CHAPTER II

THEORETICAL CONSIDERATIONS

The analysis of conical rice bin made by Kanoknukulchai (16) was summarized as the followings.

2.1 Physical Details of Conical Rice Bin

A conical rice bin, as shown in Fig. (1), consists of two conical shells joined at their outer edges by a ring girder of radius R_2 and cross-sectional area A_b. The bottom cone is completed with a semi-vertex angle α_b and a thickness h_b, while the top cone is truncated with a semi-vertex angle α_t and a thickness h_t. The ring girder at the top edge of the top frustum cone has a radius of R_1 and cross-sectional area A_t.

Two sets of orthogonal co-ordinates : y, θ and z for the top cone, and $\bar{y}$, $\bar{\theta}$ and $\bar{z}$ for the bottom cone are shown in Fig. (1). The co-ordinates y and $\bar{y}$ are extended along the generators from the apexes of the top and bottom cones respectively. The value of $\bar{y}$ at the outer edge of the bottom cone is denoted by y_o, i.e., $y_o = R_2/\sin\alpha_b$, likewise, y_1 and y_2 denote the values of y at the inner and outer edges of the top cone, i.e., $y_1 = R_1/\sin\alpha_t$ and $y_2 = R_2/\sin\alpha_t$ respectively.

The following conventions concerning the use of subscripts and superscripts should be noted. The subscripts t and b are designed to functions belonging to the top and bottom cones respectively, F to the ring girders, and o and i to those at the outer and inner edges of a cone respectively. The superscripts p and c denote the membrane and bending parts of the total solution respectively.

2.2 Method of Analysis of Conical Rice Bin.

The conical rice bin had been analyzed by Kanoknukulchai (16). Initially, the shell will be treated, under the applied loading, as a membrane (25). Under such conditions, the statically determinate stress resultants in each cone can be obtained without dependence on their geometric continuities. A consideration is then given to the effects of the statically indeterminate forces and couples which must exist at the edges of each cone to preserve the continuity. This can be done by applying the corrective shearing forces and couples in the bending analysis. Finally, by combining both parts of the solution, the total solution of the bin are obtained. Figure (2) shows the scheme of the approach.

In the analysis, it is assumed that the contact pressure of the foundation is uniformly distributed over a horizontal projection of the bottom cone of the bin. Thus, the contact pressure p_r is determined by dividing the total vertical loads by the area of the plane circle of radius R_2.

2.2.1 Membrane Solution The membrane solution has been carried out in Ref. (16) for the structure under various kinds of loads ; the dead load of the bin, the vertical live load on the top edge of the bin, and the pressure of water. The solutions are shown in Tables (1), (2) and (3). The notations and conventions of all forces and stress resultants following those in Ref. (25) are shown in Fig. (3). All other notations, parameters and arguments are defined in the list of symbols.

2.2.2 Bending Solution The governing equations, for the general case of bending due to boundary loads applied uniformly along the edges of a conical shell, have been derived and solved in Ref. (11). The solutions interms of Kelvin functions are presented in Ref. (16), and are again shown in Table (4). The notations and conventions of all stress resultants and displacements following those in Ref. (25) are shown in Fig. (4). All other notations, functions, parameters and arguments are defined in the list of symbols.

2.2.3 Total Solution In obtaining the total solution by a superposition of the membrane and bending solutions, the horizontal radial edge forces H_{ti}, H_{to} and H_{bo} and the interacting edge couple M_o as shown in Fig. (5) are first determined from the kinematic boundary and continuity conditions as shown in Ref. (16), Eqs. (54) to (57). Once the values of H_{ti}, H_{to}, H_{bo} and M_o are determined, the bending solution is completed and the total solution can be obtained by an appropriate super-position of the membrane and bending solutions.

2.3 Plate Analysis of Bin Lid.

A circular bin lid of radius a_2 and thickness h, seated on a ring support of radius a_1, may be analysed as a thin plate subjected to a uniformly distributed load q.

Employing polar coordinates (r, θ), with the origin of r at the plate center, and letting $w_1(r)$ and $w_2(r)$ denote the plate deflection for the domain $0 \leq r < a_1$ and $a_1 < r < a_2$ respectively, the axisymmetrical bending solution abtained in Ref. (16), shown below :

$$w_1(r) = \frac{qa_1^4}{64D}\left\{\frac{r^4}{a_1^4} - \left[4\left(\frac{1-\nu}{1+\nu}\right)+2\left(\frac{1+3\nu}{1+\nu}\right)\frac{a_2^2}{a_1^2} - \frac{8a_2^2}{a_1^2}\log\frac{a_2}{a_1}\right]\frac{r^2}{a_1^2} + \left[\left(\frac{3-5\nu}{1+\nu}\right) + 2\left(\frac{1+3\nu}{1+\nu}\right)\frac{a_2^2}{a_1^2} - \frac{8a_2^2}{a_1^2}\log\frac{a_2}{a_1}\right]\right\}$$

$$w_2(r) = \frac{qa_1^4}{64D}\left\{\frac{r^4}{a_1^4} - \left[4\left(\frac{1-\nu}{1+\nu}\right)+2\left(\frac{5+7\nu}{1+\nu}\right)\frac{a_2^2}{a_1^2} - \frac{8a_2^2}{a_1^2}\log\frac{a_2}{a_1}\right]\frac{r^2}{a_1^2}\right.$$

$$\left. + \left[\left(\frac{3-5\nu}{1+\nu}\right) + 2\left(\frac{1+3\nu}{1+\nu}\right)\frac{a_2^2}{a_1^2} - \frac{16a_2^2}{a_1^2}\log\frac{a_2}{a_1}\right] - \frac{8a_2^2}{a_1^2}\frac{r^2}{a_1^2}\log\frac{r}{a_1}\right\} .$$

2.4 Design Example of Conical Rice Bin.

The bin, as shown in Fig. (6), is designed for water loading which is more critical than the loading of rice grain and the vertical live load on the top edge of the bin and the bin lid. The bin has a storage capacity of 3.5 metric tons of rice (bulk density = 630 kg/cu.m.), a volume capacity = 5.57 cu.m., a surface area of revolution = 17.15 sq.m, R_1 = 38 cm. and R_2 = 136 cm. The topmost level of the bin is 175 cm. above ground and the bottommost level is 50 cm. below ground.

The designed bamboocement conical section, the top and bottom ring girders and the bin lid are shown in Fig. (6). The gross area of the top and bottom ring girders, A_t and A_b are 50.00 sq.cm. and 45.00 sq.cm. respectively. The mortar used has a cement-sand ratio of 1:2 by weight, and a water-cement ratio of 0.45. The properties of materials used in the analysis are shown in Table (5), the properties of bamboocement are determined by the formulae listed in

Appendix - C . This design bases on the distributions of the stress resultants along the shell domains due to the dead weight of the bin the edge load of the bin and the loading of water obtained in Figs (7), (8). The edge displacement, ring forces and uniform contact pressure of the foundation due to combination of loading cases are shown in Table (6a). The forces and stresses in bin cap (circular plate) are shown in Table (6b). Stresses in the extreme fibers and in the skeletal bamboos at some critical sections are calculated by the technique discussed in Appendix - C. The most severe tensile stress in bamboocement is found to be 27 kg/sq.cm. occuring at the outer fiber of the section $\bar{y}/y_o$ = 0.90 in the longitudinal direction. The most severe compressive stress is 152.27 kg/sq.cm. at the inner extreme fiber of the section $\bar{y}/y_o$ = 0.90 in the longitudinal direction. The maximum stress in the skeletal bamboo is 359.57 kg/sq.cm. at the section $\bar{y}/y_o$ = 0.90 in the longitudinal direction. Comparing these values with the yield strengths of the design section, the bamboocement has been loaded up to 96 percent in tension and to 50 percent in compression, of the yield strengths. It should be noted that this maximum stress in compression is 94 percent of the conventional allowable compressive stress corresponding to 0.45 f_c' . The skeletal bamboo has been loaded up to 19 percent of its yield strength and 39 percent of its allowable strength. Shown the limiting stresses at yield condition and allowable condition in Table (7). The tensile stress, compressive stress in bamboocement and stress in the skeletal bamboo of any sections along the shell domains are shown in Table (8) in longitudinal direction and in Table (9) in circumferential direction.