Geometric Considerations in the Design of Circular Grain Storage Systems

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ABSTRACT

CIRCULAR arrangements of grain drying and storage bins offer an efficient means of handling and storing grain in terms of initial capital investment and materials flow. Designs of these systems are influenced by many factors that relate spatial geometry, materials handling and system capacity. This study presents the geometric considerations associated with various design configurations.

INTRODUCTION

A popular grain drying and storage facility configuration is the circular arrangement (Fig. 1). The primary advantage of this system is the efficient handling of grain with portable conveying equipment. Disadvantages include the following: (a) expansion of the facility is more difficult than with centralized layouts (conveyor(s) and bins on side(s) of a driveway that passes through the facility) in that all the bins on the circle are best served when they are the same size, and expansion beyond the initial circle may require two-staged augering of grain; (b) delivery vehicles may have to back into the receiving area to unload; and (c) if a bucket elevator is used, it will generally have to be taller than for a comparable centralized arrangement. It is essential that the initial design consider these factors if the system is to function in a highly efficient manner. Therefore, the objectives of this paper are:

1. to present the overall design considerations associated with circular bin arrangements;
2. to state the geometric relationships required for location of bins in circular arrangements;
3. to provide specifications concerning typical circular arrangements and discuss some of the implications of alternate designs.

LAYOUT AND DESIGN CONSIDERATIONS

In designing circular arrangements, it is extremely important that the basic specifications be accurately stated prior to construction so as to obtain optimum efficiency. Optimum efficiency is based on the priorities assigned to factors that dictate the design; that is, the designer must decide if system capacity (both present and future), land area or delivery conveyor considerations (auger or bucket elevator) will govern the design. Many of these factors interact. For example, auger power requirements increase nonlinearly with increases in elevating height, other factors remaining constant. In addition, the length of auger needed to reach the top center of a bin may be influenced by the eave height as well as the total height of the bin. Thus, it is not sufficient to base the design on only the minimum area needed to place the bins.

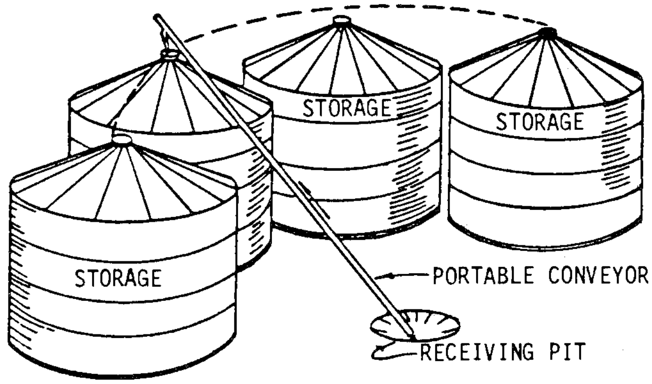

Fig. 1—Typical circular configuration of grain storage bins.

Factors such as bin sizing and the dynamics of materials handling in the design of grain storage systems are given by Loewer et al. (1976a; 1976b; 1980), Bridges et al. (1979a; 1979b) and Benock et al. (1981). The circular system is most efficiently designed when (a) all bins are the same size and (b) all bins can be filled by a portable conveyor that extends directly from a central unloading pit or receiving hopper. Similarly, the unloading auger from each bin should be directed to a point at which it can directly feed a second portable conveyor that conveys grain back to the central receiving area. Using this configuration, grain that is being unloaded into the receiving pit may be placed directly into delivery vehicles or into other storage bins. Bin unloading augers may be designed so as to reach the central receiving point directly, or they can be placed so that two bin augers may feed the portable receiving auger at the same time. Simultaneous unloading doubles the unloading rate and/or reduces the number of times that the receiving conveyor must be moved.

Given the influence of the above considerations, the following items must be specified before spatially designing the circular layout:

1. present or future capacity as determined by the maximum number of bins of a given diameter that can be constructed on the circle
2. eave height and roof slope of the bins
3. delivery conveyor geometry (if this is to be a governing factor) as to lengths, clearances and angles
4. width of the receiving area for delivery vehicles.

All of the above factors influence the center radius of

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the facility. The center radius is defined as the distance between the centers of the receiving pit and the grain bins and is the primary design dimension in a circular arrangment. It is essential that the designer specify the conditions under which auger geometry will dictate the center radius and vice versa. The following discussion indicates the design criteria under which center radius is computed.

DESIGN PROCEDURE

The design procedure for locating storage bins in a circular arrangement begins by determining the center radius. The designer must specify:

1. minimum and maximum storage capacities on the circle
2. the closest distance between the walls of any two bins except those on either side of the receiving area
3. the minimum distance allowed between two bins for entry by delivery vehicles to the receiving pit.

There are several geometric considerations that must be incorporated into a circular system design. The design procedure is iterative in that a series of design parameters must be satisfied before the system will function within the specified criteria. This will require the changing of each design component until the minimum sizing of the most limiting component is obtained. The basic criteria for circular systems are that grain must be delivered and received in a timely manner and that there must be sufficient storage capacity.

The first geometric consideration is that any two bins may be used to mark a line on which the center point of the circle will lie. The center point falls on a line that bisects and is perpendicular to another line that joins the bin centers (Fig. 2). The addition of a third bin will define the exact center location of the receiving pit regardless of the diameters of any of the bins. If the three bins do not have the same dimensions, the conveying auger may need to be altered so as to reach the top center of each bin. Once the conveying pit center has been established, all future bins should have their center unloading wells located on the center radius.

The design of circular layouts is simplified when all bins to be constructed on the circle have the same dimensions. Regardless, the center radius must be of sufficient length so that all the bins can be placed on the circle while allowing sufficient room for unloading and the movement of conveying equipment through the receiving area. The center radius must also allow for the operation of conveying equipment within the design criteria related to power, capacity and grain damage. Either conveying criteria or storage capacity will be the limiting factor in defining the center radius.

The central conveyor may be either a bucket elevator or a portable auger, the latter being most common for circular layouts. If a bucket elevator is to be used, the center radius is limited by bin diameter and space between bins while allowing for sufficient width to receive and deliver grain. The height of the bins is generally not a factor in that bucket elevators may be built high enough for filling. Portable augers present a different type of problem in terms of power requirements, capacity and grain damage. Because of these factors, a general guideline for circular systems is that the angle of delivery for the portable auger be no greater than the roof slope of the grain bin, usually about

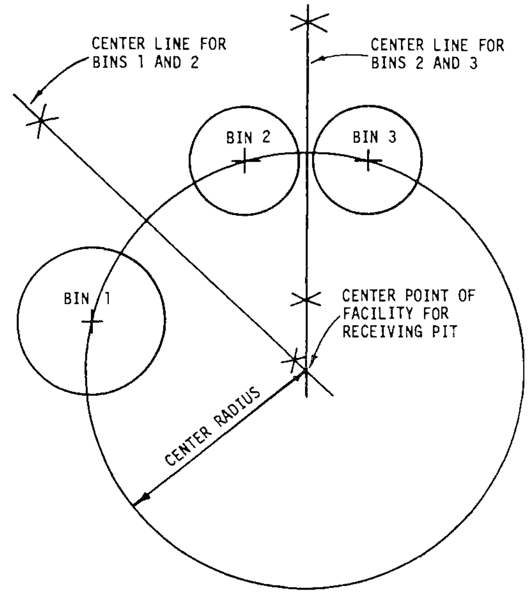


Fig. 2—The centers of any three bins define the center radius in a circular configuration.

30 deg. However, there is a savings in auger length as the unloading angle of the auger approaches 45 deg. Another factor influencing auger length is that the auger must extend into the receiving pit, usually several feet below the ground surface.

Given the appropriate design criteria, the center radius can be computed as follows:

for a<=b (Fig. 3)

$$R = (H+D)/TAN(a) \quad \text{[1]}$$

for a>b where "a" overrides "H" as a constraint (Fig. 4)

$$R = E + (B/2) + (G + D)/TAN(a) \quad \text{[2]}$$

for a>b where "H" overrides "a" as a constraint (Fig. 5)

$$R' = (H + D)/TAN(a') \quad \text{[3]}$$

$$a' = \arctan\,[(T + (B/2)*TAN\ b)/((B/2) + E)] \quad \text{[4]}$$

where

R = center radius for the system
R′ = optimum center radius for minimizing auger length

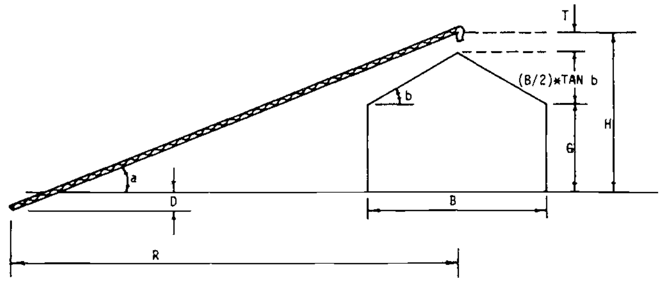


Fig. 3—Center radius "R" for systems where the slope of the auger (a) is less than or equal to the bin roof slope (b).

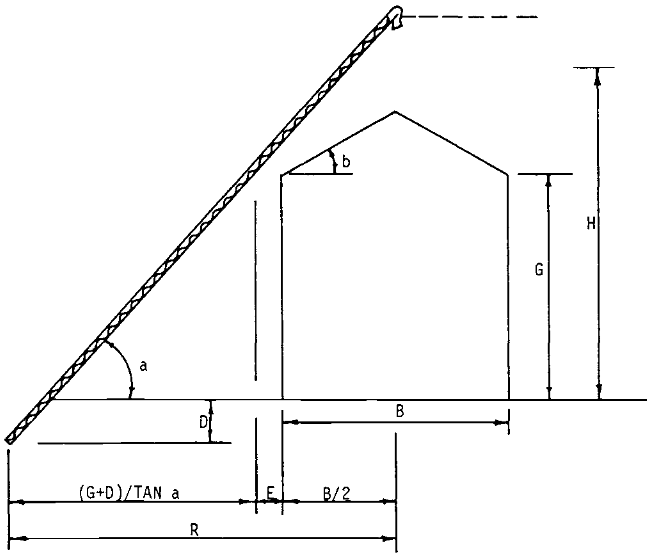


Fig. 4—Center radius "R" for systems where the specified slope of the auger (a) is greater than or equal to the bin roof slope (b) and overrides the specified value of "H" (minimum fill height) as a design consideration.

H = elevation of the auger above ground at the point of unloading to include vertical bin clearance by the auger
D = depth of the auger at its receiving point relative to the ground level of the bin
a = desired angle of elevation of the auger
a′ = optimum angle of elevation for the auger for minimizing auger length
b = slope of the bin roof, degrees
E = horizontal clearance to the closest point of the bin
B = bin diameter
G = distance from the ground to the bin eave
T = vertical clearance between the unloading auger and the bin roof

If the length of the conveying auger is to govern the design, if its specified length "L" is greater than or equal to the minimum feasible design length "L′," and if the desired auger elevation angle "a" is less than the optimum angle of elevation "a′" for "L′," the "R" may be computed as follows (Fig. 5):

$$R = (L^2 - (H + D)^2)^{0.5} \quad \ldots\ldots\ldots\ldots\ldots\ldots [5]$$

where

$$L' = (H + D)/SIN(a') \quad \ldots\ldots\ldots\ldots\ldots\ldots [6]$$

For the same situation except that "a" is greater than or equal "a′."

$$R = L*COS(a) \quad \ldots\ldots\ldots\ldots\ldots\ldots [7]$$

where

$$L' = (G + D)/SIN(a) + ((B/2) + E)/COS(a) \quad \ldots\ldots [8]$$

and
L = specified auger length
L′ = minimum auger length required to fill the bin.

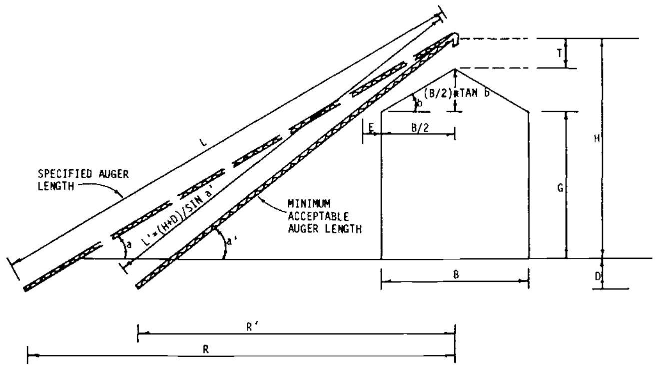


Fig. 5—Relationship among the minimum auger length (L′) and its associated center radius (R′), and specified auger length (L) and its associated center radius (R).

Once the center radius has been determined, the next step is to determine the number of bins that will fit on the circle and whether this number will allow sufficient room for unloading vehicles. This process begins by determining chord length. The chord length joining two adjacent bins of the same diameter is as follows (Fig. 6):

$$P = B + S \quad \ldots\ldots\ldots\ldots\ldots\ldots [9]$$

where
P = chord length
S = distance between adjacent bin walls

Equation [9] allows the computation of the maximum number of bins that may be placed on the circle by computing the angle between adjacent bin centers followed by determining the arc length of a segment between two adjacent bins (Fig. 6). The circumference divided by the arc length gives the maximum number of bins that may be placed on the inner circle.

In equation form,

$$e = ARC\ COS[(2*R^2 - P^2)/(2*R^2)]$$

$$\text{or } 2*ARC\ SIN(P/(2*R)) \quad \ldots\ldots\ldots\ldots [10]$$

where
e = angle (in radians) between two adjacent bin centers.

$$A = R*e \quad \ldots\ldots\ldots\ldots\ldots\ldots [11]$$

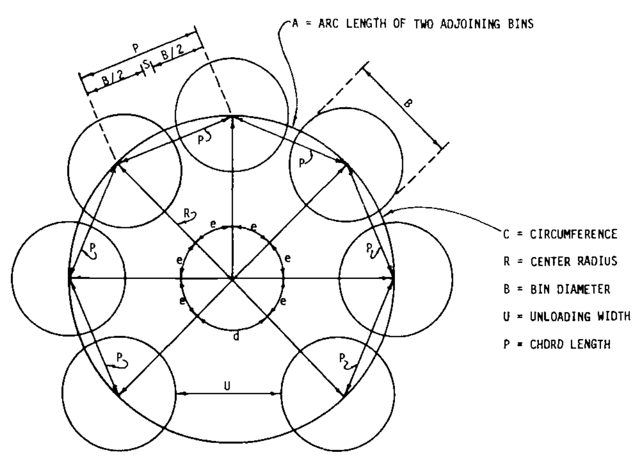


Fig. 6—Relationships among center radius, chord length, arc length, number of bins and unloading space.

where

A = arc length of two adjoining bin centers.

$$C = 2*(pi)*R \quad [12]$$

where

C = circumference of the center circle.

pi = 3.1416

$$N = C/A \quad [13]$$

where

N = number of bins that may be constructed on the circle.

The "fractional" number of bins (the decimal part of N in equation [13] is used to determine the receiving width between two of the bins.

$$F = N - N' \quad [14]$$

where

F = fractional portion of N

N′ = integer portion of N

$$d = (C - (N' - 1)*A)/R \quad [15]$$

where

d = angle (in radians) between adjacent bin centers that divide the receiving area.

$$U = 2*R*SIN(d/2) - B \quad [16]$$

where

U = unloading width.

If "U" is less than the minimum width allowed for unloading, the number of bins (N′) is reduced by one (equation [15]) and the new spacing is reevaluated (equation [16]) to see if it now meets the design criteria. This process continues until the space criteria for unloading are satisfied.

If a bucket elevator is to be located in the center of the facility, its discharge height may be calculated by the following expression:

$$Q = TAN(c)*R + G + TAN(b)*(B/2) \quad [17]$$

where

Q = discharge height for the bucket elevator

c = angle for downspouting.

CENTER RADIUS VERSUS SYSTEM CAPACITY

In the previous discussion, the emphasis was on determining the geometry of a circular bin arrangement given that the storage capacity requirements were satisfied. By using geometric ratios of selected design criteria, capacity and center radius can be directly related. For example, given a specified depth of grain, the number and diameter of bins determine the total system capacity. In turn, the number and diameter of bins plus the receiving width and the distance between adjacent bins can be used to determine the minimum center radius. The relations among these variables can be simplified by representing each bin as a circle with a diameter of "B + S" (bin diameter plus distance between adjacent bins). Then the adjacent circles are contiguous, and the unloading distance between the end bins is "U − S." For further simplification, the adjusted unloading distance and the minimum center radius are both expressed in ratio to "B + S." The resulting equations, given below, summarize equations [9] thru [17] for various configurations. Because the equations cannot be solved directly for "R′," a numerical method of solving for "R′" is used for specified values of "N."

If bins occupy more than "pi + e" radians of the circle (Fig. 6), the following equation applies:

$$N = \frac{pi\text{-}ARC\ TAN((1+U')/(4R'^2-(1+U')^2)^{0.5}}{ARC\ TAN(1/(4R'^2-1)^{0.5})} + 1 \quad [18]$$

where

U′ = (U−S)/(B+S)

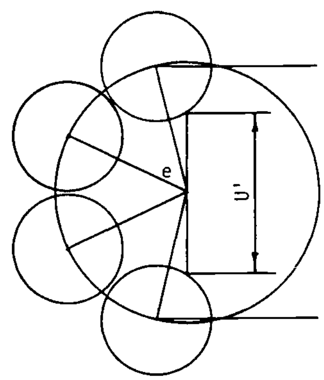
R′ = R/(B+S)

and

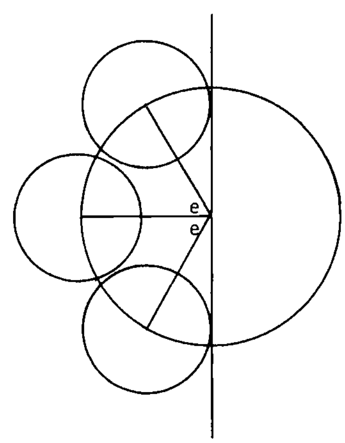
R′>(U′+1)/2 with pi being measured in radians.

For situations in which bins occupy more than "pi" but less than "pi + e" of the circle (Fig. 7a), the following equation applies:

$$N = \frac{pi\text{-}ARC\ TAN([\frac{(1+U'-2R')(1+2R'-U')}{(1+2R'+U')(2R'+U'-1)}]^{0.5})}{ARC\ TAN(1/(4R'^2-1)^{0.5})} + 1 \quad [19]$$



a. situation a.



b. situation b.

Fig. 7—Bin configurations that may be used in estimating dimensions and system capacity.

TABLE 1. MINIMUM SYSTEM CENTER RADIUS RATIO AS INFLUENCED BY THE UNLOADING SPACE RATIO AND THE MAXIMUM NUMBER OF BINS TO BE LOCATED ON THE CIRCLE.

Unloading space ratio (U')*	Minimum system center radius ratio, R'											
	Maximum number of bins, N											
	3	4	5	6	7	8	10	12	14	16	20	24
0.20	0.625	0.745	0.886	1.034	1.186	1.340	1.651	1.964	2.279	2.595	3.228	3.863
0.25	0.641	0.756	0.896	1.043	1.195	1.348	1.659	1.972	2.287	2.603	3.236	3.871
0.30	0.658	0.767	0.905	1.052	1.203	1.357	1.667	1.981	2.296	2.611	3.244	3.879
0.40	0.700	0.791	0.925	1.071	1.221	1.374	1.684	1.997	2.312	2.628	3.260	3.895
0.50	0.748	0.816	0.946	1.090	1.239	1.392	1.701	2.014	2.328	2.644	3.277	3.911
0.60	0.790	0.845	0.969	1.110	1.258	1.410	1.718	2.031	2.345	2.660	3.293	3.927
0.80	0.861	0.913	1.017	1.152	1.297	1.447	1.753	2.065	2.378	2.693	3.326	3.959
1.00	0.915	1.000	1.072	1.198	1.338	1.485	1.789	2.099	2.412	2.727	3.358	3.992
1.25	0.963	1.106	1.153	1.261	1.393	1.537	1.836	2.144	2.456	2.769	3.400	4.033
1.50	0.991	1.184	1.253	1.332	1.454	1.591	1.885	2.190	2.500	2.812	3.442	4.074
2.00	1.000	1.281	1.457	1.510	1.593	1.712	1.989	2.286	2.591	2.901	3.527	4.158
2.50	1.000	1.307	1.571	1.727	1.769	1.856	2.104	2.389	2.688	2.994	3.615	4.243

*U' = (U-S)/(B+S)
where U = unloading width, S = distance between adjacent bin walls, B = bin diameter.

TABLE 2. DESIGN SPECIFICATIONS AND CALCULATIONS WHERE BIN GEOMETRY DICTATES THE CONFIGURATION OF ALL THE SYSTEMS.

DESIGN SPECIFICATIONS FOR CIRCULAR BIN ARRANGEMENTS *

1.000 - MINIMUM HORIZONTAL DISTANCE FROM AUGER TO BIN WALL (TOP CLEARANCE HAS PRIORITY)
45.000 - SLOPE OF DOWNSPOUTING IF A BUCKET ELEVATOR IS PLACED IN THE BINS CENTER (DEGREES)
1.500 - HEIGHT OF FOUNDATION RING
6.000 - NUMBER OF RINGS PER BIN
2.667 - HEIGHT OF EACH STORAGE RING
17.500 - BIN EAVE HEIGHT (COMPUTED FROM ABOVE INFORMATION)
30.000 - BIN ROOF SLOPE, DEGREES
10.000 - AUGER LENGTH (USED ONLY IF IT DETERMINES CENTER RADIUS)
2.000 - DEPTH OF THE RECEIVING PIT
2.000 - DISTANCE BETWEEN WALLS OF ADJACENT BINS
12.000 - MINIMUM ACCEPTABLE DISTANCE BETWEEN TWO OF THE BINS FOR VEHICLE UNLOADING
1.000 - VERTICAL CLEARANCE BETWEEN TOP OF BIN AND THE UNLOADING AUGER DISCHARGE POINT
20.000 - MINIMUM SLOPE OF THE UNLOADING AUGER, DEGREES

BIN DIAMETER	MINIMUM FILL HGT.	MINIMUM AUGER LENGTH	REQUIRED AUGER LENGTH	CENTER RADIUS	AUGER SLOPE (DEG)	ACTUAL FILL HGT.	CHORD LENGTH	ANGLE BETWEEN BINS,D.	ARC LG. BETWEEN BINS	CENTER RADIUS CIRCUM.	FRACTION OF BINS ALLOWED	BUCKET ELEVATOR DISCHR
12	23.46	47.36	48.00	40.47	32.53	23.81	14.00	19.92	14.07	254.28	18.07	62.93
15	24.33	49.56	50.00	42.36	32.09	24.56	17.00	23.15	17.12	266.16	15.55	65.69
18	25.20	51.63	52.00	44.20	31.78	25.39	20.00	26.15	20.17	277.73	13.77	68.40
21	26.06	53.62	54.00	46.02	31.55	26.26	23.00	28.94	23.25	289.13	12.44	71.08
24	26.93	55.56	56.00	47.81	31.38	27.16	26.00	31.56	26.33	300.40	11.41	73.74
27	27.79	57.45	58.00	49.59	31.24	28.08	29.00	34.00	29.43	311.59	10.59	76.39
30	28.66	59.32	60.00	51.36	31.12	29.01	32.00	36.30	32.54	322.73	9.92	79.02
33	29.53	61.16	62.00	53.13	31.03	29.96	35.00	38.46	35.67	333.82	9.36	81.66
36	30.39	62.99	63.00	54.03	30.95	30.40	38.00	41.18	38.83	339.49	8.74	83.42
39	31.26	64.80	65.00	55.79	30.88	31.36	41.00	43.12	41.98	350.52	8.35	86.05
42	32.12	66.61	67.00	57.54	30.82	32.33	44.00	44.96	45.15	361.53	8.01	88.66
45	32.99	68.40	69.00	59.29	30.77	33.30	47.00	46.70	48.33	372.52	7.71	91.28
48	33.86	70.19	71.00	61.04	30.72	34.27	50.00	48.36	51.52	383.50	7.44	93.89

	[FIRST APPROXIMATION		] [SECOND APPROXIMATION			]	FINAL DESIGN				
BIN DIAMETER	BINS ALLOWED (1ST APP)	RECEIVING ANGLE (DEGREES)	UNLOAD SPACE (1ST APP)	BINS ALLOWED (2ND APP)	RECEIVING ANGLE (DEGREES)	UNLOAD SPACE (2ND APP)	]	ACTUAL BINS ALLOWED	ACTUAL UNLOAD SPACE	PER BIN CAPACITY **	FACILITY CAPACITY **	BIN DIAMETER
12	18	21.35	2.99	17	41.27	16.53	]	17	16.53	1448	24610	12
15	15	35.89	11.10	14	59.04	26.74	]	14	26.74	2262	31667	15
18	13	46.19	16.68	12	72.34	34.18	]	13	16.68	3257	42344	18
21	12	41.61	11.69	11	70.55	32.15	]	11	32.15	4433	48768	21
24	11	44.44	12.16	10	76.00	34.87	]	11	12.16	5791	63696	24
27	10	53.98	18.02	9	87.99	41.89	]	10	18.02	7329	73287	27
30	9	69.60	28.63	8	105.90	51.99	]	9	28.63	9048	81430	30
33	9	52.30	13.83	8	90.76	42.63	]	9	13.83	10948	98531	33
36	8	71.77	27.34	7	112.94	54.08	]	8	27.34	13029	104231	36
39	8	58.17	15.23	7	101.28	47.27	]	8	15.23	15291	122326	39
42	8	45.29	2.31	7	90.25	39.55	]	7	39.55	17734	124136	42
45	7	79.79	31.05	6	126.49	60.88	]	7	31.05	20358	142503	45
48	7	69.85	21.89	6	118.21	56.75	]	7	21.89	23162	162137	48

* ALL UNITS OF LENGTH ARE ASSUMED TO BE THE SAME.
** 1.25*VOLUME (BUSHELS IF FEET ARE THE UNITS OF LENGTH)

where

$(U'^2+1)^{0.5}/2 < R' < (U'+1)/2.$

If bins occupy exactly "pi" of the circle, the unloading space is unlimited by bin location, and the center radius is entirely determined by the number, diameter and distance between adjacent bins (Fig. 7b). Then,

$$N = \frac{pi}{2\ \mathrm{ARC\ TAN}(1/(4R'^2-1)^{0.5})} \qquad [20]$$

where

$R' < (U'^2+1)^{0.5}/2.$

The equation to use for calculating N is dictated by the location of R' in the range specified for each equation.

Table 1 gives the minimum center radius ratios (R') for several values of N and U' so that the minimum R can be estimated from known values of N, U and S. The ratios were calculated by iterative solution of equations [18] thru [20] with varying values of R' until integer values of N were obtained. To use Table 1, assume a bin diameter, space between adjacent bins, unloading space and number of bins, for example B=28, S=6, U=20 and N=7 (any consistent units will suffice). Then, U' = (20-6)/(28 + 6) = 0.4117, and an estimate of R' = 1.223 can be obtained by interpolation in Table 1. Thus, R = 1.223*(28+6) = 41.6.

EXAMPLE DESIGNS

Several possible design configurations are shown in Tables 2 to 5 based on equations [1] thru [17]. These equations were incorporated into a spreadsheet program so as to demonstrate some of the dynamics of the design calibrations. Each scenario was computed with the constraint that the minimum required auger length would be rounded to the next largest integer value. Each table has a first and second design approximation based

TABLE 3. DESIGN SPECIFICATIONS AND CALCULATIONS WHERE THE MINIMUM AUGER SLOPE DICTATES THE CONFIGURATIONS OF ALL THE SYSTEMS.

DESIGN SPECIFICATIONS FOR CIRCULAR BIN ARRANGEMENTS *

1.000	- MINIMUM HORIZONTAL DISTANCE FROM AUGER TO BIN WALL (TOP CLEARANCE HAS PRIORITY)
45.000	- SLOPE OF DOWNSPOUTING IF A BUCKET ELEVATOR IS PLACED IN THE BINS CENTER (DEGREES)
1.500	- HEIGHT OF FOUNDATION RING
6.000	- NUMBER OF RINGS PER BIN
2.667	- HEIGHT OF EACH STORAGE RING
17.500	- BIN EAVE HEIGHT (COMPUTED FROM ABOVE INFORMATION)
30.000	- BIN ROOF SLOPE, DEGREES
10.000	- AUGER LENGTH (USED ONLY IF IT DETERMINES CENTER RADIUS)
2.000	- DEPTH OF THE RECEIVING PIT
2.000	- DISTANCE BETWEEN WALLS OF ADJACENT BINS
12.000	- MINIMUM ACCEPTABLE DISTANCE BETWEEN TWO OF THE BINS FOR VEHICLE UNLOADING
1.000	- VERTICAL CLEARANCE BETWEEN TOP OF BIN AND THE UNLOADING AUGER DISCHARGE POINT
45.000	- MINIMUM SLOPE OF THE UNLOADING AUGER, DEGREES

BIN DIAMETER	MINIMUM FILL HGT.	MINIMUM AUGER LENGTH	REQUIRED AUGER LENGTH	CENTER RADIUS	AUGER SLOPE (DEG)	ACTUAL FILL HGT.	CHORD LENGTH	ANGLE BETWEEN BINS,D.	ARC LG. BETWEEN BINS	CENTER RADIUS CIRCUM.	FRACTION OF BINS ALLOWED	BUCKET ELEVATOR DISCHR
12	23.46	37.48	38.00	26.87	45.00	24.87	14.00	30.20	14.16	168.83	11.92	49.33
15	24.33	39.60	40.00	28.28	45.00	26.28	17.00	34.98	17.27	177.72	10.29	51.61
18	25.20	41.72	42.00	29.70	45.00	27.70	20.00	39.35	20.40	186.60	9.15	53.89
21	26.06	43.84	44.00	31.11	45.00	29.11	23.00	43.38	23.56	195.49	8.30	56.17
24	26.93	45.96	46.00	32.53	45.00	30.53	26.00	47.11	26.75	204.37	7.64	58.46
27	27.79	48.08	49.00	34.65	45.00	32.65	29.00	49.48	29.92	217.70	7.28	61.44
30	28.66	50.20	51.00	36.06	45.00	34.06	32.00	52.68	33.16	226.59	6.83	63.72
33	29.53	52.33	53.00	37.48	45.00	35.48	35.00	55.67	36.42	235.47	6.47	66.00
36	30.39	54.45	55.00	38.89	45.00	36.89	38.00	58.49	39.70	244.36	6.15	68.28
39	31.26	56.57	57.00	40.31	45.00	38.31	41.00	61.14	43.01	253.24	5.89	70.56
42	32.12	58.69	59.00	41.72	45.00	39.72	44.00	63.65	46.35	262.13	5.66	72.84
45	32.99	60.81	61.00	43.13	45.00	41.13	47.00	66.02	49.70	271.02	5.45	75.12
48	33.86	62.93	63.00	44.55	45.00	42.55	50.00	68.28	53.09	279.90	5.27	77.40

	[FIRST APPROXIMATION]			[SECOND APPROXIMATION		]	FINAL DESIGN				
BIN DIAMETER	BINS ALLOWED (1ST APP)	RECEIVING ANGLE (DEGREES)	UNLOAD SPACE (1ST APP)	BINS ALLOWED (2ND APP)	RECEIVING ANGLE (DEGREES)	UNLOAD SPACE (2ND APP)	ACTUAL BINS ALLOWED	ACTUAL UNLOAD SPACE	PER BIN CAPACITY **	FACILITY CAPACITY **	BIN DIAMETER
12	11	57.99	14.05	10	88.19	25.40	11	14.05	1448	15924	12
15	10	45.20	6.74	9	80.18	21.43	9	21.43	2262	20358	15
18	9	45.17	4.81	8	84.52	21.94	8	21.94	3257	26058	18
21	8	56.31	8.36	7	99.69	26.56	7	26.56	4433	31034	21
24	7	77.31	16.63	6	124.43	33.55	7	16.63	5791	40534	24
27	7	63.13	9.27	6	112.61	30.65	6	30.65	7329	43972	27
30	6	96.61	23.86	5	149.29	39.55	6	23.86	9048	54287	30
33	6	81.63	15.99	5	137.30	36.81	6	15.99	10948	65687	33
36	6	67.55	7.24	5	126.04	33.32	5	33.32	13029	65144	36
39	5	115.42	29.15	4	176.57	41.57	5	29.15	15291	76454	39
42	5	105.40	24.37	4	169.05	41.06	5	24.37	17734	88668	42
45	5	95.90	19.06	4	161.93	40.20	5	19.06	20358	101788	45
48	5	86.89	13.27	4	155.17	39.01	5	13.27	23162	115812	48

* ALL UNITS OF LENGTH ARE ASSUMED TO BE THE SAME.

** 1.25*VOLUME (BUSHELS IF FEET ARE THE UNITS OF LENGTH)

on the iterative process required to insure that there is sufficient width to unload a vehicle directly into the receiving pit. The common design creteria for all of these designs are:

- minimum horizontal distance from auger to bin wall = 0.3 m (1 ft)
- slope of downspouting if a bucket elevator is placed in the center of the bin arrangement = 45 deg
- foundation ring height = 0.457 m(1.5 ft)
- number of rings in bin = 6
- ring height = 0.813 m (2.667 ft)
- depth of receiving pit = 0.61 m (2 ft)
- distance between bins = 0.61 m (2 ft)
- receiving width of unloading space = 3.658 m (12 ft)
- minimum vertical clearance between auger and bin = 0.3 m (1 ft)

In Table 2, the computed auger length is based on a minimum auger slope of 20 deg. The design auger length is given as 3 m (10 ft) so as to insure that the program will calculate a minimum auger length greater than the initial specification but based on top and side clearances rather than on slope of delivery. The Table 2 values reflect the situation in which auger length, center radius and total capacity are minimized given the design specifications. In other words, the table values give design information for a bin arrangement in which auger length is not an overriding consideration or in which a bucket elevator is to be added to the system after portable augers have been used.

Table 3 differs from Table 2 in that the minimum slope of the portable auger is 45 deg. This gives the shortest possible auger under the condition in which vertical and horizontal clearance do not dictate a longer auger length. A comparison between Tables 2 and 3 indicates that the minimum auger length, center radius

TABLE 4. DESIGN SPECIFICATIONS AND CALCULATIONS WHERE A SPECIFIED AUGER LENGTH INFLUENCES THE CONFIGURATIONS OF SOME OF THE SYSTEMS.

DESIGN SPECIFICATIONS FOR CIRCULAR BIN ARRANGEMENTS *

1.000 - MINIMUM HORIZONTAL DISTANCE FROM AUGER TO BIN WALL (TOP CLEARANCE HAS PRIORITY)
45.000 - SLOPE OF DOWNSPOUTING IF A BUCKET ELEVATOR IS PLACED IN THE BINS CENTER (DEGREES)
1.500 - HEIGHT OF FOUNDATION RING
6.000 - NUMBER OF RINGS PER BIN
2.667 - HEIGHT OF EACH STORAGE RING
17.500 - BIN EAVE HEIGHT (COMPUTED FROM ABOVE INFORMATION)
30.000 - BIN ROOF SLOPE, DEGREES
60.000 - AUGER LENGTH (USED ONLY IF IT DETERMINES CENTER RADIUS)
2.000 - DEPTH OF THE RECEIVING PIT
2.000 - DISTANCE BETWEEN WALLS OF ADJACENT BINS
12.000 - MINIMUM ACCEPTABLE DISTANCE BETWEEN TWO OF THE BINS FOR VEHICLE UNLOADING
1.000 - VERTICAL CLEARANCE BETWEEN TOP OF BIN AND THE UNLOADING AUGER DISCHARGE POINT
20.000 - MINIMUM SLOPE OF THE UNLOADING AUGER, DEGREES

BIN DIAMETER	MINIMUM FILL HGT.	MINIMUM AUGER LENGTH	REQUIRED AUGER LENGTH	CENTER RADIUS	AUGER SLOPE (DEG)	ACTUAL FILL HGT.	CHORD LENGTH	ANGLE BETWEEN BINS,D.	ARC LG. BETWEEN BINS	CENTER RADIUS CIRCUM.	FRACTION OF BINS ALLOWED	BUCKET ELEVATOR DISCHR
12	23.46	47.36	60.00	50.59	32.53	30.26	14.00	15.91	14.05	317.86	22.63	73.05
15	24.33	49.56	60.00	50.83	32.09	29.88	17.00	19.25	17.08	319.39	18.70	74.16
18	25.20	51.63	60.00	51.00	31.78	29.60	20.00	22.61	20.13	320.46	15.92	75.20
21	26.06	53.62	60.00	51.13	31.55	29.40	23.00	26.00	23.20	321.25	13.85	76.19
24	26.93	55.56	60.00	51.23	31.38	29.24	26.00	29.40	26.29	321.86	12.24	77.15
27	27.79	57.45	60.00	51.30	31.24	29.11	29.00	32.84	29.40	322.34	10.96	78.10
30	28.66	59.32	60.00	51.36	31.12	29.01	32.00	36.30	32.54	322.73	9.92	79.02
33	29.53	61.16	62.00	53.13	31.03	29.96	35.00	38.46	35.67	333.82	9.36	81.66
36	30.39	62.99	63.00	54.03	30.95	30.40	38.00	41.18	38.83	339.49	8.74	83.42
39	31.26	64.80	65.00	55.79	30.88	31.36	41.00	43.12	41.98	350.52	8.35	86.05
42	32.12	66.61	67.00	57.54	30.82	32.33	44.00	44.96	45.15	361.53	8.01	88.66
45	32.99	68.40	69.00	59.29	30.77	33.30	47.00	46.70	48.33	372.52	7.71	91.28
48	33.86	70.19	71.00	61.04	30.72	34.27	50.00	48.36	51.52	383.50	7.44	93.89

	[FIRST APPROXIMATION]			[SECOND APPROXIMATION]			FINAL DESIGN				
BIN DIAMETER	BINS ALLOWED (1ST APP)	RECEIVING ANGLE (DEGREES)	UNLOAD SPACE (1ST APP)	BINS ALLOWED (2ND APP)	RECEIVING ANGLE (DEGREES)	UNLOAD SPACE (2ND APP)]	ACTUAL BINS ALLOWED	ACTUAL UNLOAD SPACE	PER BIN CAPACITY **	FACILITY CAPACITY **	BIN DIAMETER
12	22	25.95	10.71	21	41.85	24.14]	21	24.14	1448	30401	12
15	18	32.72	13.63	17	51.97	29.54]	18	13.63	2262	40715	15
18	15	43.40	19.72	14	66.02	37.57]	15	19.72	3257	48858	18
21	13	48.04	20.62	12	74.04	40.57]	13	20.62	4433	57634	21
24	12	36.57	8.14	11	65.97	31.78]	11	31.78	5791	63696	24
27	10	64.48	27.73	9	97.31	50.03]	10	27.73	7329	73287	27
30	9	69.60	28.63	8	105.90	51.99]	9	28.63	9048	81430	30
33	9	52.30	13.83	8	90.76	42.63]	9	13.83	10948	98531	33
36	8	71.77	27.34	7	112.94	54.08]	8	27.34	13029	104231	36
39	8	58.17	15.23	7	101.28	47.27]	8	15.23	15291	122326	39
42	8	45.29	2.31	7	90.25	39.55]	7	39.55	17734	124136	42
45	7	79.79	31.05	6	126.49	60.88]	7	31.05	20358	142503	45
48	7	69.85	21.89	6	118.21	56.75]	7	21.89	23162	162137	48

* ALL UNITS OF LENGTH ARE ASSUMED TO BE THE SAME.
** 1.25*VOLUME (BUSHELS IF FEET ARE THE UNITS OF LENGTH)

and capacity are reduced when the 45 deg slope specification is used. Again, this says nothing about the power requirements and capacity of the auger at 45 deg as compared to lesser slopes. However, this design is optimum for systems in which bucket elevators are to be installed initially in that a 45 deg downspouting slope is specified. The constant auger slope of 45 deg for all diameter bins indicates that this specification is the dominant factor in determining the center radius rather than bin top clearance.

In Table 4, an 18.3 m (60 ft) portable auger is specified, the minimum slope not to be less than 20 deg. This design is similar to that given in Table 2 except that the 18.3 m (60 ft) auger governs the design until a 10.06 m (33 ft) diameter is used. The design is essentially like that in Table 2 for bins equal to or greater than 9.14 m (30 ft) in diameter.

In Table 5, the 18.3 m (60 ft) auger is extended at a minimum angle of 45 deg. This design is like that of Table 3 except the specified auger length controls the design for all bins less than 13.72 m (45 ft) in diameter. For diameters of 13.72 m (45 ft) or more, the top and horizontal clearances require a longer auger than that specified.

SUMMARY

Circular arrangements of grain drying and storage bins offer an efficient means of handling and storing grain. This arrangment is best suited to systems in which portable handling equipment is used and in which expansion beyond the inner circle of bins is not needed. Total storage capacity is very much related to the center radius. A minimum auger slope of 45 deg will give the shortest portable auger length but may result in reduced capacity or greater energy input. Using a specified auger length or delivery angle may dictate the entire design. The combinations of design considerations result in a situation more complex than would be expected initially.

TABLE 5. DESIGN SPECIFICATIONS AND CALCULATIONS WHERE A SPECIFIED AUGER LENGTH AND ELEVATIONS INFLUENCE THE CONFIGURATIONS OF SOME OF THE SYSTEMS.

DESIGN SPECIFICATIONS FOR CIRCULAR BIN ARRANGEMENTS *

1.000	MINIMUM HORIZONTAL DISTANCE FROM AUGER TO BIN WALL (TOP CLEARANCE HAS PRIORITY)
45.000	SLOPE OF DOWNSPOUTING IF A BUCKET ELEVATOR IS PLACED IN THE BINS CENTER (DEGREES)
1.500	HEIGHT OF FOUNDATION RING
6.000	NUMBER OF RINGS PER BIN
2.667	HEIGHT OF EACH STORAGE RING
17.500	BIN EAVE HEIGHT (COMPUTED FROM ABOVE INFORMATION)
30.000	BIN ROOF SLOPE, DEGREES
60.000	AUGER LENGTH (USED ONLY IF IT DETERMINES CENTER RADIUS)
2.000	DEPTH OF THE RECEIVING PIT
2.000	DISTANCE BETWEEN WALLS OF ADJACENT BINS
12.000	MINIMUM ACCEPTABLE DISTANCE BETWEEN TWO OF THE BINS FOR VEHICLE UNLOADING
1.000	VERTICAL CLEARANCE BETWEEN TOP OF BIN AND THE UNLOADING AUGER DISCHARGE POINT
45.000	MINIMUM SLOPE OF THE UNLOADING AUGER, DEGREES

BIN DIAMETER	MINIMUM FILL HGT.	MINIMUM AUGER LENGTH	REQUIRED AUGER LENGTH	CENTER RADIUS	AUGER SLOPE (DEG)	ACTUAL FILL HGT.	CHORD LENGTH	ANGLE BETWEEN BINS,D.	ARC LG. BETWEEN BINS	CENTER RADIUS CIRCUM.	FRACTION OF BINS ALLOWED	BUCKET ELEVATOR DISCHR
12	23.46	37.48	60.00	42.43	45.00	40.43	14.00	18.99	14.06	266.57	18.95	64.89
15	24.33	39.60	60.00	42.43	45.00	40.43	17.00	23.11	17.12	266.57	15.57	65.76
18	25.20	41.72	60.00	42.43	45.00	40.43	20.00	27.27	20.19	266.57	13.20	66.62
21	26.06	43.84	60.00	42.43	45.00	40.43	23.00	31.45	23.29	266.57	11.45	67.49
24	26.93	45.96	60.00	42.43	45.00	40.43	26.00	35.69	26.43	266.57	10.09	68.35
27	27.79	48.08	60.00	42.43	45.00	40.43	29.00	39.97	29.60	266.57	9.01	69.22
30	28.66	50.20	60.00	42.43	45.00	40.43	32.00	44.31	32.81	266.57	8.12	70.09
33	29.53	52.33	60.00	42.43	45.00	40.43	35.00	48.72	36.08	266.57	7.39	70.95
36	30.39	54.45	60.00	42.43	45.00	40.43	38.00	53.21	39.40	266.57	6.77	71.82
39	31.26	56.57	60.00	42.43	45.00	40.43	41.00	57.79	42.79	266.57	6.23	72.68
42	32.12	58.69	60.00	42.43	45.00	40.43	44.00	62.47	46.26	266.57	5.76	73.55
45	32.99	60.81	61.00	43.13	45.00	41.13	47.00	66.02	49.70	271.02	5.45	75.12
48	33.86	62.93	63.00	44.55	45.00	42.55	50.00	68.28	53.09	279.90	5.27	77.40

	[FIRST APPROXIMATION		] [SECOND APPROXIMATION			]	FINAL DESIGN				
BIN DIAMETER	BINS ALLOWED (1ST APP)	RECEIVING ANGLE (DEGREES)	UNLOAD SPACE (1ST APP)	BINS ALLOWED (2ND APP)	RECEIVING ANGLE (DEGREES)	UNLOAD SPACE (2ND APP)	]	ACTUAL BINS ALLOWED	ACTUAL UNLOAD SPACE	PER BIN CAPACITY **	FACILITY CAPACITY **	BIN DIAMETER
12	18	37.11	15.00	17	56.10	27.90	]	18	15.00	1448	26058	12
15	15	36.40	11.50	14	59.51	27.11	]	14	27.11	2262	31667	15
18	13	32.81	5.96	12	60.07	24.47	]	12	24.47	3257	39086	18
21	11	45.46	11.78	10	76.91	31.77	]	10	31.77	4433	44334	21
24	10	38.82	4.20	9	74.51	27.37	]	9	27.37	5791	52115	24
27	9	40.25	2.19	8	80.21	27.66	]	8	27.66	7329	58630	27
30	8	49.82	5.74	7	94.13	32.12	]	7	32.12	9048	63335	30
33	7	67.67	14.25	6	116.39	39.11	]	7	14.25	10948	76635	33
36	6	93.95	26.03	5	147.16	45.39	]	6	26.03	13029	78173	36
39	6	71.06	10.31	5	128.85	37.54	]	5	37.54	15291	76454	39
42	5	110.12	27.56	4	172.59	42.68	]	5	27.56	17734	88668	42
45	5	95.90	19.06	4	161.93	40.20	]	5	19.06	20358	101788	45
48	5	86.89	13.27	4	155.17	39.01	]	5	13.27	23162	115812	48

* ALL UNITS OF LENGTH ARE ASSUMED TO BE THE SAME.

** 1.25*VOLUME (BUSHELS IF FEET ARE THE UNITS OF LENGTH)

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