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Conceptual Breakaway Swimming Pool Design For Coastal Areas

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ABSTRACT

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Swimming pools have become an essential attachment to most habitable coastal construction such as hotels, condominiums and single family residences. A large swimming pool type structure may obstruct the free flow of floodwater and increase the turbulence. This in turn may increase the scour potential and the wave/debris action on the building and foundation. A conceptual breakaway concrete swimming pool design is described herein. It is demonstrated that this pool will withstand everyday factored water/soil loading, but will collapse and break away under extreme wave action, thereby minimizing the detrimental effects of a solid pool.

ADDITIONAL INDEX WORDS: *Breakaway, swimming pool, scour, coastal construction.*

INTRODUCTION

The State of Florida has an extensive tidal shoreline. In recent years, this shoreline has been subjected to rapid development and construction due to a massive population influx. Swimming pools have become essential accessories attached to habitable coastal construction in terms of property value and the tourism industry in Florida. Virtually all of these pools are situated seaward of the habitable structures.

The Federal Emergency Management Agency (FEMA) oversees the construction of all structures (including pools) in the Coastal High Area Hazard Areas (V-zones) in order for these structures to be insured under the National Flood Insurance Program (NFIP). These requirements are contained in 44CFR Section 60.3 which states that all new construction and substantial improvements in Zones V1–V30, VE, and V shall have the area below the lowest floor level either free of obstruction, or constructed with non-supporting breakaway walls or similar structures.

If a swimming pool is placed below the level of a coastal building, but above natural grade, it may behave as an obstruction to the free flow of floodwater. A large object, such as a swimming pool, placed above the natural grade may increase the turbulence of the floodwater, resulting in an increase in the scour potential under and around pools, and around the pile supports. The extra turbulence created by the presence of the pool structure may also cause increased wave and debris action on the elevated portion of the building or other adjacent structures and foundations.

Coastal swimming pools should withstand everyday water and soil loads with an adequate factor of safety, but should collapse and break away in case of a 100-year flood event without acting as an obstruction to the flow of floodwater. If pools located below the base flood elevation in V-zones were designed to disintegrate and not cause water build-up or act as debris on upland structures or their piles during a specified storm, the detrimental effect on the beach/dune system or adjacent structures would be drastically reduced. Swimming pools designed to be frangible will help preserve the integrity of the beach/dune system and other structures in extreme flooding conditions.

The effect of a swimming pool type massive structure on coastal topography during a storm has been apparent over the years; however, documentation of this effect has started only recently. No basic research has been performed on understanding this effect, or on ways to minimize such costly damage.

DATA ON EXISTING POOLS

The Florida Department of Environmental Protection (FDEP) is responsible for permitting of coastal construction in the coastal zone. Permitting files from FDEP were searched to investigate common scenarios for swimming pools on the Florida coast. Important variables that were recorded include: the shape, dimensions, orientation to the Coastal Construction Control Line (CCCL), location relative to CCCL, maximum depth, 100 year storm surge, distance above or below the sand level and material used. Pool data for 23 swimming pools located in coastal regions of Florida are presented in Table 1. Data was gathered from the FDEP permitting files for the last four years.

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Table 1. *Florida coastal swimming pool characteristics.*

Pool #	Shape	Dimensions	Orientation to CCCL	Loc. Rel. to CCCL	Max. Depth	100 Year Storm Surge (NGVD)	Bottom Elev. (NVGD)	Material
1	Rect.	20′ × 40′	10′//	<47′ seaward	6′	13.2′		shotcrete
2	Rect.	18′ × 26′	18′//	<158′	6′	12.8′	5′	shotcrete
3	Rect.	17′ × 42.5′	42.5′//	<162.5′	6′		10.5′	conc. shell on grade
4	Rect.	18′ × 38′	38′//	<9′	5′	12.3′	13′	conc. shell and stem wall
5	Rect.	20′ × 40′	40′//	<77′	8′		4.5′	reinf. gunite shell
6	Rect.	20′ × 60′	60′//	<64′	8′	12.6′	0.0′	6″ conc. shell
7	Rect.	20′ × 32′	20′//	<7′	6′	11.3′	10.4′	5″ reinf. conc. shell
8	Rect.	15′ × 40′	40′//	<125′	6′	11.4′	16′	conc. shell
9	Rect.	18′ × 38′	38′//	<183′	6′	12.2′	<1.0′	6″ reinf. conc. shell
10	Kidney	14′ × 28′	28′//	<340′	6′	14.8′	0.6′	4–6″ conc. shell
11	Rect.	14′ × 28′	14′//	<9′	5.5′	14.7′	1.2′	6″ conc. shell
12	Rect.	10′ × 28′	28′//	<300′	4′	12.2′	5.8′	manufact. fiberglass
13	Rect.	17′ × 29′	29′//	<75′	6′	12.5′	4.7′	8″ conc. shell
14	2 Rect.	12′–18′ × 24	24′//	<94′	5.5′	13.1′		5″ conc. shell
15	Kidney	20′ × 31′	31′//	<132′			12′	conc. shell
16	Rect.	19′ × 41′	19′//	<138′	6′	13.1′	6.5′	6″ conc. slab shell
17	Odd	35′ × 44′	35′//	<216′	8′	12.3′	2.0′	conc. shell
18	Rect.	18′ × 40′	8′//	<60′	4.5′		6.0′	conc. shell
19	Round	16′ × 20′	16′//	<20′	5′	14.7′	0.0′	6″ gunite shell
20	Rect.	14′ × 27′	app. 45 deg.	<19′	5′	12.5′	4.3′	6″ shotcrete
21	Odd	22′ × 33′	33′//	<295′	5.5′	12.8′	2.0′	conc. shell
22	Oval	16′ × 26′	26′//	<38′	2.5′		11′	reinf. gunite shell
23	Kidney	15′ × 36′	36′//	<12′	6′	11.5′	9.8′	4″–6″ conc. shell

From Table 1, it is observed that only one of the pools is fiberglass; the remainder are concrete or gunite. The distribution of the shapes of the pools is: 70% rectangular, 13% kidney, 4% oval, 9% odd and 4% round. The average largest dimension is 34.4 feet; the average smallest dimension is 17.4 feet.

BREAKAWAY POOL LAYOUT

To force breakaway mechanism in a coastal swimming pool under an extreme storm, joints at 2 ft. on center in the top 3 ft. of the pool walls will be assumed. The ACI Code minimum required flexural reinforcement will be used. Splices will be provided at 3 ft. below the top of the wall. This depth corresponds to the depth at shallow ends for most coastal swimming pools. To provide a failure mechanism at the bottom of the wall near the deep end, another splice will be provided above the floor/wall joint when the depth is 5 feet and more. The depth of 5 feet was chosen so that the bar that extends below the splice at 3 feet could be more than 2 feet long. The vertical joints will allow the walls to breakaway vertically. The splices will allow the walls to break horizontally.

BREAKAWAY POOL DESIGN

Swimming pools have been built from several materials, which include concrete, fiberglass, timber, masonry, and vinyl. The FDEP considers timber pools as frangible because they are vinyl-lined. The authors spoke with many pool builders about typical construction practices. Most of them liked the on-site ease and rapid construction of concrete or pressure sprayed (gunite) pools.

The authors suggest that fiberglass or timber be used for frangible pools because they breakaway easily and result in smaller and lighter debris. However, for pool owners who wish to build a concrete pool, the authors present a recommended breakaway design methodology. It is entirely possible to develop other equally effective breakaway designs for concrete pools.

EVERYDAY LOAD DESIGN

A swimming pool must be able to withstand everyday maximum loading. For pools situated above ground, these loads include the water load inside the pool when it is full, as shown in Fig. 1. The total load is:

$$W_A = 0.5\gamma_w H^2 \text{ per unit width of wall} \quad (1)$$

in which γ_w = unit weight of water, and H = height of pool.

The bending moment at the pool base is given by:

$$M_A = 0.083\gamma_w H^3 \text{ per unit width of wall} \quad (2)$$

For a below ground pool, the maximum everyday forces are caused by soil outside the pool when it is empty, as shown in Figure 2. This force and the corresponding moment are expressed as the following for a 32° coefficient of internal friction for soil:

$$W_B = 0.235\gamma_s H^2 \text{ per unit width of wall} \quad (3)$$

$$M_B = 0.078\gamma_s H^3 \text{ per unit width of wall} \quad (4)$$

in which γ_s = unit weight of soil.

The groundwater table was assumed to be low, which would cause negligible force on a below ground pool. For higher water levels to pool should remain filled with water to prevent it from floating up. A floating pool is likely to crack and will rarely settle back in the original position after flooding subsides.

The everyday maximum forces and moments expected on

Table 2. *Everyday maximum forces and moments on pool wall.*

Wall Height (ft)	Above Ground Pool (lb/ft width)	Below Ground Pool (lb/ft width)
(a) Everyday Forces		
4	499	451
5	780	705
6	1,123	1,015
7	1,529	1,382
(b) Everyday Moments at the Base		
4	666	602
5	1,300	1,175
6	2,246	2,030
7	3,567	3,224

Depth from Pool Top (ft)	Ultimate Shear (lb)	Ultimate Moment (lb-ft)	Reinforcement Design
(c) Ultimate Shears and Moments in Wall (on 2′ width)			
3	786	786	1–#4 (2–#4 provided)
6	3,145	6,290	3–#4

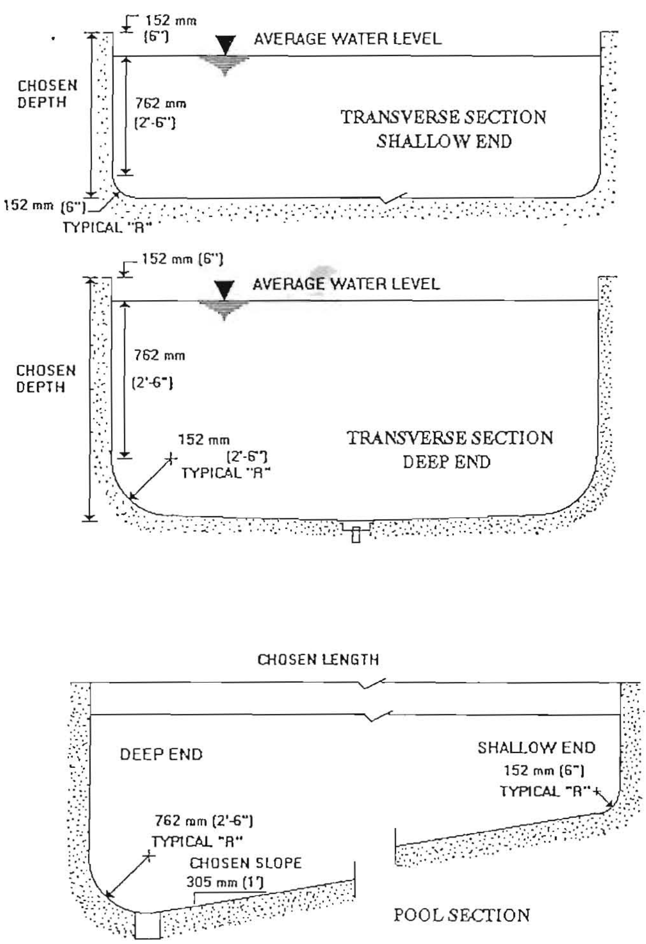

Figure 1. Typical sections for breakaway concrete pools.

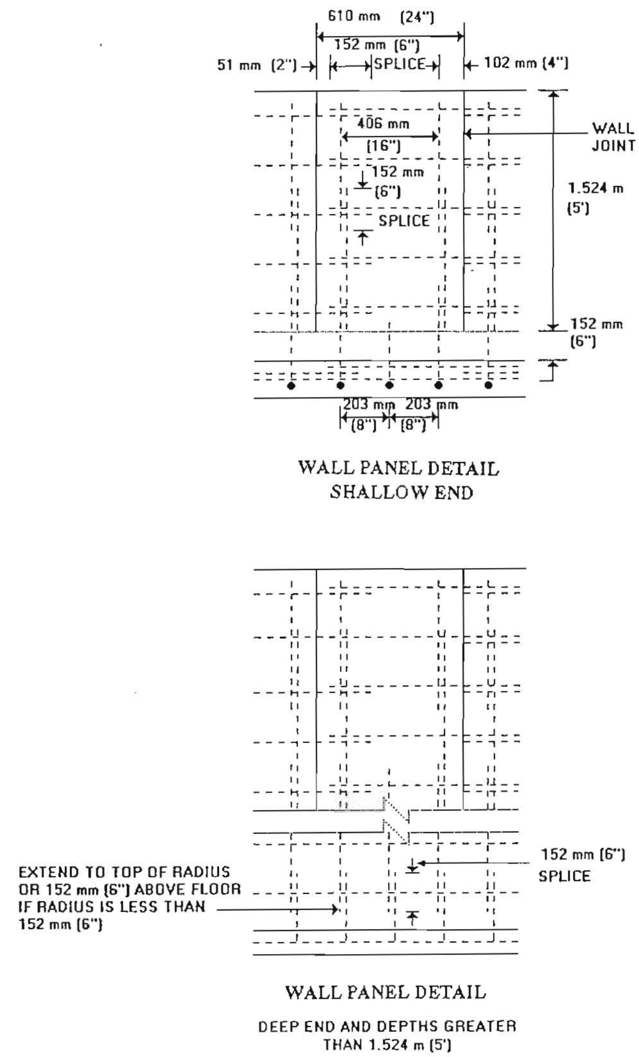

Figure 2. Wall panel joints and splices layout.

the pool wall are presented in Tables 2(a) and (b). The waterload on an aboveground pool is slightly higher than the soil load on a belowground pool; the two forces just act in opposite directions. Therefore, only the design of an above ground pool with waterload is presented herein.

Design shear forces and moments with ACI load factors on a 2 foot width of pool wall are shown in Table 2(c). Corresponding vertical steel design at the splice (3 feet from top) and at the bottom (6 feet from top) are also presented. Two #4 bars are needed at the splice to satisfy ACI code limitation for maximum spacing. Typical sections chosen for the breakaway concrete pool are shown in Figure 1. Wall panel design layout showing joints and bar splices are shown in Figure 2. Pool wall and floor reinforcement details are shown in Figure 3.

WAVE LOADING

The forces from breaking waves may be found from the Minikin Method, which is "based on observations of full-scale

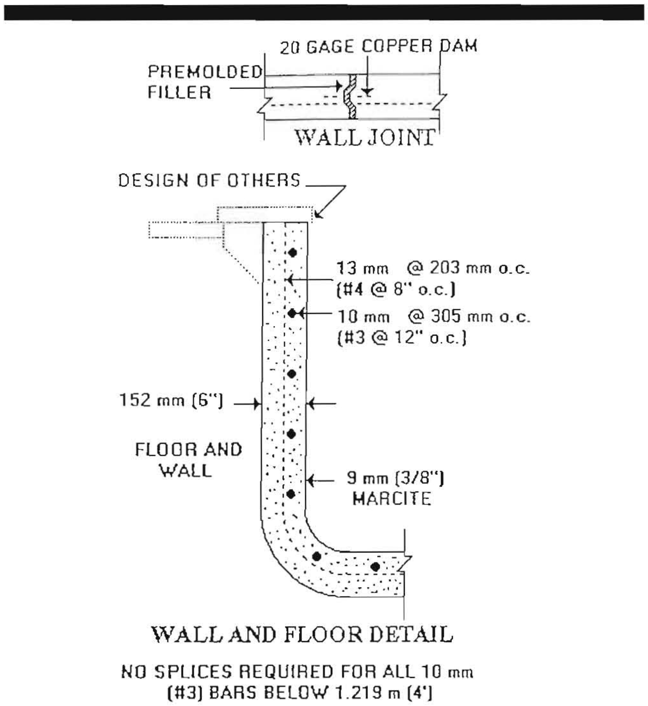

Figure 3. Pool wall and floor design details.

breakwaters and the results of Bagnold's study," and is presented in the *Shore Protection Manual* (1984). Because this method can result in wave forces that may be 15 to 18 times those for nonbreaking waves, the *Shore Protection Manual* warns that this method be used with caution. The variables are: the depth to the still water level (SWL) at the pool wall, the slope of the shore in front of the pool, and the wave period. The forces and moments on a typical pool wall for a 6 second conservative wave period are presented in Table 3.

Non-breaking waves obviously cause smaller forces on a pool than breaking waves. The non-breaking wave forces can be estimated from the Miche-Rundgren Method contained in the *Shore Protection Manual.* These forces depend on the free wave height, the depth of water to the SWL, the wave period, the wave reflection coefficient and the height of the wall above ground. The calculated non-breaking wave forces for a 6-second wave, a reflection coefficient of unit and the wall height equal to the water depth are presented in Table 4. The last condition represents no overtopping of the wall by the wave.

VERIFICATION OF BREAKAWAY

A comparison of Tables 2 and 3 reveals some interesting conditions. Breaking waves during a storm are expected to generate shear forces and bending moments which in most cases will easily exceed those caused by the everyday forces. This observation is valid for most water depths of 4 ft. or more and wall heights of 5 ft. or more. Non-breaking waves generate forces and moments on the pool wall which may exceed the everyday forces and moments if the water depth is generally 6 ft. or more or the wave height is 2.5 ft. or more. These critical water/wave depths are situation specific, i.e., they may occur if the shore slope is high and the pool is close to the water line. The wave height also depends on the intensity of the storm.

It may be inferred that the breakaway pool design described herein is expected to perform well in many coastal situations under an intense storm. The strength of the designed pool under wave action is found to be less than the strength needed for everyday loading, for most conditions. Therefore, the pool is expected to withstand the daily normal loading, while it is expected to breakaway along lines of weaknesses under extreme wave action. It is understood that many simplifying assumptions were made and parametric values assumed in the design of the breakaway pool, changes which will affect the design and the validity of the breakaway

Table 3. *Breaking wave forces & moments on pool wall.*

Shore Slope	Depth to SWL (ft) 1	2	3	4	5	6	7
			(a) Forces on Pool Wall (lb/ft)				
0.00	31	125	281	499	780	1,123	1,529
0.01	136	683	1,787	3,552	6,083	9,506	13,881
0.02	140	709	1,861	3,712	6,380	10,038	14,739
0.03	146	741	1,950	3,896	6,710	10,611	15,648
0.04	153	779	2,049	4,097	7,065	11,221	16,601
0.05	162	820	2,157	4,132	7,443	11,861	17,607
0.07	181	912	2,394	4,780	8,258	13,236	19,726
0.10	213	1,067	2,792	5,561	9,607	15,478	23,187
			(b) Moments on Pool Wall (lb-ft/ft)				
0.00	10	83	281	666	1,300	2,246	3,567
0.01	102	1,100	4,459	12,078	26,257	49,853	85,766
0.02	105	1,142	4,656	12,660	27,633	52,854	91,462
0.03	110	1,199	4,898	13,337	29,176	56,112	97,537
0.04	117	1,267	5,173	14,088	30,852	59,593	103,942
0.05	124	1,343	5,475	14,900	32,647	63,273	110,713
0.07	142	1,514	6,146	16,681	36,547	71,217	125,072
0.10	172	1,810	7,291	19,690	43,075	84,295	148,702

Table 4. *Non-breaking wave forces & moments on pool wall.*

Free Wave Height (ft)	Depth of Water from SWL (ft) 1	2	3	4	5	6	7
			(a) Forces on Pool Wall				
0.5	48.4	110.9	178.6	250.0	300.9	>	>
1.0	>	191.7	306.0	428.7	553.1	677.1	795.9
1.5	>	>	426.6	598.1	766.7	953.6	1,132.1
2.0	>	>	537.6	750.0	975.5	1,206.7	1,434.7
2.5	>	>	>	894.4	1,160.9	1,441.7	1,728.7
3.0	>	>	>	>	1,336.6	1,661.2	1,995.9
4.0	>	>	>	>	>	2,076.8	2,489.0
			(b) Moments on Pool Wall				
0.5	19.0	97.9	243.3	461.6	631.7	>	>
1.0	>	152.1	387.5	760.3	1,257.5	1,866.8	2,552.7
1.5	>	>	514.6	1,007.5	1,671.1	2,615.8	3,715.6
2.0	>	>	634.3	1,222.7	2,045.5	3,179.2	4,554.1
2.5	>	>	>	1,428.5	2,390.5	3,665.2	5,317.9
3.0	>	>	>	>	2,692.6	4,124.1	5,970.7
4.0	>	>	>	>	>	5,056.0	7,179.4

> Beyond range for nonbreaking waves.

Table 5. *Impulse on foundation from debris.*

$H/\sqrt{d}$*	Impulse ($\int Fdt$) (lb-sec)
0.5	20
1.0	40
1.5	60
2.0	80
2.5	100
3.0	120
3.5	140
4.0	160
4.5	180
5.0	200

*H and d are in feet.

criteria. Only a conceptual breakaway pool design is detailed herein, which shows that it is possible to design a frangible pool for coastal areas.

IMPACT OF DEBRIS ON FOUNDATION

If a pool is designed to be frangible, it is likely to breakaway in several pieces during an extreme flooding. It is possible that the broken debris may be carried away by wave action and impact on the adjacent house or foundation. The foundation should be designed with proper consideration for this impact force from a frangible pool.

There are many variables which are likely to influence the magnitude of the debris impact force, such as the size of the pieces that will break away, the velocity of the broken pieces, the wave height and wave depth, the amount of time the broken pieces will remain in contact with the foundation, and the manner in which the pieces come in contact with the foundation. The position of the pieces in the wave is also a factor for transitional or deep water.

Simplifying assumptions were made in order to develop an expression for the debris impact force on adjoining foundations. It was assumed that the pool wall will break into 2 foot by 3 foot by 6 inch thick pieces (according to the breakaway design for concrete pools developed in this study) and will impact at a velocity equal to the velocity of the water (a conservative assumption).

From Impulse-Momentum relationships (BEER and JOHNSTON, 1988):

$$\int F\,dt = m\nu \quad (5)$$

in which F = impact force, dt = increment of time, m = mass of broken piece, and ν = velocity of piece when it comes in contact with the foundation.

The velocity of the piece, assuming shallow water conditions, is as follows (HERBICH *et al.*, 1984):

$$\nu = H/2\,(g/d)^{1/2}\cos\theta \quad (6)$$

in which H = wave height, d = depth to SWL, θ = phase angle of wave, and g = acceleration due to gravity = 32.2 ft/sec^2.

For maximum velocity, assuming θ = 0 degrees:

$$\int F\,dt = 13.98\,(0.5H)(g/d)^{1/2} \quad (7)$$

Values of the impulse force from Equation 7 for various values of $\sqrt{H/d}$ are shown in Table 5. If a frangible coastal concrete pool is designed, the adjacent foundation should be designed to withstand debris impact forces similar to the presentation in this table.

CONCLUSIONS

The following conclusions may be made based on the findings of the study:

(1) There have been no previous or continuing studies which address frangibility criteria for coastal swimming pools.

(2) Most coastal swimming pools are rectangular; the average dimensions are about 17 feet by 34 feet. Almost all coastal pools are made of concrete or gunite. The average distance from the CCCL is 112.2 feet; and the average maximum depth is 5.75 feet. The average storm surge is 6.7 feet above the grade. These conclusions are based on a survey of 23 coastal pools from the Florida Department of Environmental Protection permit files.

(3) Most coastal pool builders like the ease of working with gunite.

(4) It is feasible to theoretically and practically design and construct a good and safe breakaway swimming pool made of concrete. A good breakaway concrete pool design includes vertical joints and splices in the reinforcing steel.

(5) Scour that causes undermining of the pool wall may cause failure. For example, for the concrete swimming pool design, a 6 foot wall undermined approximately 3 feet will fail due to the weight of the water inside the pool.

(6) The debris from a breakaway pool may impact the pool or house foundation due to wave and current action. The foundation must be designed to withstand the debris impact force from a frangible pool.

(7) The authors recommend that for high hazard areas, in which frangibility is desired, fiberglass or plywood be used for the pools. If the pool must be concrete, a design such as the one presented in this report may be used as an option. If a concrete pool is to be situated above ground, the authors recommend that the pool be no more than 3 feet above ground.

These figures were used in this paper:

dt = increment of time;
F = impact force;
g = acceleration due to gravity;
H = wave height;
M_A = bending moment at pool base (above ground pool);
M_B = bending moment at pool base (below ground pool);
m = mass of broken piece;
W_A = water load inside pool when full (above ground pool);
W_B = water load inside pool when full (below ground pool);
γ_s = unit weight of soil;
γ_w = unit weight of water;
θ = phase angle of wave;
ν = velocity of piece on impact.

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