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The Diffusion of Transverse Loads in a Reinforced Circular Cylinder with Non-rigid Frames

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The Diffusion of Transverse Loads in a
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S.R. Lewis, B.Sc.,
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Summary

This report is based upon the work of
W.J. Goodey[1]. It explores the variation of shear
stress distribution at a loaded frame in a reinforced
circular cylinder, consequent upon the variation of
several geometrical parameters such as frame stiff-
ness, skin thickness, stringer spacing, etc. The
results are given in Figures 5-17 which indicate the
shear distribution around a frame for a single con-
centrated radial load of 1000 lb. The parameters
chosen are those common to aircraft design, and it
is possible to obtain a reasonably accurate shear
distribution around a frame from the data supplied,
without doing the actual lengthy shear calculation.

The work is confined to the particular case
where the loaded frame is removed from the end of the
cylinder (see Figure 1).

Indication is also given as to when the
beam theory distribution of shear can be used with
a reasonable degree of accuracy

The Appendix gives the method of obtaining
the shear load due to a tangential load and moment
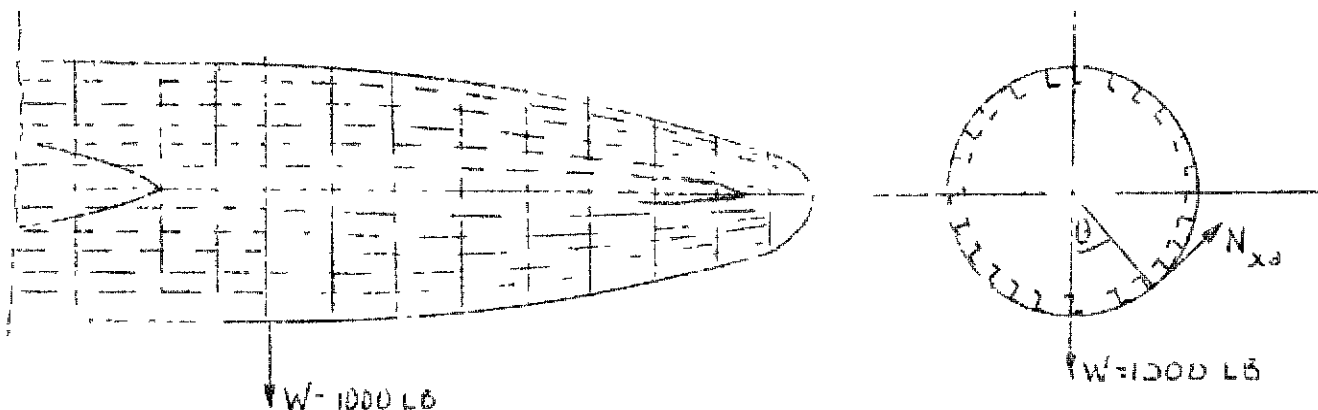from the radial load expressions.

W- 1000 LB

W=1000 LB

FIGURE 1.

NOTATION

The notation used is:

R = the radius of the frame at the skin line. ins.

t = the actual skin thickness ins.

I_f = the moment of inertia of the adjacent frames about an axis parallel to the skin line ins.^{4}

I_2 = the moment of inertia of the loaded frame about an axis parallel to the skin line ins.^{4}

L = frame spacing ins.

ν = Poissons ratio, value taken as 0.3.

$N_{x\theta}$ = shear per ins in the skin.

m = $\dfrac{R}{L}$

e = $3 m^2 \left(2 k_x (1 + \nu) - \nu \right)$

$\emptyset$ = $\dfrac{R^3 k_x t}{I_f}$

c = $6 m^3 \emptyset$

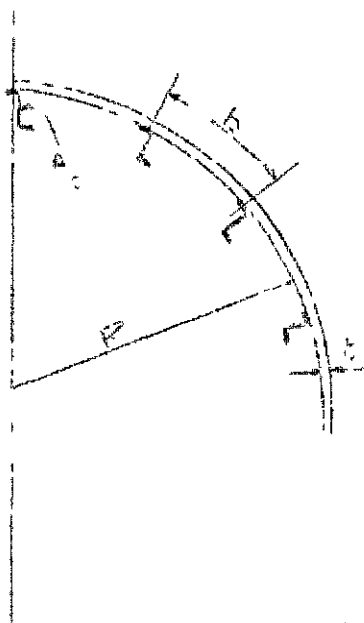k_x ratio of equivalent skin thickness to actual skin thickness, see fig. (2)

Fig. (2)

If the skin is not buckled $\quad k_x = \dfrac{(A_s + bt)}{bt}$

If the skin is buckled and the effective width of skin is b' $\quad k_x = \dfrac{(A_s + b't)}{bt}$

Introduction

The problem considered is that of the shear distribution around a non-rigid frame of a reinforced circular cylinder, with the loaded frame at a distance away from the ends. The method of solution is obtained by superimposing the results of the two cases indicated below and shown in Figure 3.

Cases: (i) A long circular cylinder with the loaded frame at the middle,

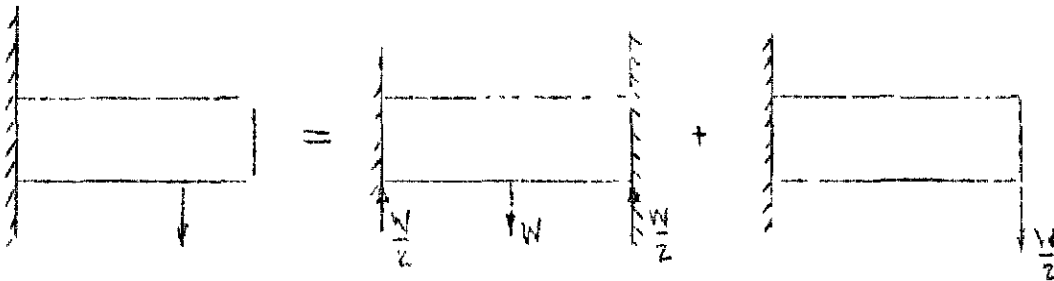(ii) A long circular cylinder with the loaded frame at the free end.

FIGURE 3

Solutions

The solutions contained in this report are for the cases (i) and (ii) above, and the expression for the shear in the skin at the loaded frame, due to a radially applied load W, is given by

$$N_{x\theta} = \frac{W}{\pi R} \sum_{n=1}^{\infty} \left[\frac{\left\{ (\lambda_2+1)(\lambda_1-1)^2 - (\lambda_1+1)(\lambda_2-1)^2 \right\} n \, \text{Sin} \, n\theta}{(\lambda_2+1)(\lambda_1-1)^2 (\frac{r}{\lambda_1}+2-r) - (\lambda_1+1)(\lambda_2-1)^2 (\frac{r}{\lambda_2}+2-r)} \right]$$

$$+ \frac{W}{2\pi R} \text{Sin} \, \theta, \quad \ldots\ldots(1)$$

or

$$N_{x\theta} = \frac{W}{\pi R} \sum_{n=1}^{\infty} \left[\frac{a\left[a^2 \text{Sin} \, 2\gamma + a(a^2-2)\text{Sin}\gamma - a \, \text{Sin}\gamma\right] n \, \text{Sin} \, n\theta}{\text{Sin}\gamma\left\{2a^2(a^2+2a \, \text{Cos}\gamma-3) - r(a^4-6a^2+1) - 2ra(1+a^2)\text{Cos}\gamma\right\}} \right]$$

$$+ \frac{W}{2\pi R} \text{Sin} \, \theta. \quad \ldots\ldots(2)$$

The above expressions for $N_{x\theta}$ are given by Goodey where, for the loaded frame, $k = 1$.

In expression (1) above λ_1 and λ_2 are obtained as shown below.

Solve the equation

$$X^2 + UX + V = 0 \quad \ldots\ldots(3)$$

where

$$U = \left\{ \frac{n^2(n^2-1)^2(n^2-2e)}{c} - 4 \right\}, \quad \ldots\ldots(4)$$

$$V = 4 \left\{ 1 + \frac{n^2(n^2-1)^2 (n^2+e)^2}{c} \right\} \quad \text{---------------(5)}$$

The roots of equation (3) are X_1 and X_2

Next solve the equations

$$\lambda + \frac{1}{\lambda} = X_1 \quad \text{and} \quad \lambda + \frac{1}{\lambda} = X_2 \quad \text{----------------(6)}$$

The roots of equations (6) are λ_1 and λ_3 , and λ_2 and

λ_4 respectively, where $\lambda_1 = \frac{1}{\lambda_3}$ and $\lambda_2 = \frac{1}{\lambda_4}$.

The values of λ used in the expression (1) for $N_{x\theta}$

are those <u>less</u> than unity.

If the roots X_1 and X_2 of equation (3) are less than 2.0
then we use expression (2) for $N_{x\theta}$.

" a " and " ψ " are obtained as shown below.

$$Y^2 - (V+4)Y + U^2 = 0 \quad \text{-----------------(7)}$$

where U and V are given by expressions 4 and 5.
The roots of equation (7) are Y_1 and Y_2 where one
root is greater than 4.0 and one less than 4.0.

Let Y_1 be the root greater than 4.0 and Y_2
the root less than 4.0, we then solve the equations

$$\left(a + \frac{1}{a} \right) = +\sqrt{Y_1} \quad \text{and} \quad (2 \cos \psi)^2 = Y_2 \quad \text{---(8)}$$

The values of " a " found are a_1 and a_2 where $a_1 = \frac{1}{a_2}$

and the value of " a " used in the expression (2) for
$N_{x\theta}$ is that which is <u>less</u> than unity.
The value of ' ψ " used in the expression (2) for $N_{x\theta}$
is the value given by Y_2 which is of opposite sign
to " U " in expression (4). This is so, because

$$- U = 2 \left(a + \frac{1}{a} \right) \cos \psi$$

the term $\left(a + \frac{1}{a}\right)$ is always +ve hence $\cos \psi$ must be -ve,

i.e. the sign of " ψ " must be opposite to that of " U "

The expression for $N_{x\theta}$ can be written in the form

$$N_{x\theta} = \frac{W}{\pi R} \sum_{n=1} F(\lambda_1 \lambda_2 k, r) \; n \sin n\theta + \frac{W}{2\pi R} \sin \theta \quad \text{------(9)}$$

or

$$N_{x\theta} = \frac{W}{\pi R} \sum_{n=1} F(a, \psi, k, r) \; n \sin n\theta + \frac{W}{2\pi R} \sin \theta \quad \text{------(10)}$$

In both expressions 9 and 10 the value of $F(\text{----})$
$n \sin n\theta$ for $n=1$ is equal to $\frac{\sin \theta}{2}$

For practical purposes it is sufficiently accurate to
take the $\sum_{n=1}$ term up to a value of $n=6$, hence the

expression for shear can be written as

$$N_{x\theta} = \frac{W}{\pi R} \sin\theta + \frac{W}{\pi R} \sum_{n=2}^{6} F(----)n \sin n\theta \quad ------------(11)$$

The curves of figs. 5-20 were obtained by putting numerical values in the expression (11) above. The parameters for each particular case are given in the accompanying curves.

I am indebted to Dr. Kirkby and the computing section of the Aerodynamics Department for the valuable aid given in the computation of the numerical examples.

Conclusions

1) The distribution of shear around the frame is not sensitive to variations in values of " k_x" the results show a maximum increase of 7% in value of $N_{x\theta}$ at 30° (i.e. maximum value) for a 100% increase in value of k_x, see figs. 15, 16 and 17.

2) The distribution of shear around the frame is not sensitive to variations in skin thickness " t ". In aircraft structures going from one gauge to the next is approximately an increase of 30% and for this increase in skin thickness the average percentage decrease in maximum value of $N_{x\theta}$ is 4%. This is assuming that k_x remains constant.

3) The distribution of shear is not sensitive for reasonably large variations in the moment of inertia of the adjacent frames, and to take a mean value of I_f is sufficiently accurate for the results. The effect can be obtained from fig. (5) where it is seen that increasing the stiffness of the adjacent frames, the loaded frame remaining constant increases the maximum value of $N_{x\theta}$. For the parameters chosen it is seen that the average percentage increase in value of $N_{x\theta}$ at 30° is 0.12% for a 1.0% increase in value of I_f.

4) The distribution of shear is not sensitive for reasonably large variations in the moment of inertia of the loaded frame, and a mean value is sufficiently accurate for the results. This effect can be obtained from figs. 12, 13, 14, 18, 19 and 20.

5) The distribution of shear is not sensitive for moderate variations in frame spacing. For a frame radius up to 40" the average increase in value of $N_{x\theta}$ at 30° is 0.4% for a 1.0% increase in value of 'm" and for a radius of 60" the increase in value of $N_{x\theta}$ at 30° is 0.22% for a 1.0% increase in 'm" . This effect can be obtained from figs. 18, 19, and 20.

6) The beam theory distribution of shear is sufficiently accurate if the value of rI_f lies above the line of fig. 21. This curve is obtained by extrapolation of the curves figs. 12, 13 and 14, and is intended to give the lowest value of rI_f for which the beam theory is a reasonable approximation.

7) The shear loading on frames adjacent to the loaded
frame can be obtained with sufficient accuracy for
practical purposes by interpolation.   The shear dis-
tribution on a frame $\underline{3}$ frame spacings distant from the

loaded frame can be taken as that given by the beam
theory and intermediate frames can be obtained by a
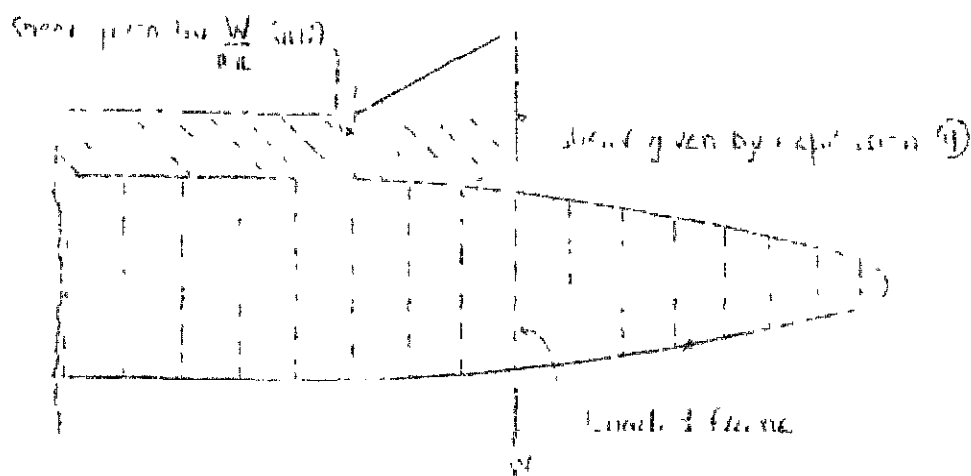straight line interpolation between the frames, see
fig. 4.

Fig. (4)

Reference

(1)   Royal Aeronautical Society Journal Nov.1946.
" The stresses in a circular fuselage" by W.J.Goodey.

APPENDIX A

Derivation of the shear load due to tangential load and moment from the radial load expression.

Goodey in his work indicates a method by which the shear load for a radial load and moment may be obtained from the expression for a tangentially applied load. Here the complete solution is given for obtaining the shear load due to a tangential load and moment from the radial load expressions.
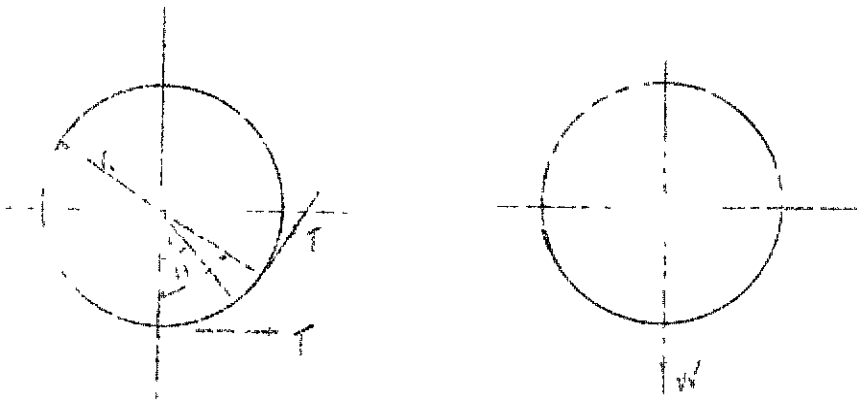
Let $(N_{x\theta})_T$ = shear load due to a tangentially applied load T

This will be a function of T and θ.

$$(N_{x\theta})_T = -Tf(\theta-\alpha) = -Tf(\theta) + T\alpha f'(\theta)$$

when α is small

$$T\alpha = W \quad \text{and} \quad T = T \cos \alpha.$$

$$\therefore \triangle(N_{x\theta})_\prime = T\alpha f'(\theta) = Wf'(\theta) = (N_{x\theta})_W$$

$$\therefore (N_{x\theta})_W = \frac{d}{d\theta} \frac{W}{T} (N_{x\theta}).$$

$$(N_{x\theta})_T = \left[(N_{x\theta})_T\right]_{\theta=0} + \frac{T}{W} \int_0^\theta (N_{x\theta})_W \, d\theta \quad \text{------(12)}$$

where the term $\left[(N_{x\theta})_T\right]_{\theta=0}$ is a constant of integration and can be evaluated by considering the equilibrium of the frame.

$$- TR = \int_0^{2\pi} (N_{x\theta})_T R^2 \, d\theta.$$

$$= \left[(N_{x\theta})\right]_{\theta=0} 2\pi R^2 + \frac{T}{W} R^2 \int_0^{2\pi} \int_0^\theta (N_{x\theta})_W (\emptyset) \, d\emptyset \, d\theta.$$

$$= 2\pi R^2 \left[(N_{x\theta})\right]_{T,\theta=0} + \frac{T}{W} R^2 \int_0^{2\pi} (2\pi-\emptyset)(N_{x\theta})_W (\emptyset) \, d\emptyset \, d\theta$$

$$= 2\pi R^2 \left\{ (N_{x\theta})_{\theta=0} - \frac{T}{W} R^2 \int_0^{2\pi} \emptyset (N_{x\theta})_w \, \emptyset \, d\emptyset \right.$$

$$\therefore (N_{x\theta})_{\theta=0} = -\frac{T}{2\pi R} + \frac{T}{2\pi W} \int_0^{2\pi} \emptyset \, (N_{x\theta})_w (\emptyset) d\emptyset \quad \text{which gives}$$

the constant of integration for (12) above.

$$\therefore (N_{x\theta}) = -\frac{T}{2\pi R} + \frac{T}{2\pi W} \int_0^{2\pi} \emptyset \, (N_{x\theta})_w \emptyset d\emptyset + \frac{T}{W} \int_0^\theta (N_{x\theta})_w d\theta \quad --(13)$$

For the case considered, of a loaded frame along a cylinder

$$(N_{x\theta})_w = \frac{W}{\pi R} \sum_{n=1} F(----) n \, \text{Sin} \, n\theta + \frac{W}{2\pi R} \, \text{Sin} \, \theta$$

$$= \frac{W}{\pi R} \, \text{Sin} \, \theta + \frac{W}{\pi R} \sum_{n=2}^6 F(----) n \, \text{Sin} \, n\theta$$

$$\therefore \frac{T}{2\pi W} \int_0^{2\pi} \emptyset (N_{x\theta})_w \emptyset d\emptyset = \frac{T}{2\pi W} \int_0^{2\pi} \emptyset \frac{W}{\pi R} \, \text{Sin} \, \theta + \frac{W}{\pi R} \sum_{n=2}^6 F(----) n \, \text{Sin} \, n\theta \, d\theta$$

$$= \frac{T}{2\pi^2 R} \int_0^{2\pi} \theta \, \text{Sin} \, \theta \, d\theta + \frac{T}{2\pi W} \frac{W}{\pi R} \sum_{n=2}^6 F(---) \int_0^{2\pi} \theta \, n \, \text{Sin} \, n \, \theta \, d\theta$$

$$= \frac{T}{2\pi^2 R} \left[\text{Sin} \, \theta - \theta \, \text{Cos} \, \theta \right]_0^{2\pi} + \frac{T}{2\pi^2 R} \sum_{n=2}^6 F(----) n \, \frac{\text{Sin} \, n\theta - n\theta \, \text{Cos} \, n\theta}{n} \Big|_0^{2\pi}$$

$$= \frac{T}{2\pi^2 R} \left[-2\pi \right] + \frac{T}{2\pi^2 R} \sum_{n=2}^6 F(----) \frac{n}{n^2} \left[-2\pi n \right]$$

$$= -\frac{T}{\pi R} - \frac{T}{\pi R} \sum_{n=2}^6 F(----) .$$

substituting in equation (13)

$$(N_{x\theta}) = -\frac{T}{2\pi R} - \frac{T}{\pi R} - \frac{T}{\pi R} \sum_{n=2}^6 F(----) + \frac{T}{W} \int_0^\theta (N_{x\theta})_w \, d\theta$$

$$= -\frac{3T}{2\pi R} - \frac{T}{\pi R} \sum_{n=2}^6 F(----) + \frac{T}{W} \int_0^\theta \frac{W}{\pi R} \, \text{Sin} \theta \, d\theta$$

$$+ \frac{W}{\pi R} \sum_{n=2}^6 F(----) \int_0^\theta n \, \text{Sin} \, n\theta \, d\theta$$

$$= -\frac{3T}{2\pi R} - \frac{T}{\pi R} \sum_{n=2}^{6} F(----) - \frac{T}{W} \frac{W}{\pi R} \cos\theta + \frac{T}{W} \frac{W}{\pi R} \sum_{n=2}^{6} F(----)n \frac{1}{n} \left[\cos n\theta - 1\right]$$

$$= -\frac{3T}{2\pi R} - \frac{T}{\pi R} \sum_{n=2}^{6} F(----) - \frac{T}{\pi R} \cos\theta$$

$$+ \frac{T}{\pi R} + \frac{T}{\pi R} \sum_{n=2}^{6} F(----) - \frac{T}{\pi R} \sum_{n=2}^{6} F(----) \cos n\theta$$

$$\frac{T}{2\pi R} - \frac{T}{\pi R} \cos\theta - \frac{T}{\pi R} \sum_{n=2}^{6} F(----) \cos n\theta.$$

$$= \frac{T}{\pi R} \left[-\frac{1}{2} - \cos\theta - \sum_{n=2}^{6} F(----) \cos n\theta \right] \quad ----------(14)$$

———0———

Let $(N_{x\theta})$ = shear load due to an applied moment.

$$(N_{x\theta}) = \frac{M}{R} \left[f(\theta) + \frac{d^2 f(\theta)}{d\theta^2}\right]$$

where $f(\theta)_\tau$ is the shear due to **unit** tangential load.

$$f(\theta)_\tau = \frac{1}{\pi R} \left[\frac{1}{2} - \cos\theta - \sum_{n=2}^{6} F(----) \cos n\theta\right] \quad \text{see (14) above}$$

$$f'(\theta)_\tau = \frac{1}{\pi R} \left[\sin\theta + \sum_{n=2}^{6} F(----)n \sin n\theta\right]$$

$$\frac{d^2 f(\theta)_\tau}{d^2\theta} = \frac{1}{\pi R} \left[\cos\theta + \sum_{n=2}^{6} F(----)n^2 \cos n\theta\right]$$

$$(N_{x\theta}) = \frac{M}{R} \left[\frac{1}{2\pi R} - \frac{\cos\theta}{\pi R} - \frac{1}{\pi R} \sum_{n=2}^{6} F(----) \cos n\theta\right.$$

$$\left. + \frac{\cos\theta}{\pi R} + \frac{1}{\pi R} \sum_{n=2}^{6} F(----)n^2 \cos n\theta\right]$$

$$= \frac{M}{\pi R^2} \left[\frac{1}{2} - \sum_{n=2}^{6} (1-n^2)F(----) \cos n\theta\right]$$

———oooOooo———

VALUES OF SHEAR/INS FOR VARYING STIFFNESS OF THE
ADJACENT FRAME, THE LOADED FRAME HAVING CONSTANT STIFFNESS.
RADIAL APPLIED LOAD OF 1000 lbs.

$r I_f = \cdot 4343$ INS^4
$m = 1 \cdot 62$
$R = 24 \cdot 25$ INS
$K_x = 1 \cdot 53$
$t = \cdot 028$ INS

- $I_f = \cdot 05$ INS^4 $r = 8686$
+ $I_f = \cdot 10$ " $r = 4 \cdot 343$
○ $I_f = \cdot 20$ " $r = 2172$
* $I_f = \cdot 40$ " $r = 1 \cdot 086$

$N_{x\theta}$

1000 lb.

FIG 5.

θ DEGREES

VALUES OF SHEAR/INS FOR VARYING RADII OF FRAMES.
FRAME SPACING CONSTANT AT 15 INS.
RADIAL APPLIED LOAD OF 1000 lb.

$I_f = .05$ INS^4
$r = 8.686$
$k_x = 1.53$
$t = .028$ INS

·	R = 16.2 INS	m = 1.08
+	R = 24.25 "	m = 1.62
⊙	R = 40 "	m = 2.67
△	R = 60 "	m = 4.

$N_{x\theta}$ lb/ins

30 — 20 — 10 — 0

0   20   60   100   140   180

$\theta°$

FIG.6.

VALUES OF SHEAR/INS FOR VARYING RADII OF FRAMES AND CONSTANT
FRAME SPACING.
RADIAL APPLIED LOAD OF 1000 lb

• R = 162 INS	m = 1·08	
+ R = 40 INS	m = 2·67	
o R = 60 INS	m = 4·0	

L = 15·0 INS
I_f = ·05 INS⁴
r = 10
k_x = 153
t = ·028 INS
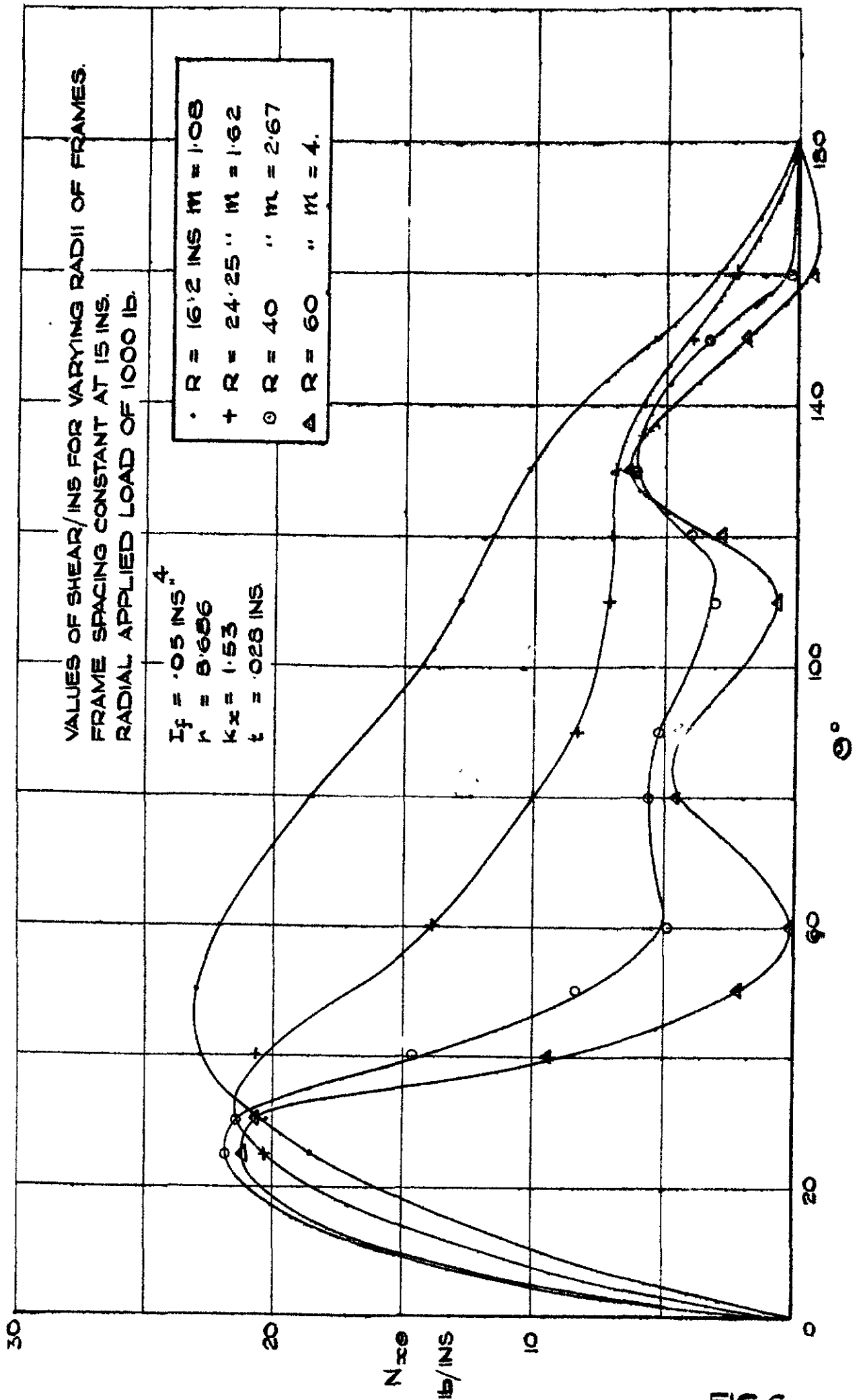
FIG 7.

VALUES OF SHEAR/INS FOR VARYING RADII OF FRAMES
AND FRAME SPACING
RADIAL APPLIED LOAD OF 1000 lb.

$m = 1.62$
$I_f = .1946 \text{ INS}^4$
$r = 3.892$
$k_x = 1.53$
$t = .028 \text{ INS}$

· R = 16.2 INS

+ R = 40 ,, ,,

⊙ R = 60 ,, ,,

$N_{x\theta}$ lb/ INS

FIG.8.

VALUES OF SHEAR/INS FOR VARYING RADII OF FRAMES
AND FRAME SPACING.
RADIAL APPLIED LOAD OF 1000 lb

$m = 1.62$
$I_f = .1946$ INS.^{4}
$\mu = 1.0$
$k_x = 153$
$t = .028$ INS

• R = 16.2 INS
+ R = 40 INS
O R = 60 INS

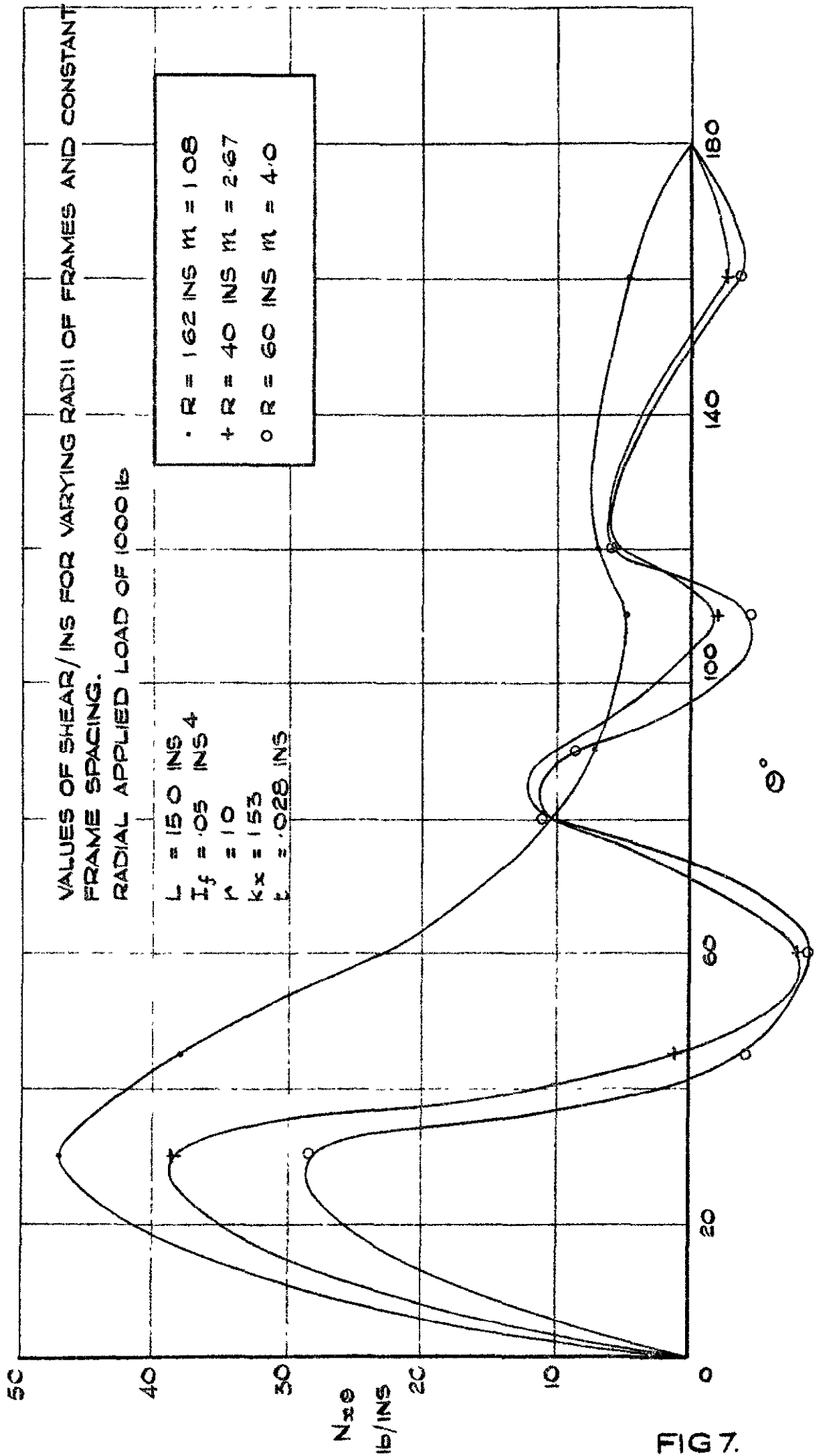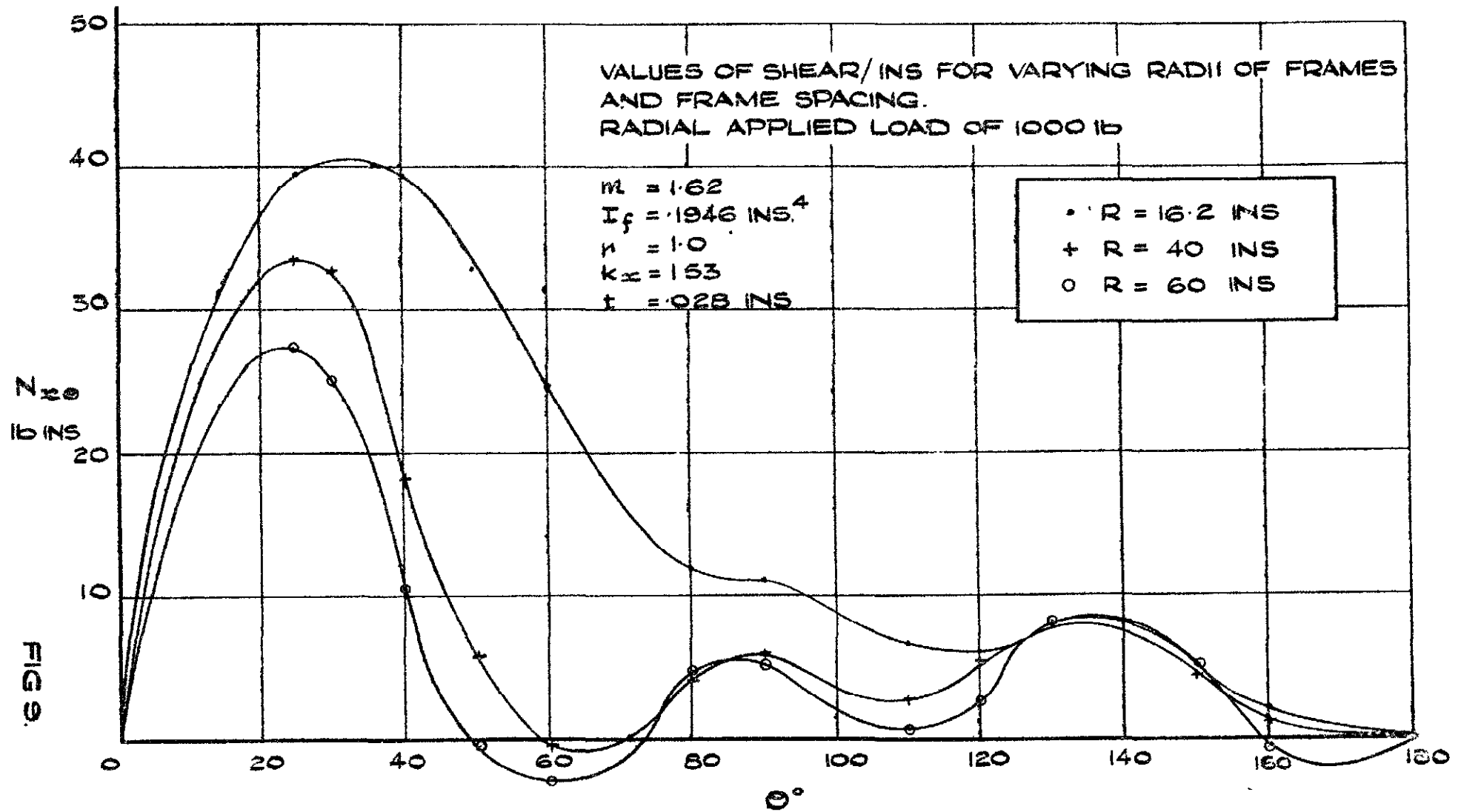$\dfrac{Z_{x\theta}}{lb} \dfrac{}{INS}$

FIG 9.

$\Theta°$

FIG.10.

VALUES OF SHEAR/INS FOR VARYING RADII OF FRAMES AND FRAME SPACING.
RADIAL APPLIED LOAD OF 1000 lb.

$m = 2.0$
$I_f = .1946 \text{ INS}^4$
$r = 3.892$
$k_x = 1.53$
$t = .028 \text{ INS}$

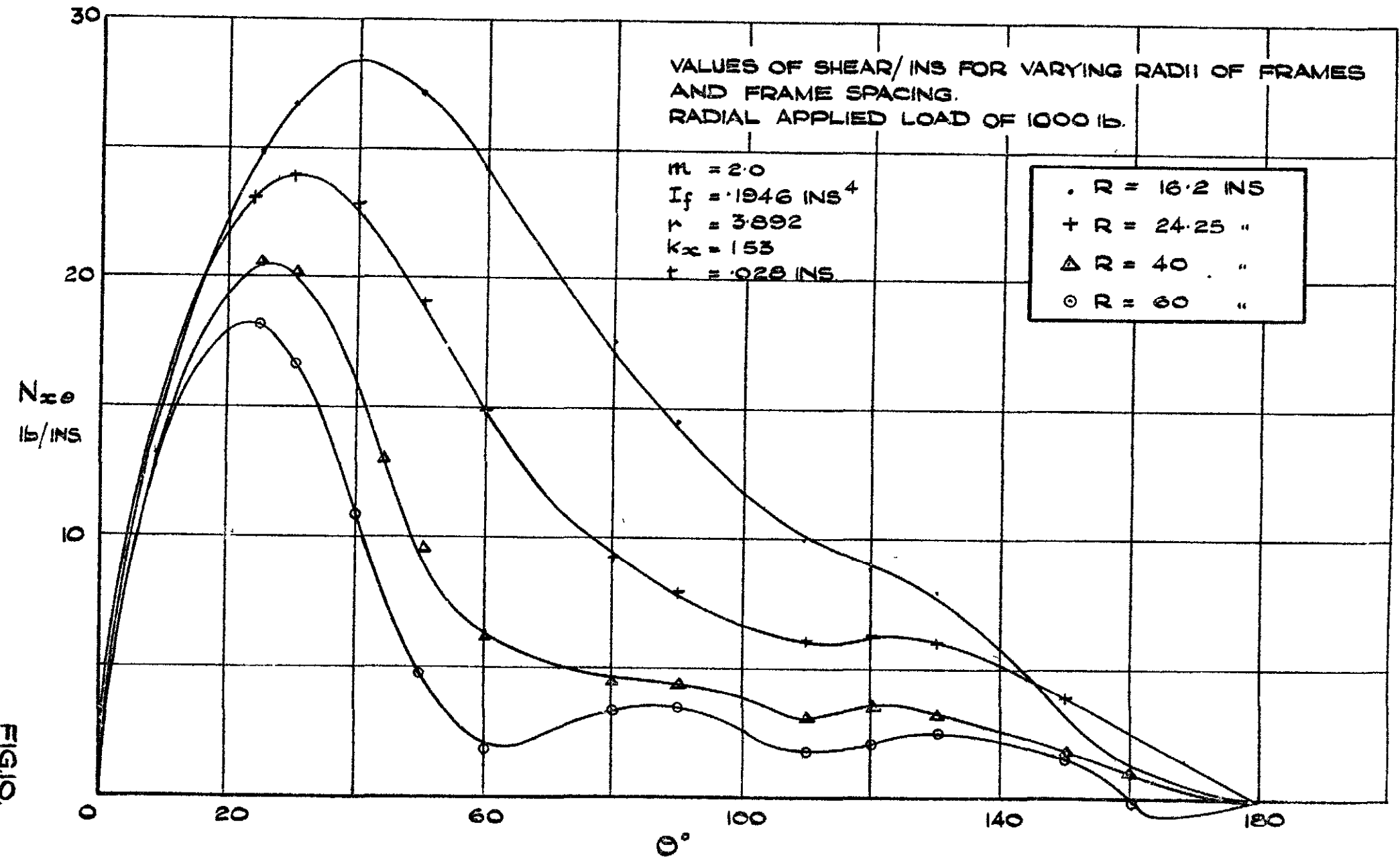|		
.	R =	16.2 INS
+	R =	24.25 "
△	R =	40 "
⊙	R =	60 "

$N_{x\theta}$ lb/INS

$\theta°$

VALUES OF SHEAR/INS FOR VARYING RADII OF FRAMES.
RADIAL APPLIED LOAD OF 1000 lb.

m = 20
r = 25
k_x = 153
t = .028 INS

. I_f = .1946 INS^4 R = 40 INS
+ I_f = .1946 INS^4 R = 60 INS.

$Z_{x\theta}$ lb/INS

FIG.11.

$\Theta°$

VALUES OF SHEAR/INS FOR VARYING STIFFNESS OF LOADED FRAME, FRAME
RADIUS CONSTANT.
RADIAL APPLIED LOAD OF 1000 lb

I_f = .05 INS⁴

R = 29 INS

m = 2.0

k = 1.53

t = .028 INS

. r = 25   rI_f = 1.25 INS⁴

+ r = 50   rI_f = 2.5 INS.⁴
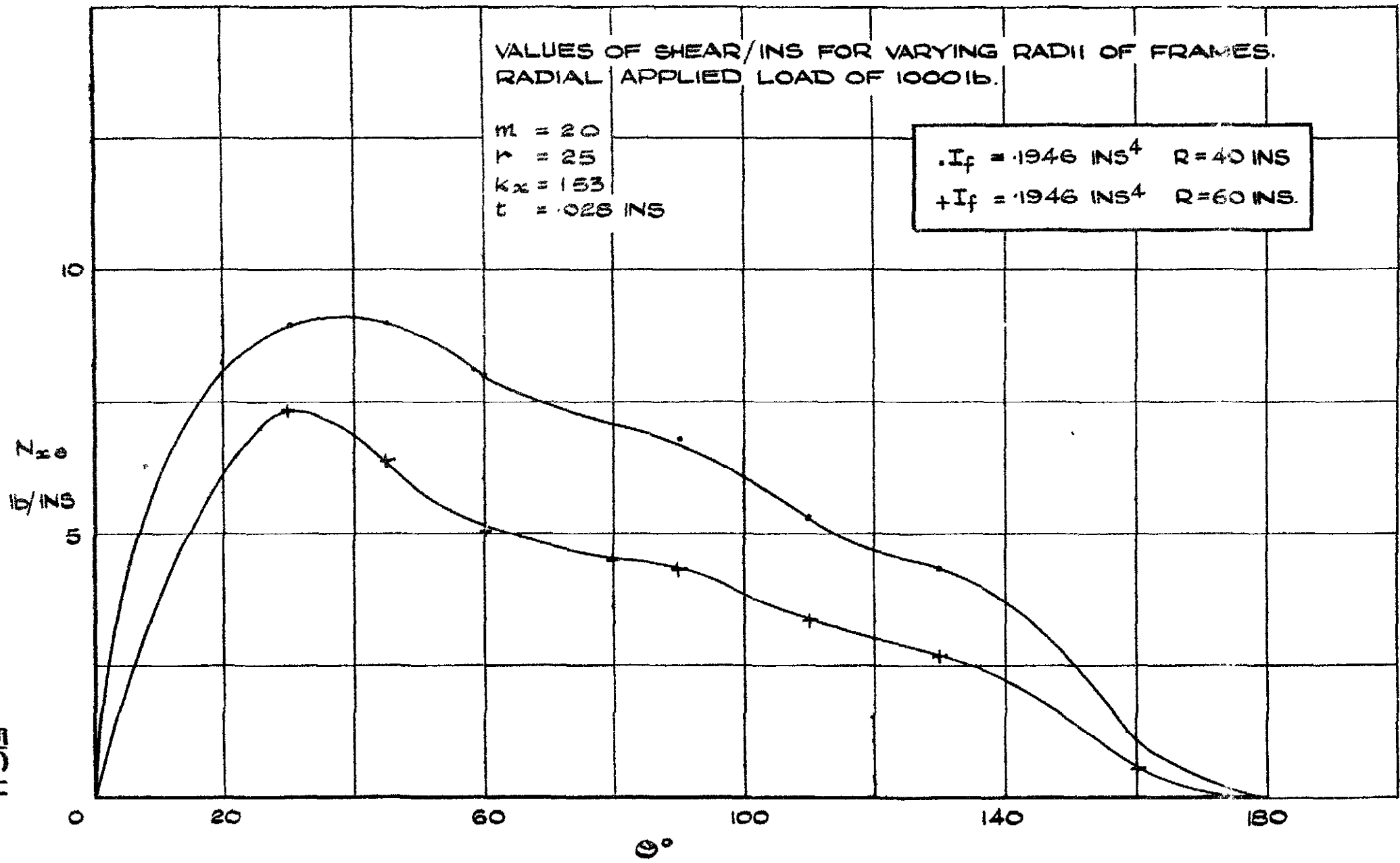
○ r = 100   rI_f = 5.0 INS⁴

▲ = BEAM THEORY

$N_{x\theta}$ lb/INS

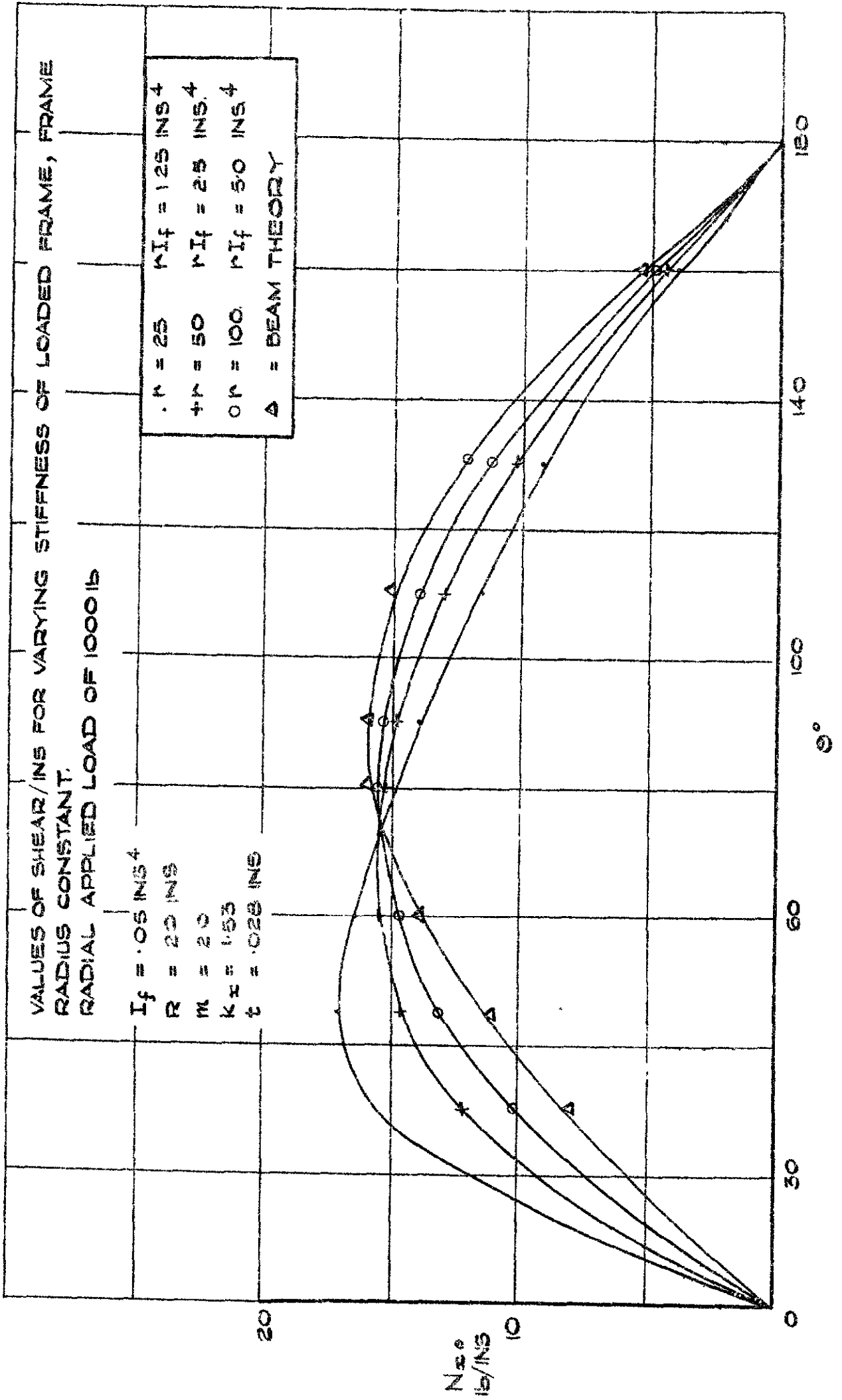FIG 12.

VALUES OF SHEAR/INS FOR VARYING STIFFNESS OF LOADED FRAME
FRAME RADIUS CONSTANT
RADIAL APPLIED LOAD OF 1000 lb

$I_f = .05$ INS
$R = 40$ INS
$m = 20$
$k_x = 1.55$
$t = .028$ INS.

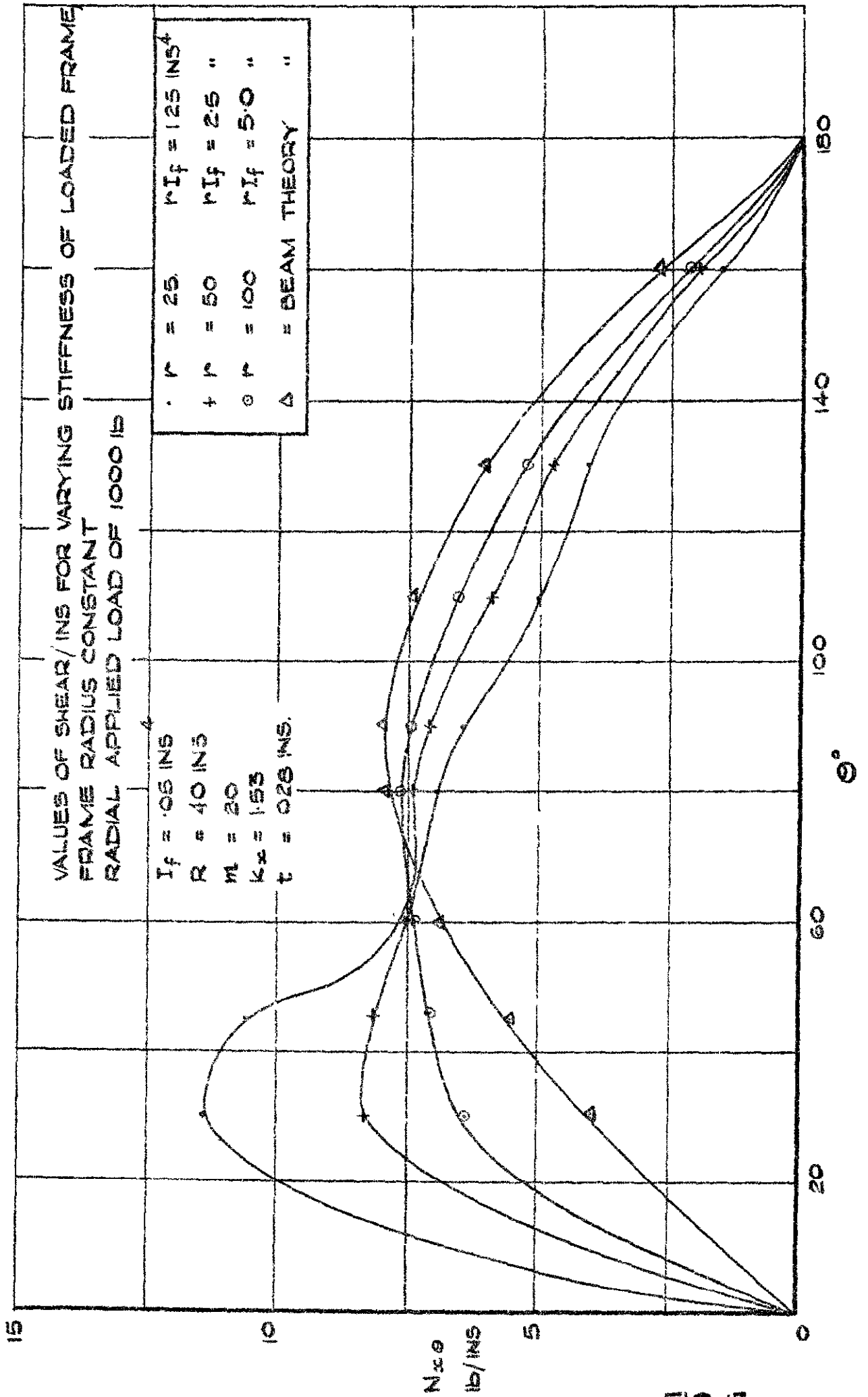|		
• $r = 25$,	$rI_f = 125$ INS^4
+ $r = 50$	$rI_f = 2.5$ "
⊙ $r = 100$	$rI_f = 5.0$ "
△ $= $ BEAM THEORY	"

$\theta°$

$N_{x\theta}$ lb/INS

FIG. 13.

VALUES OF SHEAR/INS FOR VARYING STIFFNESS OF
LOADED FRAME, FRAME RADIUS CONSTANT.
RADIAL APPLIED LOAD OF 1000 lb.

$I_f = 05 \text{ INS}^4$
$R = 60 \text{ INS}.$
$m = 2.0$
$k_x = 1.53$
$t = .028 \text{ INS}$

· $n = 25$ $\sqcap I_f = 1.25 \text{ INS}^4$
+ $n = 50$ $\sqcap I_f = .25$ "
○ $n = 100$ $\sqcap I_f = .50$ "
△ = BEAM THEORY

FIG.14.

VALUES OF SHEAR/INS FOR VARIATIONS IN VALUES OF kx
RADIAL APPLIED LOAD OF 1000 lb.

RADIUS = 24.25 INS
m = 2.0
I_f = 3.946 INS^4
r = 3.692
t = .023 INS.

· R = 24.25 INS Kx = 0.5
⊙ R = 24.25 INS Kx = 10
+ R = 24.25 INS. Kx = 20

FIG.15.

VALUES OF SHEAR/INS FOR VARIATIONS IN VALUES OF k_x
RADIAL APPLIED LOAD OF 1000 lb

RADIUS = 40 INS

m = 2.0
I_f = .1946 INS.⁴
r = 3.392
t = .026 INS.

	R = 40 INS.	k_x = 0.5
o	R = 40 "	k_x = 1.0
+	R = 40 "	k_x = 2.0

FIG. 16.

VALUES OF SHEAR/INS FOR VARIATIONS IN VALUES OF k_x
RADIAL APPLIED LOAD OF 1000 lb.

RADIUS = 60 INS.
m = 2·0
I_f = ·1946 INS^4
r = 3·892
t = ·028 INS.

. R = 60 INS $k_x = ·5$
⊙ R = 60 " $k_x = 10$
+ R = 60 " $k_x = 20$

FIG.17.

$\overline{N}_{x\theta}$
$\overline{lb}$/INS

$\Theta°$

VARIATIONS IN VALUES OF $N_{x\theta}$ AT 30°
FOR VARYING VALUES OF rI_f AND m.
RADIAL APPLIED LOAD OF 1000 lb

$k_x = 1.53$
$t = .028$ INS

⊙	$m = 1.08$	
+	$m = 1.62$	$R = 16.2$ INS
✕	$m = 2.0$	

$I_f = .1946$ INS.^{4}
$I_f = .05$ INS^4

$N_{x\theta}$ lb/INS.

rI_f INS.^{4}

FIG.18

VARIATIONS IN VALUES OF $N_{x\theta}$ AT 30°
FOR VARYING VALUES OF rI_f, m. & I_f.
RADIAL APPLIED LOAD OF 1000 lb.

$k_x = 1.53$
$t = .028$ INS

⊙	$m = 1.62$	
+	$m = 2.0$	$R = 40$ INS.
✕	$m = 2.67$	

$I_f = 1946$ INS^4
$I_f = .05$ INS.^{4}

$N_{x\theta}$ lb/INS.

rI_f INS.^{4}

FIG.19.

VARIATIONS IN VALUES OF $N_{x\theta}$ AT $\theta = 30°$ FOR VARYING VALUES OF rI_f, m & I_f.
RADIAL APPLIED LOAD OF 1000 lb

$k_x = 1.53$

$t = 028$ INS.

○ m = 1.62 ⎫
+ m = 2.0 ⎬ R = 6.0 INS
× m = 4.0 ⎭

$I_f = 1946$ INS.⁴

$I_f = .05$ INS⁴

$N_{x\theta}$ lb/INS

rI_f ins.⁴

FIG 20.

VALUES OF THE MOMENT OF INERTIA OF THE LOADED FRAME (rI_f) ABOVE WHICH, THE BEAM THEORY DISTRIBUTION OF SHEAR GIVES A REASONABLE DEGREE OF ACCURACY.

rI_f INS.⁴

R. INS.

FIG. 21.