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APPENDIX A - COMPARISON OF BIN LOADS

Water was used for the loading during the experimental work of this research, so, the designed bin was investigated by the comparison of the loadings as a result of water and grained stored.

Using the principle of pressure, it was abtained by Rankine's method, Janssen's method (14), and this study is guided by Ref. (16).

<u>For water</u>, the water pressure P_w in kg per sq.cm. is the following

$$\gamma_w = 0.001 \text{ kg per cu.cm.}$$

$$\alpha_t = 29.15^\circ$$

$$y_1 = 77.70 \text{ cm.}$$

At a depth

$$h = (y-y_1) \cos\alpha_t$$

$$= (y-77.70) \cos 29.15^\circ$$

$$P_w = \gamma_w h$$

$$= 0.001 (y-77.70) \times 0.87334$$

$$P_w = 0.00087 (y-77.70) \qquad (1)$$

<u>For grain</u>, the horizontal pressure is obtained by Rankine's method as follows : $P_h = K \gamma_r h$

γ_γ = 0.00063 kg per cu.cm.

φ = 26°

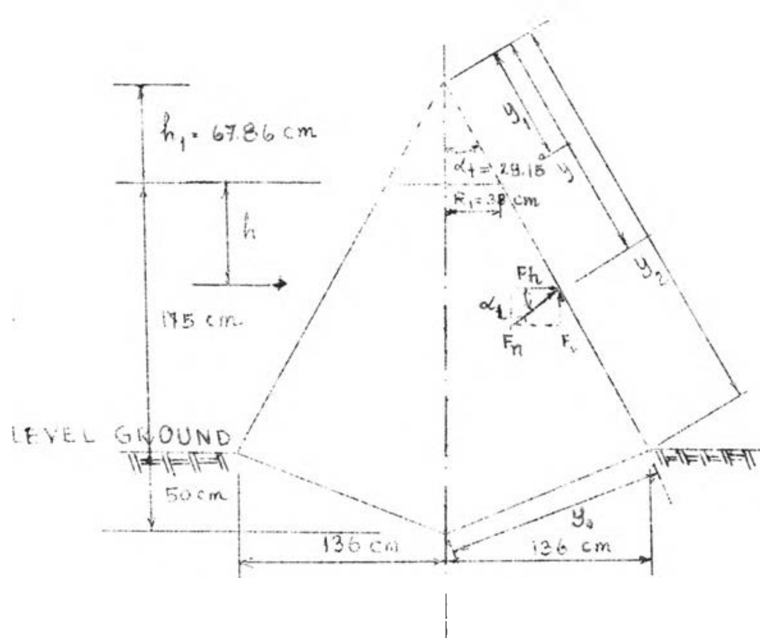
φ' = 24°

$$K = \frac{\cos^2(\varphi + \alpha_t)}{\cos\alpha_t\,(\cos\alpha_t + \sin\varphi)^2}$$

$$K = \frac{\cos^2(26^\circ + 29.15^\circ)}{\cos 29.15^\circ(\cos 29.15^\circ + \sin 26^\circ)^2}$$

$$= 0.22$$

The normal pressure P_n on the wall is obtained from the following



Geometry of Conical Rice Bin

$$F_h = P_h . h \qquad (a)$$

$$F_v = P_v . h . \tan\alpha_t \qquad (b)$$

From Static Equilibrium, $\Sigma F_n = 0$

$$F_n + F_h \cos\alpha_t + F_v \sin\alpha_t = 0 \qquad (c)$$

Substituting Equs (a) and (b) into Eq. (c) leads to

$$F_n = -(P_h . h \cos\alpha_t + P_v . h \frac{\sin^2\alpha_t}{\cos\alpha_t})$$

$$= -\frac{h}{\cos\alpha_t}(P_h . \cos^2\alpha_t + P_v \sin^2\alpha_t)$$

$$-F_n / \frac{h}{\cos\alpha_t} = P_h \cos^2\alpha_t + P_v \sin^2\alpha_t$$

$$P_n = P_h \cos^2\alpha_t + P_v \sin^2\alpha_t \qquad (d)$$

in which the vertical pressure at the point considered

$$P_v = \gamma_r . h$$

substituting P_h and P_v in to Eq. (d) leads to

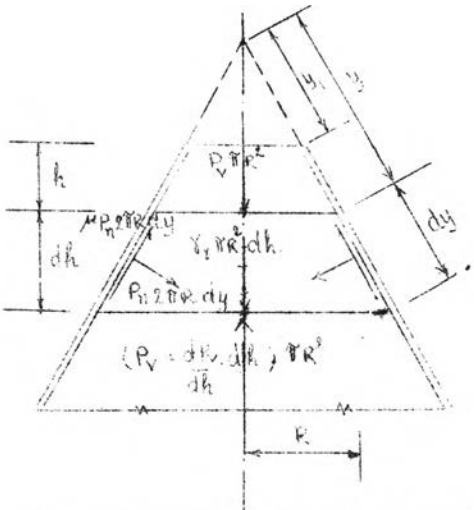
$$P_n = \gamma_r . h (K \cos^2\alpha_t + \sin^2\alpha_t) \qquad (e)$$

substituting the values of γ_r and K for rice in Eq.(e), in view of $h = (y-y_1)\cos\alpha_t$, leads to

$$P_n = 0.00063(y-77.70)\cos 29.15^\circ$$
$$.(0.22 \cos^2 29.15^\circ + \sin^2 29.15^\circ)$$

$$P_n = 0.00025 (y - 77.70) \qquad (2)$$

According to Janssen's method in deriving the pressure distribution of the grain,



Lamina of Grains in Equilibrium

Cosider a circular lamina of grain at the depth h below the top of the bin under the normal and friction forces, as shown above Figure Summation of the Vertical forces leads to the governing equation of the grain pressure in the bin as.

$$\frac{dP_v}{dh} - \frac{2K_n\ (1-\mu\cot\alpha_t)\ P_v}{h} = \gamma_r \qquad (f)$$

in which $\mu = \tan\varphi'$ and $K_n = \frac{P_n}{P_v} = K\cos^2\alpha_t + \sin^2\alpha_t$

Solving Eq. (f) in view of the boundary condition $P_v = 0$ for $h = 0$ leads to

$$P_v = \frac{\gamma_r \, y \cos\alpha_t}{\eta} \left[1 - \left(\frac{y_1}{y}\right)^{\eta} \right]$$

Hence, $$P_n = K_n P_v = \frac{K_n \gamma_r \, y \cos\alpha_t}{\eta} \left[1 - \left(\frac{y_1}{y}\right)^{\eta} \right] \qquad (g)$$

in which $\eta = 1 - 2K_n (1-\mu \cot\alpha_t)$ applying Eq. (g) to the bin consider leads to

$$P_n = 0.00028 \, y \left[1 - \left(\frac{77.70}{y}\right)^{0.847} \right] \qquad (3)$$

The graphs representing the normal pressure in (2) and (3) are almost indistinguishable and are compared with that of water pressure in Fig. (A). It is obvious that the normal pressure on the bin wall due to water is always greater than that due to rice grain.

When the season of harvest has pass the rice bin could be used to store water instead of the rice grain, this is reason of using the water is loading.

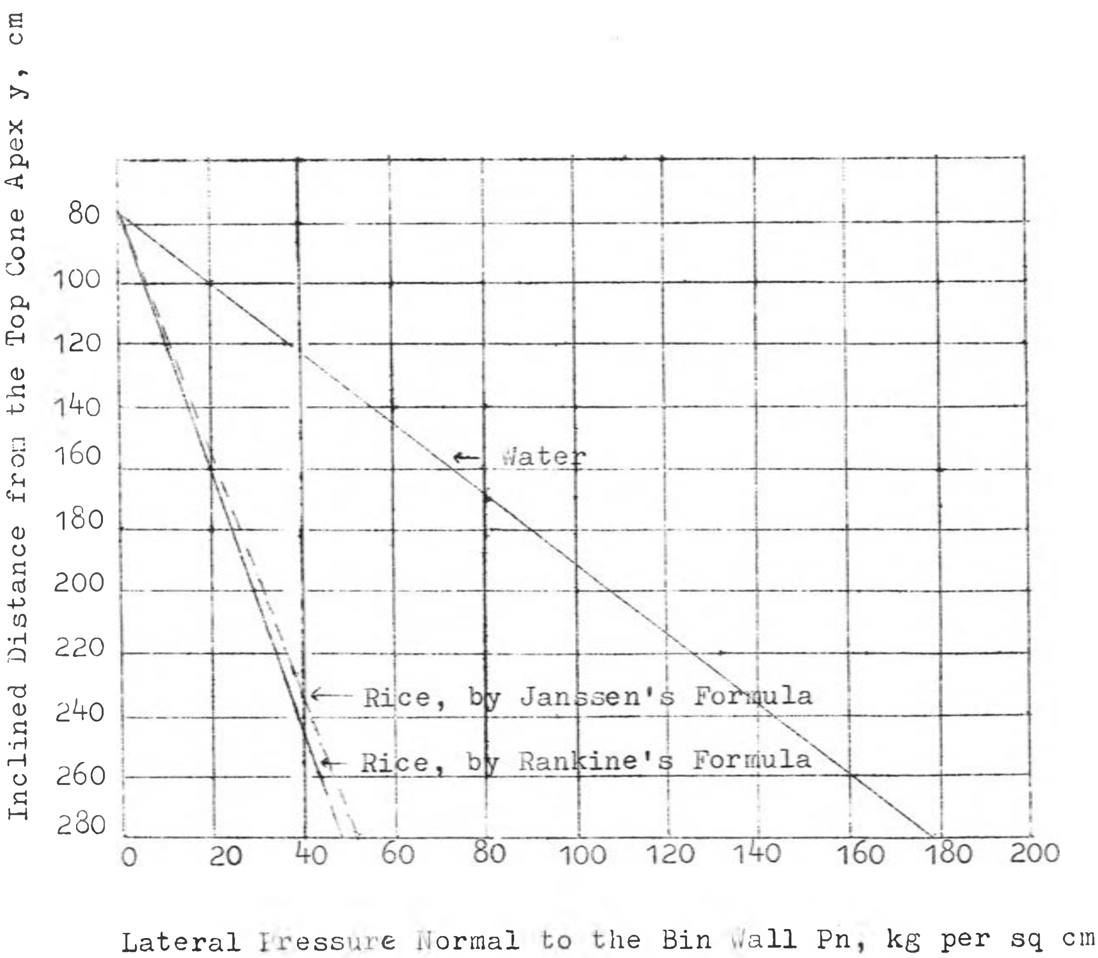


FIG (A) - COMPARISON OF LATERAL PRESSURES DUE TO WATER AND RICE GRAIN

APPENDIX B - MECHANICAL PROPERTIES OF BAMBOO

Bamboo is a native plant of tropical and sub-tropical areas and is defined as a parennial grass belonging to the monocotyledoneae class. According to AUSTIN and UEDA (1972) Ref. 5, about 1250 Species of bamboo are known to exist in the world. Although it is really grass, some species grow as tall as trees, being usually 40 or 50 or sometimes 100 or more feet tall, which diameter up to 12 inches or more.

Bamboo can be classified into main groups according to its growth pattern namely, sympodial and monopodial as shown in Fig. (B-1). The structure of an individual bamboo culm, shown in Fig. (B-2), is divided into nodes and inter-nodes. The greatest amount of meristematic tissue for the elongation of the internode is found just above the node. The internodal tissue is made up of parenchymal cells and vascular bundles with the latter consisting of vessels, thick wall fibres, and sieve tubes. The water movement take - place through the vessels, the fibres being primarily responsible for the strength of the bamboo.

The purpose of this review and investigation is to study the behaviour of bamboo as related to its use as reinforcement and formwork for rice bins, Pai Ruak (Thyrsostachys oliveri Gamble) a common cheap variety of bamboo found in Thailand will be used in this investigations.

H.E. GLENN (1950) reported that the average maximum tensile strength of all varieties and species was about 37,500 psi (2,637 ksc) between nodes and about 32,500 psi (2,285 ksc) at the node, the average modulus of elasticity of the several species and varieties of species shows a low value of slightly over 2.0×10^6 psi (140,628 ksc) and a high value of over 4.5×10^6 psi (316,414 ksc) with individual species and varieties of species falling well between these limits and the ultimate bond stress between concrete and bamboo ranged from a high of approximately 350 psi (25 ksc) to a low of zero psi.

S.R. MEHRA, H.L. UPPAL and L.R. CHADDA (1951) determined the tensile strength of Indian Varieties of bamboo as 14,000 psi (984 ksc) and its modulus of elasticity as 2.4×10^6 psi (168,754 ksc).

MESSRS. KENNETH L. SAUCIER and FRANKS STEWART (1964) observed the ultimate tensile strength and modulus of elasticity of bamboo as 9480 psi (667 ksc) and 1.86×10^6 psi (130,784 ksc) respectively and attributed these low values to difference in bamboo species, age and condition of specimens.

ROBERT J. MENTZINGER and RODNEY P. PLOURDE (1966) reported that the average values of tensile strength for varnish and sealer-treated samples 16,710 psi (1175 ksc) and 17,780 psi (1250 ksc) respectively differed from the tensile strength of the untreated samples 17,910 psi (1259 ksc) by only 6.7 % and 0.75 % respectively, both small deviations when one considers the non-homogeneity of bamboo. In addition, considering the fact that the tensile strengths obtained by other researchers have varied between 14,000 psi (984 ksc) and 37,500 psi (2,637 ksc), it can be concluded that the tensile strength of bamboo was not significantly effected by treatment, the average elastic modulus of the untraeted samples was calculated to be 2.03×10^6 psi (142,738 ksc). The varnish-treated samples had a greater average elastic modulus value, 2.7×10^6 psi (189,848 ksc), while the sealer-treated samples had a lower average elastic modulus value of 1.78×10^6 psi (125,159 ksc) and the sealer-treated bond strengths averaged 104.5 psi (7.35 ksc), compared to the untreated bond strength average of 35 psi (2.46 ksc) varnish too was proven to be an effective water proofing treatment, averaging 43.3 psi (3.04 ksc) without being coated with an abrasive, and 55.7 psi (3.92 ksc) when coated with an abrasive.

HELMUT G. GEYMAYER and FRANK B. COX (1969) determined the tensile strength of bamboo varies greatly with the type and the condition of the specimen tested values as high as 53,894 psi (3790 ksc) and as low as 5550 psi (390 ksc) have been reported for individual culm. For the design of bamboo reinforced concrete members, a value for the elastic modulus of 2.0 x 10^6 psi (140,614 ksc) is tentatively suggested. However, for deflection calculations, it appears advisable to use a reduced modulus [tentatively 1.5 x 10^6 psi (105,860 ksc)] For individual bond strength values given in literature for different bamboo specimens obtained in pullout tests on whole, seasoned and unseasoned, treated and untreated culms vary between 0 and 350 spi (24.61 ksc), with average ranging between 3.5 and 168 psi (2.5 and 11.81 ksc). They suggested that the coefficients of thermal expansion of bamboo are are not compatible with that of concrete. Tests on local small cane averaging approximately 26.00 x $10^{-6}/o_F$ (46.8 x $10^{-5}/o_C$) across the fibers and 2.00 x $10^{-6}/o_F$ (3.6 x $10^{-6}/o_C$) parallel to their fibers, and poisson's ratios of whole, indigenous, small cane culms ranged between 0.25 and 0.41, the average being about 0.32, very close to the values assumed for most other construction materials.

ALI ZAHID (1974) suggested that the ultimate tensile strength for internodal and nodal section ranges from 37,400 psi (2630 ksc) to 73,300 psi (5154 ksc) and 23,900 psi (1680 ksc) to 39,700 psi (2791 ksc) respectively. The modulus of elasticity in tension varies from 2.87 x 10^6 psi (201,801 ksc) to 4.40 x 10^6 psi (309,382 ksc). An average tensile strength and modulus of elasticity of 34,000 psi (2391 ksc) and 3.6 x 10^6 psi (253,131 ksc) respectively may be assumed for use in design, and average bond stress was found to be 161 psi (11.32 ksc) and the embedment length was 7.23 inches.

A.H.M. ABU SADEQUE (1975) said that both nodal and inter-nodal samples were tested and it was found that the inter-nodal specimens. The modulus of elasticity does not vary consistently with its strength. The mean, standard deviation and co-efficint of variation for tensile strength of all the nodal specimens were found to be 25,860 psi (1818 ksc), 2570 psi (181 ksc) and 9.94 % while for the modulus of elasticity these quantities are 4.36 x 10^6 psi (306,570 ksc), 0.48 x 10^6 psi (33,751 ksc) and 11.07 % respectively. The specimen with the node inside the concrete block showed higher bond strength than the internal specimens. None of the specimens were subjected to any treatment to improve its bond strength. The average bond strength was found to be approximately 64 psi (4.5 ksc).

AHMAD JAN DURRANI (1975) suggested that Pai Ruak variety of bamboo has an average tensile strength of about 19,000 psi (1336 ksc) at nodes and 24,000 psi (1687 ksc) between the nodes, the average value for the modulus of elasticity is approximately 2.1 x 10^6 psi (147,660 ksc) and the bond strength of plane, unsoaked seasoned bamboo with the node is approximately fifty per cent higher than that of specimens with-out node. The bond stress decrease as the soaking period for bamboo is increased. Deposition of sand on epoxy coated surface of bamboo effectively increase the bond stress. Wire wrapping of bamboo does not increase the bond. He suggested that average bond stress is approximately 180 psi (12.66 ksc) at the node.

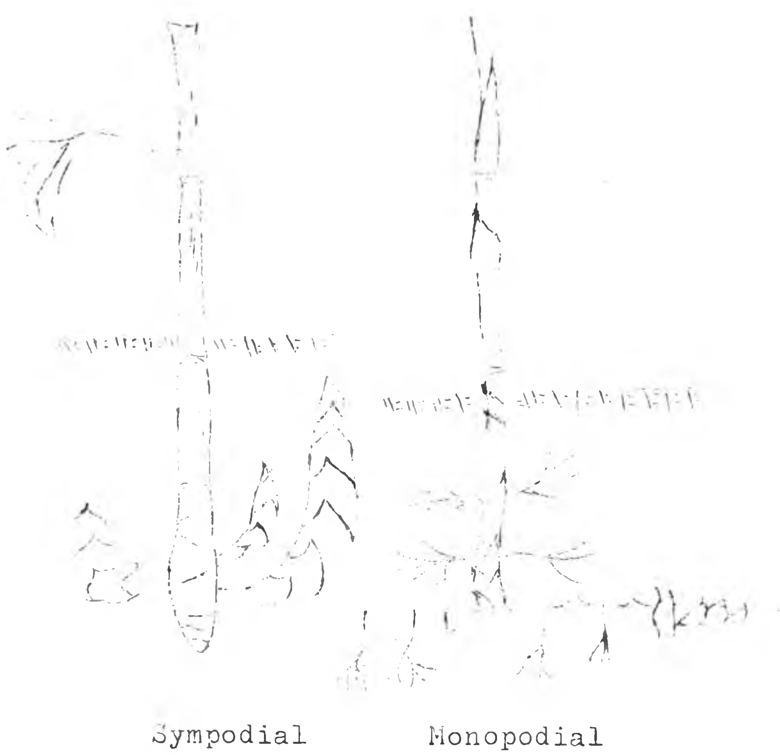


FIG (B-1)-GROWTH PATTERNS OF-BAMBOO

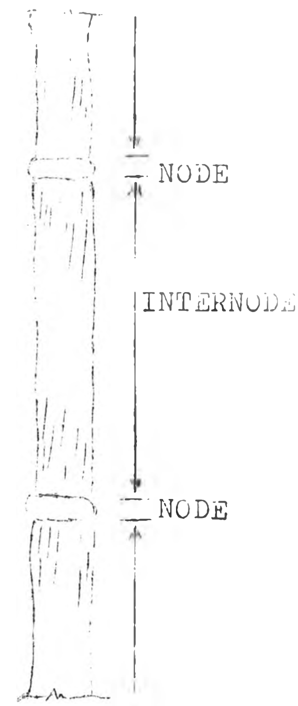


FIG (B-2) DETAILS OF BAMBOO CULM

APPENDIX C - MECHANICAL PROPERTIES OF BAMBOO-CEMENT

The purpose of this investigation is to study the mechanical properties of bamboo-cement, which is used in the construction of the rice bin.

It will be assumed that the bamboo-cement is a composite material which the bamboo fibres are firmly bonded to the cement mortar matrix so that no slippage occurs at the surface of the fibres. The load acting on a composite section per unit area carried by the matrix and N types of fibres oriented at an angle with the loading direction are expressed as the followings.

<u>Modulus of Elasticity for Uncracked Bamboocement.</u> Using the principle of composite material, it is obtained in Ref. (7) that

$$E_{c1} = E_{m1} \cdot Vm_1 + \frac{V_f}{\lambda_1} \sum_{i=1}^{N_1} F_{1i}^4 \; E_{1i} \alpha_{1i} \qquad (1)$$

$$E_{c2} = E_{m2} \cdot V_{m2} + \frac{V_f}{\lambda_2} \sum_{i=1}^{N_2} F_{2i}^4 \; E_{2i} \alpha_{2i} \qquad (2)$$

where E_{c1}, E_{m1} and E_{1i} are the moduli of elasticity of the composite, matrix and fibre i respectively in the upper part and E_{c2}, E_{m2} and E_{2i} the corresponding values in the lower part, F_{1i}, N_1 and α_{1i} are the direction cosine of fiber i with the direction of loading, the total number of fibres and the volume of fibre i divided by the total volume of the fibres in the upper part of the segment respectively, F_{2i}, N_2 and α_{2i} the corresponding values in the lower part.

The parameters λ_1 and λ_2 denote the length fractions of the upper and lower parts of a typical segment.

V_{m1} and V_{m2} which are also the volume fraction of the matrix in the upper and lower parts of the segment that

$$V_{m1} = 1 - \frac{V_f}{\lambda_1} \sum_{i=1}^{N_1} \alpha_{1i} \qquad (3)$$

$$V_{m2} = 1 - \frac{V_f}{\lambda_2} \sum_{i=1}^{N_2} \alpha_{2i} \qquad (4)$$

For a typical segment, the effective modulus of elasticity of composite E_c can be obtained by considering the strain of each part, thus

$$\frac{1}{E_c} = \frac{\lambda_1}{E_{c1}} + \frac{\lambda_2}{E_{c2}}$$

and

$$E_c = E_{c1} \left[\frac{1}{\lambda_1 + \lambda_2 \left(\frac{E_{c1}}{E_{c2}}\right)} \right] \qquad (5)$$

In this case $\lambda_1 = \lambda_2 = 0.5$

$$E_{1v} = E_{2v} = E_{1H} = E_{2H} = E_f$$

$$E_{m1} = E_{m2} = E_m$$

$$F_{1v} = F_{2v} = 0$$

$$F_{1H} = F_{2H} = 1$$

$$N_1 = N_2 = 2$$

$$\alpha_{1v} = \alpha_{2v} = \alpha_{1H} = \alpha_{2H} = \frac{1}{2}$$

Subscripts V and H denote the direction in vertical and Horizontal fibres respectively, substituting this values in Eque (1), (2), (3), (4) and (5) leads to follows :

$$E_{c1} = E_m V_{m1} + 0.5 E_f V_f \qquad (6)$$

$$E_{c2} = E_m Vm_2 + 0.5 E_f V_f \qquad (7)$$

$$V_{m1} = 1 - 0.5 V_f \qquad (8)$$

$$V_{m2} = 1 - 0.5 V_f \qquad (9)$$

$$E_c = E_{c1} \left[\frac{2}{1 + \frac{E_{c1}}{E_{c2}}} \right] \qquad (10)$$

Modulus of Elasticity for Cracked Bamboo-cement.

Introducing an empirical factor β_m for the reduced contribution of the mortar in the cracked range, from Ref. (21), the modulus of elasticity of bamboo-cement may be written as in Eqs. (6) and (7) as follows :

$$E_{t1} = \beta_m E_m V_{m1} + 0.5 E_f V_f \qquad (11)$$

$$E_{t2} = \beta_m E_m V_{m2} + 0.5 E_f V_f \qquad (12)$$

in which E_{t1} and E_{t2} denote the modulus of elasticity for the lower and upper part in the cracked range. By curve fitting, it was found that β_m varies linearly with V_f and the expression obtained is

$$\beta_m = .001 + 0.543 V_f \qquad (13)$$

Similarly, in the cracked range the effective modulus of elasticity E_t for a typical segment becomes

$$E_t = E_{t1} \left[\frac{2}{1 + \frac{E_{t1}}{E_{t2}}} \right] \qquad (14)$$

Modulus of shear Rigidity for uncracked Bamboo-cement.

Using the principle of composite material, it is obtained in Ref. (27) that

$$G_{c1} = G_{m1} V_{m1} + \frac{V_f}{\lambda_1} \sum_{i=1}^{N_1} F_{1i}^2 (1-F_{1i}^2) E_{1i} \alpha_{1i} \qquad (15)$$

$$G_{c2} = G_{m_2} V_{m2} + \frac{V_f}{\lambda_2} \sum_{i=1}^{N_2} F_{2i}^2 (1-F_{2i}^2) E_{2i} \alpha_{2i} \qquad (16)$$

Where G_{c1} and G_{m1} denote the modulus of shear rigidity of the composite and matrix respectively for the upper part of the typical segment. The corresponding values in the lower part are G_{c2} and G_{m2}. Similarly, the effective modulus of shear rigidity G_c of a typical segment is obtained as in Eq (5) in which

$$G_c = G_{c1} \left[\frac{1}{\lambda_1 + \lambda_2 \left(\frac{G_{c1}}{G_{c2}}\right)} \right] \qquad (17)$$

In this case $\lambda_1 = \lambda_2 = 0.5$

$$E_{1v} = E_{2v} = E_{1H} = E_{2H} = E_f$$

$$G_{m1} = G_{m2} = G_m$$

$$F_{1v} = F_{2v} = 0$$

$$F_{1H} = F_{2H} = 1$$

$$N_1 = N_2 = 2$$

$$\alpha_{1v} = \alpha_{2v} = \alpha_{1H} = \alpha_{2H} = \frac{1}{2}$$

Substituting in this values in Eqs. (15), (16) and (17) leads to follows.

$$G_{c1} = G_m V_{m1} \tag{18}$$

$$G_{c2} = G_m V_{m2} \tag{19}$$

$$G_c = G_{c1} \left[\frac{2}{1 + \frac{G_{c1}}{G_{c2}}} \right] \tag{20}$$

Modulus of shear Rigidity for cracked Bamboo-cement.

Introducing another empirical factor φ_m for the reduced contribution of the mortar in the cracked range, the modulus of shear rigidity can be obtained from Eqs. (18) and (19) as follows :

$$G_{t1} = \varphi_m G_m V_{m1} \tag{21}$$

$$G_{t2} = \varphi_m G_m V_{m2} \tag{22}$$

in which G_{t1} and G_{t2} denote the modulus of shear rigidity for the lower and upper part in the cracked range, the value of φ_m used in this investigation is taken to be equal to β_m expressed in Eq. (13). Similarly, the effective modulus of shear rigidity G_t of a typical segment in the cracked range is

$$G_t = G_{t1} \left[\frac{2}{1 + \frac{G_{t1}}{G_{t2}}} \right] \qquad (23)$$

Poisson's Ratio of Bamboo-cement. By definition, Poisson's ratio ν_c is the ratio of the lateral strain to the longitudinal strain. This is expressed in terms of the modulus of elasticity and the modulus of shear rigidity, thus

$$\nu_c = \frac{E_c}{2G_c} - 1 \qquad (24)$$

Ultimate Strength in Axial Tension and Compression of Bamboo-cement. When fibres of relatively high strength and modulus are embeded in a brittle matrix, the ultimate strength of composite is derived from the ultimate strength of fibres only, it is found in Ref.(21), the ultimate tensile strength of bamboo-cement is

$$\sigma_{tu1} = \frac{V_f}{\lambda_1} \sum_{i=1}^{N_1} F_{1i}^2 \alpha_{1i} \sigma_{1i} \tag{25}$$

$$\sigma_{tu2} = \frac{V_f}{\lambda_2} \sum_{i=1}^{N_2} F_{2i}^2 \alpha_{2i} \sigma_{2i} \tag{26}$$

in which σ_{1i}, σ_{2i}, σ_{tu1} and σ_{tu2} are the ultimate tensile strength of fibre i and the ultimate tensile strength of bamboo-cement in the upper and lower part of the segment respectively.

Substituting $\sigma_{1i} = \sigma_{2i} = \sigma_{ty}$ = the tensile yield strength of the fibre bamboo in Eqs. (25) and (26) leads to

$$\sigma_{tu1} = \sigma_{tu2} = 0.5 V_f \sigma_{fy} \tag{27}$$

In axial compression, the ultimate compressive strength of bamboo-cement is controlled by mortar only and is given in Ref. (21) as

$$\sigma_{cu1} = 0.85 f_c' V_{m1} \tag{28}$$

$$\sigma_{cu2} = 0.85 f_c' V_{m2} \tag{29}$$

in which σ_{cu1}, σ'_{cu2}, σ_{m1} and σ_{m2} are the ultimate compressive strength of bamboo-cement and the crushing strength of the mortar are assumed to be equal to $0.85\ f'_c$ in the upper and lower part of the segment respectively.

<u>In plane Force and Couple in Bamboo-cement Section in Terms of Fiber stress.</u> The Sections, as shown in Figs (C-1) and (c-2), consist of a skeletal grid of bamboo bars, sandwiched at center by two layers of bamboo-cement. The volume fractions of fibre bamboo and mortar are V_f and V_m respectively. The skeletal Bamboo has a diameter = d and bamboo area = As per unit width. The stress distributions, as shown in Figs (c-1) and (c-2) are bilinear. The neutral axes lie at h_c from the compressive extreme fiber. The strain distributions are linear as long as shear distortion in the sections is not permitted.

(a) Stress resultants in longitudinal - In this case, As is the area of the bottom most layer of the skeletal bamboo Fig (c-1). If the section is loaded until the tensile and compressive extreme fiber stresses are σ_t and σ_c respectively, the summations of forces and moments lead to

$$P = T_s + \frac{1}{2}\sigma_t(h-h_c)\left[1-\frac{(\frac{h}{2}+\frac{3d}{2}-h_c)^2}{(h-h_c)^2}\right] - \frac{1}{2}\sigma_c h_c \quad (30)$$

and

$$M+\frac{P(h-2h_c)}{2} = \frac{1}{3}\sigma_c h_c^2 + \frac{1}{3}\sigma_t(h-h_c)^2\left[1-\frac{(\frac{h}{2}+\frac{3d}{2}-h_c)^3}{(h-h_c)^3}\right].$$

$$+ T_s\left(\frac{h}{2}+d-h_c\right) \quad (31)$$

in which P and M = resultant in-plane force and couple, T_s = the resisting force in the bottommost layer of the skeletal bamboo = $E_b\,\epsilon_s\,A_s$; h = thickness of the bamboo-cement section. Using the compatibility between the bamboo-cement and skeletal bamboo, T_s is obtained as

$$T_s = \lambda n A_s \frac{(\frac{h}{2}+d-h_c)}{(h-h_c)} \quad (31)$$

in which $\lambda = \frac{E_c}{E_t}$ and $n = \frac{E_b}{E_c}$ Substituting Eq. (31) into Eqs. (30) and (31) and simplifying lead to respectively.

$$2\bar{P} = \sigma_t(1-\alpha_c)(1-r_1) - \sigma_c\alpha_c + \lambda n A_{sk}\frac{(1+2\alpha_d-3\alpha_c)\sigma_t}{(1-\alpha_c)} \quad (32)$$

$$3\bar{M}+\frac{3}{2}(1-2\alpha_c)\bar{P} = \sigma_c\alpha_c^2+\sigma_t(1-\alpha_c)^2(1-r_2)+\frac{3}{4}\lambda r_1 A_{sk}\frac{(1+2\alpha_d-2\alpha_c)^2}{(1-\alpha_c)} \quad (33)$$

in which $\alpha_c = \frac{h_c}{h}$, $\alpha_d = \frac{d}{h}$, $A_{sk} = \frac{A_s}{h}$, $\bar{M} = \frac{M}{h^2}$, $\bar{P} = \frac{P}{h}$

$$r_1 = \frac{(1+3\alpha_d-2\alpha_c)^2}{4(1-\alpha_c)^2} \quad (34)$$

and

$$r_2 = \frac{(1+3\alpha_d-2\alpha_c)^3}{8\,(1-\alpha_c)^2} \quad (35)$$

The assumption of a linear distribution of strain yields

$$\frac{1-\alpha_c}{\alpha_c} = \frac{\epsilon_t}{\epsilon_c} \quad (36)$$

and in view of the stress-strain relations, $\epsilon_c = \frac{\sigma_c}{E_c}$ and $\epsilon_t = \frac{\sigma_t}{E_t}$ Eq. (36) becomes

$$\frac{1-\alpha_c}{\alpha_c} = \frac{\lambda\sigma_t}{\sigma_c} \quad (37)$$

Equations (32), (33) and (37) are the three governing equations that are solved for three unknowns . . $\bar{P}$, $\bar{M}$ and α_c. The values of σ_t and σ_c can be determined from the stress-strain relations since the strain ϵ_t and ϵ_c can be measured by some methods.

It should be noted that the governing equations are valid only when extreme fiber stresses are not both compressive or both tensile, i.e., when $0 < \alpha_c < 1$. Other-wise, the stress distribution must be formulated based on a single modulus of elasticity of bamboo-cement.

Solving the governing equations leads to.

$$\frac{3\lambda n A_{sk}(1+2\alpha_d-2\alpha_c)^2 + 4(1-r_2)(1-\alpha_c)^3 + 4\lambda\alpha_c^3}{\lambda n A_{sk}(1+2\alpha_d-2\alpha_c) + (1-r_1)(1-\alpha_c)^2 - \lambda\alpha_c^2} = 6\frac{\bar{M}}{\bar{P}} + 3(1-2\alpha_c) \quad (38)$$

$$\sigma_t = \frac{12\bar{M}(1-\alpha_c) + 6\bar{P}(1-\alpha_c)(1-2\alpha_c)}{3\lambda n A_{sk}(1+2\alpha_d-2\alpha_c)^2+4(1-r_2)(1-\alpha_c)^3+4\lambda\alpha_c^3} \quad (39)$$

$$\sigma_c = \frac{\lambda\alpha_c\sigma_t}{1-\alpha_c} \quad (40)$$

$$\sigma_s = \lambda n\frac{(1 + 2\alpha_d - 2\alpha_c)}{2(1 - \alpha_c)} \quad (41)$$

(b) Stress resultants in circum-ferential direction

In this case A_s is the area of the middle layer of the skeletal bamboo Fig. (c-2). The governing equations, similar to those in the longitudinal direction, are

$$T_s = \lambda n A_s \frac{(\frac{h}{2} - h_c)}{(h - h_c)} \sigma_t \qquad (42)$$

$$2P = \sigma_t(1-\alpha_c)(1-r_1) - \sigma_c\alpha_c + \lambda n A_{sk}\frac{(1-2\alpha_c)}{(1-\alpha_c)}\sigma_t \qquad (43)$$

$$3\overline{M}+\frac{3}{2}(1-2\alpha_c)\overline{P} = \sigma_c\alpha_c^2 + \sigma_t(1-\alpha_c)^2(1-r_2)+\frac{3}{4}\lambda n A_{sk}\frac{(1-2\alpha_c)^2}{(1-\alpha_c)}\sigma_t \qquad (44)$$

and

$$\frac{1-\alpha_c}{\alpha_c} = \frac{\lambda\sigma_t}{\sigma_c} \qquad (45)$$

Solving the governing equations leads to

$$\frac{3\lambda n A_{sk}(1-2\alpha_c)^2+4(1-r_2)(1-\alpha_c)^3+4\lambda\alpha_c^3}{\lambda n A_{sk}(1-2\alpha_c) + (1-r_1)(1-\alpha_c)^2-\lambda\alpha_c^2} = \frac{6\overline{M}}{\overline{P}} + 3(1-2\alpha_c) \qquad (46)$$

$$\sigma_t = \frac{12\overline{M}(1-\alpha_c)+6\overline{P}(1-\alpha_c)(1-2\alpha_c)}{3\lambda n A_{sk}(1-2\alpha_c)^2+4(1-r_2)(1-\alpha_c)^3+4\lambda\alpha_c^3} \qquad (47)$$

$$\sigma_c = \frac{\lambda\alpha_c\sigma_t}{1-\alpha_c}$$

$$\sigma_s = \frac{\lambda n(1-2\alpha_c)}{2(1-\alpha_c)} \qquad (48)$$

The above discussions were determined mechanical properties of bamboo-cement by theoretical of composite material. But in this experiment investigation of the rice bin, the bamboo and mortar were assumed to carry all the tension and compression respectively, so, $E_t = E_b$ and $E_c = E_m$.

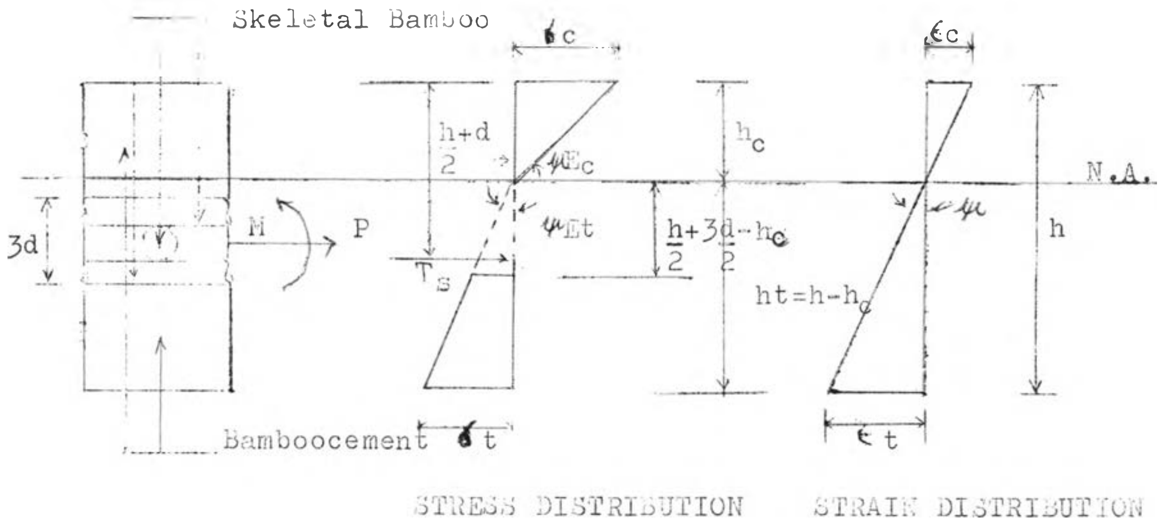


FIG (C-1)-STRESS-STRAIN DISTRIBUTIONS IN BAMBOOCEMENT SECTION IN LONGITUDINAL DIRECTION SUBJECTED TO IN-PLANE FORCE AND COUPLE

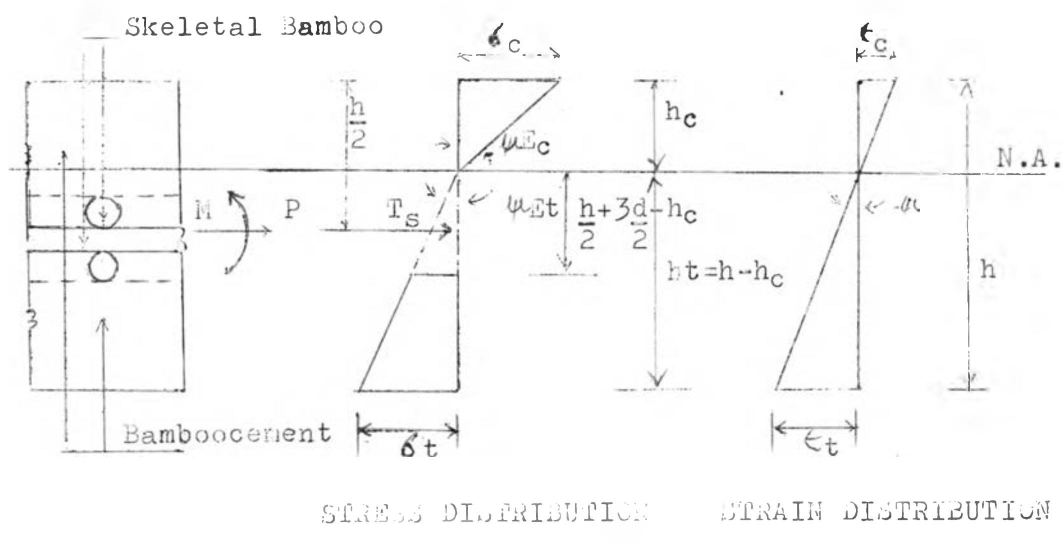
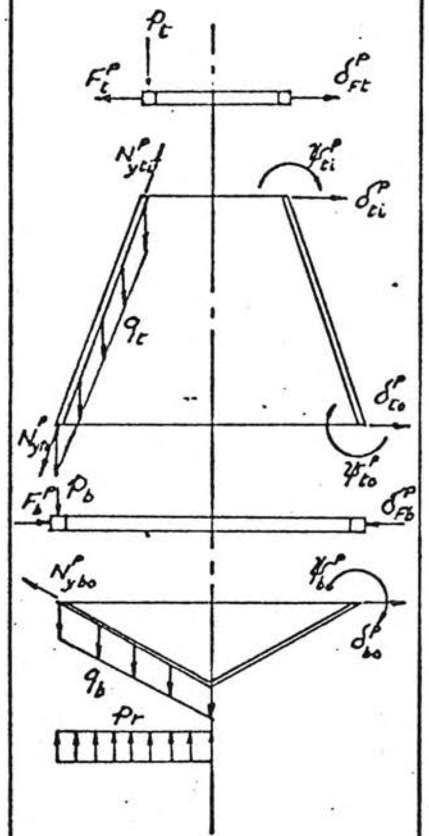
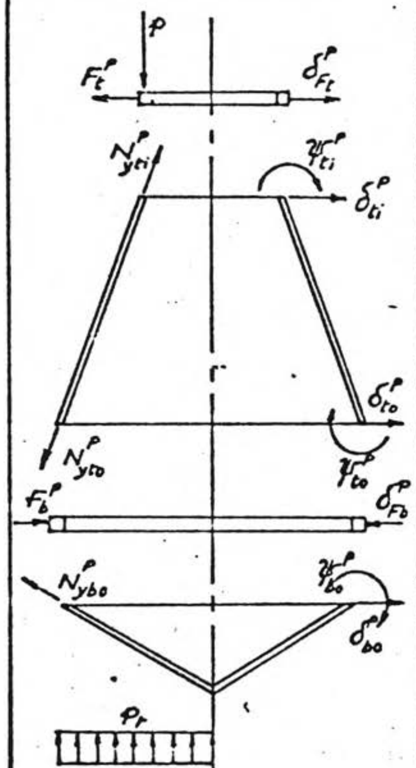


FIG (C-2)-STRESS-STRAIN DISTRIBUTIONS IN BAMBOOCEMENT SECTION IN CIRCUMFERENTIAL DIRECTION SUBJECTED TO IN-PLANE FORCE AND COUPLE

Table(1)- Membrane Analysis of Bin under Dead Load

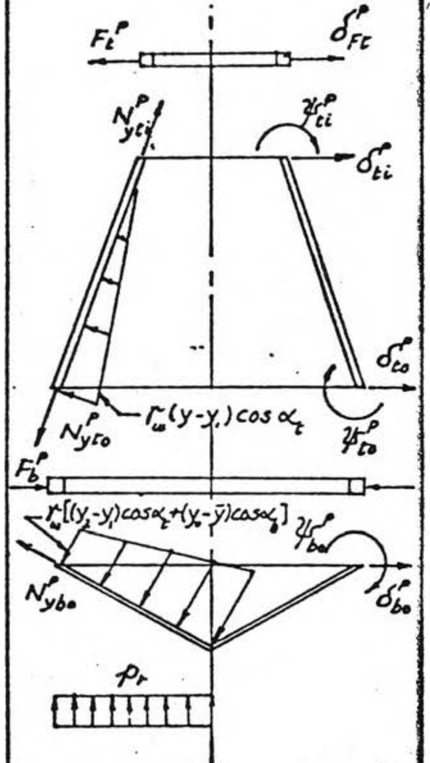
Loading, Notations and Conventions.	Load Components	Membrane Stress Resultants and Displacements
	$\omega_t = p_t$	$F_t^p = -p_t \tan\alpha_t$ $Eh_t\delta_{Ft}^p = -\dfrac{\tau_t^2\tan\alpha_t\sin^2\alpha_t}{m_t^2\lambda_t}p_t h_t$
	$Y_t = q_t\cos\alpha_t$	$N_{\theta t}^p = -\dfrac{\xi_t\tan\alpha_t\sin\alpha_t}{m_t}q_t h_t$ $N_{yt}^p = -\dfrac{1}{2m_t\xi_t\cos\alpha_t}[(\xi_t^2-\tau_t^2)q_t h_t + 2m_t\tau_t p_t]$
	$Z_t = q_t\sin\alpha_t$	$Eh_t\delta_t^p = \dfrac{\tan\alpha_t}{2}\{\dfrac{\nu}{m_t^2}[(\xi_t^2-\tau_t^2)q_t h_t^2+2m_t\tau_t p_t h_t] - \dfrac{2\xi_t^2\sin^2\alpha_t}{m_t^2}q_t h_t^2\}$ $Eh_t^2\psi_t^p = \dfrac{\tan\alpha_t}{2m_t\cos\alpha_t\xi_t}\{\xi_t^2[4\sin^2\alpha_t-1-2\nu\cos^2\alpha_t]q_t h_t^2 - \tau_t^2 q_t h_t^2$ $-2m_t\tau_t p_t h_t\}$
	$\omega_b = p_b$	$F_b^p = -\dfrac{1}{2m_t}\{[(1-\tau_t^2)q_t h_t + 2m_t\tau_t p_t](\tan\alpha_t+\tan\alpha_b)+2m_t p_b\tan\alpha_b\}$ $Eh_t\delta_{Fb}^p = -\dfrac{\sin^2\alpha_t}{2m_t^3\lambda}\{[(1-\tau_t^2)q_t h_t^2+2m_t\tau_t h_t p_t](\tan\alpha_t+\tan\alpha_b)$ $+ 2m_t h_t p_b\tan\alpha_b$
$p_r = \dfrac{1}{h_t\sin\alpha_t}[2m_t p_b$ $+ 2m_t\tau_t p_t + (1-\tau_t)q_t h_t$ $+ \dfrac{\sin\alpha_t}{\sin\alpha_b}q_b h_t]$	$Y_b = p_r\cos\alpha_b\sin\alpha_b$ $-q_b\cos\alpha_b$	$N_{\theta b}^p = -\dfrac{\xi_b\tan\alpha_b\sin\alpha_b}{m_t}[(1-\tau_t^2)q_t h_t + 2m_t p_b + 2m_t\tau_t p_t]$ $N_{yb}^p = -\dfrac{\xi_b\sec\alpha_b}{2m_t}[(1-\tau_t^2)q_t h_t + 2m_t p_b + 2m_t\tau_t p_t]$
	$Z_b = p_r\sin^2\alpha_b$ $- q_b\sin\alpha_b$	$Eh_t\delta_b^p = \dfrac{\xi_b^2\tan\alpha_b}{2m_t m_b}(\nu-2\sin^2\alpha_b)[(1-\tau_t^2)q_t h_t^2+2m_t h_t p_b+2m_t\tau_t h_t p_t]$ $Eh_t^2\psi_b^p = \dfrac{\xi_b^2\tan^2\alpha_b}{2m_t m_b}[4\sin^2\alpha_b-1-2\nu\cos^2\alpha_t][(1-\tau_t^2)q_t h_t^2+2m_t h_t p_b$ $+ 2m_t\tau_t h_t p_t]$

Table(2) - Membrane Analysis of Bin under Edge Load



Loading, Notations and Conventions	Load Components	Membrane Stress Resultants and Displacements
(see figure above)	$\omega_t = p$	$F_t^p = -p\tan\alpha_t$
		$Eh_t\delta_{Ft}^p = -\dfrac{\tau_t^2\tan\alpha_t\sin^2\alpha_t}{m_t\lambda_t}ph_t$
	$Y_t = 0$	$N_{\theta t}^p = 0$
		$N_{yt}^p = -\dfrac{\tau_t}{\cos\alpha_t\xi_t}p$
	$Z_t = 0$	$Eh_t\delta_t^p = \dfrac{\nu\tau_t\tan\alpha_t}{m_t}ph_t$
		$Eh_t^2\psi_t^p = -\dfrac{\tau_t\tan\alpha_t}{\cos\alpha_t\xi_t}ph_t$
	$\omega_b = 0$	$F_b^p = -\tau_t(\tan\alpha_b + \tan\alpha_t)p$
		$Eh_t\delta_{Ft}^p = -\dfrac{\tau_t\sin^2\alpha_t}{m_t\lambda_b}(\tan\alpha_b + \tan\alpha_t)ph_t$
	$Y_b = p_r\cos\alpha_b\sin\alpha_b$	$N_{\theta b}^p = -2\tau_t\sin\alpha_b\tan\alpha_b\xi_b p$
		$N_{yb}^p = -\tau_t\sec\alpha_b\xi_b p$
	$Z_b = p_r\sin^2\alpha_b$	$Eh_t\delta_b^p = -\dfrac{\tau_t\tan\alpha_b}{m_b}(2\sin^2\alpha_b - \nu)\xi_b^2 ph_t$
$p_r = 2\tau_t m_t p/h_t\sin\alpha_t$		$Eh_t^2\psi_b^p = \dfrac{m_t\tau_t\tan^2\alpha_t}{m_b\sin\alpha_t}[4\sin^2\alpha_b - 1 - 2\nu\cos^2\alpha_b]\xi_b ph_t$

Table (3) - Membrane Analysis of Bin under Water Loading

Loading Diagram	Load Components	Membrane Stress Resultants and Displacements
	$\omega_t = 0$	$F_t^P = 0$ $\delta_{Ft}^P = 0$
	$Y_t = 0$	$N_{\theta t}^P = \frac{\xi_t(\xi_t-\tau_t)\sin\alpha_t}{m_t^2}\gamma h_t^2$ $N_{yt}^P = \frac{(\xi_t-\tau_t)^2(2\xi_t+\tau_t)\sin\alpha_t}{6m_t^2\xi_t}\gamma h_t^2$
	$Z_t = -\gamma(y-y_1)\cos\alpha_t$	$Eh_t\delta_t^P = \frac{\sin^2\alpha_t}{6m_t^3}(\xi_t-\tau_t)[6\xi_t^2-\nu(\xi_t-\tau_t)(2\xi_t+\tau_t)]\gamma h_t^3$ $Eh_t^2\psi_t^P = \frac{\tan\alpha_t\sin\alpha_t}{6m_t^2\xi_t}[\tau_t^3+9\tau_t\xi_t^2-16\xi_t^3]\gamma h_t^3$
	$\omega_b = 0$	$F_b^P = \frac{(1-\tau_t)^2(2+\tau_t)\sin^2\alpha_t}{6m_t^2}(1+\frac{\tan\alpha_b}{\tan\alpha_t})\gamma h_t^2$ $Eh_t\delta_{Fb}^P = \frac{(1-\tau_t)^2(2+\tau_t)\sin^4\alpha_t}{6m_t^4\lambda_b}(1+\frac{\tan\alpha_b}{\tan\alpha_t})\gamma h_t^3$
	$Y_b = p_r\cos\alpha_b\sin\alpha_b$	$N_{\theta b}^P = \frac{\sin^2\alpha_t\,\xi_b}{3m_t^2\sin\alpha_t}\{3(1-\xi_b)-\sin^2\alpha_b-\frac{\tan\alpha_b}{\tan\alpha_t}[\sin^2\alpha_b(1-\tau_t^3)-3(1-\tau_t)]\}$ $N_{yb}^P = \frac{\sin^2\alpha_t\,\xi_b}{6m_t^2\sin\alpha_b}[2(1-\xi_b)+\frac{\tan\alpha_b}{\tan\alpha_t}(1-\tau_t)^2(2+\tau_t)]\gamma h_t^2$
$P_r = \frac{1}{3m_t}\cos\alpha_t[1-\tau_t^3 + \frac{\tan\alpha_t}{\tan\alpha_b}]\gamma h_t$	$Z_b = p_r\sin^2\alpha_b - \gamma[(y_2-y_1)\cos\alpha_t + (y_o-\bar{y})\cos\alpha_b]$	$Eh_t\delta_b^P = \frac{\sin_t^2\alpha\,\xi_b^2}{6m_t^2m_b}\{2(3-\nu)(1-\xi_b)-2\sin^2\alpha_b+\frac{\tan\alpha_b}{\tan\alpha_t}[3(1-\tau_t)(2-\nu) - (1-\tau_t^3)(2\sin^2\alpha_b-\nu)]\}\gamma h_t^3$ $Eh_t^2\psi_b^P = \frac{\xi_b\sin\alpha_t\tan\alpha_b}{6m_t^2m_b}\{16\xi_b-10-2\nu\cos^2\alpha_b+4\sin^2\alpha_b + \frac{\tan\alpha_b}{\tan\alpha_t}[(1-\tau_t^3)(4\sin^2\alpha_b-1-2\nu\cos^2\alpha_b)-9(1-\tau_t)]\}\gamma h_t^3$

Table(4) - Contributions of Edge Loads to the Stress Resultants and Displacements

	$\frac{H_i}{\Delta_k(z_1)} = 1$	$\frac{M_i}{\Delta_k(z_1)} = 1$	$\frac{H_o}{\Delta_b(z_2)} = 1$	$\frac{M_o}{\Delta_b(z_2)} = 1$
N_y	$\sin\alpha\tau\Phi_k[z_1, \mathrm{ker}_2 z, \mathrm{kei}_2 z]\frac{1}{\xi}$	$2k\tau K[z_1, \mathrm{kei}_2 z, - \mathrm{ker}_2 z]\frac{1}{h\xi}$	$\sin\alpha\Phi_b[z_2, \mathrm{ber}_2 z, \mathrm{bei}_2 z]\frac{1}{\xi}$	$2kB[z_2, \mathrm{bei}_2 z, - \mathrm{ber}_2 z]\frac{1}{h\xi}$
N_θ	$\frac{\sin\alpha\tau}{2}\Phi_k[z_1, \mathrm{ker}'_2 z, \mathrm{kei}'_2 z]\frac{1}{\xi}$	$k\tau K[z_1, \mathrm{kei}'_2 z, - \mathrm{ker}' z]\frac{1}{h\xi}$	$\frac{\sin\alpha}{2}\Phi_b[z_2, \mathrm{ber}'_2 z, \mathrm{bei}'_2 z]\frac{1}{\xi}$	$kB[z_2, \mathrm{bei}'_2 z, - \mathrm{ber}'_2 z]\frac{1}{h\xi}$
M_y	$-\frac{\sin\alpha\tau}{2k}\Phi_k[z_1, \varphi_{ki}(z), - \varphi_{kr}(z)]\frac{h}{\xi}$	$\tau K[z_1, \varphi_{kr}(z), \varphi_{ki}(z)]\frac{1}{\xi}$	$-\frac{\sin\alpha}{2k}\Phi_b[z_2, \varphi_{bi}(z), - \varphi_{br}(z)]\frac{h}{\xi}$	$B[z_2, \varphi_{br}(z), \varphi_{bi}(z)]\frac{1}{\xi}$
M_θ	$-\frac{\sin\alpha\tau}{2k}\Phi_k[z_1, \rho_{ki}(z), - \rho_{kr}(z)]\frac{h}{\xi}$	$\tau K[z_1, \rho_{kr}(z), \rho_{ki}(z)]\frac{1}{\xi}$	$-\frac{\sin\alpha}{2k}\Phi_b[z_2, \rho_{bi}(z), - \rho_{br}(z)]\frac{h}{\xi}$	$B[z_2, \rho_{br}(z), \rho_{bi}(z)]\frac{1}{\xi}$
$Eh\delta$	$\frac{\sin^2\alpha}{2}\Phi_k[z_1, \theta_{kr}(z), \theta_{ki}(z)]y_1$	$k\sin\alpha K[z_1, \theta_{ki}(z), - \theta_{kr}(z)]\frac{y_1}{h}$	$\frac{\sin^2\alpha}{2}\Phi_b[z_2, \theta_{br}(z), \theta_{bi}(z)]y_2$	$k\sin\alpha B[z_2, \theta_{bi}(z), - \theta_{br}(z)]\frac{y_2}{h}$
$Eh^2\psi$	$k\sin\alpha\Phi_k[z_1, \mathrm{kei}_2 z, - \mathrm{ker}_2 z]y_1$	$-2k^2K[z_1, \mathrm{ker}_2 z, \mathrm{kei}_2 z]\frac{y_1}{h}$	$k\sin\alpha\Phi_b[z_2, \mathrm{bei}_2 z, - \mathrm{ber}_2 z]y_2$	$-2k^2B[z_2, \mathrm{ber}_2 z, \mathrm{bei}_2 z]\frac{y_2}{h}$

Table (5a)-Properties of Materials Used in Design of Conical Rice Bin.

Item	Value
Mortar	
Ultimate Compressive Strength of Mortar f'_c, kg/sq.cm	325
Modulus of Elasticity of Mortar E_m, kg/sq.cm	3.25×10^5
Bomboo	
Ultimate Tensile Strength of Fiber Bamboo, kg/sq.cm	1937
Modulus of Elasticity of Fiber Bamboo E_f, kg/sq.cm	2.64×10^5
Ultimate Tensile Strength of Skeletal Bamboo, kg/sq.cm	1937
Modulus of Elasticity of Skeletal Bamboo E_b, kg/sq.cm	2.64×10^5
Bamboocement Section	
Modulus of Elasticity of Uncracked Bamboocement E_c, kg/sq.cm	2.58×10^5
Modulus of Elasticity of cracked Bamboocement E_t, kg/sq.cm	0.066×10^5
Poisson's Ratio of Bamboocement (Appendix-C), ν	0.2643
Ultimate Strength of Bamboocement in Tension, kg/sq.cm	28
Ultimate Conpressive Strength of Bamboocement, kg/sq.cm	307
Bond Stress Between Bamboo and Mortar, kg/sq.cm	8.35

Table (5b) - Details and Properties of Bamboocement Section.

Item	Value
Thickness h, cm	5.00
Size of the Skeletal Bamboo, cm x cm	0.50x1.00
Spacing of Skeletal Bamboo in Longitudinal direction, cm	10
Spacing of Skeletal Bamboo in Circumferential direction, cm	20
Layer of Fibers Bamboo Mesh L	2
Volume of Fibers Bamboo Mesh per Unit area per layer w, cu.cm/sq.cm/layer	0.064
Volume Fraction of Fibers Bamboo Mesh $V_f = L\omega/h$	0.03
Volume Fraction of Mortar, $V_m = 1 - V_f$	0.97
Skeletal Bamboo Area per Unit Section in Longitudinal direction Ask_1	0.014
Skeletal Bamboo Area per Unit Section in Circumferential direction Ask_c	0.007
Modulus of Elasticity of Uncracked Bamboocement E_c, kg/sq.cm	2.58×10^5
Modulus of Elasticity of cracked Bamboocement E_t, kg/sq.cm	0.066×10^5
Poisson's Ratio of Bamboocement	0.2643
Ultimate Strength of Bamboocement in Tension, kg/sq.cm	28
Ultimate Compressive Strength of Bamboocement, kg/sq.cm	307

TABLE (6a) - EDGE DISPLACEMENT, RING FORCES AND UNIFORM CONTACT PRESSURE OF THE FOUNDATION DUE TO COMBINATION OF LOADING CASES.					
	TYPE	DL.	EL.	WL.	DL+WL+EL
TOP RING GIRDER	F_t (kg/cm)	-0.9225648×10^{-1}	-0.1743882	0.0000000	-0.2666447
	δ_{ft} (cm)	-0.1720166×10^{-4}	-0.3251551×10^{-4}	0.0000000	-0.4971717×10^{-4}
BOTTOM RING GIRDER	F_b (kg/cm)	-0.1143169×10^{-1}	-0.1790762×10^{-2}	0.3906072×10	0.3892849×10
	δ_{fb} (cm)	-0.5873094×10^{-3}	-0.9200364×10^{-4}	0.1337902×10^{-1}	0.1269971×10^{-1}
	P_r (kg/sq.cm)	0.288575×10^{-1}	0.2876297×10^{-2}	0.9585320×10^{-1}	0.1275870

TABLE (6b) - FORCES AND STRESSES IN BIN CAP (CIRCULAR PLATE)				
r/a (cm/cm)	w (cm)	Q_r (kg/cm)	M_r (kg.cm/cm)	M_θ (kg.cm/cm)
0.00	0.11491×10^{-2}	0.00000	0.88617×10	0.88617×10
0.10	0.11341×10^{-2}	-0.69539×10^{-1}	0.87539×10	0.88025×10
0.20	0.10896×10^{-2}	-0.13907	0.84304×10	0.86248×10
0.30	0.10167×10^{-2}	-0.20861	0.78913×10	0.83287×10
0.40	0.91771×10^{-3}	-0.27815	0.71365×10	0.79141×10
0.50	0.79547×10^{-3}	-0.34770	0.61661×10	0.73811×10
0.60	0.65386×10^{-3}	-0.41723	0.49800×10	0.67297×10
0.70	0.49756×10^{-3}	-0.48677	0.35783×10	0.59598×10
0.80	0.33208×10^{-3}	-0.55631	0.19609×10	0.50715×10
0.90	0.16382×10^{-3}	-0.62585	0.12795	0.40647×10
1.00	-0.13096×10^{-9}	-0.69540	-0.19207×10	0.29395×10
1.10	-0.15395×10^{-3}	0.16144	-0.61591	0.27928×10
1.21	-0.31667×10^{-3}	-0.31357×10^{-8}	-0.25331×10^{-6}	0.25984×10

Table (7) - Limiting Stresses at All Conditions

LIMITING STRESSES AT YIELD CONDITION		
BAMBOO CEMENT IN TENSION	LONGITUDINAL DIRECTION $= 0.5\ V_f \sigma_{fy}$ (kg/cm^2)	28
	CIRCUMFERENTIAL DIRECTION $= 0.5\ V_f \sigma_{fy}$ (kg/cm^2)	28
BAMBOO CEMENT IN COMPRESSION	$= 0.85\ V_m f'_c$ (kg/cm^2)	307
SKELETAL BAMBOO	(kg/cm^2)	1937

LIMITING STRESSES AT ALLOWABLE CONDITION		
BAMBOO CEMENT IN TENSION	LONGITUDINAL DIRECTION $= 0.5\ V_f \sigma_f$ (kg/cm^2)	14
	CIRCUMFERENTIAL DIRECTION $= 0.5\ V_f \sigma_f$ (kg/cm^2)	14
BAMBOO CEMENT IN COMPRESSION	$= 0.45\ V_m f'_c$ (kg/cm^2)	162
SKELETAL BAMBOO	(kg/cm^2)	968.5

Table (8) - Theoretical Results of Stresses in Longitudinal Direction.

y/y_2 (cm/cm)	M_y (kg.cm/cm)	N_y (kg/cm)	α_c (cm/cm)	σ_t (kg/cm^2)	σ_c (kg/cm^2)	σ_b (kg/cm^2)
0.70	5.74	1.51	0.210	-0.357	-4.960	-4.050
0.80	3.41	3.46	0.850	-0.006	-1.496	-0.181
0.85	-23.90	5.33	0.090	4.629	20.143	60.319
0.90	-81.43	7.31	0.111	12.726	69.914	163.266
0.95	-151.71	7.74	0.118	22.083	129.994	281.779
1.00	-161.65	3.73	0.124	22.267	138.686	282.785

$\bar{y}/y_2$ (cm/cm)	M_y (kg.cm/cm)	N_y (kg/cm)	α_c (cm/cm)	σ_t (kg/cm^2)	σ_c (kg/cm^2)	σ_b (kg/cm^2)
1.00	-161.65	7.15	0.120	23.218	139.308	295.797
0.90	-176.34	18.84	0.110	27.00	152.270	359.572
0.80	-143.25	23.90	0.100	25.465	124.495	329.415
0.70	-91.10	23.63	0.090	17.523	58.847	200.215
0.60	-41.19	19.85	0.050	10.987	25.444	147.115
0.50	-5.77	14.49	0.010	5.012	2.228	68.765

Table (9) - Theoretical Results of Strasses in Circumferential Direction

y/y_2 (cm/cm)	M_θ (kg.cm/cm)	N_θ (kg/cm)	σ_t (kg/cm^2)	σ_c (kg/cm^2)	σ_b (kg/cm^2)
0.70	1.75	10.48	-0.42	-0.42	59.886
0.80	1.96	30.35	-0.47	-0.47	173.429
0.85	-5.77	42.77	1.385	1.385	244.400
0.90	-23.59	37.94	5.662	5.662	216.800
0.95	-47.75	-13.80	11.460	14.220	-
1.00	-57.60	-140.33	13.820	41.886	-

$\bar{y}/y_o$ (cm/cm)	M_θ (kg.cm/cm)	N_θ (kg/cm)	σ_t (kg/cm^2)	σ_c (kg/cm^2)	σ_b (kg/cm^2)
1.00	-88.47	-139.14	21.233	49.061	-
0.90	-80.59	-50.14	19.342	29.37	-
0.80	-58.07	11.41	13.937	13.937	65.200
0.70	-32.02	43.90	7.685	7.685	250.857
0.60	-10.14	52.31	2.434	2.434	298.914
0.50	3.66	45.04	-0.878	-0.878	257.371

Table (10) - Tensile Strength of Bamboo

Specimen No	Cross Section (cm x cm)	Gage Length (cm)	Ultimate Tensile Stress (ksc)	Modulus of Elasticity (ksc)	Remarks
1	0.52x0.84	11.00	1840	$2.73x10^5$	Failed Near the Grips
2	0.53x0.83	"	2000	$2.56x10^5$	"
3	0.50x0.80	"	1700	$2.75x10^5$	Failed at the Node
4	0.50x0.80	"	1900	$2.43x10^5$	"
5	0.54x0.82	"	2100	$2.74x10^5$	Failed Near the Grips
6	0.54x0.80	"	2080	$2.60x10^5$	"

AVERAGE ULTIMATE TENSILE STRESS = 1937 kg/cm^2

AVERAGE MODULUS OF ELASTICITY = $2.64x10^5$ kg/cm^2

Table (11) - Results of Bond Test on Bamboo Skin

Specimen No	Weight of Specimen (kgs)	Size of Bamboo (cm x cm)	Failure load (kgs)	Type of Failure	Embeded Length (cm)	Bond Stress (kg/cm^2)
1	17.53	0.50x1.00	465	Slip	19.5	7.95
2	17.90	0.45x1.05	450	"	19.8	7.58
3	18.00	0.50x1.00	510	"	19.6	8.67
4	17.93	0.45x1.05	490	"	19.8	8.25
5	17.90	0.49x1.00	480	"	19.[illegible]	8.09
6	17.80	0.48x1.00	470	"	19.7	8.06
7	17.70	0.47x1.00	500	"	19.5	8.72
8	17.80	0.46x1.00	510	"	19.4	9.00
9	18.00	0.48x1.00	520	"	19.9	8.83
AVERAGE BOND STRESS = 8.35 kg/cm^2						

Table (12) - Results of Compression Test on Mortar Cube Specimens.

Specimen No	Weights (grams)	Size (cm x cm x cm)	Ultimate Load (tons)	Ultimate Stress (kg/cm^2)	Modulus of Elasticity (kg/cm^2)
1	294	5.00x5.00x5.00	9.90	396	3.96×10^5
2	304	"	9.00	360	3.60×10^5
3	275	"	9.60	384	3.84×10^5
4	288	"	8.40	336	3.36×10^5
5	295	"	7.40	296	2.96×10^5
6	290	"	7.65	306	3.06×10^5
7	295	"	6.60	264	2.64×10^5
8	275	"	7.35	294	2.94×10^5
9	280	"	8.95	358	3.58×10^5
10	290	"	7.40	296	2.96×10^5
11	280	"	8.35	334	3.34×10^5
12	295	"	7.00	280	2.80×10^5
CEMENT - SAND MORTAR, RATIO 1 : 2 (BY WEIGHT)					
WATER - CEMENT RATIO = 0.45					
$E_m = 1000 f'_m$					
AVERAGE MODULUS OF ELASTICITY = 3.25×10^5 kg/cm^2					
AVERAGE ULTIMATE COMPRESSIVE STRESS = 325 kg/cm^2					

Table (13) - Results of Compression Test on Mortar Cylinder Specimens.

Specimen No	Size (cm x cm)	Weights (kgs)	Gage Length (cm)	Ultimate load (tons)	Ultimate Stress (kg/cm^2)	Modulus of Elasticity (kg/cm^2)
1	∅ 15x30	12.50	20.00	69.50	393	$3.04x10^5$
2	∅ 15x30	12.10	20.00	73.00	413	$2.80x10^5$
3	∅ 15x30	12.15	20.00	75.40	427	$2.92x10^5$
4	∅ 15x30	11.50	20.00	71.00	402	$2.86x10^5$
5	∅ 15x30	12.25	20.00	72.00	407	$3.11x10^5$

AVERAGE COMPRESSIVE STRESS = 408 kg/cm^2

AVERAGE MODULUS OF ELASTICITY = $2.95x10^5$ kg/cm^2

Table (14a) - Experimental Results of Horizontal Radial Deflections at Position (a)

POSITION OF DIAL GAUGES y/y_2 (cm/cm)	DIAL GAUGE READING AT VARIOUS STAGES OF LOADING (cm) x 10^{-3}				
	D.L.	D.L+$\frac{17.4}{100}$L.L.	D.L.+$\frac{1}{3}$L.L.	D.L+$\frac{2}{3}$L.L.	D.L.+L.L.
1.00	0	0.50	1.00	1.50	3.00
0.95	0	2.00	4.00	9.80	19.30
0.90	0	3.50	7.00	16.20	25.00
0.85	0	4.00	7.70	17.00	25.40

POSITION OF DIAL GAUGES y/y_2 (cm/cm)	DIAL GAUGE READING AT VARIOUS STAGES OF REBOUND LOADING (cm) x 10^{-3}				
	D.L.	D.L+$\frac{17.4}{100}$L.L.	D.L+$\frac{1}{3}$L.L.	D.L+$\frac{2}{3}$L.L.	D.L.+L.L.
1.00	-7.20	-5.90	-4.70	-3.20	0
0.95	-22.00	-20.00	-18.00	-10.90	0
0.90	-26.00	-22.50	-19.00	-10.00	0
0.85	-25.80	-22.30	-18.80	-8.80	0

Table (14b) - Experimental Results of Horizontal Radial Deflections at Position (b)

POSITION OF DIAL GAUGES y/y_2 (cm/cm)	DIAL GAUGE READING AT VARIOUS STAGES OF LOADING (cm) x 10^{-3}				
	D.L.	D.L+$\frac{17.4}{100}$L.L.	D.L.+$\frac{1}{3}$L.L.	D.L.+$\frac{2}{3}$L.L.	D.L.+L.L.
1.00	0	1.00	1.20	2.20	2.60
0.95	0	3.00	5.20	10.00	18.00
0.90	0	3.90	6.80	14.90	23.80
0.85	0	4.20	7.10	15.20	24.00

POSITION OF DIAL GAUGES y/y_2 (cm/cm)	DIAL GAUGE READING AT VARIOUS STAGES OF REBOUND LOADING (cm) x 10^{-3}				
	D.L.	D.L+$\frac{17.4}{100}$L.L.	D.L.+$\frac{1}{3}$L.L.	D.L.+$\frac{2}{3}$L.L.	D.L.+L.L.
1.00	-6.80	-5.80	-5.50	-3.00	0
0.95	-19.60	-18.10	-15.00	-9.20	0
0.90	-24.50	-20.80	-17.80	-10.00	0
0.85	-24.50	-20.60	-17.70	-9.50	0

Table (14c) - Experimental Results of Horizontal Radial Deflections at Position (c)

POSITION OF DIAL GAUGES y/y_2 (cm/cm)	DIAL GAUGE READING AT VARIOUS STAGES OF LOADING (cm) x 10^{-3}				
	D.L.	D.L+$\frac{17.4}{100}$L.L.	D.L.+$\frac{1}{3}$L.L.	D.L.+$\frac{2}{3}$L.L.	D.L.+L.L.
1.00	0	0.50	1.30	3.20	4.80
0.95	0	3.50	6.50	10.50	18.00
0.90	0	4.20	9.20	16.00	22.00
0.85	0	5.00	10.00	17.00	23.00

POSITION OF DIAL GAUGES y/y_2 (cm/cm)	DIAL GAUGE READING AT VARIOUS STAGES OF REBOUND LOADING (cm) x 10^{-3}				
	D.L.	D.L+$\frac{17.4}{100}$L.L.	D.L.+$\frac{1}{3}$L.L.	D.L.+$\frac{2}{3}$L.L.	D.L.+L.L.
1.00	-7.25	-6.00	-5.10	-2.80	0
0.95	-19.00	-16.00	-12.30	-8.00	0
0.90	-22.50	-19.00	-13.50	-7.00	0
0.85	-23.60	-18.40	-13.40	-6.50	0

Table (15a) - Experionental Results of Stresses in Longitudinal Direction at Inner Fiber

LONGITUDINAL DIRECTION AT INNER FIBER							
POSITION OF STRAIN GAUGES (cm/cm)	STRAIN INDICATOR READING AT VARIOUS STAGES OF LOADING (cm/cm) x 10^{-3}					MODULUS OF ELASTICITY (kg/cm^2)	STRESSES (kg/cm^2)
	D.L.	D.L.+ $\frac{17.4}{100}$L.L.	D.L+$\frac{1}{3}$L.L	D.L+$\frac{2}{3}$L.L	D.L.+L.L.		
y/y_2=0.70	0	0.08	0.15	0.28	0.45	0.066x10^5	3.00
0.80	0	0.01	0.02	0.05	0.08	"	0.50
0.85	0	0.10	0.24	0.50	0.79	"	5.20
0.90	0	0.25	0.43	1.10	1.76	"	11.60
0.95	0	0.53	0.95	1.89	2.94	"	19.40
1.00	0	0.59	1.09	2.14	3.21	"	21.20
$\bar{y}/y_o$=0.90	0	0.60	1.25	2.69	4.09	"	27.00
0.80	0	0.50	1.10	2.59	3.83	"	25.30
0.70	0	0.43	1.00	2.05	3.09	"	20.40
0.60	0	0.15	0.32	0.79	1.24	"	8.20
0.50	0	0.09	0.21	0.45	0.61	"	4.00

Table (15b) - Experimental Results of Stresses in Circumferential Direction at Inner Fiber

CIRCUMFERENTIAL DIRECTION AT INNER FIBER							
POSITION OF STRAIN GAUGES (cm/cm)	STRAIN INDICATOR READING AT VARIOUS STAGES OF LOADING (cm/cm) x 10^{-3}					MODULUS OF ELASTICITY (kg/cm^2)	STRESSES (kg/cm^2)
	D.L.	D.L. + $\frac{17.4 L.L.}{100}$	D.L+$\frac{1}{3}$L.L.	D.L+$\frac{2}{3}$L.L	D.L+L.L.		
y/y_2=0.70	0	0.06	0.11	0.25	0.39	0.066×10^5	2.50
0.80	0	0.09	0.14	0.30	0.59	"	3.90
0.85	0	0.13	0.17	0.48	0.73	"	4.80
0.90	0	0.14	0.21	0.56	0.75	"	4.93
0.95	0	0.20	0.41	0.83	1.28	"	8.43
1.00	0	0.25	0.51	1.08	1.61	"	10.62
$\bar{y}/y_o$=0.90	0	0.35	0.95	1.89	2.94	"	19.40
0.80	0	0.40	0.93	1.74	2.62	"	17.32
0.70	0	0.30	0.49	0.98	1.59	"	10.48
0.60	0	0.18	0.29	0.54	0.85	"	5.61
0.50	0	0.05	0.09	0.12	0.15	"	1.00

Table (15c) - Experimental Results of Stresses in Longitudinal Direction at Outer Fiber

LONGITUDINAL DIRECTION AT OUTER FIBER							
POSITION OF STRAIN GAUGES (cm/cm)	STRAIN INDICATOR READING AT VARIOUS STAGES OF LOADING (cm/cm) x 10^{-3}					MOUDULUS OF ELASTICITY (kg/cm^2)	STRESSES (kg/cm^2)
	D.L.	D.L. + $\frac{17.4 L.L.}{100}$	D.L+$\frac{1}{3}$L.L	D.L+$\frac{2}{3}$L.L	D.L.+L.L.		
y/y_2=0.70	0	0.01	0.02	0.02	0.03	2.58x10^5	7.74
0.80	0	0.01	0.02	0.03	0.04	"	10.32
0.85	0	-0.01	-0.03	-0.05	-0.07	"	-18.06
0.90	0	-0.05	-0.09	-0.17	-0.25	"	-64.50
0.95	0	-0.07	-0.12	-0.30	-0.46	"	-118.68
1.00	0	-0.09	-0.15	-0.31	-0.48	"	-123.84
CIRCUMFERENTIAL DIRECTION AT OUTER FIBER							
y/y_2=0.70	0	0.01	0.02	0.02	0.02	"	5.16
0.80	0	0.02	0.02	0.03	0.04	"	10.32
0.85	0	-0.03	-0.04	-0.05	-0.06	"	-15.48
0.90	0	-0.05	-0.09	-0.14	-0.20	"	-15.60
0.95	0	-0.07	-0.12	-0.21	-0.35	"	-90.30
1.00	0	-0.10	-0.19	-0.30	-0.42	"	-108.36

Table (15d) - Experimental Results of Stresses in Longitudinal Direction at Skeletal Bamboos

LONGITUDINAL DIRECTION AT SKELETAL BAMBOOS							
POSITION OF STRAIN GAUGES (cm/cm)	STRAIN INDICATOR READING AT VARIOUS STAGES OF LOADING (cm/cm) x 10^{-3}					MODULUS OF ELASTICITY (kg/cm^2)	STRESSES (kg/cm^2)
	D.L.	D.L. + $\frac{17.4}{100}$L.L.	D.L+$\frac{1}{3}$L.L	D.L+$\frac{2}{3}$L.L	D.L.+L.L.		
y/y_2=0.70	0	-0.07	-0.03	-0.08	0.02	$1.5x10^5$	3.0
0.80	0	0.01	0.00	0.05	0.08	"	12.0
0.85	0	0.06	0.18	0.37	0.58	"	87.0
0.90	0	0.20	0.41	0.85	1.20	"	180.0
0.95	0	0.25	0.44	1.19	2.00	"	300.0
1.00	0	0.11	0.65	1.27	1.91	"	286.5
$\bar{y}/y_o$=0.90	0	0.33	0.61	1.53	2.48	"	372.0
0.80	0	0.18	0.47	1.49	2.36	"	354.0
0.70	0	0.21	0.49	1.10	1.63	"	244.5
0.60	0	0.21	0.39	0.83	1.27	"	190.5
0.50	0	0.09	0.15	0.39	0.54	"	81.0

Table (15e) - Experimental Results of Stresses in Circumferential Direction at Skeletal Bamboos

CIRCUMFERENTIAL DIRECTION AT SKELETAL BAMBOOS							
POSITION OF STRAIN GAUGES (cm/cm)	STRAIN INDICATOR READING AT VARIOUS STAGES OF LOADING (cm/cm) x 10^{-3}					MODULUS OF ELASTICITY (kg/cm^2)	STRESSES (kg/cm^2)
	D.L.	D.L. + $\frac{17.4}{100}$L.L	D.L+$\frac{1}{3}$L.L	D.L+$\frac{2}{3}$L.L	D.L.+L.L.		
y/y_2=0.70	0	0.06	0.12	0.30	0.48	$1.5x10^5$	72.
0.80	0	0.30	0.60	1.10	1.50	"	225.
0.85	0	0.22	0.48	1.12	1.72	"	258.
0.90	0	0.28	0.47	0.94	1.54	"	231.
1.00	0	0.01	0.01	0.02	0.09	"	13.5
$\bar{y}/y_o$=0.90	0	0.03	0.08	0.10	0.15	"	22.5
0.80	0	0.13	0.21	0.52	0.70	"	105.
0.60	0	0.21	0.40	1.23	2.00	"	300.
0.50	0	0.22	0.50	1.12	1.75	"	263.

Table (16) - Cost Analysis

Operation	A	B	C	D	E	Total	Unit Cost Baht	Cost Baht
Labour (man - days)								
Skilled	2	5	2	2	1	12	45	540
Unskilled	2	5	2	5	1	15	25	375
Material								
Cement, kg	323	-	-	765	34	1122	0.54	606
Sand, Cu.m.	0.74	-	-	0.60	0.03	1.37	70	96
Fine Aggregate, Cu.m.	0.50	-	-	-	-	0.50	70	35
Bamboo Skeletal 4 m.,	-	48	-	-	-	48	2	96
Bamboo Fiber 4 m.,	-	100	-	-	-	100	2	200
Plywood, sheet (4m.m.x1.20m.x2.40m.)	-	-	4	-	-	4	67	268
Wood, sheet (1 in x 2 in x 2.00m.)	-	-	2	-	-	2	50	100
Total Cost Baht								2316

Detail of Operation :

A. Preparation of Foundation

B. Fabrication of Reinforcements

C. Formwork of Inner Top Cone

D. Casting of Prototype Rice Bin

E. Prefabrication of Bin Lid

Cost of labour and materials were enquired in February, 1976

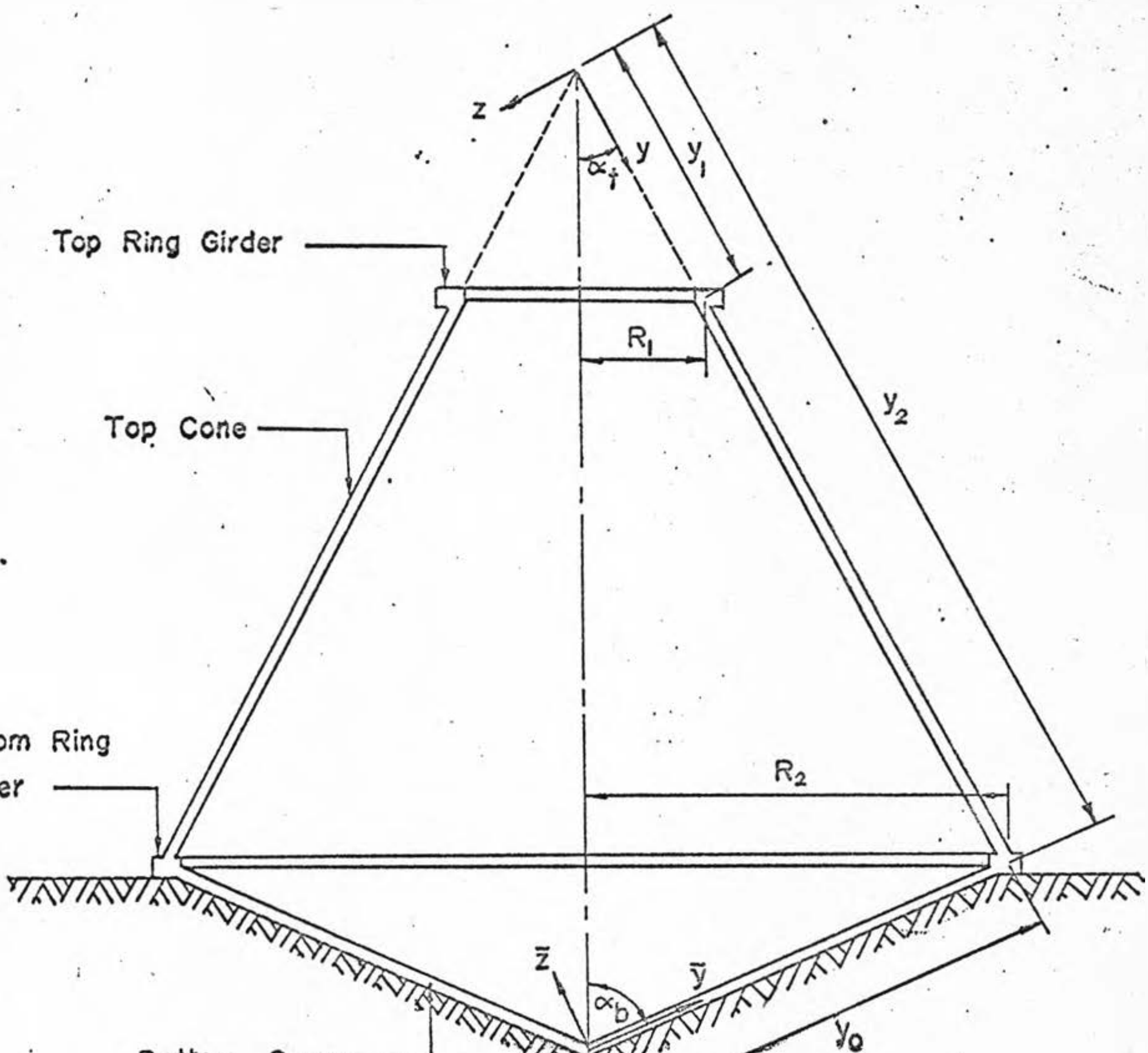
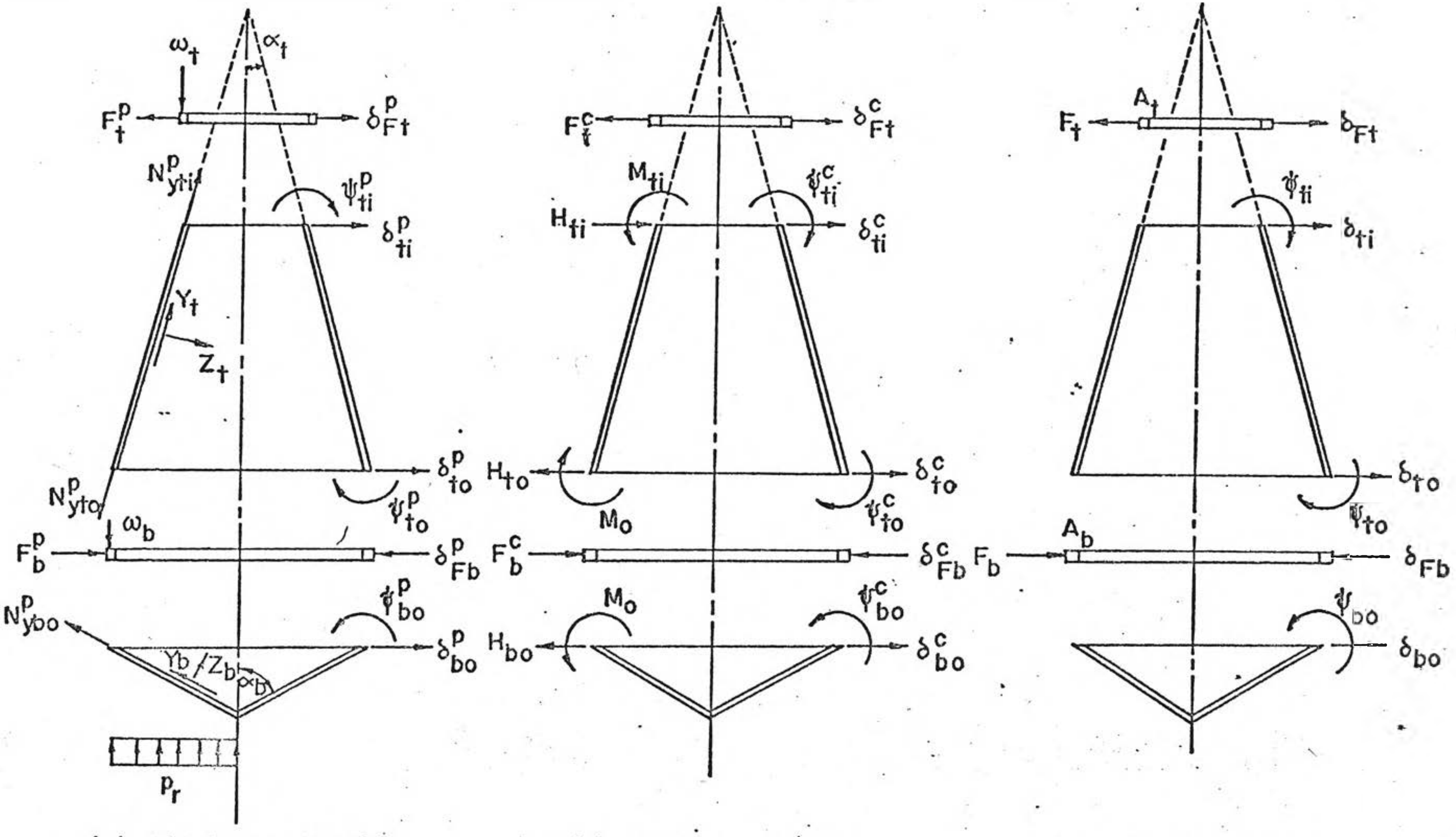


FIG. 1 - CONICAL RICE BIN



(a) Membrane Solution (b) Bending Solution (c) Total Solution

FIG. 2 - SUPERPOSITION OF SOLUTIONS

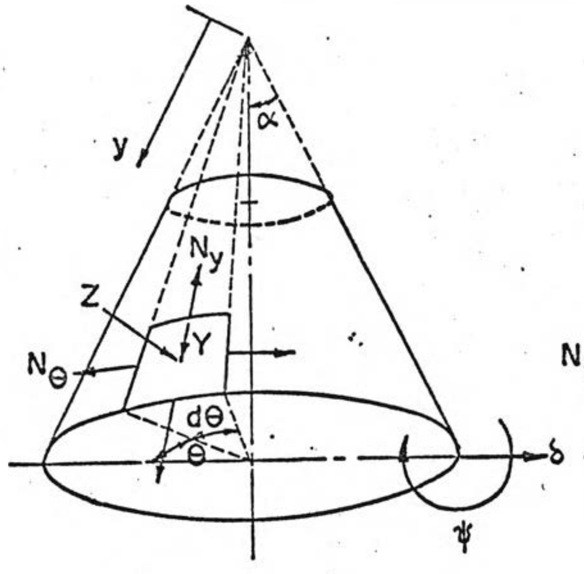


FIG. 3 - DISPLACEMENTS AND STRESS RESULTANTS IN MEMBRANE ANALYSIS OF CONICAL SHELL

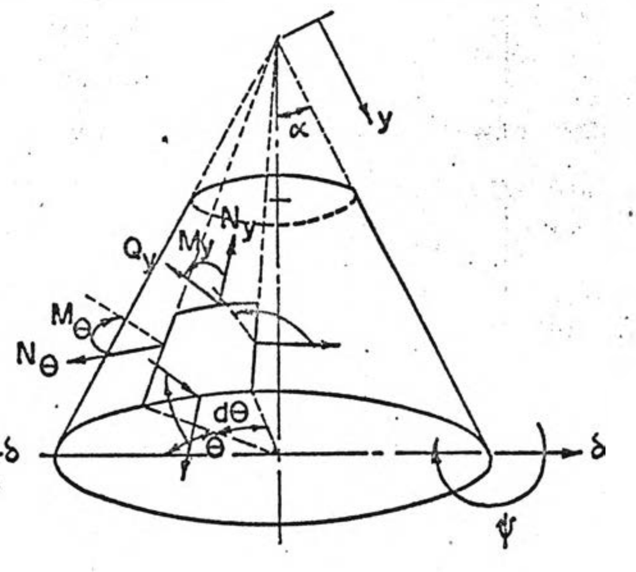


FIG. 4 - DISPLACEMENTS AND STRESS RESULTANTS IN BENDING ANALYSIS OF CONICAL SHELL

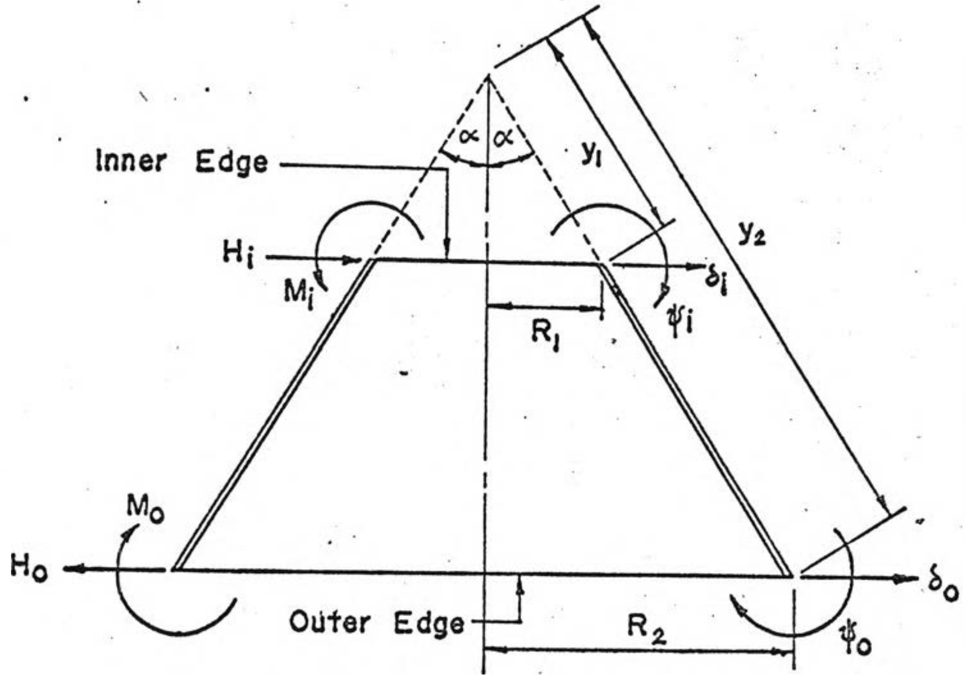


FIG. 5 - EDGE LOADS AND DISPLACEMENTS OF CONICAL FRUSTUM

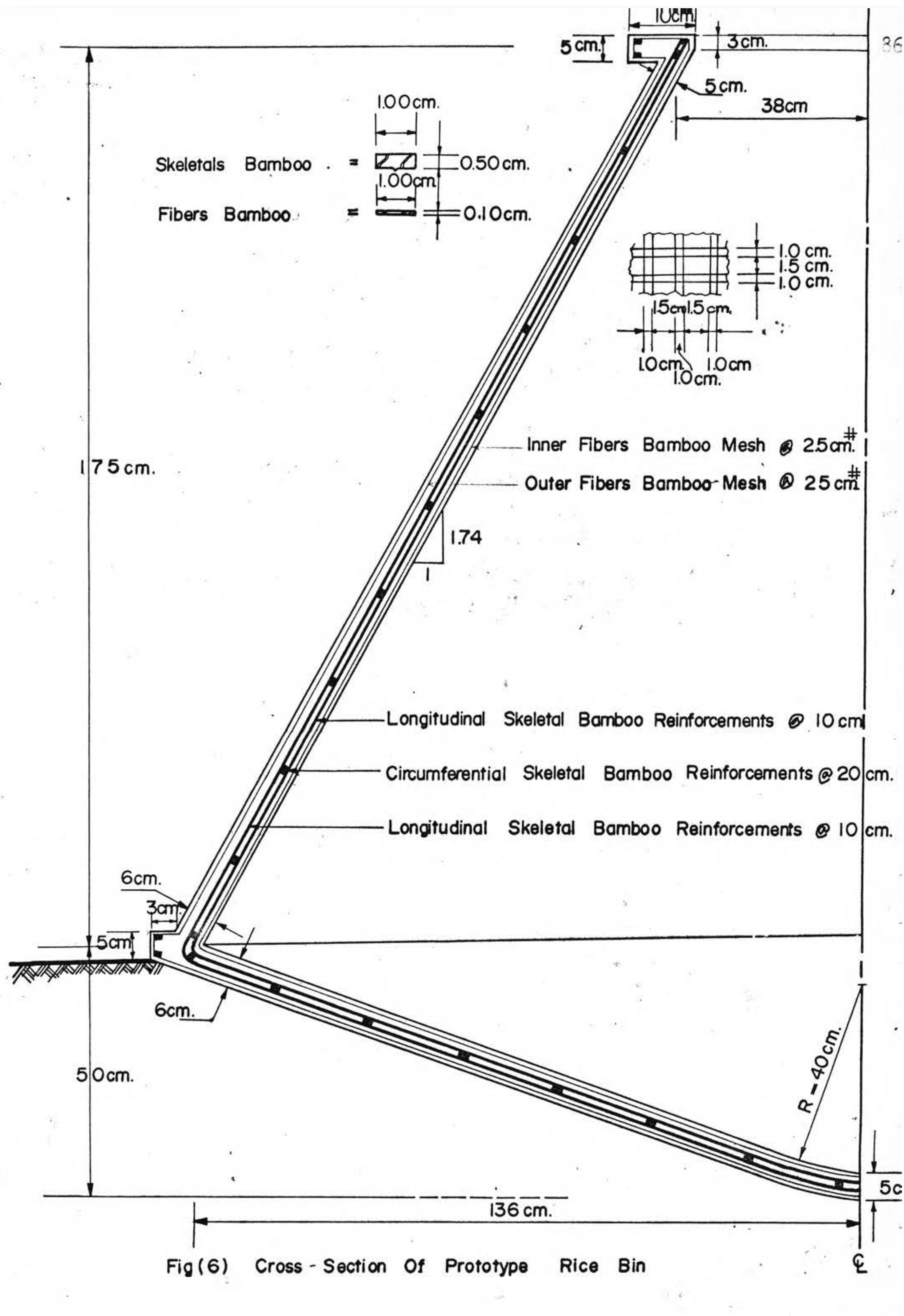


Fig (6) Cross - Section Of Prototype Rice Bin

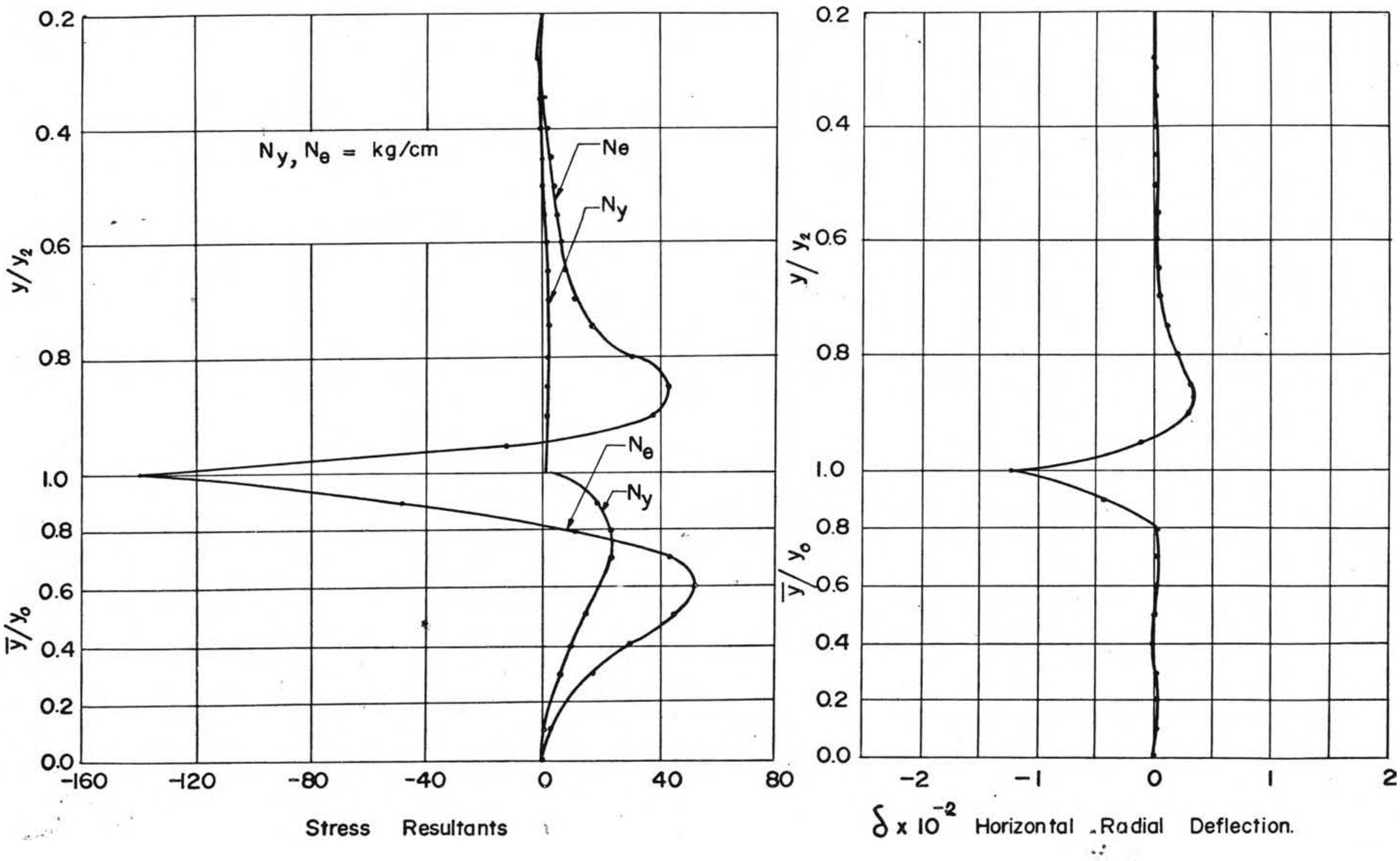


Fig.(7)– Distributions of Normal Stress Resultants and Horizontal Radial Deflection Due to The Pressure of Water, Dead Load and Vertical Edge Load.

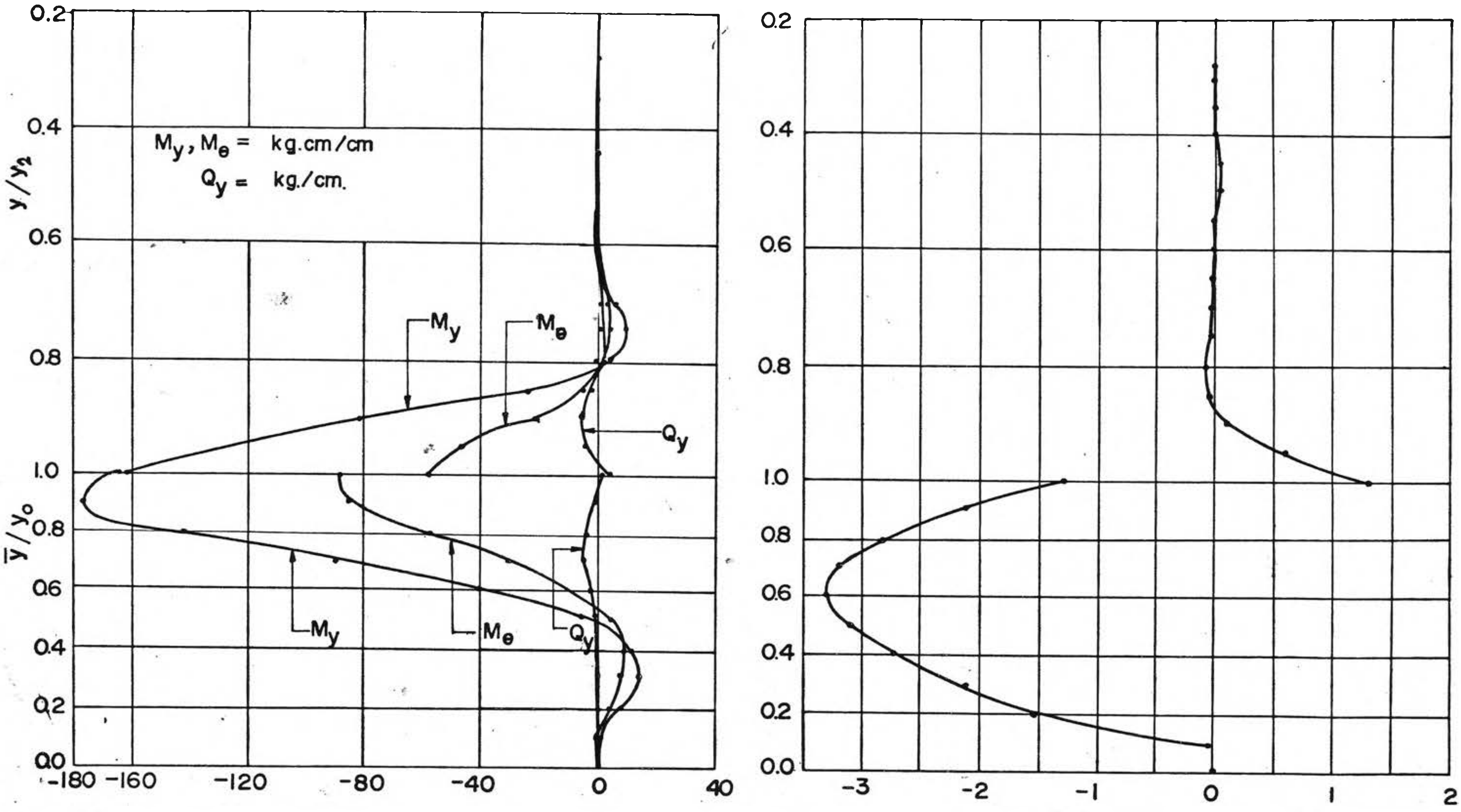
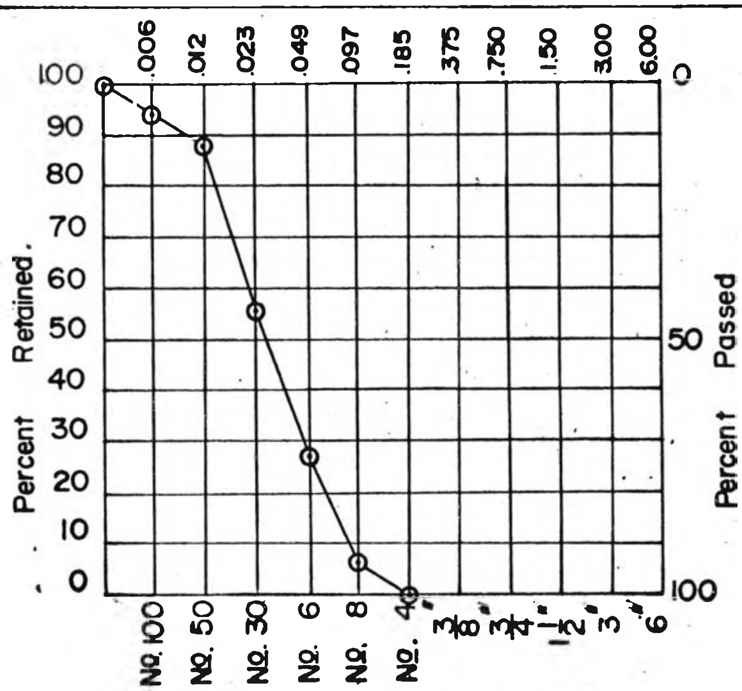
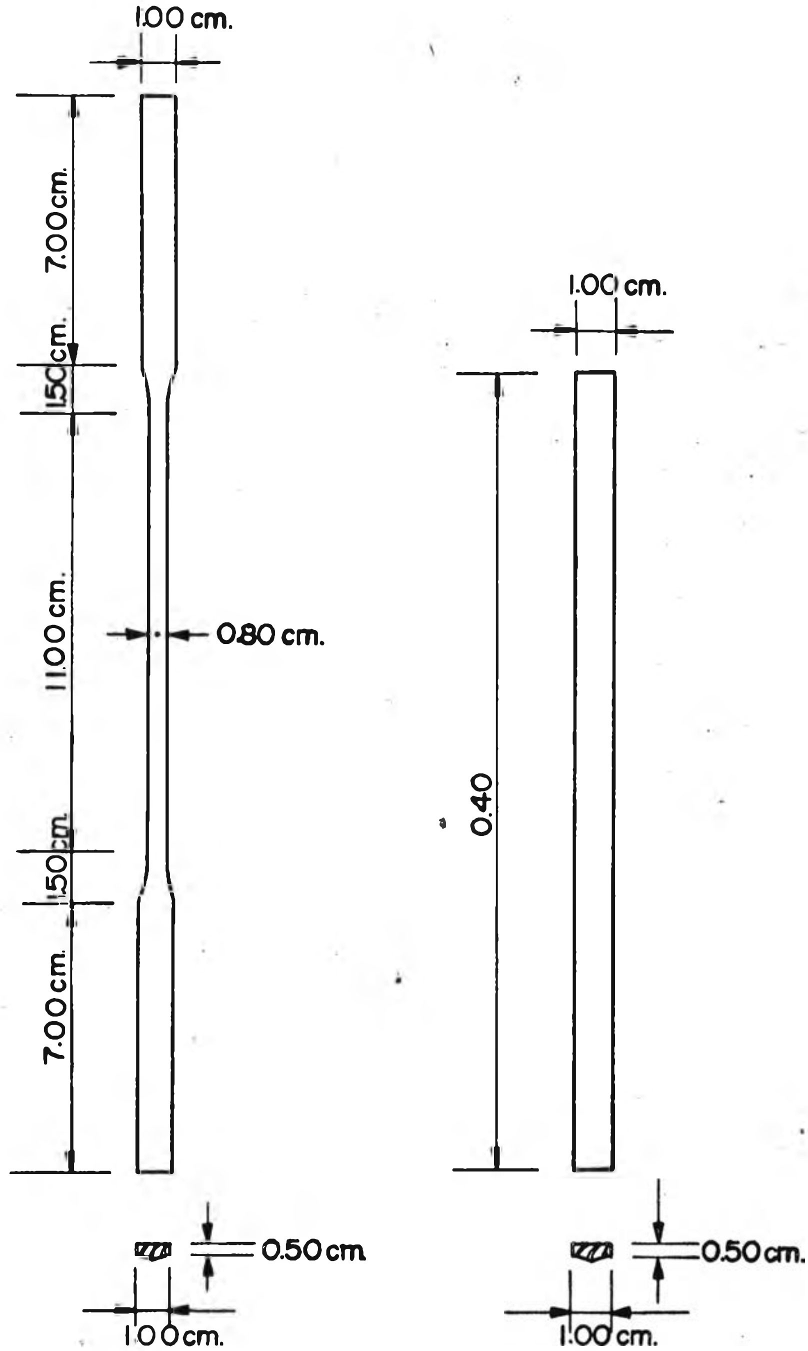


Fig. (8) — Distributions of Bending and Shearing Stress Resultants and Rotation Due to The Pressure of Water, Dead Load and Vertical Edge Load

FIG.(9) Gradation of Natural Coarse Sand.

Screen Size	Cumulative	
	Persent Passed	Persent Retained
1½"	100	—
¾"	100	—
⅜"	100	—
No 4	100	—
No 8	93.6	6.4
No 16	71.9	28.1
No 30	44.8	55.2
No 50	11.4	88.6
No 100	1.3	93.7
PAN	—	100
Finess Modulus	2.77	





(a) Tension Test Specimen.

(b) Bond Test Specimen.

Fig.(10) Dimensions Of Test Specimen Of Bamboo.

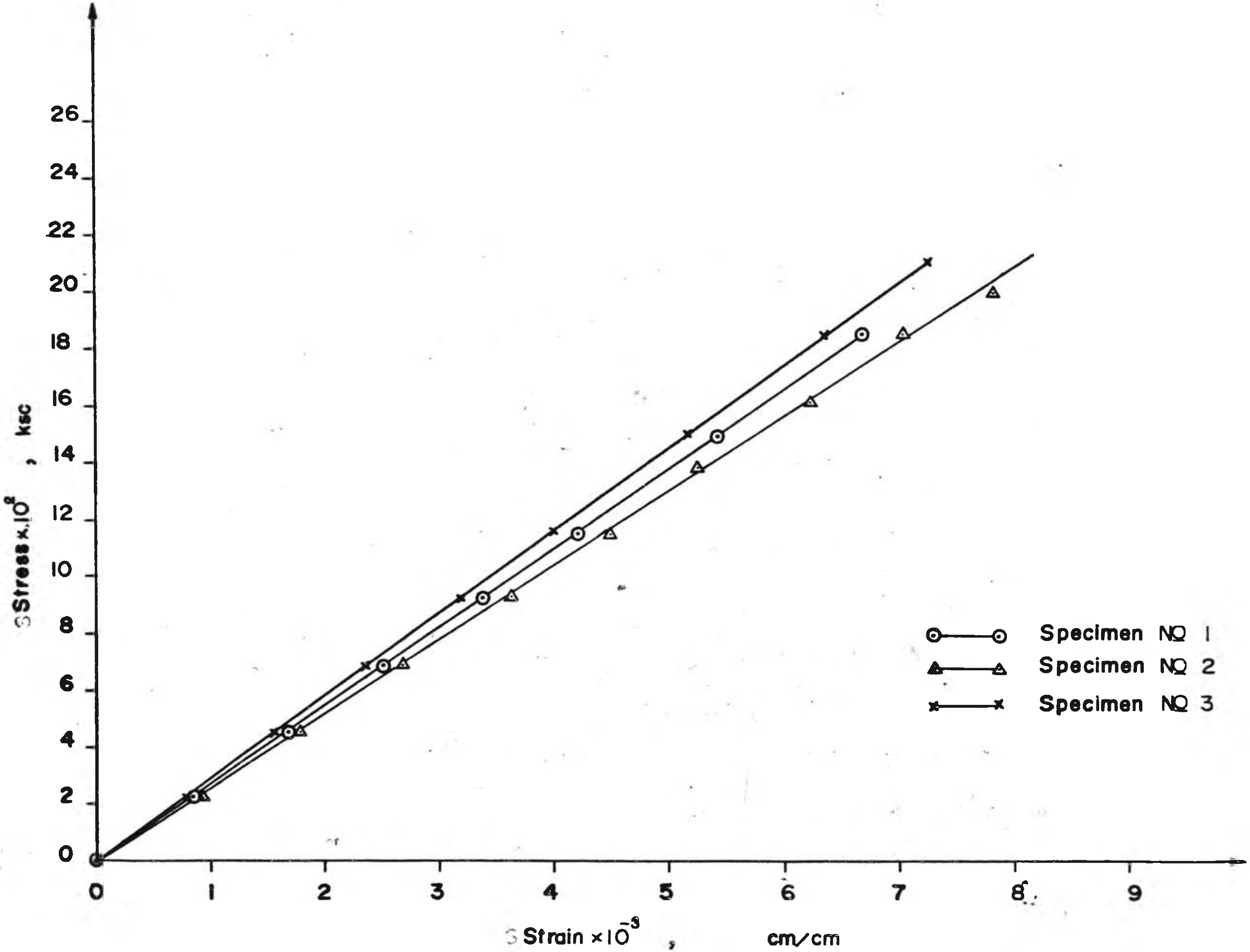
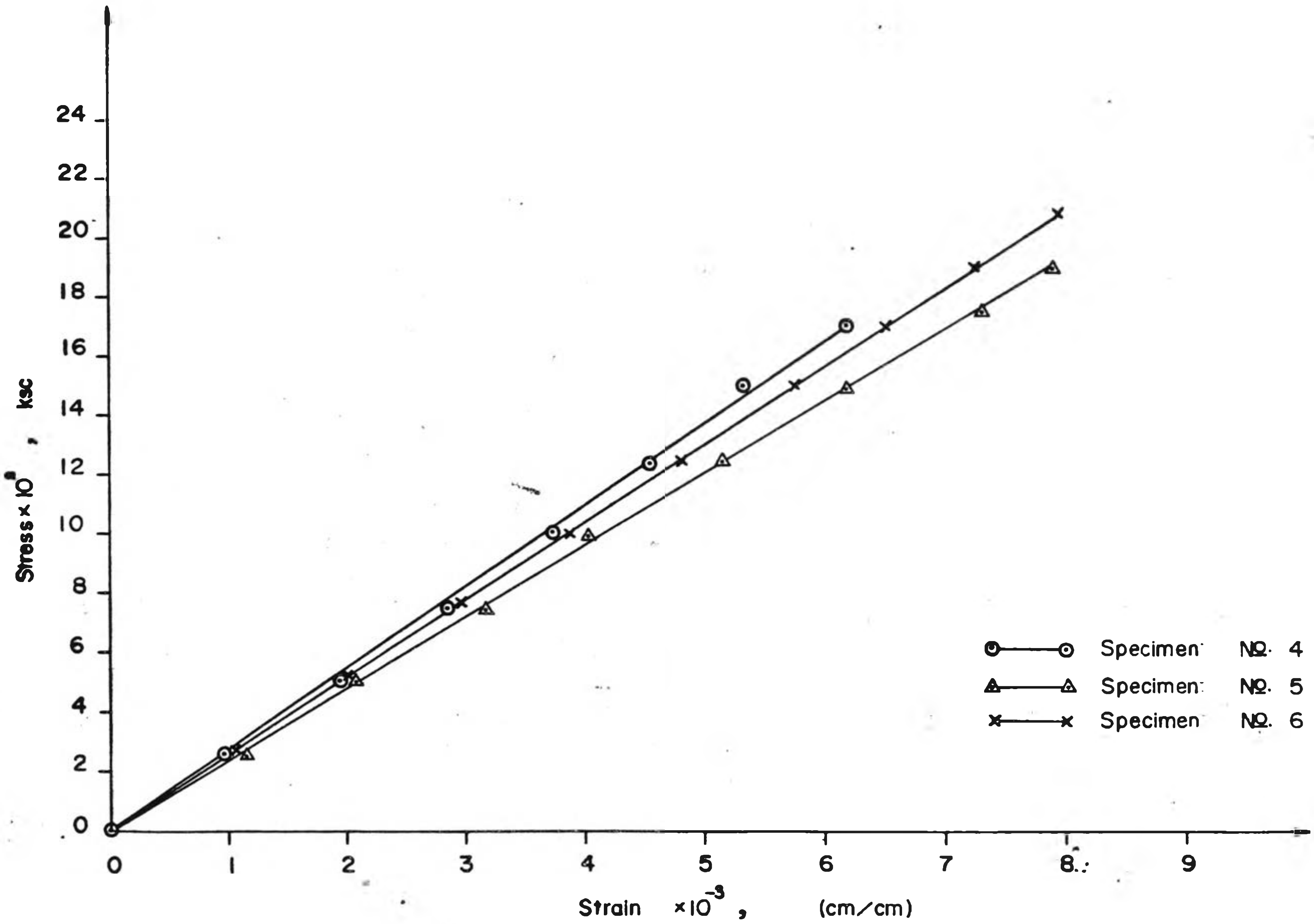


FIG.(11a)—Stress-Strain Curve Of Bamboo Specimen In Direct Tension Test.



Fig(11 b) — Stress — Strain Curve of Bamboo Specimen In Direct Tension Test

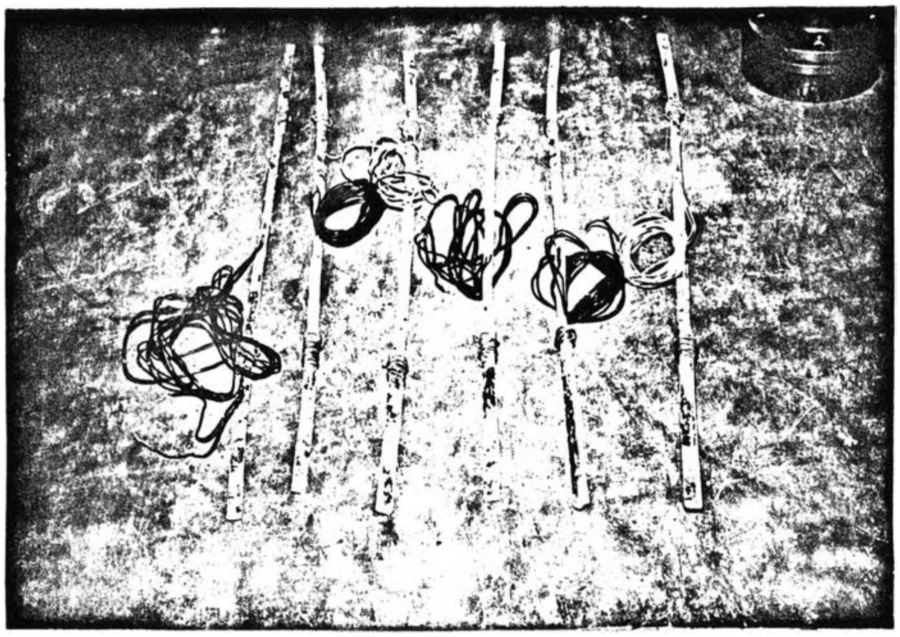


FIG.(12a) - TENSION SPECIMENS OF BAMBOO FITTING WITH DEMEC STRAIN GAUGES

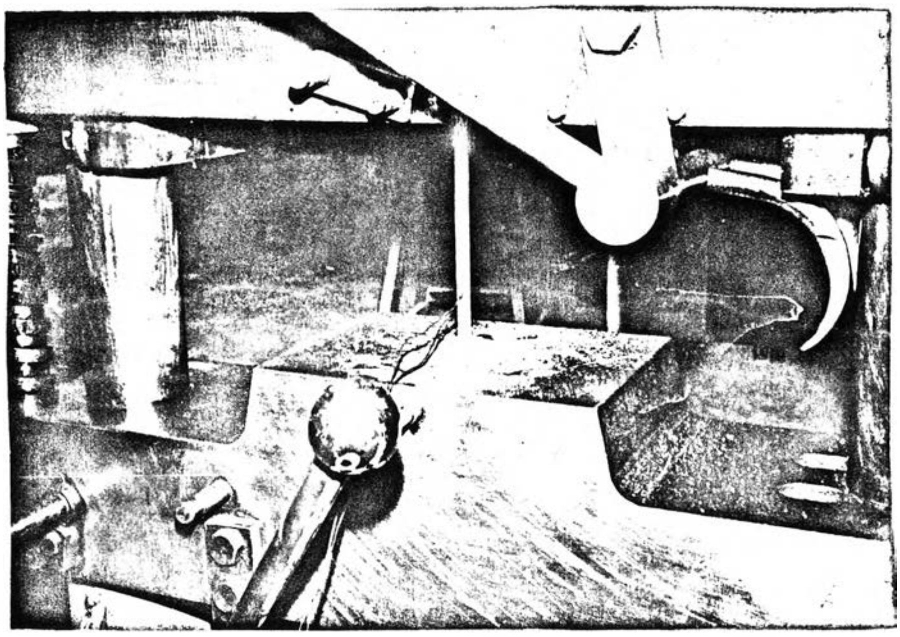


FIG.(12b) - TENSION SPECIMEN IN DIRECT TENSION TEST

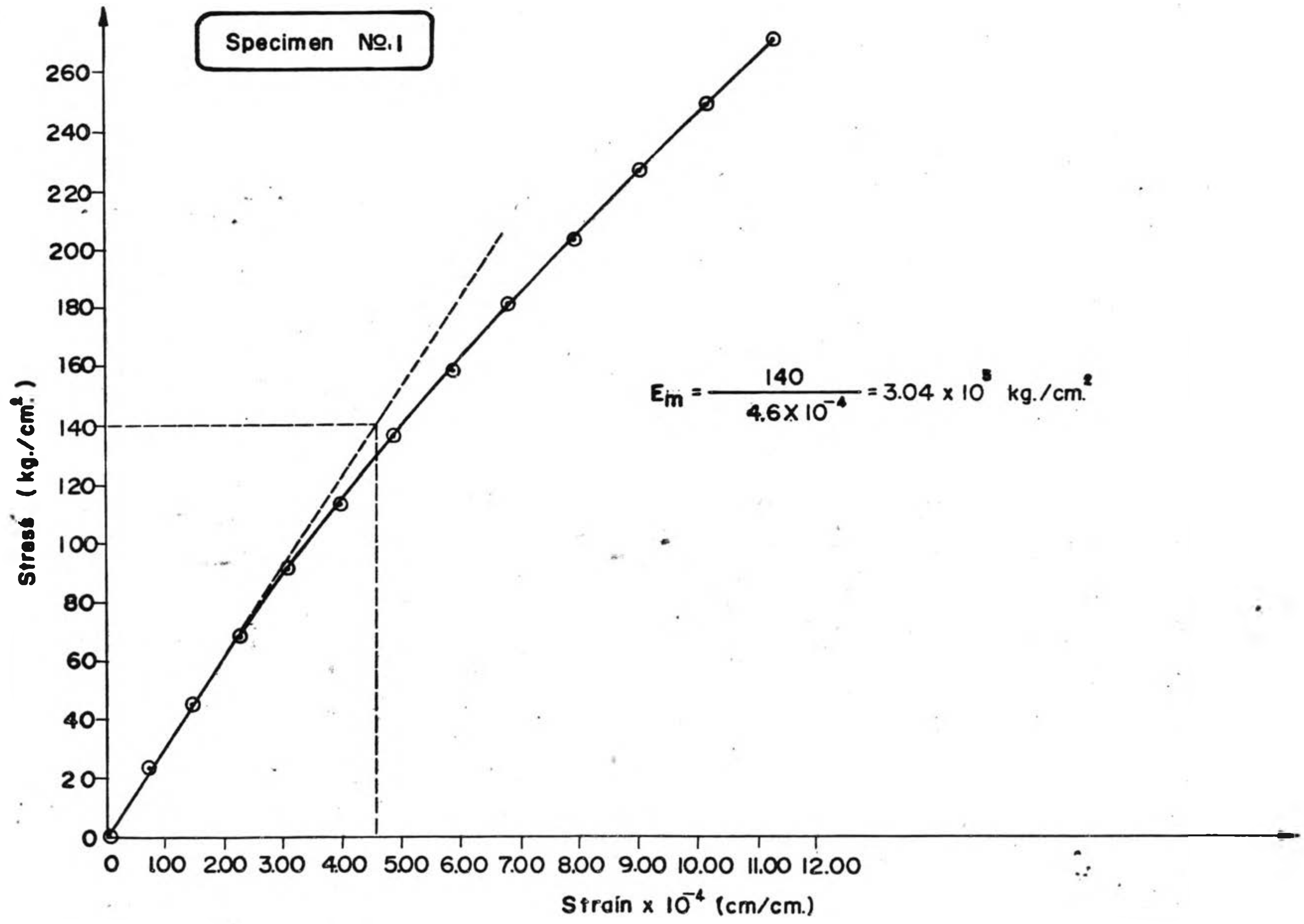


Fig.(14a) — Stress— Strain Curve Of Mortar Cylinder Specimen In Compression Test.

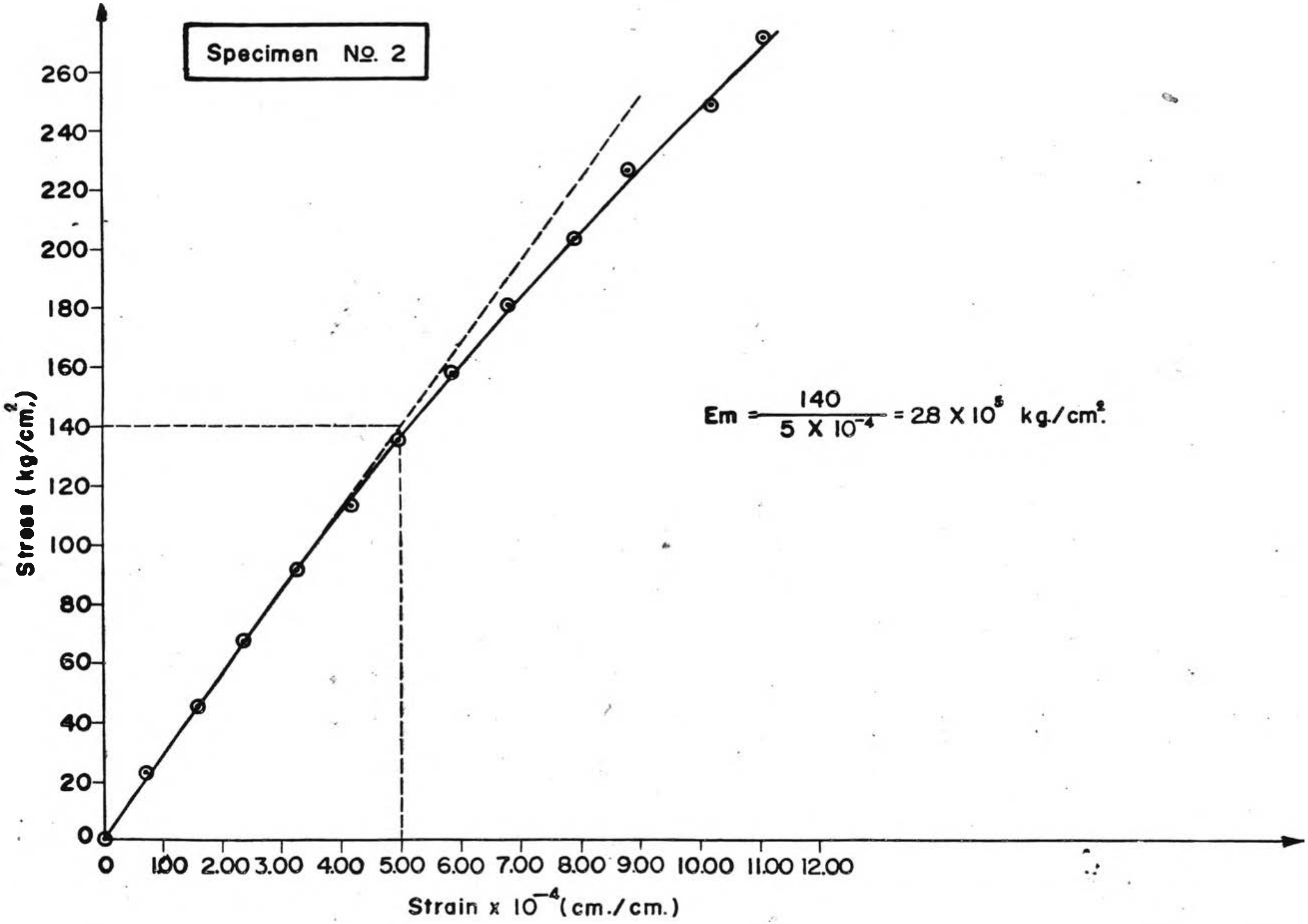


Fig (14 b) —— Stress-Strain Curve Of Mortar Cylinder Specimen In Compression Test.

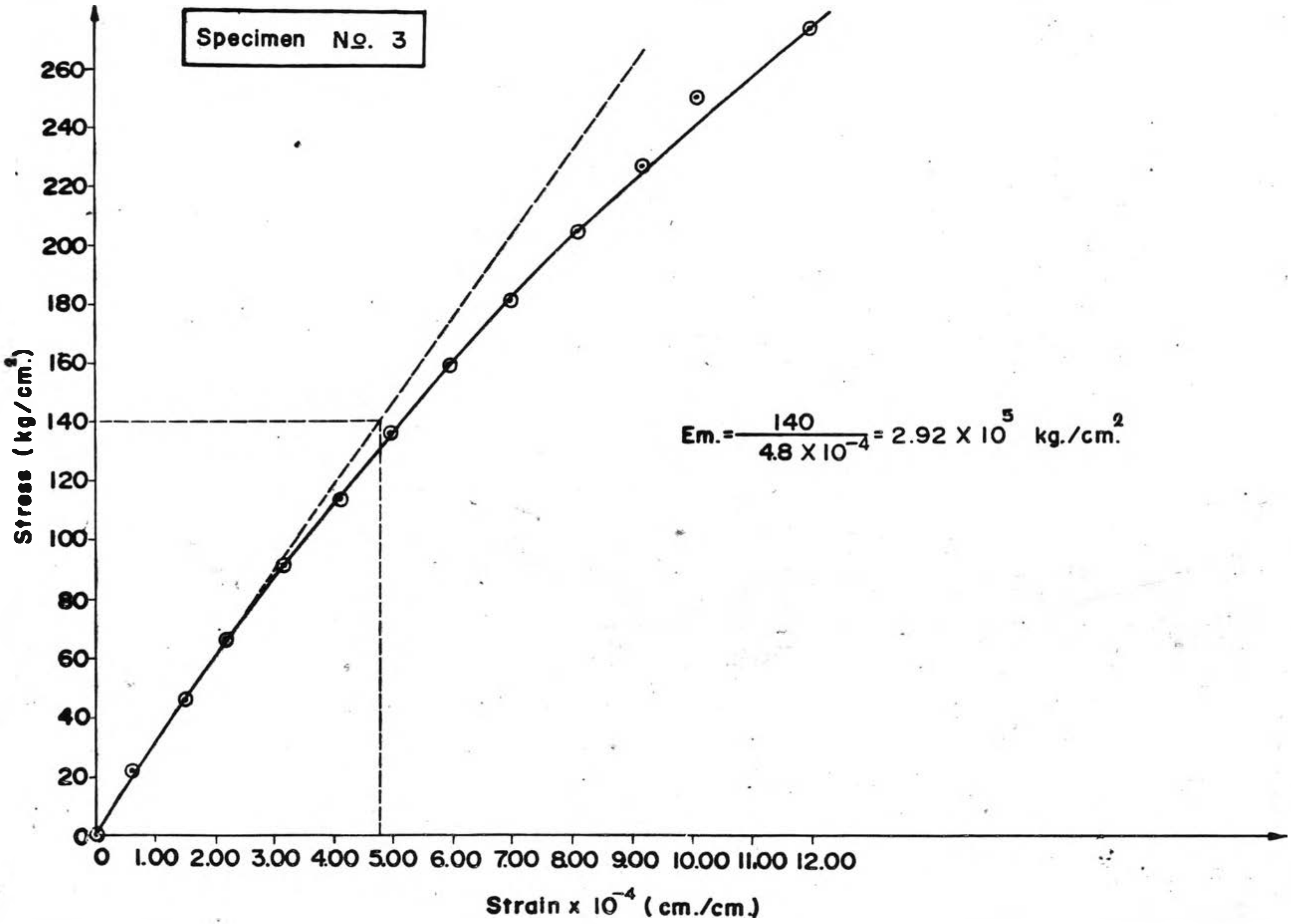


Fig (14c) — Stress–Strain Curve Of Mortar Cylinder Specimen In Compression Test.

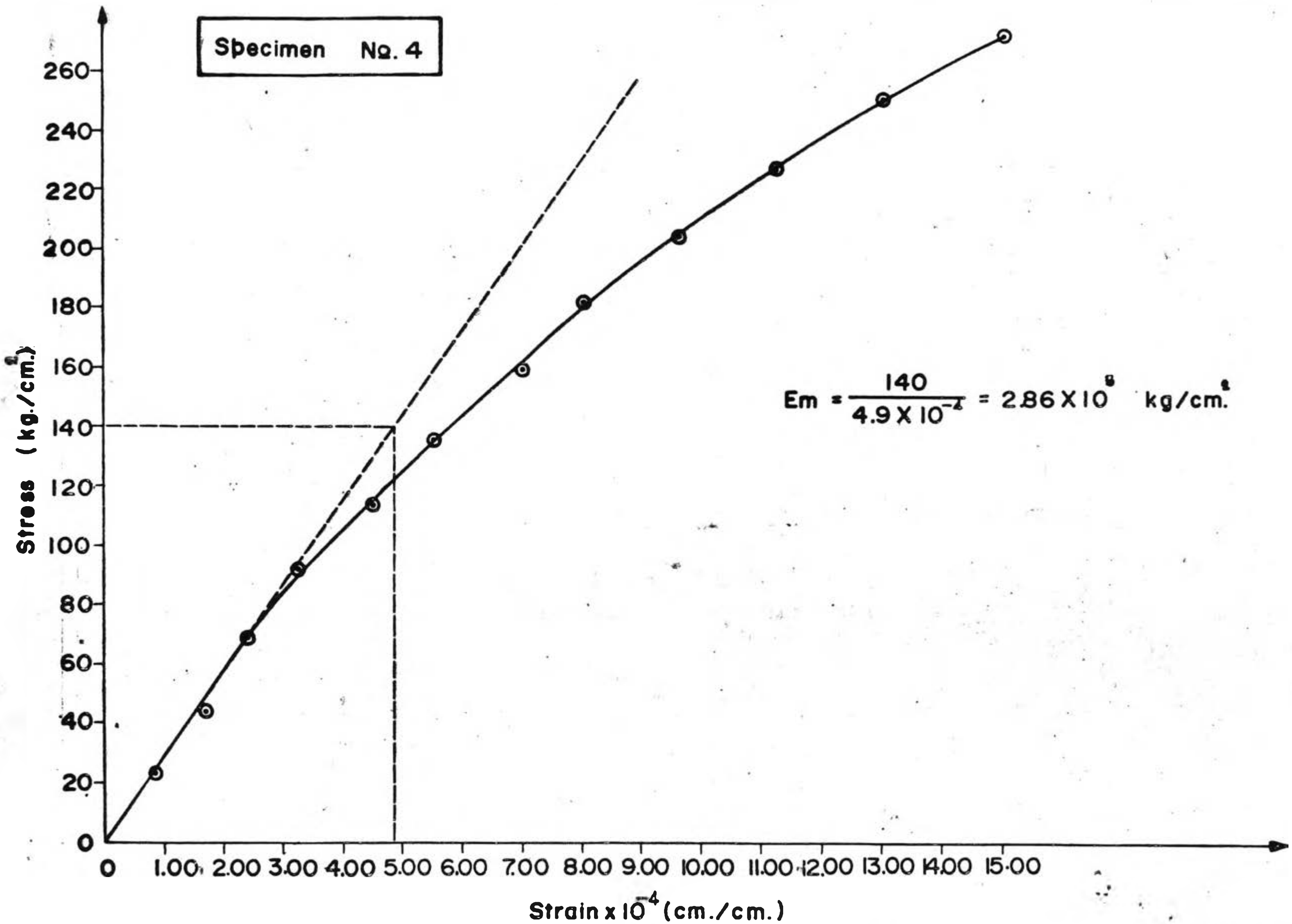


Fig (14d) — Stress-Strain Curve Of Mortar Cylinder Specimen In Compression Test.

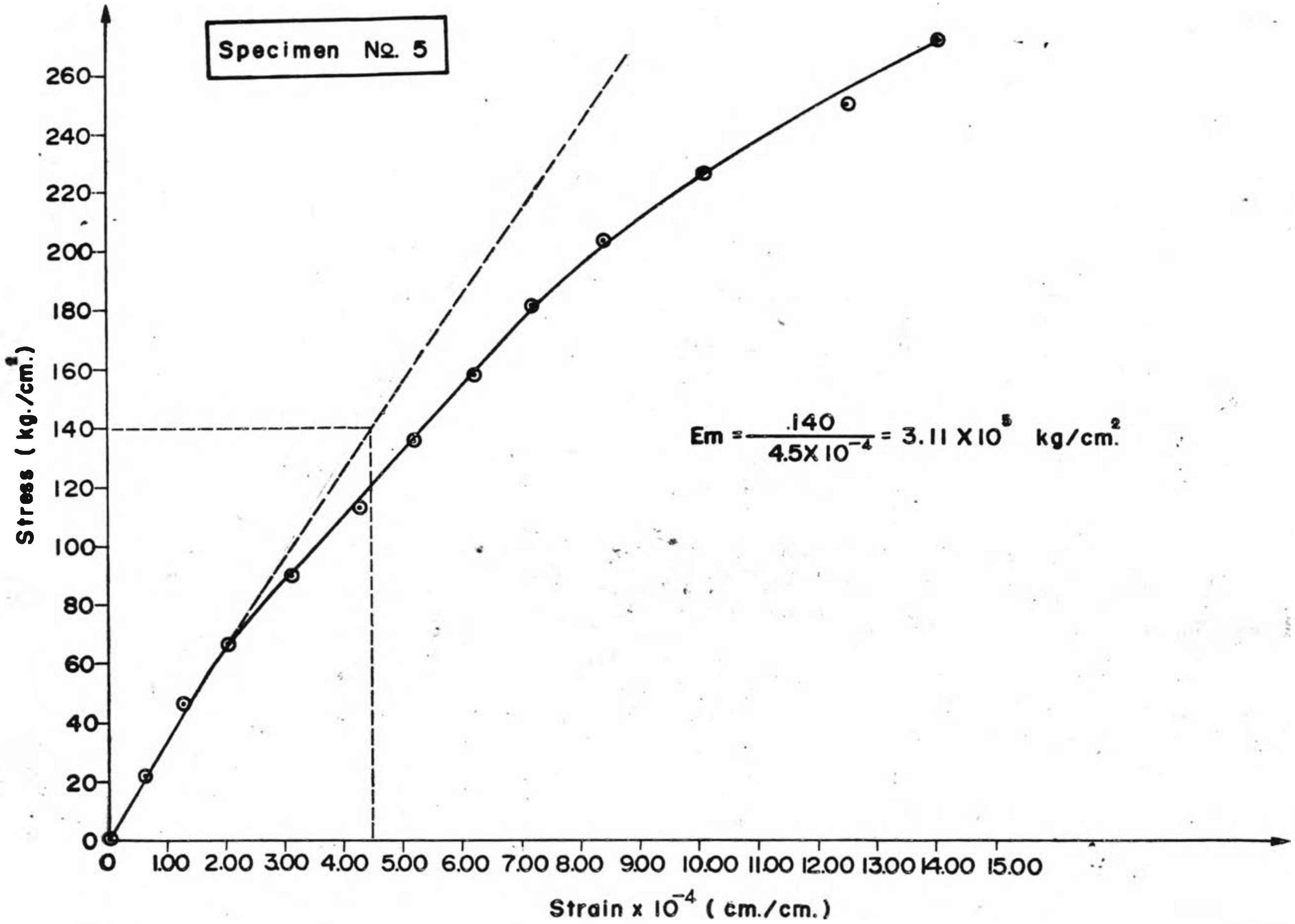


Fig (14 e) — Stress— Strain Curve Of Mortar Cylinder Specimen In Compression Test

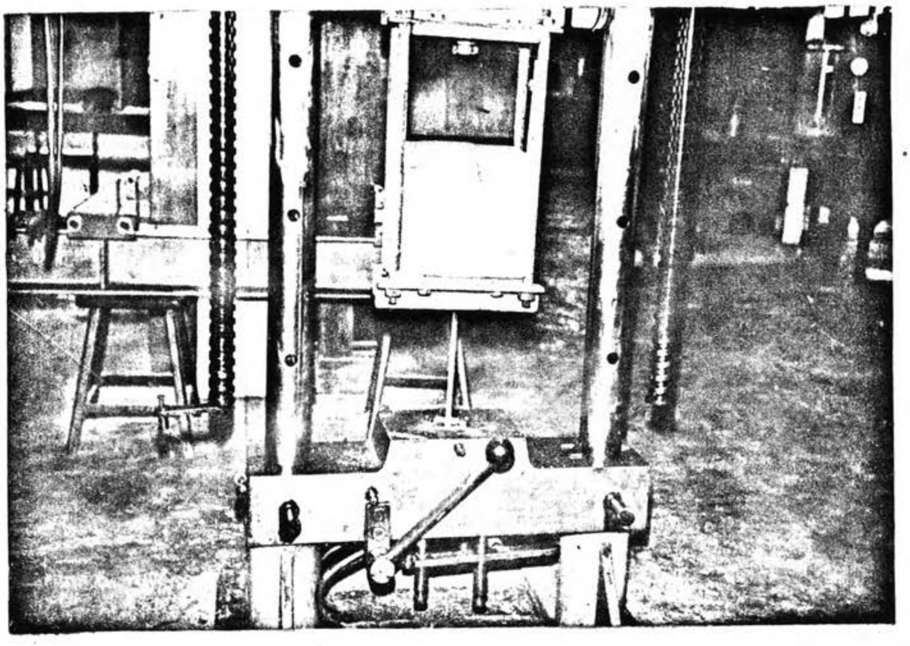


FIG.(13) - BOND SPECIMEN IN BOND TEST

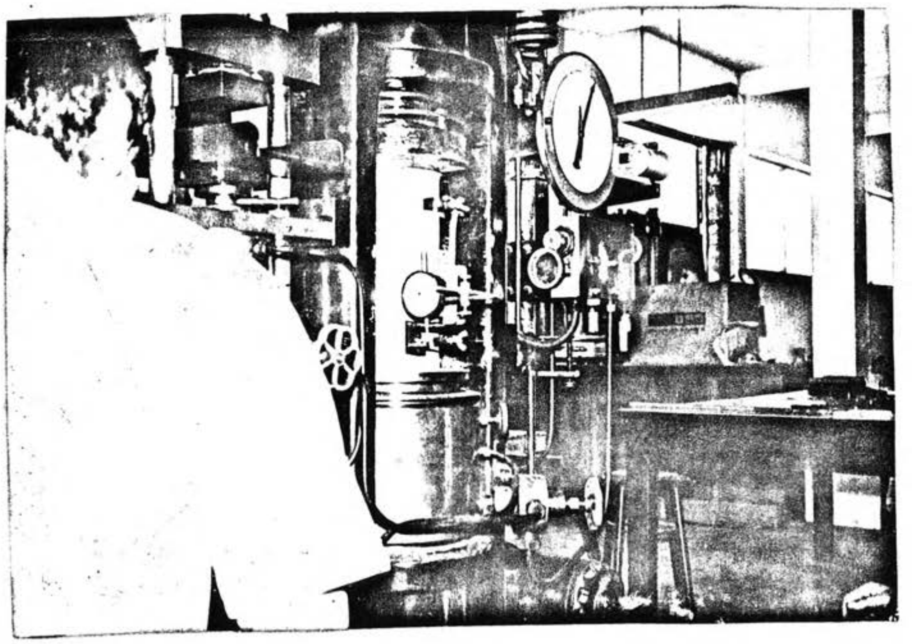


FIG.(15) - CYLINDER SPECIMEN IN COMPRESSION TEST FIX WITH COMPRESSOMETER

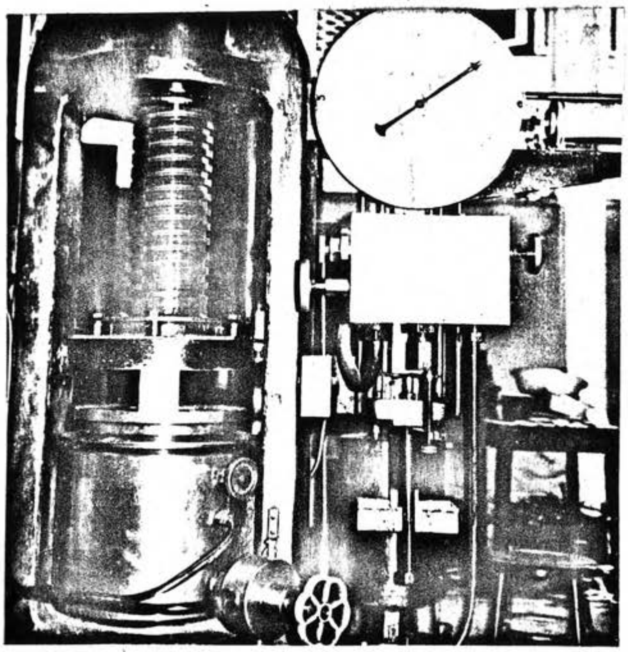


FIG.(16) - CUBE SPECIMEN IN COMPRESSION TEST

FIG.(17) - PREPARATION OF FOUNDATION

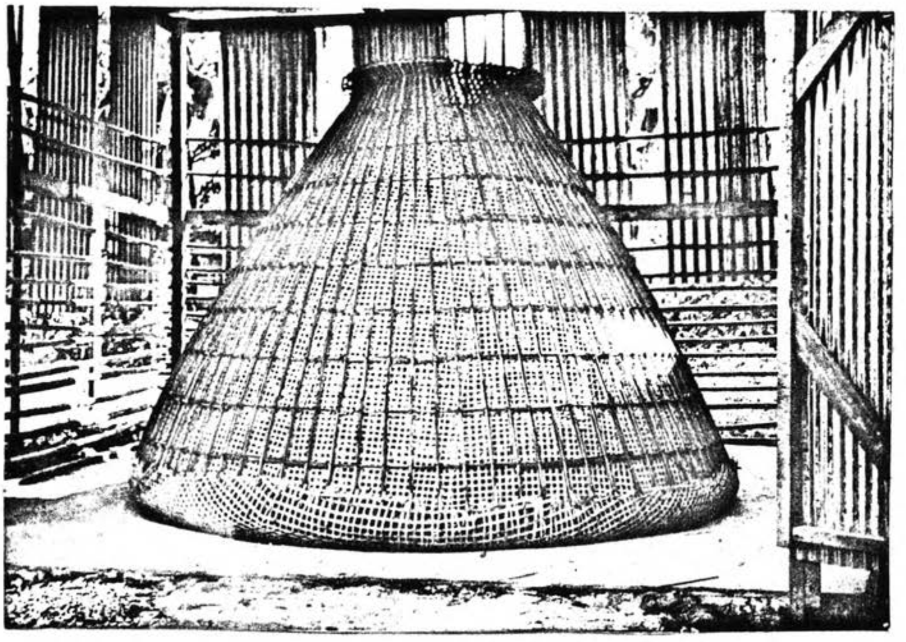


FIG.(18a) - SKELETAL BAMBOO REINFORCEMENTS OF THE RICE BIN

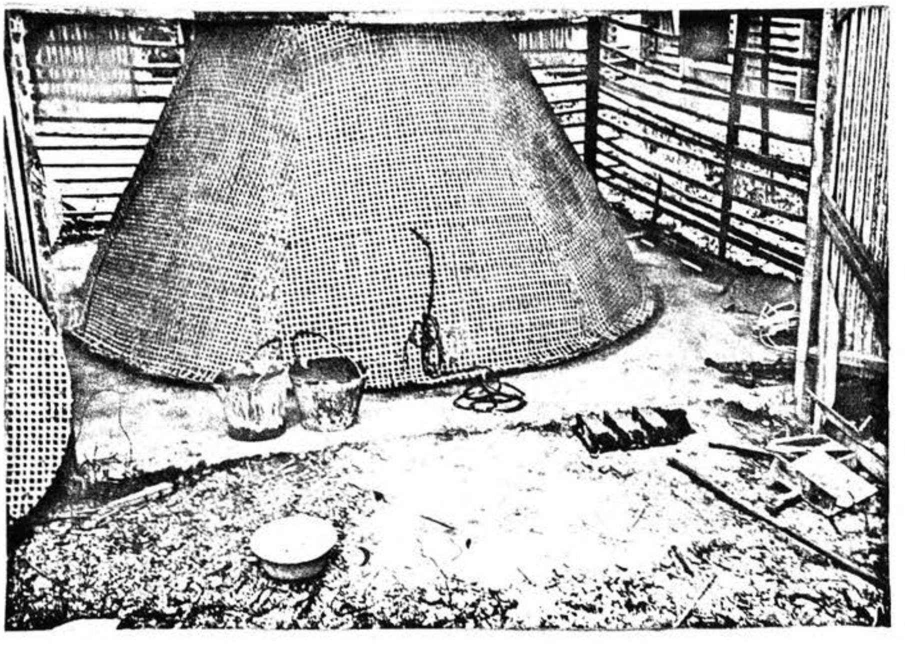


FIG.(18b) - TYING OF FIBERS BAMBOO MESH OF THE RICE BIN

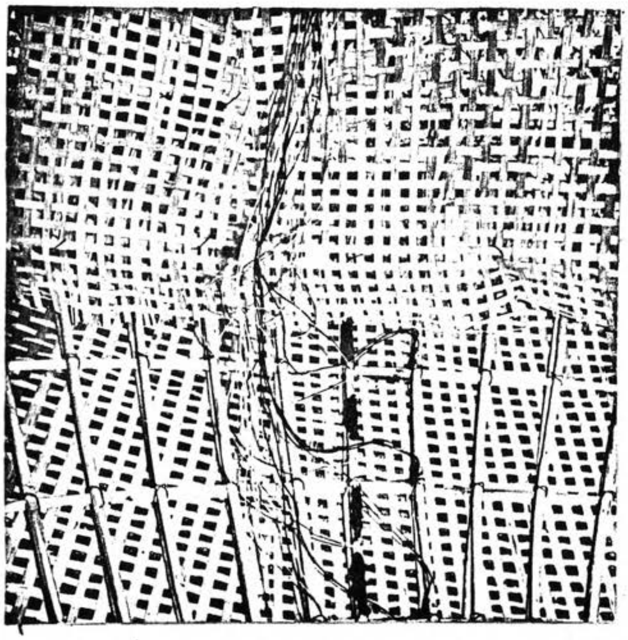


FIG.(19a) - STICKING STRAIN GAUGES IN SKELETAL BAMBOO FOR BOTTOM CONE

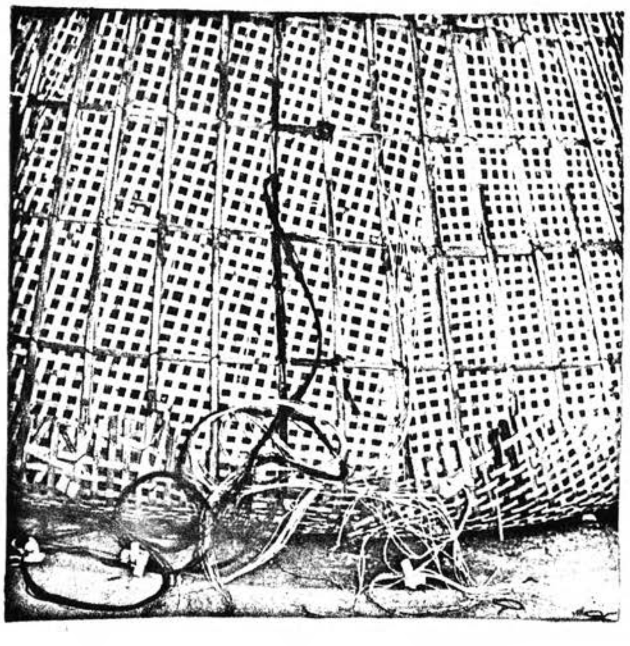


FIG.(19b) - STICKING STRAIN GAUGES IN SKELETAL BAMBOO FOR TOP CONE

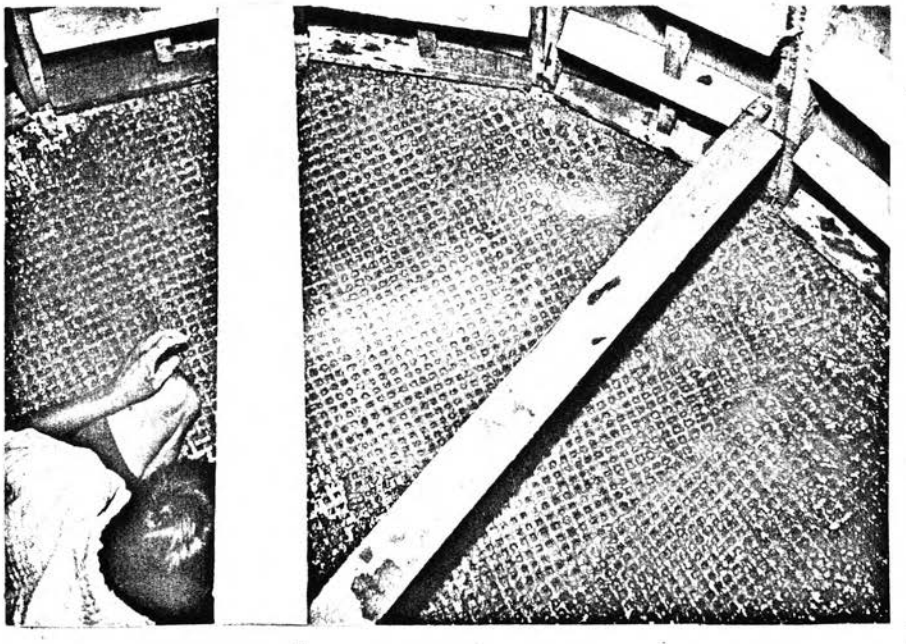


FIG.(20) - CASTING OF BOTTOM CONE

FIG.(21) - CASTING OF TOP CONE

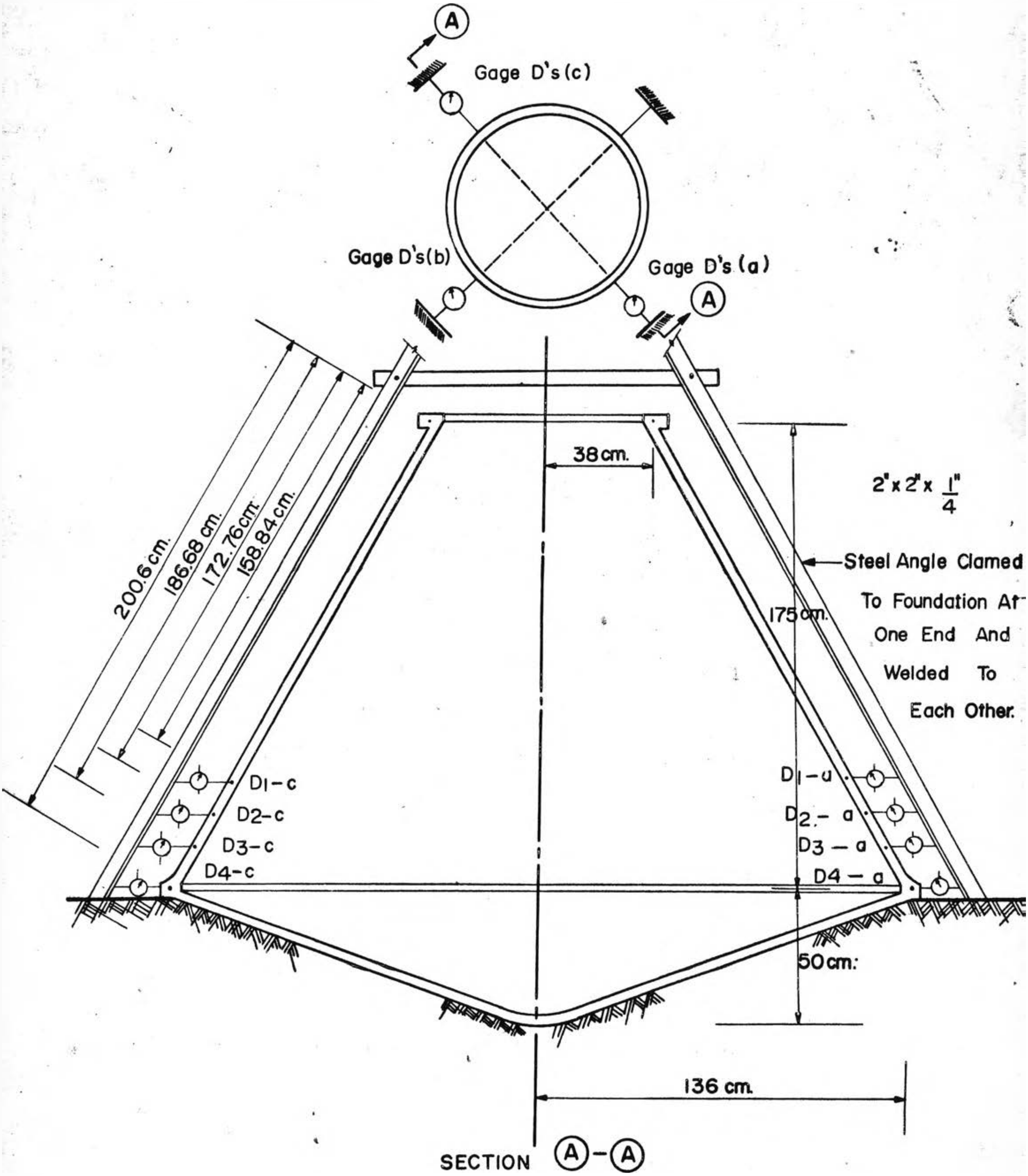
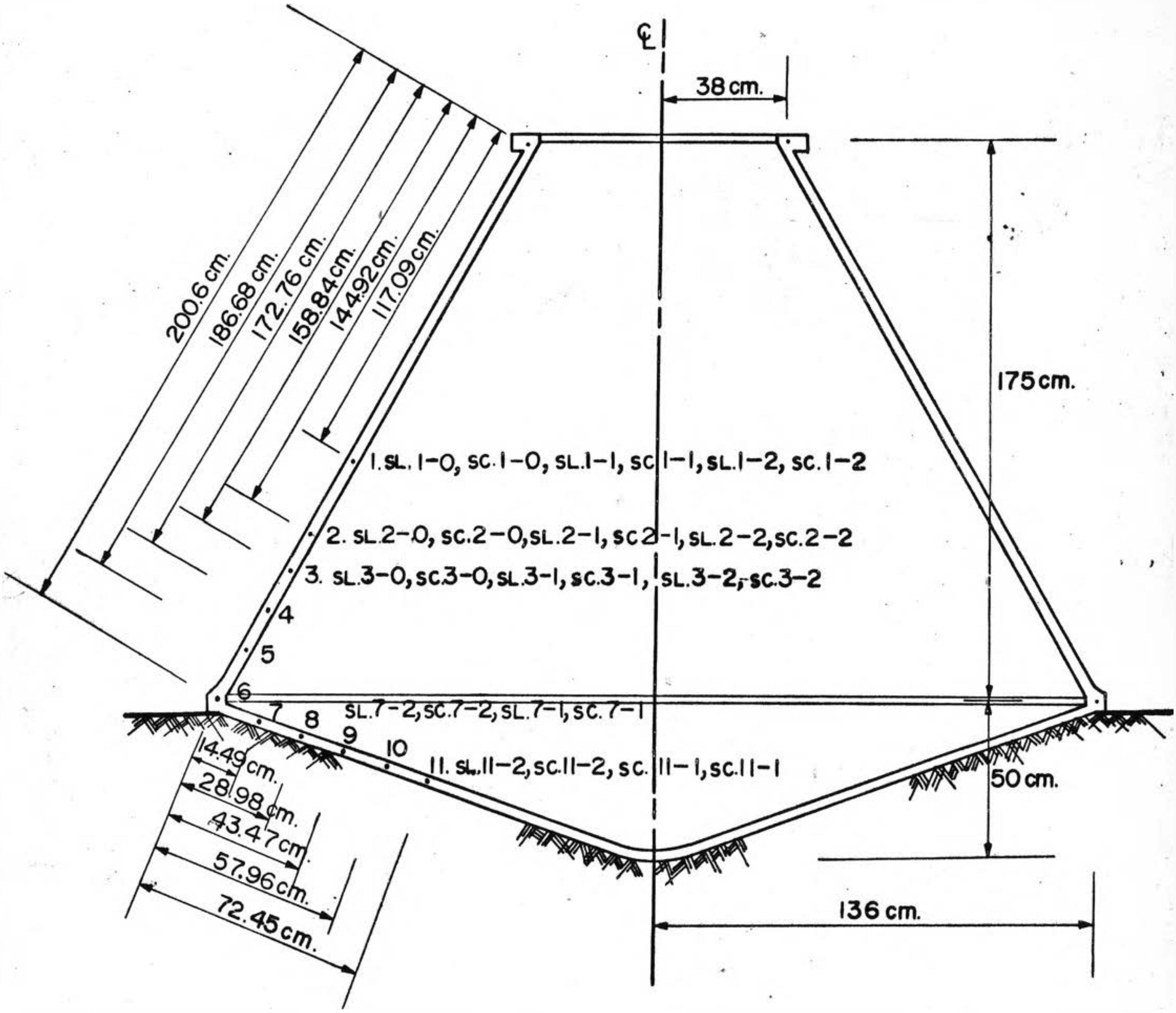


Fig.(22) Arrangement Of Dial Gages.



"SL" Denotes Strain Gages In Longitudinal Direction And "SC" In Circumferential Direction.

"-0" Denotes Strain Gages At Outer Fiber, "-1" At Inner Fiber And "-2" In Skeletal Bamboos.

Fig. (23) — Positions Of Strain Gages.

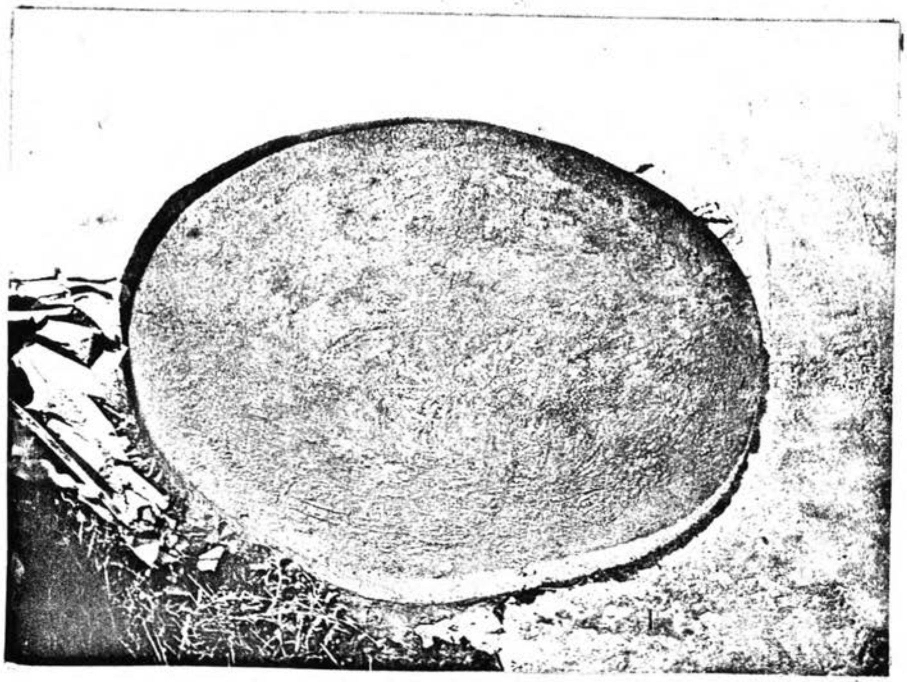


FIG.(24) - CASTING OF BIN LID

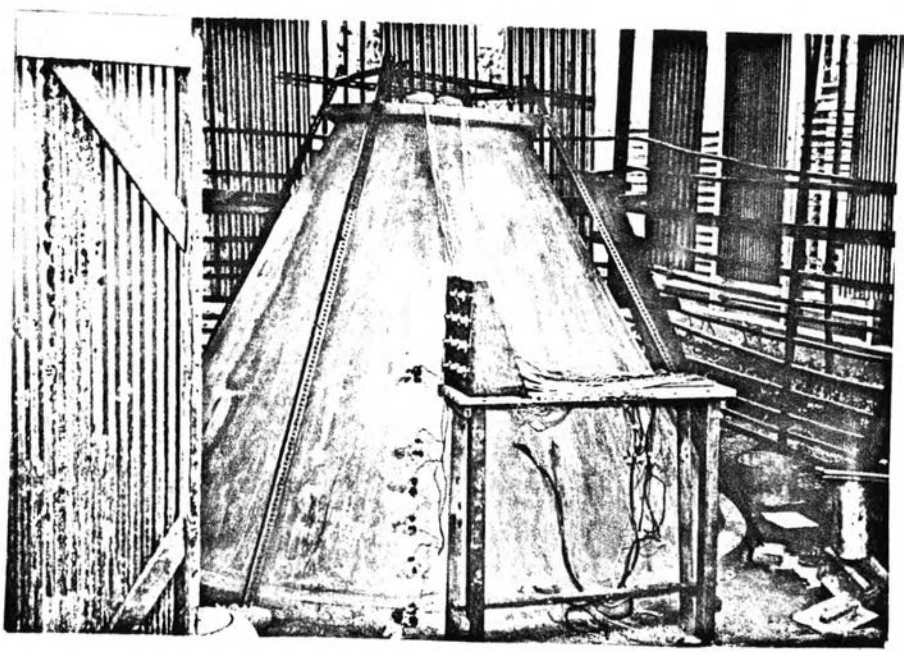


FIG.(25) - TEST EQUIPMENT AND INSTRUMENTATION OF PROTOTYPE BIN

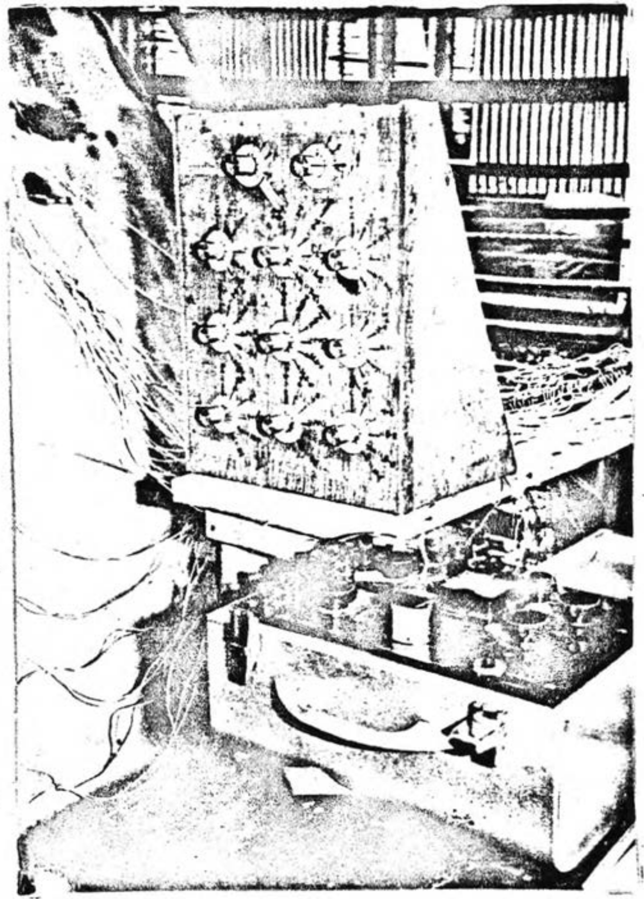


FIG.(26a) - STRAIN INDICATOR AND SELECTOR SWITCHES

FIG.(26b) - CIRCUITS OF SELECTOR SWITCHES

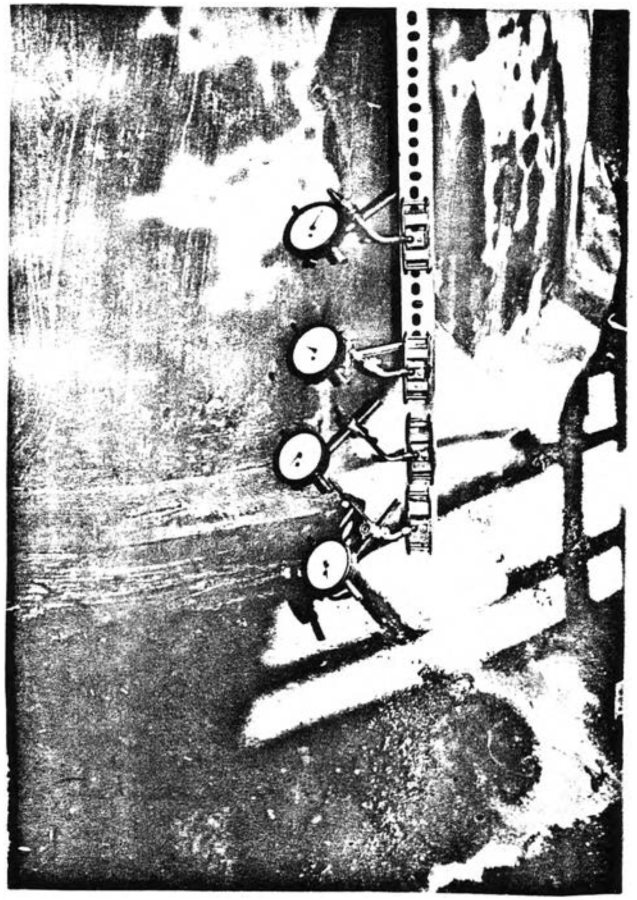


FIG.(27a) - METHOD OF ATTACHING DIAL GAUGES

FIG.(27b) - METHOD OF STICKING STRAIN GAUGES

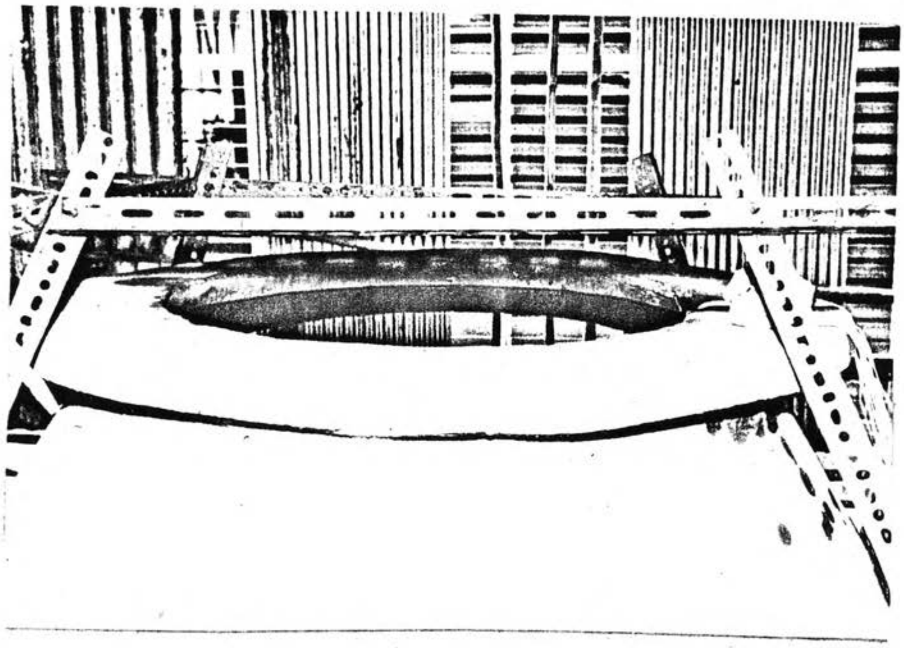


FIG.(28) - PROTOTYPE BIN WITH FULL OF WATER LOADING

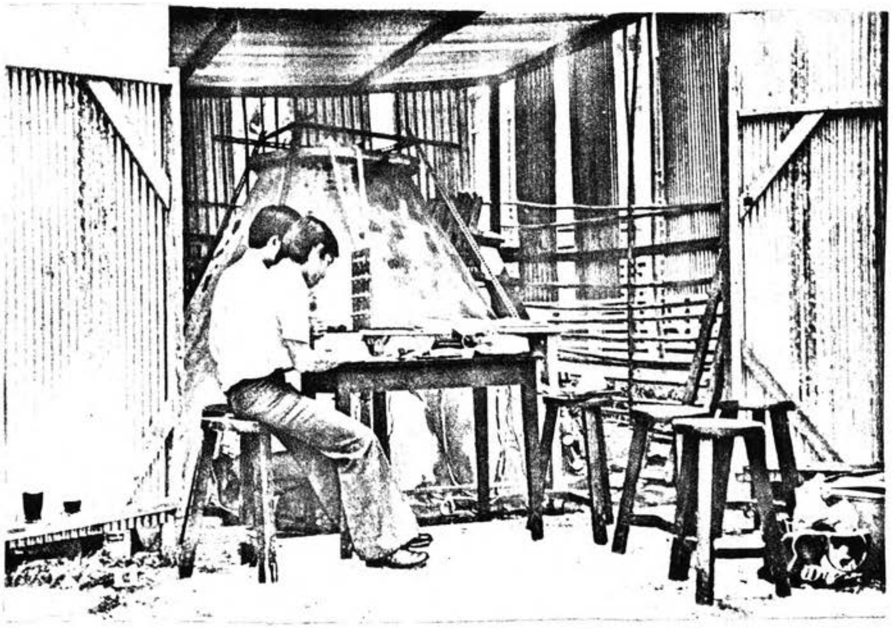


FIG.(29) - GENERAL VIEW OF TEST SET-UP

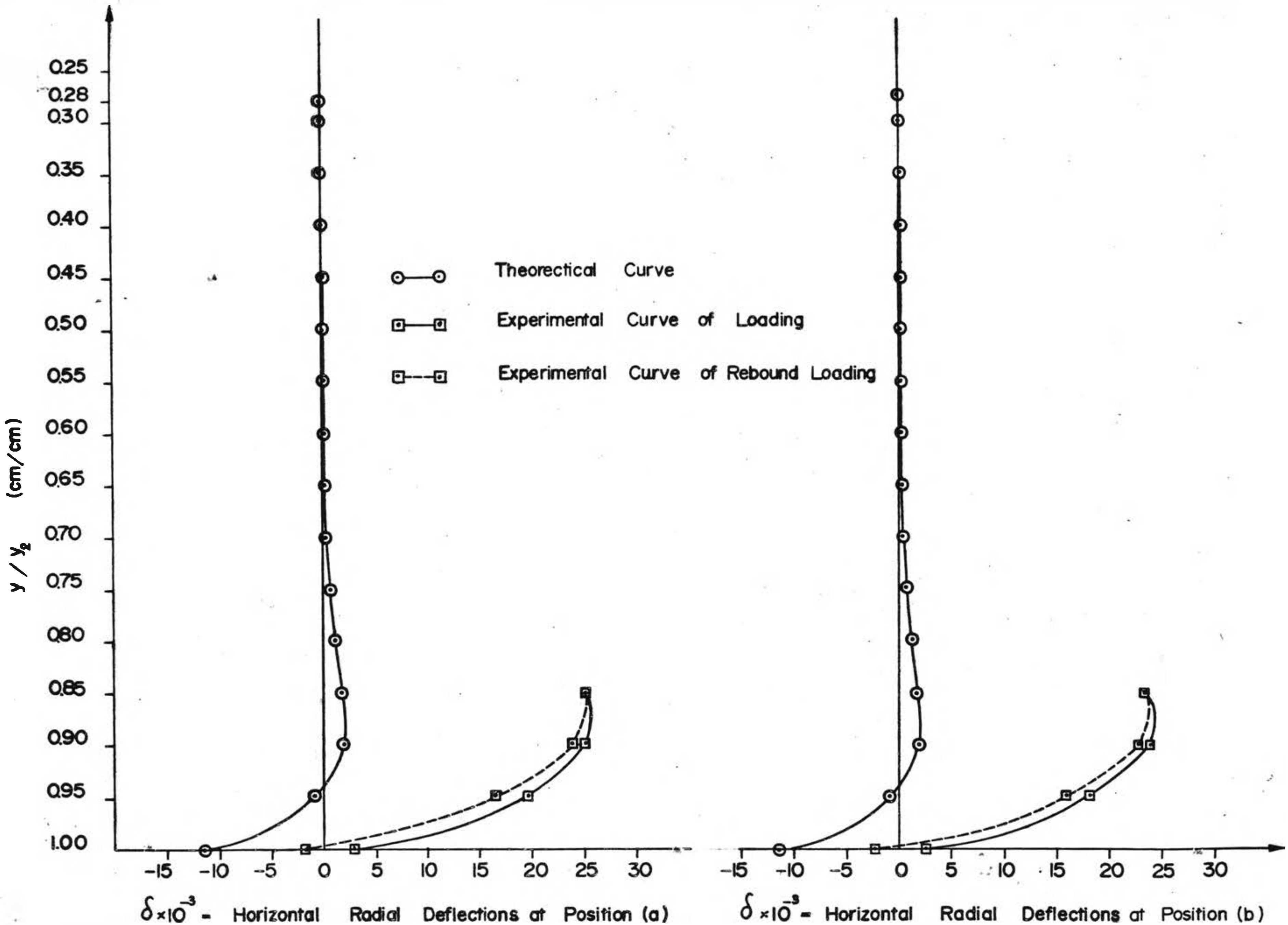


Fig.(30a) — Comparative Horizontal Radial Deflection Curves at Position (a), (b)

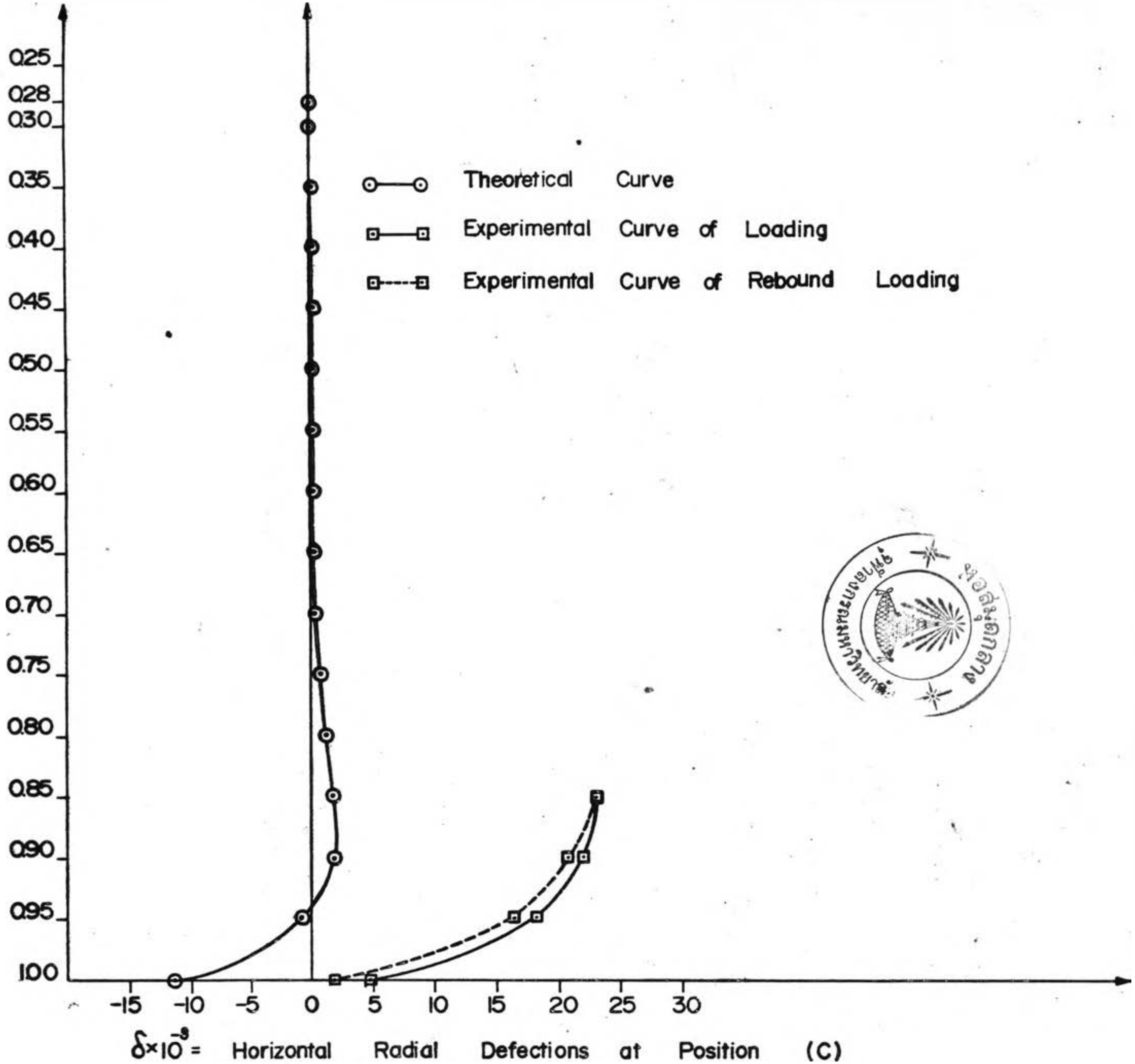


Fig.(30b) — Comparative Horizontal Radial Defection Curve at Position (C)

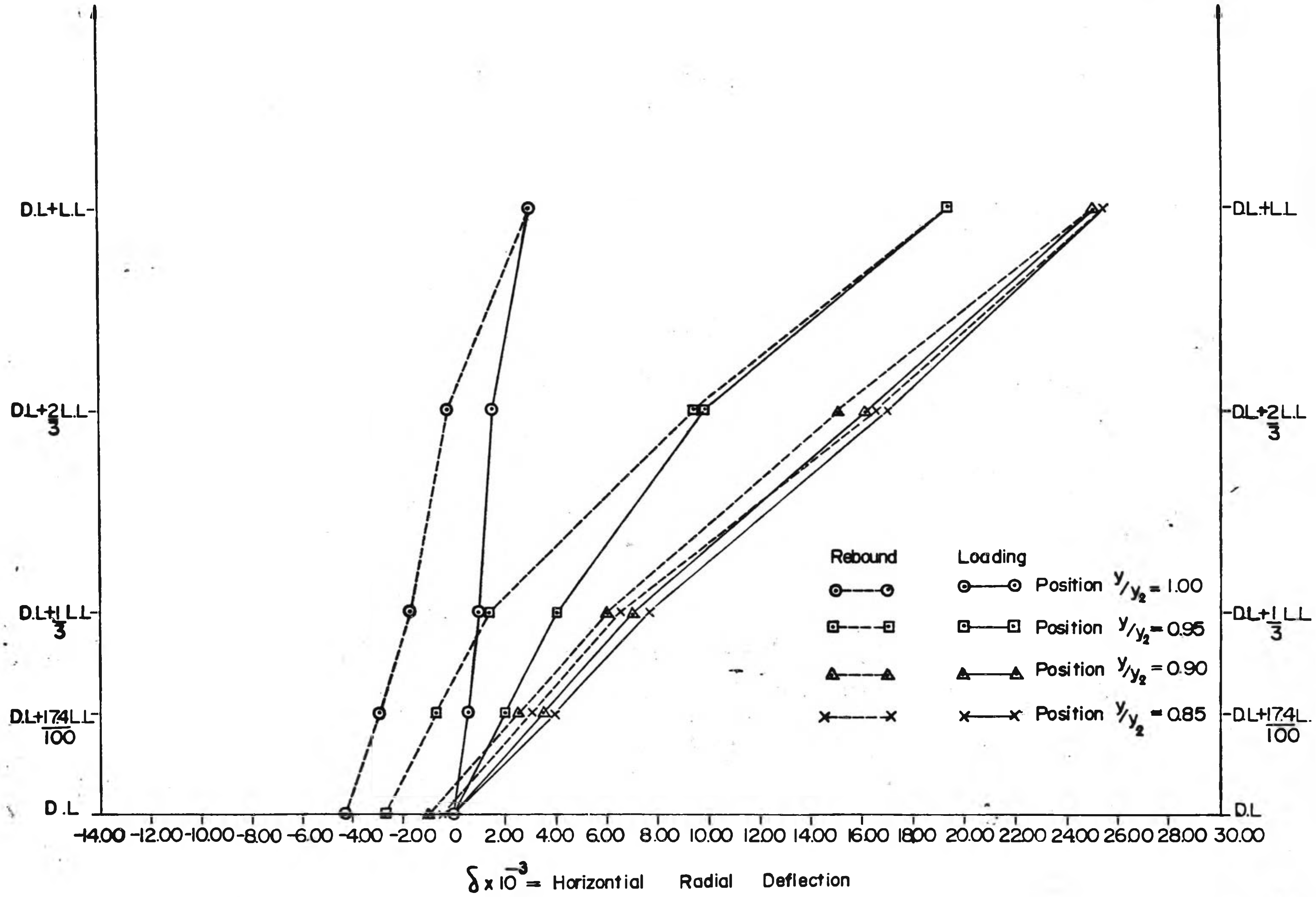


Fig.(31a)— Experiment Horizontal Radial Deflection Curves of Various Loading at Position.(a)

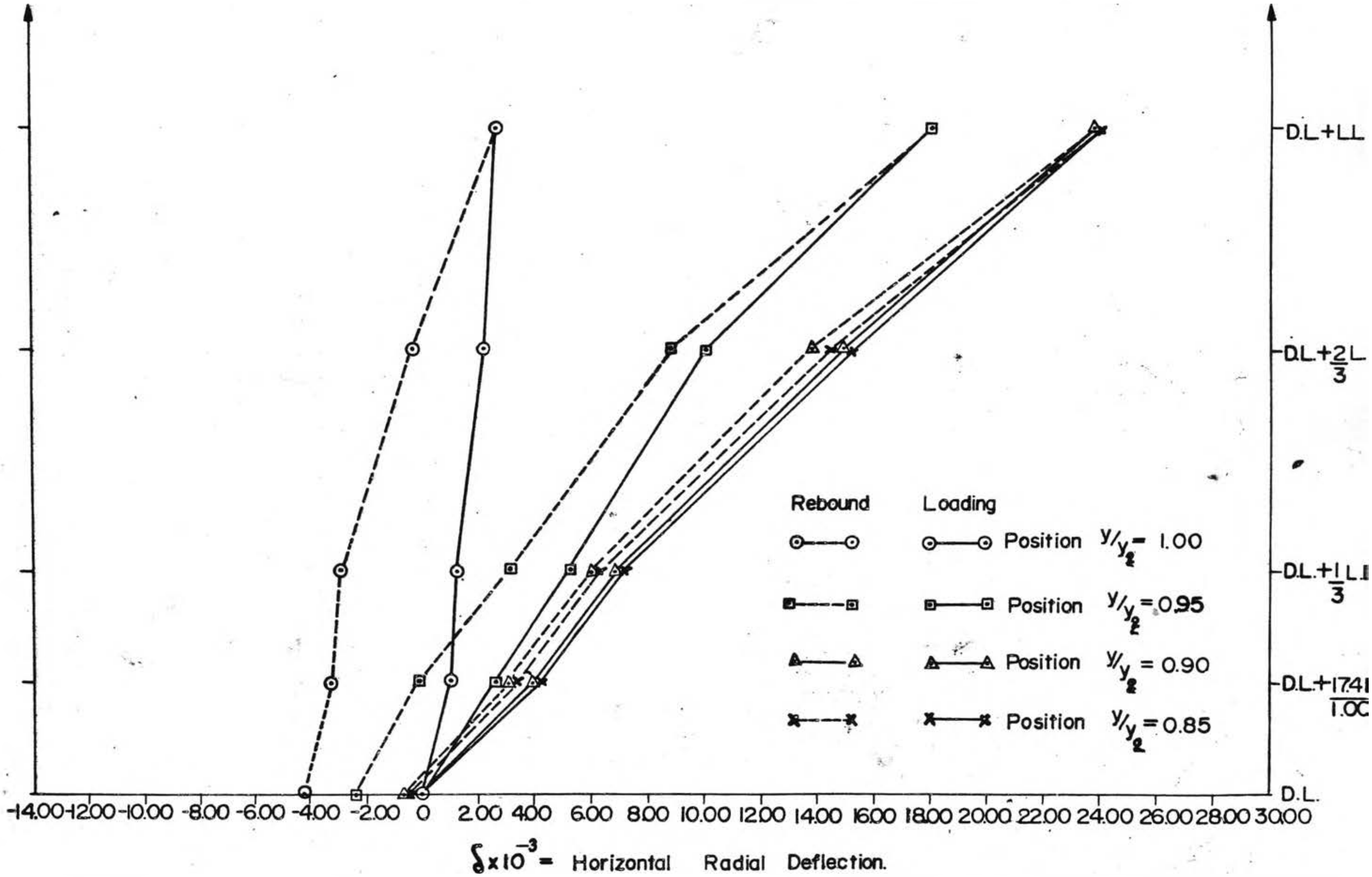


Fig.(31b) — Experiment Horizontal Radial Deflection Curves Of Various Loading at Position (b)

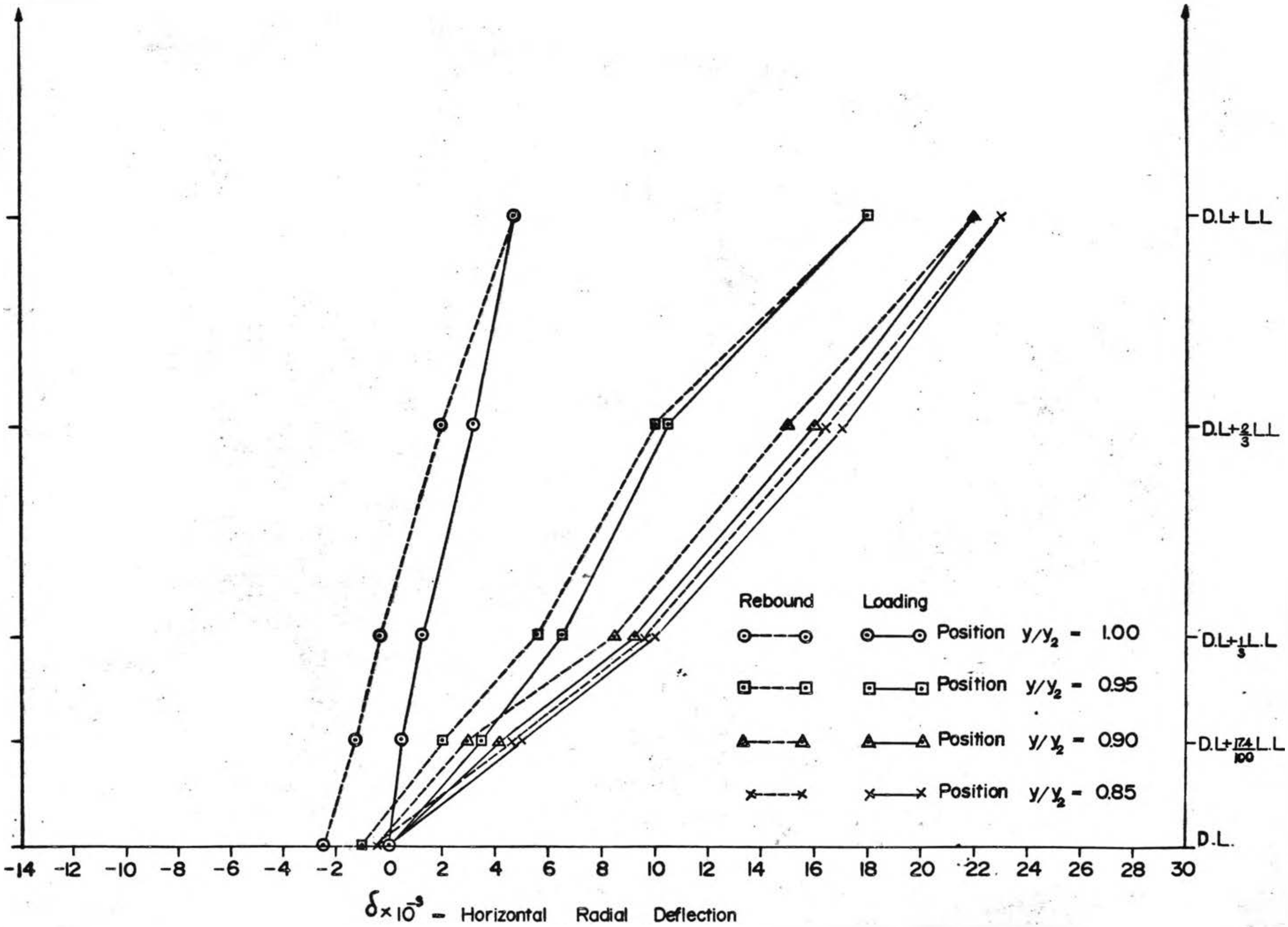


Fig. (31c) – Experiment Horizontal Radial Deflection Curves of Various Loading at Position (c)

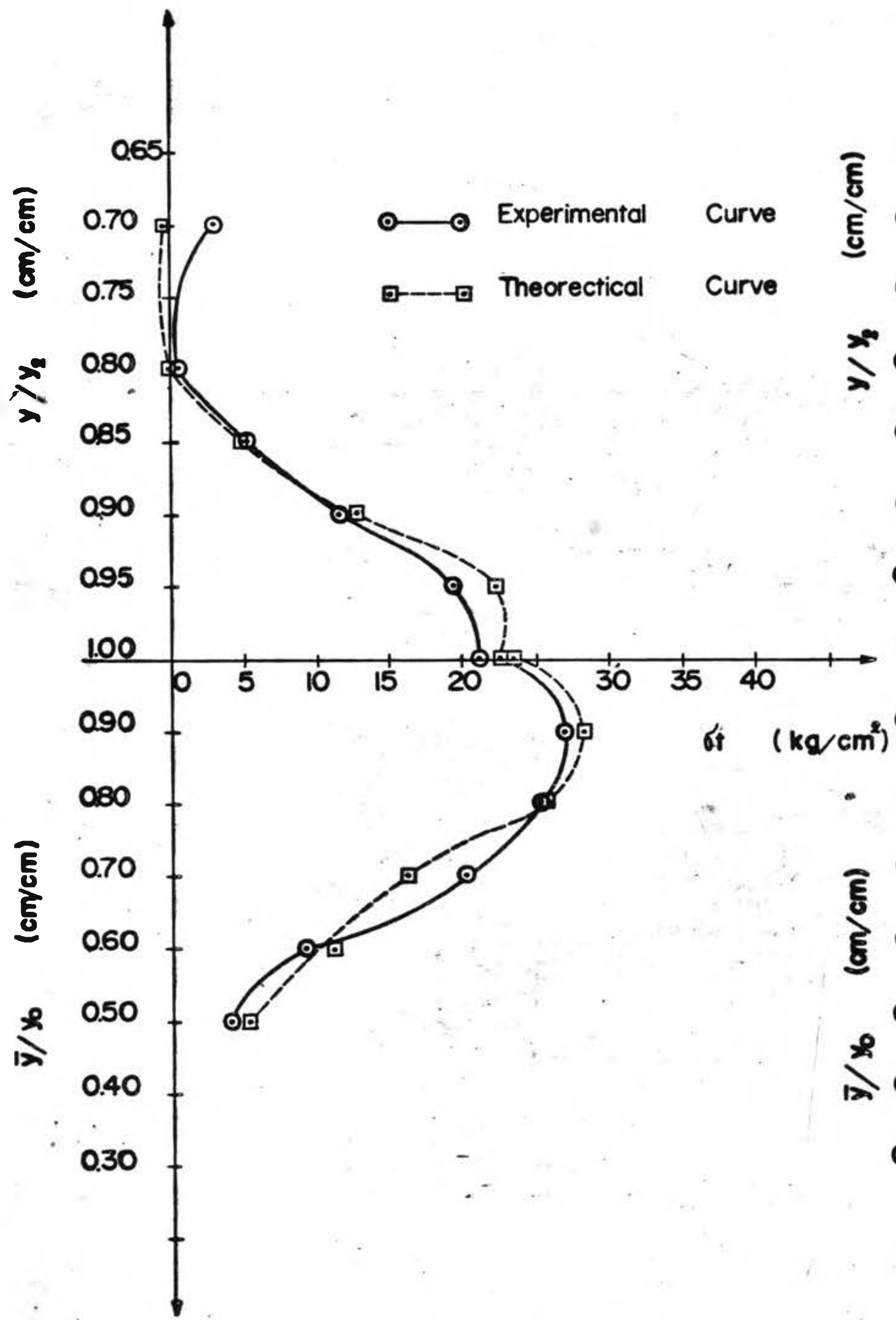


Fig.(32a) Comparative Stress in longitudinal Direction

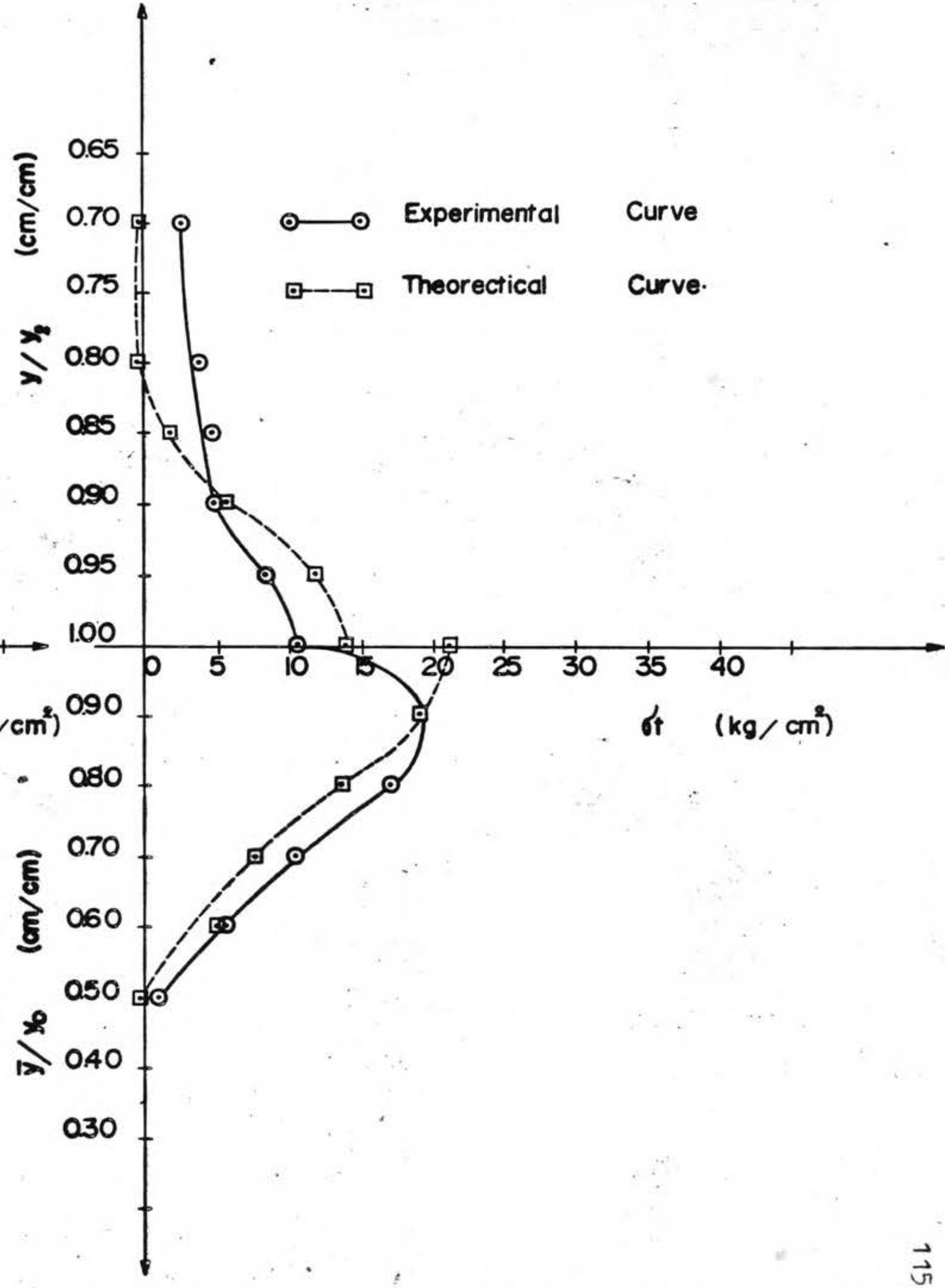


Fig.(32b) Comparative Stress in Circumferential Direction at Inner Fibers

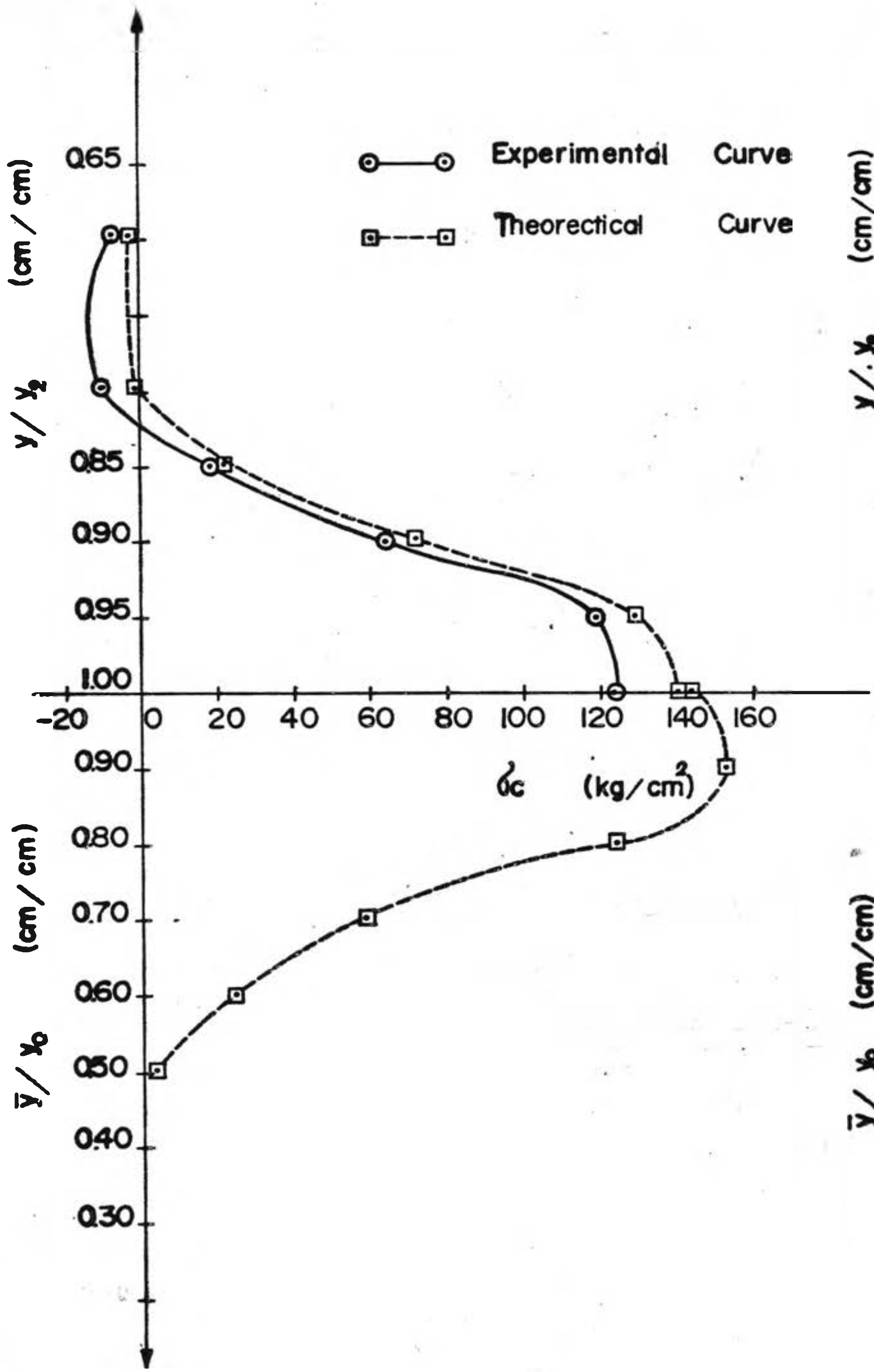


Fig.(33a) Comparative Stress in Longitudinal Direction at Outer Fibers

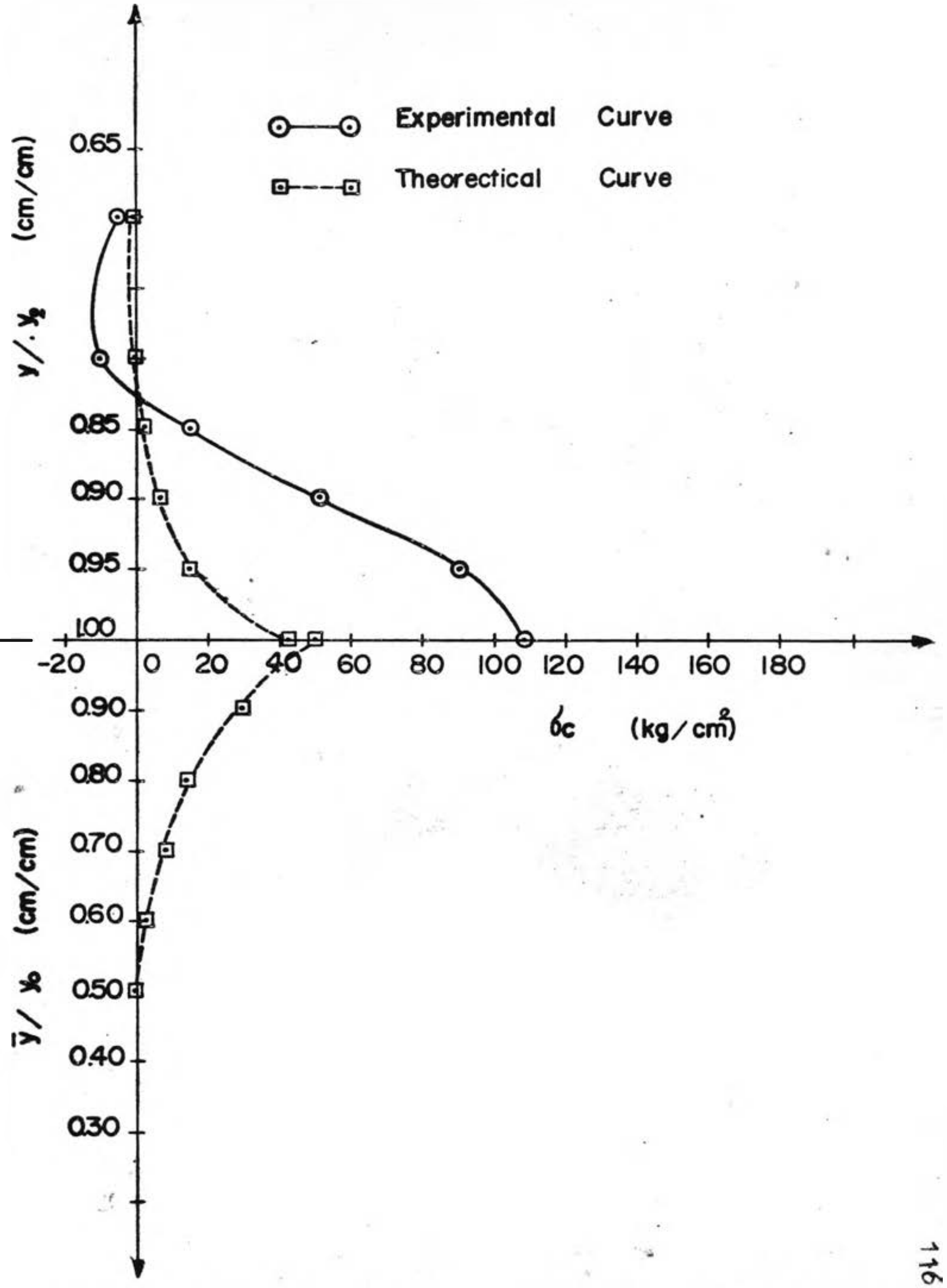


Fig.(33b) Comparative Stress. in Circumferential Direction at Outer

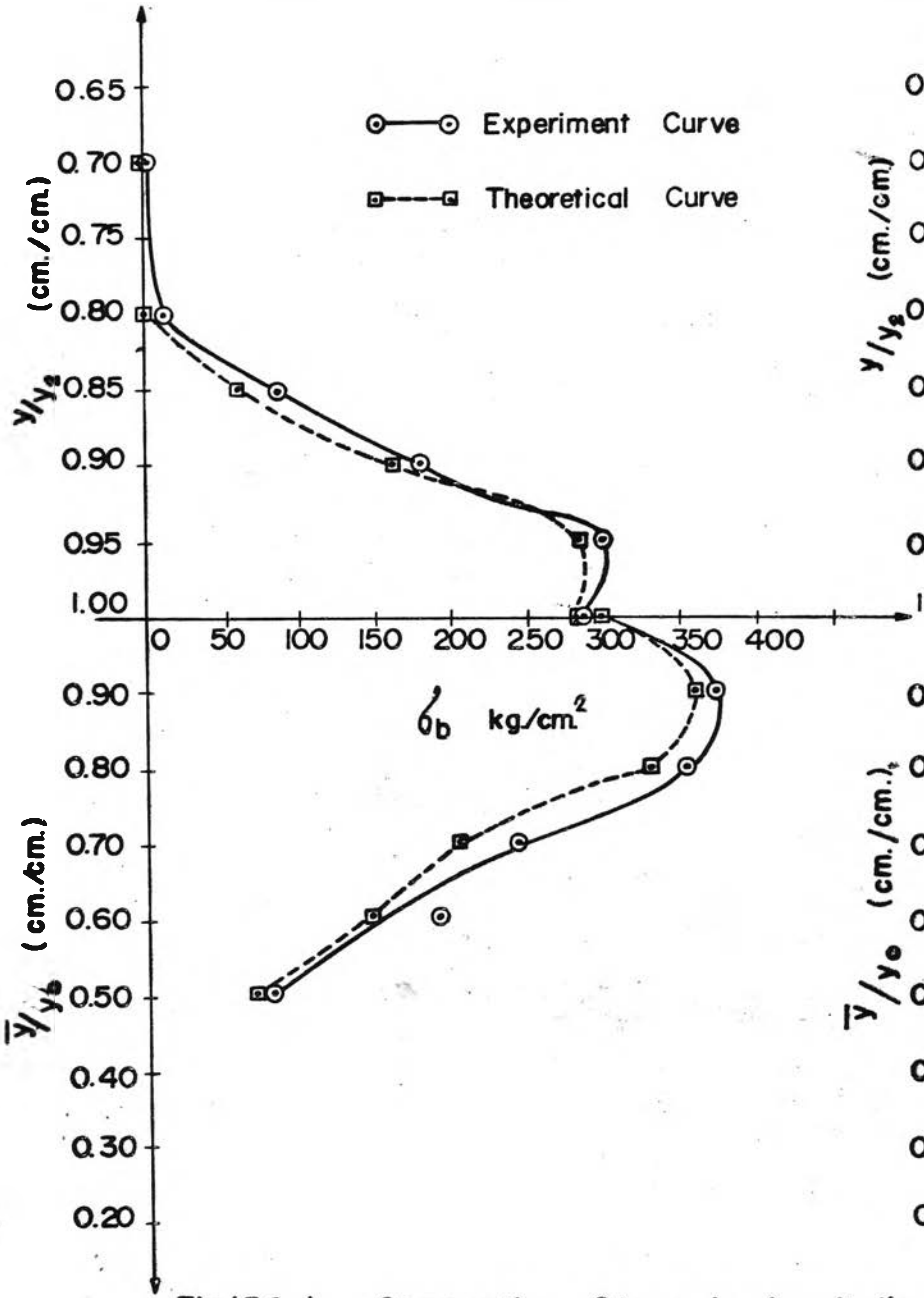


Fig (34 a) — Comparative Stress in Longitudinal Direction at Skeletal Bamboos.

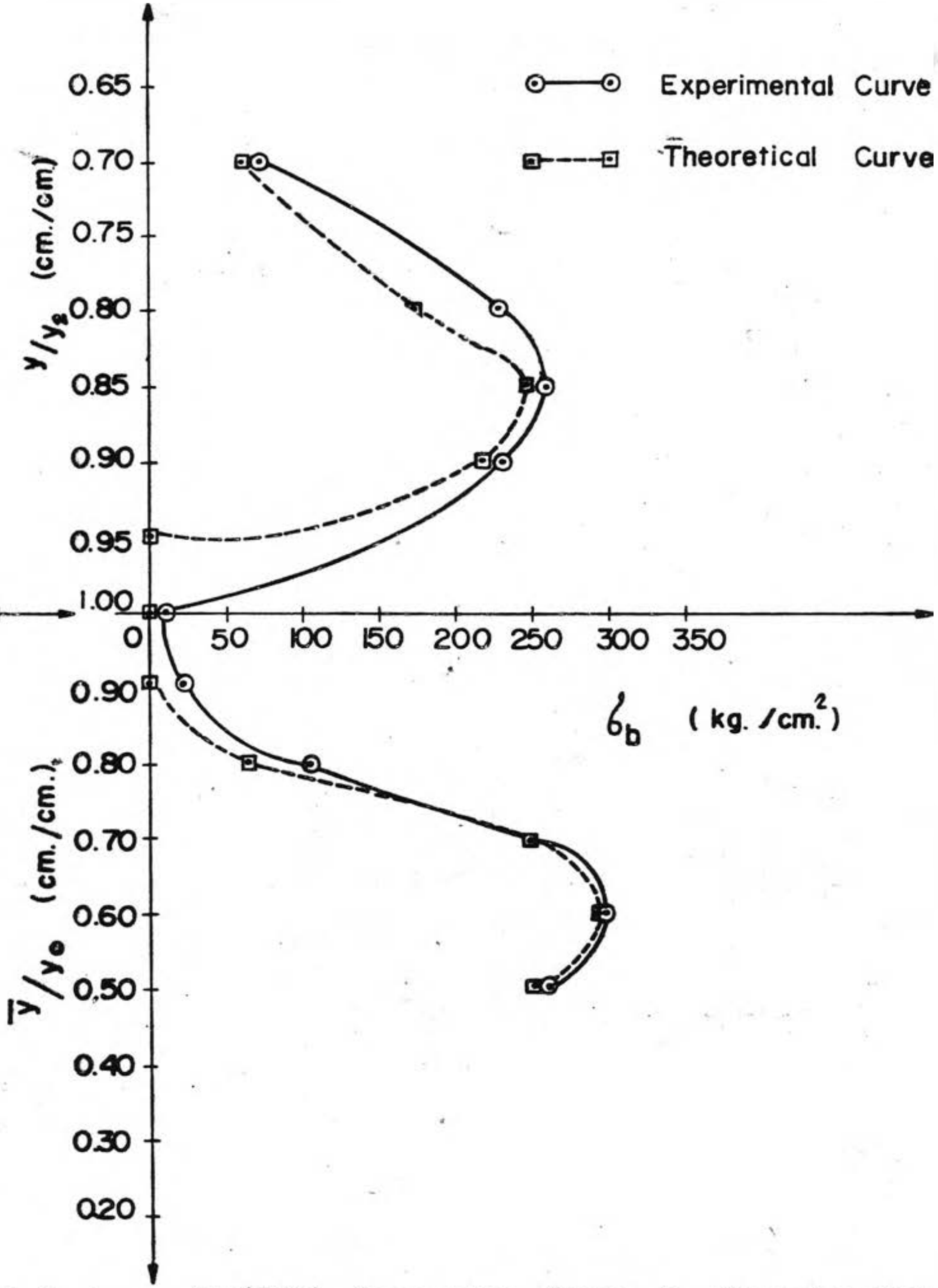


Fig.(34b) — Comparative Stress in Circumferential Direction at Skeletal Bamboos.

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