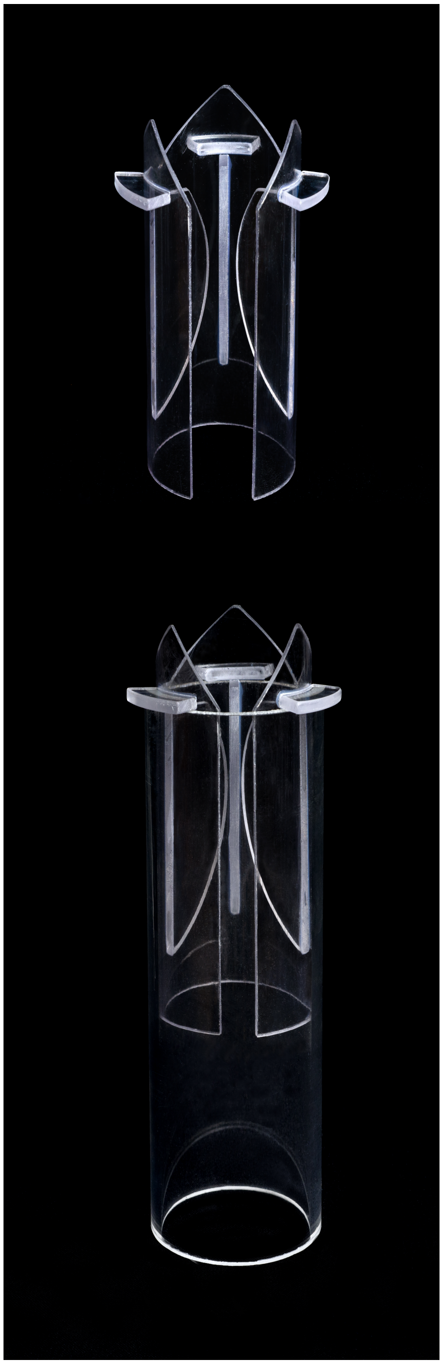
E. The iso-friction profile of the fins causes hair loops to shed. Even a rubber band is immediately cast off.

F. The scallops provide an anti-hair snare geometry that quickly sheds both hair loops and rubber bands. Their cantilever construction always provides escape geometry for hair strands.

G. The scallops prevent sealing of the outlet pipe. Children will not be exposed to forces greater than 15 lb_f (67 N). Sealing forces can range from 50 to 100 lb_f (222 to 445 N) using a 2 inch to 3 inch PVC pipe.

H. Mechanical and finger entrapment are mitigated by the prismatic sectors formed by the fins. The inscribed central circle defined by the fins for a pinch point that passes the UL Probe test.

I. Figures 9a and 15 are photographs of the insert before and after insertion into a plastic pipe.



15) Side Elevation After Insertion Into Plastic Pipe - Photograph

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