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Anti-Hair Entanglement

Cantilevered Grating Elements

by Peter J. Poczynok,* Adam K. Dybek,** and Ralph L. Barnett ***

I. INTRODUCTION

Hair entrapment is a failure mode shared by swimming pools, wading pools, spas, hot tubs, and whirlpool bathtub appliances. When hair is entrained in the discharge flow through a suction fitting or drain, it's withdrawal will generally be resisted by gravity, drag, friction, buoyancy and interference. Large withdrawal forces obviously lead to a horrifying safety problem. In an attempt to manage the magnitude of these forces, the pool industry introduced their first standard relative to hair entrapment on November 3, 1987; ASME/ANSI A112.19.8M - 1987, Suction Fittings for Use in Swimming Pools, Wading Pools, Spas, Hot Tubs, and Whirlpool Bathtub Appliances.

In section 5.2 of this standard, a test protocol is outlined for measuring the withdrawal force required to extricate a 16" long strand of hair that has previously been fed into a test suction fitting. Figure 1 depicts the test status at the last stage where the pull force is measured. Quoting paragraph 5.2(j) from the standard,

"With the pump still operating, test for the amount of pull necessary to free the hair from the fitting. Measure the force of entanglement by pulling the scale and dowel vertically. Repeat the test ten times."

The performance requirement for an acceptable fitting is given in paragraph 5.3;

"A pull of 5 lb. or greater on any one of the ten tests, including the weight of the saturated test apparatus, shall be deemed a failure..."

There are several implications of the ANSI standard that are worth noting:

- The standard assumes that a force level exists that will free hair from a fitting. It is called the "force of entanglement." Unfortunately, the ANSI standard is incorrect. Two modes of entanglement are shown in Fig. 2. If the knot and the wrap are self-locking (the more you pull the tighter they become) one cannot escape the entanglement without fracturing the hair strands.
- The likelihood of achieving a self-locking type of entanglement cannot be explored with a sample size of ten. Furthermore, the test protocol specifies hair samples of medium to fine straight hair which is kept tangle-free by periodic brushing.
- When self-locking modes of entrapment are not present, the force of entanglement is installation specific. It will depend on the precise piping geometry, the orientation of the suction fitting, the exact materials of construction, etc. The latest standard for Whirlpool Bathtub Appliances, ASME A112.19.7M - 1995, solves this simulation dilemma by specifying that the tests be conducted using an exemplar whirlpool bathtub appliance installed per the manufacturer's instructions.
- The 1987 ANSI standard does not recognize self-locking types of entanglement. Nevertheless, 30 cases were reported to the Consumer Products Safety Commission from January 1990 through May 1996 where hair entanglement occurred because of tangling rather than strong suction forces [Ref. 1]. An additional four cases of entanglement are reported by the CPSC from April, 1981 through February, 1985.

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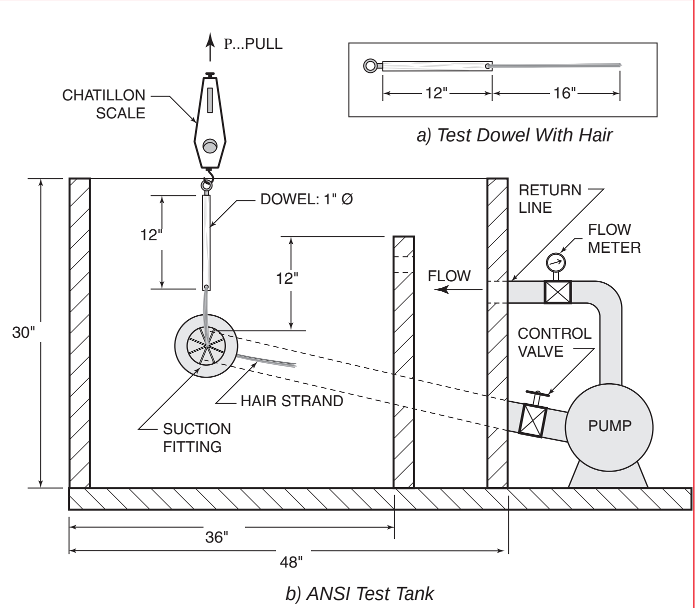


Figure 1 – Test Set-up for Measuring ANSI Force of Entanglement

II. CANTILEVERED GRATING ELEMENTS

A number of concepts were proposed in [Ref. 2] which address entanglement modes that involve self-locking knots and wraps. Referring to Fig. 3, the cantilevered elements shown offer an escape geometry for the knotting mode and the wrapping mode that is not available for the beam elements illustrated in Fig. 2 that are supported at both ends. Furthermore, the steep angle on the bottom of the cantilevered elements will shed hair lassos for a wide range of hair escape angles that will be experimentally determined. In particular, this paper focuses on the rectangular and the circular gratings shown in Fig. 4. Test protocols are described in the Appendix.

A. Rectangular Grating: Cantilevered Elements

Assume that the tangled hair of a bather envelopes a single cantilevered element in the rectangular grating shown in Fig. 4a. This situation is depicted in Fig. 5 where the victim exerts an upward escape force at an angle $\varnothing$ measured from the horizontal. The bottom slope of the element is characterized by the shedding angle α. At incipient sliding, the laws of statics provide the following sliding criterion:

$$\tan(\varnothing - \alpha) > \mu \text{... sliding criterion} \qquad (1)$$

where $\varnothing > \alpha$ and μ is the coefficient of friction of submerged hair against the cantilevered elements. Equation 1 may be used to determine μ experimentally; it may also be used to define the critical escape angle $\varnothing_c$ when μ is known:

$$\varnothing_c = \alpha + \tan^{-1}\mu \qquad (2)$$

At escape angles $\varnothing$ that are greater than the critical angle $\varnothing_c$, the bather's hair will shed the cantilevered element at any force level. When $\varnothing$ is less than or equal to $\varnothing_c$, a self-locking condition is achieved that will not release the hair regardless of the magnitude of the escape force.

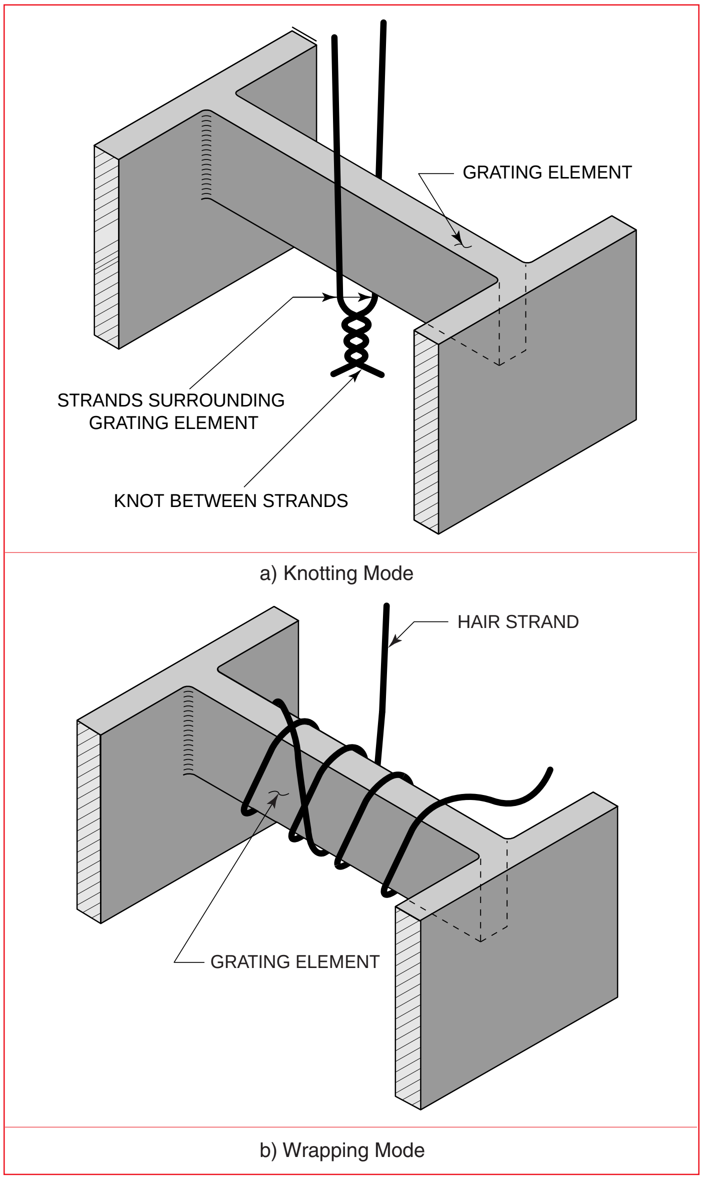
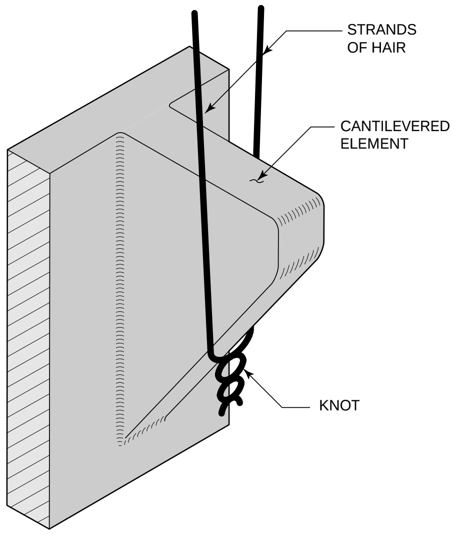


Figure 2 – Hair Entanglement Modes

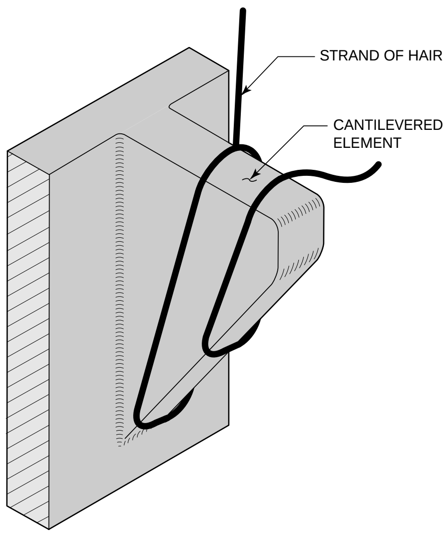
Table I records the measured values of $\varnothing_c$ for three escape scenarios. The test model was constructed with a shedding angle $\alpha = 45°$. For the loading condition shown in the first column, $\varnothing_c$ was measured at 57.7˚. This angle was used in Equation 1 to derive the hair friction $\mu = 0.225$ as shown in the first column of Table I. The critical angle $\varnothing_c$ associated with other shedding angles α can be calculated using Equation 2. For example, when $\alpha = 30˚$, $\varnothing_c$ is calculated to be 42.7˚.

B. Circular Grating: Cantilevered Elements

As illustrated in Table II, the radial deployment of double tapered cantilevered elements makes it possible to produce a circular array of elements with constant width openings. Two escape scenarios are examined experimentally with the view toward establishing the critical escape angle. Values of $\varnothing_c$ are displayed in Table II. The second column of this table shows an entanglement scheme where $\varnothing_c \approx$ zero, i.e., shedding automatically proceeds under any force in any



a) Knotting Mode



b) Wrapping Mode

Figure 3 – Cantilevered Grating Elements

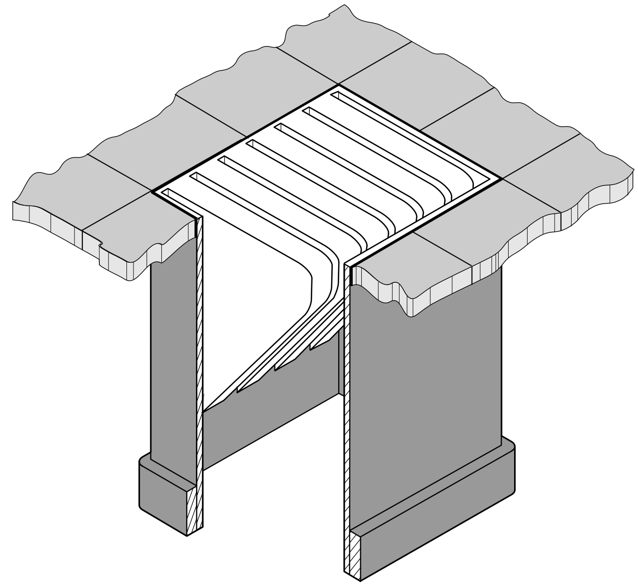
direction. The first column of Table II provides the worst case scenario; $\varnothing_c = 24.5°$. All angles α larger than 45˚ provide automatic shedding.

III. OBSERVATIONS

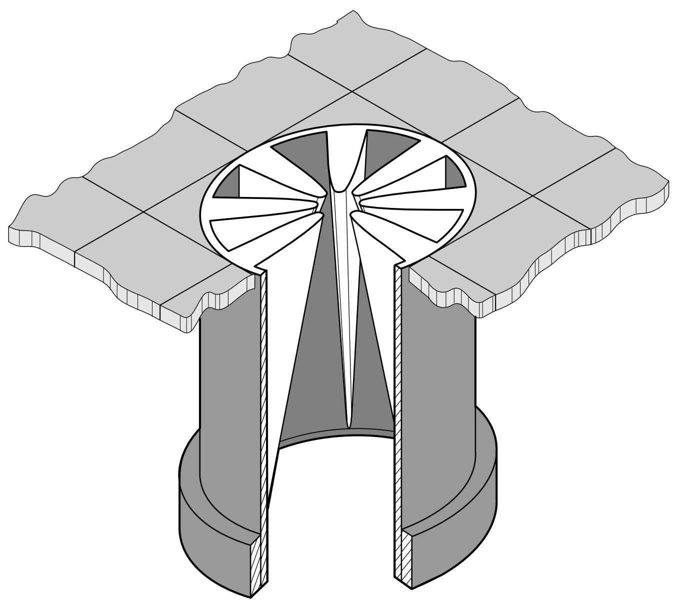
1. The ASME/ANSI A112.19.8 M - 1987 pool standard ignores self-locking types of hair entanglement that cannot be forced loose.

2. The cantilevered grating element provides two release concepts for self-locking hair loops and wraps; an escape geometry and self-shedding.

3. Escaping entanglement is essentially a vertical activity. Large sideways forces cannot be developed under water, whereas huge vertical forces are generated by pushing against the bottom of a pool with arms and/or legs.



a) Rectangular Drain



b) Circular Drain

Figure 4 – Cantilevered Grating Concepts

4. Cantilevered grating elements always allow vertical escape modes with self-shedding.

5. Manual extraction of a bather's hair from cantilevered grating elements is very similar to removing a comb from hair when tangles become too tenacious. Furthermore, manual extraction may be taught.

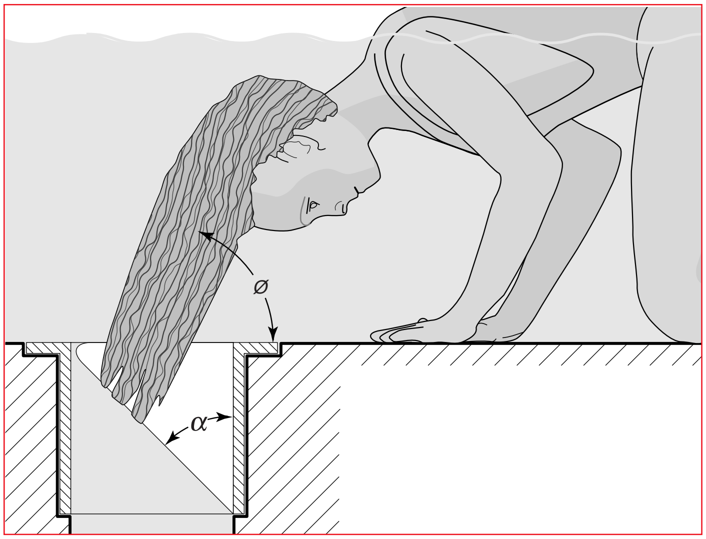


Figure 5 Escape Scenario

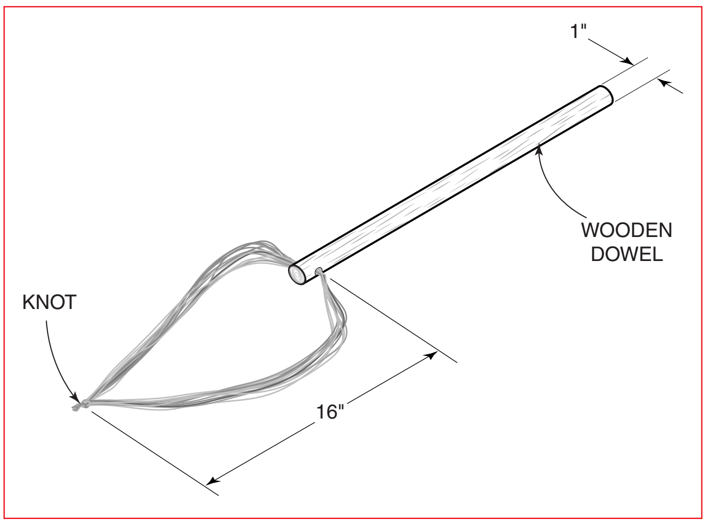
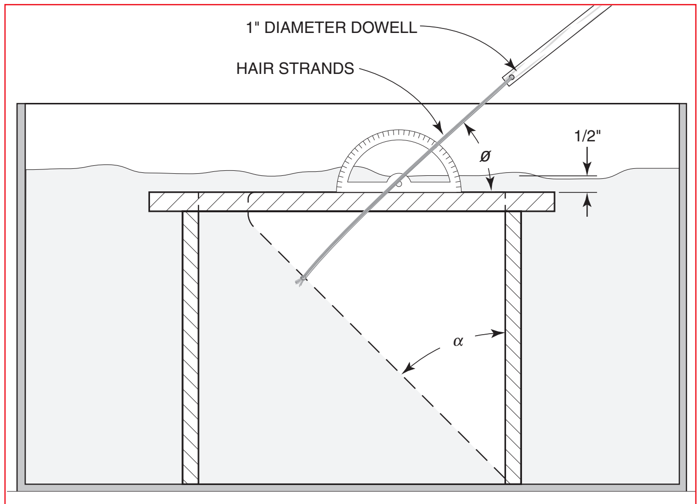
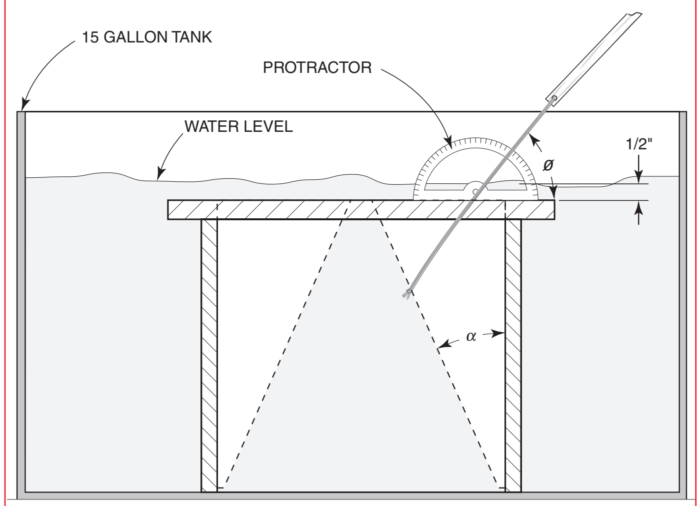


Figure 6 Test Apparatus



a) Test Procedure and Set-up For Rectangular Grating



b) Test Procedure and Set-up For Circular Grating

Figure 7 Test Procedure and Set-up

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1. "Guidelines for Entrapment Hazards: Making Pools and Spas Safer", *U.S. Consumer Product Safety Commission*, Publication No. 363, 009801, Washington D.C., Pg. 3.
2. Barnett, Ralph L., "Anti-Hair Entanglement," *Triodyne Safety Alert*, Vol. 1, No. 1, Feb. 1998.

ADDITIONAL REFERENCES

1. "Suction Fittings for Use in Swimming Pools, Wading Pools, Spas, Hot Tubs, and Whirlpool Bathtub Appliances," *ASME/ANSI A112.19.8M-1987*, American Society of Mechanical Engineers, New York, Dec. 1987.
2. "Whirlpool Bathtub Appliances," *ASME A112.19.7.M-1995*, American Society of Mechanical Engineers, New York, Dec. 1995.

APPENDIX

I. Specification of Materials and Geometry

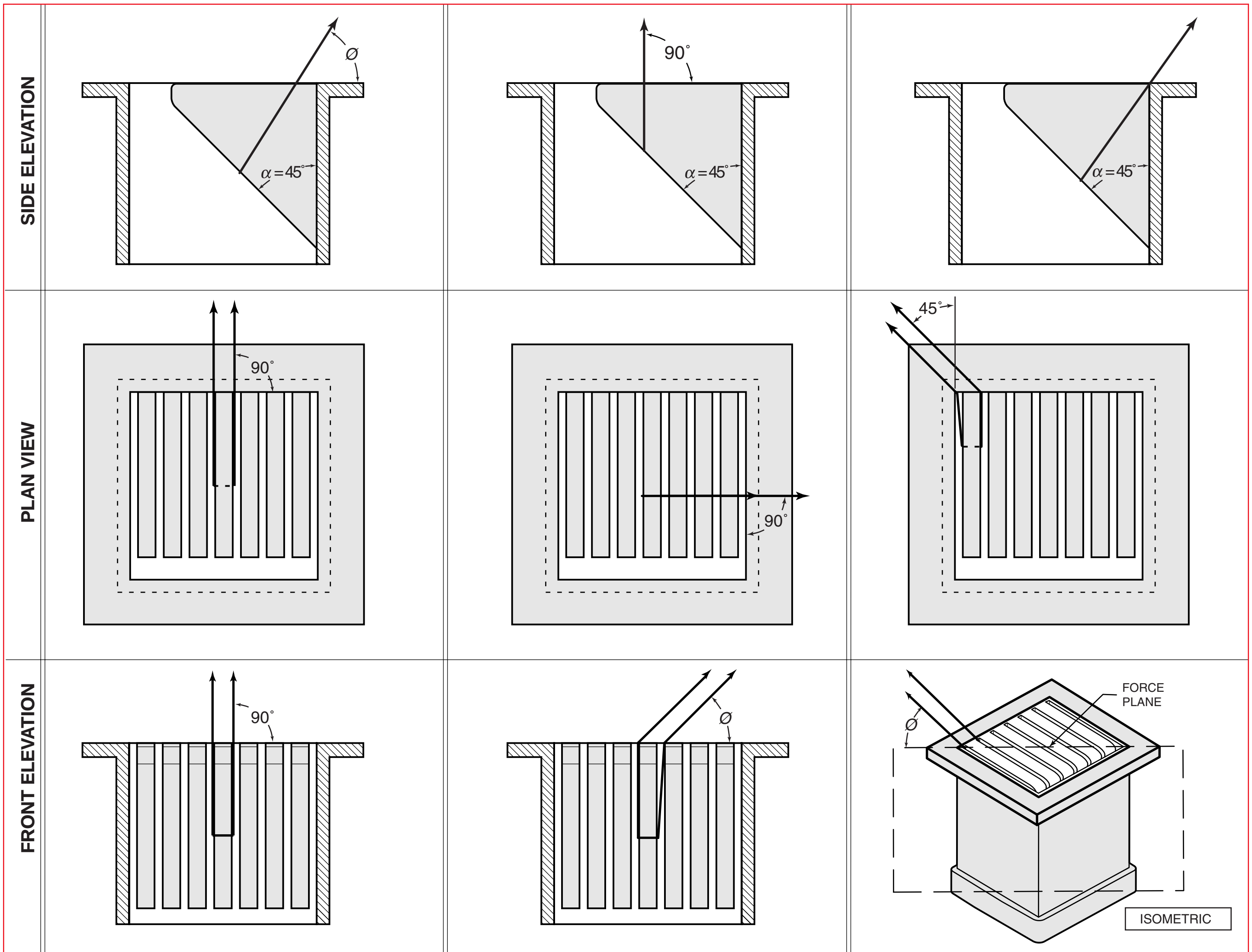
A. Rectangular Drain Model. The rectangular drain prototype was fabricated using 1/2 inch cast acrylic plastic. All sharp corners were rounded off and sanded to a smooth surface. Parts were joined using an acrylic adhesive (Fig. 4a).

B. Circular Drain Model. The outer wall of the circular drain prototype was fabricated using 1/4 inch thick cast acrylic tubing. The individual cantilevers were constructed out of Ren-Shape 440 low density foam and sanded with very fine sandpaper (Fig. 4b). They were affixed to the wall using brass screws.

II. Test Protocol

A. Hair. 40 g of natural, medium to fine, straight, dark colored hair, 406 mm (16 in.) in length was tied into a self-locking knot at one end and affixed to a 25 mm (1 in.) diameter wooden dowel at the opposite end. The hair was affixed to the dowel such that the knot was equidistant to each end as illustrated in Fig. 6.

Table I Critical Escape Angles - Rectangular Grating



α = 45° $\varnothing_c$ = 57.7° (measured) μ = 0.225 (derived)	α = 45° $\varnothing_c$ = 0° (measured)	α = 45° $\varnothing_c$ = 35.3° (measured)
α = 30° $\varnothing_c$ = 42.7° (calculated)		

B. Number of Tests. Testing was done on two cantilevered grating concepts, rectangular and circular drains (Fig. 4). Each grating concept was tested for three escape scenarios of ten trials each.

C. Test Procedure.

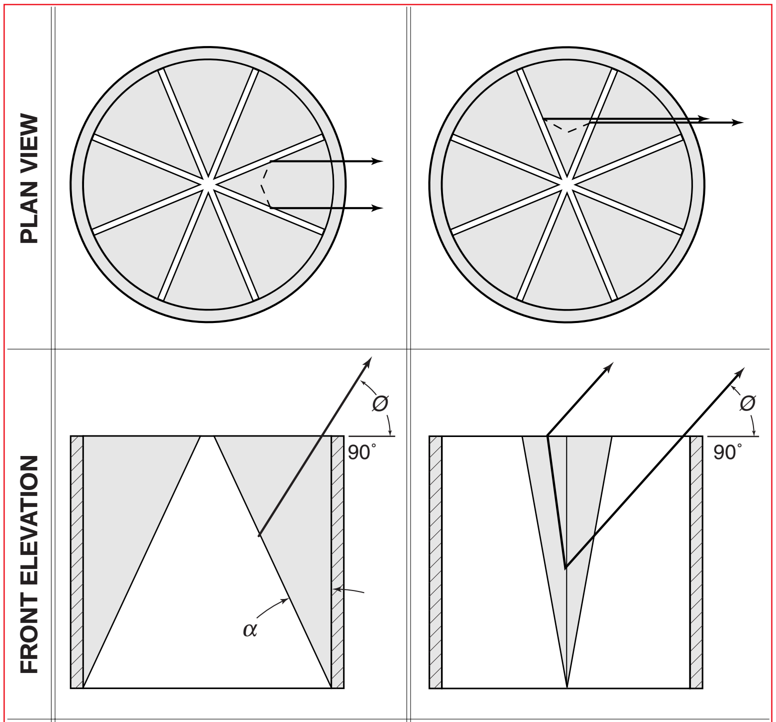
1) A 15 gallon translucent tank was filled with room temperature (72° F) water such that the submerged cantilevered grating fixture was no more than 1/2 inch below the water level (Fig. 7a and 7b).

2) The hair and grating were saturated for a minimum of 2 minutes in testing water. After being saturated, the knotted end of the hair was placed around a cantilevered grating in a wrapping fashion consistent with each scenario tested, which is described thoroughly in section D. The angle of tension was minimized to promote entrapment. A protractor was placed on the horizontal surface of the grating and was utilized for angle measurements.

3) While exerting tension, the hair's angle ø measured from the horizontal was slowly increased to a point of release. At this point the angle ø was measured and recorded. Different types and locations of hair release were examined depending on the scenario and are discussed in detail for each cantilevered grating design in section D.

4) Steps 1 through 3 were repeated for each scenario in conjunction with section D for each specific case of escape.

Table II Measured Critical Escape Angles - Circular Grating



	Column #1	Column #2
	$\varnothing_c = 24.5^\circ$ $\alpha = 25^\circ$	$\varnothing_c \approx$ zero $\alpha = 25^\circ$

D. Release Types and Locations

Critical Escape Angles - Rectangular Grating

Scenario #1 - Column #1 of Table I

The knotted end of the hair is wrapped around the center cantilever and tension is exerted in a plane perpendicular to the cantilever's support wall. A force is initially applied at a small angle ø, with ø increasing until slippage occurs at $ø = ø_c$.

Scenario #2 - Column #2 of Table I

The knotted end of the hair is wrapped around the center cantilever and tension is exerted in a plane parallel to the cantilever's support wall. Referring to Table 1, the force is exerted in the direction defined by the angle ø. A small ø is increased until slipping takes place.

Scenario #3 - Column #3 of Table I

The knotted end of the hair is wrapped around the outer cantilever. A vertical force plane is established at a 45˚ angle to the drain side walls. A force is applied to the hair in the force plane at a small angle ø measured from the horizontal. ø is increased until slippage occurs at $ø = ø_c$.

Critical Escape Angles - Circular Grating

Scenario #1 - Column #1 of Table II

The knotted end of the hair is wrapped around a cantilever as shown in Table II and tension is applied in a direction toward the support wall and at an angle ø from the horizontal. ø is increased until slippage occurs at $ø = ø_c$.

Scenario #2 - Column #2 of Table II

The knotted end of the hair is wrapped around a cantilever and tension is exerted perpendicular to its vertical center plane and at an angle ø from the horizontal. A small ø is increased until slipping takes place.

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