DESIGN OPTIMIZATION OF A SHAFT ON TWO BEARINGS

DESIGN OPTIMIZATION OF A SHAFT ON TWO BEARINGS

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ABSTRACT

The purpose of this project was to develop an aid to designing machinery shafts to find the optimum design for most shaft design applications met in design engineers' practices, to reduce the cost of the shafts.

The result was a computer package capable of handling the design optimization of step shafts supported on two bearings which will find the shaft design with minimum cost.

Additional benefits were obtained such as reducing engineering time and cost, increasing reliability of the design, etc.

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1. INTRODUCTION

The design of a step shaft is a laborious Starting from assumed diameter sizes, the process. stresses along the shaft, deflections and the natural frequency would be determined for these diameters. This could be done by hand in which case a graphical method would probably be used to determine deflections and natural frequencies (see references 3, 5, 10 and 11), or it could be done by using computer packages as is the package "Stress" (25) available from McMaster University or "Multi-Span" (26) from Massachusetts Institute of Technology, in which case the shaft will be considered as a piece of structure. Considerable effort will be required from the user to provide the data concerning the shaft to be fed in these vast application packages.

The stresses determined by hand or by computer would be multiplied by stress concentration factors available from handbooks or manuals to obtain intensified stresses at shaft shoulders, keyways, holes and other stress raising irregularities on the shaft.

If the values obtained for stresses, deflections and natural frequency are not satisfactory, the process will be repeated for a different set of diameters. After a number of cycles, all the stresses would be below the allowable stress, the deflections below allowable deflection and natural frequency above allowable value, but it is unlikely that the weight of the shaft will be minimum. More cycles could be repeated at expensive engineering time to obtain a decreased weight or the process could be stopped at the risk of having an overdimensioned shaft.

The object of this project was to create a computer package applicable specifically to a step shaft on two bearings that will determine the optimum design of the shaft at low engineering cost. To the best knowledge of the authors of this package, there are no other packages available to treat the design optimization of a shaft. Compared with the design of a shaft by hand or by hand and some computer package help as described above, the use of this package will present the following advantages:

- 1. The weight of the shaft will likely be lower. How low the weight of a shaft designed by hand is depends on the ability of the designer. A number of trials done during the progress of this project have shown that the weight could be reduced by roughly 10% as an average. On a hoist shaft weighing 40,000 lbs., this would mean 4,000 lbs. which at a cost of about \$1./lb. means a \$4,000. savings.
- 2. The engineering time required to design a shaft with this package will be low. While by hand the time required will be between 8 to 24 hours, this package will only require 2 to 3 hours to prepare the input data and run the program. This would result in an average savings of about 14 hours which at a cost of \$25./hr. means a \$350. savings.
- 3. While a design done by hand could be subjected to errors, the result given by this package will be accurate and correct and reliability of the shaft might be greater.

2.

The application of this package is limited to horizontal shafts on two bearings with or without cantilever extension subjected to concentrated and uniformly distributed loads and torsional moments. This covers most of the shaft designs met in practice. It could be developed to cover a larger range of shafts including multi-span shafts and shafts with other cases of loading. The work done so far will be useful for such a development.

The use of the package is especially attractive for shafts for heavy machinery such as mine hoists, naval machinery, steel mill machinery, presses, etc. where a reduction of the weight of the shaft results in substantial savings and for shafts for spacecraft machinery, aircraft machinery, nuclear reactor machinery etc. where the reliability and the weight of the shaft is important.

2. DESCRIPTION OF THE PROBLEM

2.1 GEOMETRICAL CONFIGURATION OF THE SHAFT

The shaft consists of a series of cylindrical sections of various diameter size. It is supported on two bearings and can have a cantilever extension. The bearings permit slopes of the shaft at the bearing point and one of them is free to translate along the axis of the shaft. (See a typical configuration shown in Fig. 1).

The location of the bearings and the location of the shaft shoulder and shoulder radius is known. The diameters of the shaft will be determined as the result of the optimization process with the exception of certain diameters that can be of predetermined sizes that will not be changed during the optimization (as it may be required by the bearing size, coupling size, standard parts mounted on the shaft, etc.).





The configuration of the shaft may be restricted by some diameters having to be greater than others for assembly considerations. A minimum shoulder may be required for example adjacent to bearings, a gear, coupling, etc.

The shaft may have keyways, grooves, holes, etc. 2.2 LOADING

The axis of the shaft is situated in the horizontal plane. The shaft can be subjected to any concentrated or uniformly distributed forces perpendicular to axis of shaft, projected in vertical and horizontal plane and any torsional moments. (See Fig. 2.) showing typical loading on the shaft.



5.

2.3 OPTIMIZATION PROBLEM

We wish to optimize the shaft of a geometrical configuration and loading as described above. Our optimization problem is to find the unknown diameter sizes of the shaft for which the weight of the shaft will be minimum and the following constraints will be satisfied:

- the stress at any point along the shaft will be below the allowable value;
- the maximum deflection will be less than an allowable deflection;
- the slope of the shaft in bearings will be below an allowable slope;
- the torsional deflection will be less than the allowable limit;
- the critical speed will be greater than a specified value;
- the shoulder size at specified points along the shaft will be greater than certain given values.

Fig. 2 Typical Loading on the Shaft

2.4 INDEPENDENT VARIABLES

Of all diameters of the shaft D_1 , $D_2 \cdots D_m$, some are of predetermined size and cannot be changed through optimization. The unknown diameters form the independent variables d_1 , $d_2 \cdots d_n$ $(n \leq m)$.

2.5 SPECIFICATIONS

The user will define the geometrical configuration of the shaft and the loading. He will also set the specifications to which the design of the shaft will have to conform. The references 7, 12, 13, 14, 15, 16, 17 and other manuals, codes and standards could be to users' assistance to set some of the following specifications required to be supplied:

- 1. allowable stress;
- 2. allowable bending deflection;
- 3. allowable slope in bearings;
- 4. allowable torsional deflection;
- 5. critical speed to be above a minimum value;
- size and location of diameters that the user wishes to stay unchanged, diameters that will not be optimized;
- 7. minimum diameter increase or decrease and location for cases in which the shoulder cannot be below a given value;
- 8. stress concentration factor for stress raising irregularities other than shaft shoulders. For shaft shoulders, the stress concentration factor is selected internally from tables extracted from (6).

2.6 OBJECTIVE FUNCTION

We wish to find the design of the shaft that can be manufactured at a minimum cost. The cost of the shaft could depend on the size of the shaft, on geometrical configuration and could vary from one manufacturer to another.

By decreasing the weight of the shaft, the cost will decrease and for a shaft of defined geometrical configuration manufactured by a certain company, the design of minimum weight will cost the least.

The objective function of our optimization problem is the total weight of the shaft which is to be minimized.

$$\mathbb{W}(d_{1}, d_{2} \dots d_{n}) = \sum_{i=2}^{m} \mathbb{V} \frac{\widetilde{\pi} D_{i-i}^{2}}{4} (X_{i} - X_{i-1})$$

= $\sum_{j=2}^{n} \mathbb{V} \frac{\widetilde{\pi} d_{j-i}^{2}}{4} (X_{j} - X_{j-1}) + \sum_{k=n}^{m} \mathbb{V} \frac{\widetilde{\pi} D_{k-i}^{2}}{4} (X_{k} - X_{k-i})$

Where:

D_i, d_i are shaft diameters as described in 2.4;

W $(d_1, d_2 \dots d_n)$ is the weight of the shaft;

 X_{i} is the abscisa at the point where the shaft section of a diameter d_{i} or D_{i} starts;

T is the specific weight for steel.

2.7 CONSTRAINT FUNCTIONS

Our optimization problem has inequality constraints only:

1. The maximum stress on the shaft $\overline{U_{cmax}}$ shall be less than the allowable stress $\overline{U_{al}}$. Our first constraint function is:

$$\Phi_1 = \overline{\sigma}_{al} - \overline{\sigma}_{cmax} \ge 0 \tag{2.2}$$

2. The maximum deflection \mathcal{J}_{max} shall be less than the allowable deflection \mathcal{J}_{al}

$$\Phi_2 = J_{al} - J_{max} \ge 0 \tag{2.3}$$

3. The slope of the shaft in bearings α_A and α_B shall be less than the allowable limit α_{al}

$$\begin{split}
\Phi_{3} &= \alpha_{a1} - \alpha_{A} \geqslant 0 \\
\Phi_{4} &= \alpha_{a1} - \alpha_{B} \geqslant 0
\end{split}$$
(2.4)

4. The maximum rotational deflection $\varphi_{m\alpha_r}$ shall be less than the allowable torsional deflection φ_{α_l}

$$\Phi_5 = \varphi_{\alpha l} - \varphi_{max} \ge 0 \tag{2.5}$$

5. The critical speed of the shaft RPM_{CR} shall be greater than the allowable critical speed RPM_{al}

$$\Phi_6 = RPM_{cR} - RPM_{al} \ge 0 \tag{2.6}$$

6. The increase or decrease in diameter size in particular points $d_i - d_{i-1}$ shall be greater than a minimum value Δd_i

$$\Phi_{j} = (d_{i} - d_{i-i}) - \Delta d_{i} \ge 0 \qquad j = 7, 8...p \qquad (2.7)$$

for an increase in diameter, or

$$\bar{\Phi}_{i} = (d_{i-1} - d_{i}) - \Delta d_{i} \ge 0$$
(2.8)

for decrease

p is the number of inequality constraints

The increase or decrease in diameter size is chosen depending whether the starting diameters in that point are increasing or decreasing.

In the above expressions $\int_{\alpha l_1} \int_{\alpha l_2} \varphi_{\alpha l_3} RPM_{\alpha l} and \Delta di$ are values specified by user while $\int_{CM\alpha r_1} \int_{M\alpha r_1} \varphi_{\alpha \beta} \varphi_{\alpha \alpha r_3} and RPM_{ca}$ are calculated as shown in §5.

3. OPTIMIZATION METHOD

To minimize the objective function $W(d_1, d_2 \dots d_n)$ subjected to the constraints $\phi_1(d_1, d_2 \dots d_n) \ge 0$, $j = 1, 2 \dots p$ as defined at 2.6 and 2.7, use is made of a direct search method employing the subroutine "SEEK3" from "OPTISE?" package (Reference 2) developed by Prof. James N. Siddall from McMaster University, Hamilton. The method is described in Ref. 1, 2, 20 & 21. With this method, an artificial, unconstrained objective function is defined as follows:

$$P(d_{1}, d_{2}...d_{n}, r) = W(d_{1}, d_{2}...d_{n}) + r \sum_{j=1}^{p} \frac{1}{\Phi_{j}(d_{1}, d_{2}...d_{n})} + \sum_{k=1}^{p} \frac{\psi_{k}(d_{1}, d_{2}...d_{n})^{2}}{\sqrt{r}}$$
(3.1)

In this function Ψ_k (d₁, d₂ ... _n) would be equality constraint function. Since we do not have any equality constraints, the last term of the function is not used and the function is reduced to

 $P(d_1, d_2, \dots, d_n, r) = W(d_1, d_2, \dots, d_n) + r \sum_{j=1}^{L} \frac{1}{\Phi_j(d_1, d_2, \dots, d_n)}$ r is a parameter that is 1.0 at the beginning. With this value for r, a direct search method is used to minimize P(d1, d2 ... dn, r). Starting from an initial base point with d1, d2 ... dn having starting values given by user, an exploration search is made. One of the variables is increased a small amount; and if the function P is improved the new value of the variable is retained. If the move does not improve P, a negative step is tried. If this also fails, then the variable takes its base point value. The process is repeated for each variable and if no improvement of P is obtained, the step lengths are halved and the search is repeated until the step lengths are smaller than a preset small value when an optimum is assumed.

If this search yields a smaller value of P, then a new base point is established and a pattern move equal to the vector joining the original and the new base point is attempted. If the search is successful, the new search starts from that point, otherwise starts from the previous point. The process is repeated until a preset number of cycles have been exceeded or until the step lengths are less than the preset value.

After this cycle, the parameter r is reduced and the artificial function is minimized again. The process continues until no improvement in the function $W(d_1, d_2 \dots d_n)$ can be reached when it is assumed that the optimum solution has been found. The subroutine has shown to be powerful, reaching the optimum solution after a few minimizations of the artificial objective function.

No feasible starting point is required. A feasible solution is desirable to reduce the computer time and cost of the run.

A typical cost to run the program for a shaft of average complexity would be between \$10.-\$50. at a computer cost of \$416/hr.

The subroutine "SEEK1" (Reference 1, 2 and 21) that follows the same direct search method but combined with a random search has also been tried. The results have not been satisfactory, the subroutine tending to hang up in constraints. If a sufficient number of random shots are tried, the subroutine would eventually converge but slowly, using more computer time than "SEEK3".

The subroutine "SIMPLEX" (Reference 1,2,22,23 and 24) that uses the same artificial function as "SEEK3" but gropes towards the optimum by contracting and expanding an n dimensional space, called SIMPLEX, has been tried but without success. It hangs up in constraints. An optimum solution has not been found at a reasonable computer time and expense.

4. OUTPUT INFORMATION

4.1 OUTPUT FORMAT

A typical output format is shown in the sample run 8 from Appendix A "User's Manual".

4.2 INFORMATION PROVIDED

The following information is printed out:

11.

- 1. Input data as supplied by user containing:
 - 1.1 length of first span in inches;
 - 1.2 length of the cantilever span in inches;
 - 1.3 concentrated weights attached to the shaft in lbs. provided separately for calculation of natural frequency. Location in inches measured from the first bearing and the weight in lbs. is shown;
 - 1.4 concentrated vertical forces in lbs. and location in inches;
 - 1.5 concentrated horizontal forces in lbs. and location in inches;
 - 1.6 uniformly distributed weights attached to the shaft in lbs./inches and location of the beginning and the end of the force in inches;
 - 1.7 vertical uniformly distributed forces in lbs./inches and location in inches;
 - 1.8 horizontal uniformly distributed forces in lbs./inches and location in inches;
 - 1.9 torsional moments in lbs./inches and location of the beginning and the end of the portion of the shaft between which it is applied in inches;
 - 1.10 diameter size and the location of the point of the shaft where that diameter size starts in inches;
 - 1.11 stress concentration factor for stress raising irregularities and location in inches;
 - 1.12 shoulder radii and location in inches;
 - 1.13 the table 'Dimensions and Loading' systemizing the above information;
 - 1.14 allowable stress in lbs./sq. inches;

12.

- 1.15 allowable bending deflection in inches;
- 1.16 allowable slope in bearings in radians;
- 1.17 allowable torsional deflection in radians;
- 1.18 minimum critical speed in RPM;
- 1.19 diameters of predetermined size and point of beginning in inches;
- 1.20 diameter increase or decrease and location
 in inches;
- Information required by optimization subroutine "SEEK3". No user input is required to supply this information. The following data is printed out:
 - 2.1 N number of independent variables X(I) that is the number of shaft diameter sizes d; to be determined;
 - 2.2 IPRINT = 1 indicates that after each
 optimization cycle of a constant
 parameter R the independent variables
 X and the objective function
 U = W (d₁, d₂ ... d_n) will be printed
 out:
 - 2.3 IDATA = 1 indicates that the input data for SEEK 3 is printed out;
 - 2.4 NCONS is the number of inequality constraints
 - 2.5 NEQUS is the number of equality constraints set at 0;
 - 2.6 RMIN(I) is the estimated lower bound of range of X(I), set at

$$RMIN(I) = .9 XSTART(I)$$
(4.1)

2.7 RMAX(I) is the estimated upper bound of range of X(I), set at

$$RMAX(I) = 1.1 XSTART(I)$$
(4.2)

- 2.9 G is the step size fraction used to establish the minimum step size;
- 2.10 M = 20 is the maximum number of cycles
 permitted;
- 2.11 R is the penalty multiplier used in SEEK3
 (See ch.3);
- 2.12 Reduce = .05 is the reduction factor for r after each minimization;
- Results after each minimization cycle of U including values for R, U and X(I);
- 4. Optimum solution if found including U, X(I) and PHI(I) = Φ_i
- 5. 'Output Data' concerning the optimum design of the shaft, as follows:
 - 5.1 The vertical, horizontal and the geometrical resultant of the reactions in the two bearings in lbs. and the location of the bearings in inches;
 - 5.2 The vertical, horizontal and geometrical resultant of the bending moment and torsional moment in lbs. ins. at all points on the shaft specified by user in input data;
 - 5.3 Bending deflections in inches, slopes and rotations of the axis of the shaft in radians in all specified points along the shaft, in vertical and horizontal plane and the geometrical resultant;
 - 5.4 Vertical, horizontal and the resultant of bending stresses, torsion stresses, combined stresses and intensified stresses as well as the stress intensification factor for bending and torsion in all specified points along the shaft;

- 5.5 The weight of the shaft in lbs.;
- 5.6 Angular frequency of dundamental mode of vibrations in rad./sec. and the critical speed in RPM;

4.3 PLOT OF SHAFT

The optimum design of the shaft is plotted on a Benson-Lenner Plotter. Depending on the size of the shaft, a suitable scale is chosen so that the plot of the lengths of the shaft is between $12\frac{1}{2} - 31\frac{1}{4}$ inches for shaft shorter than 500 inches, from the following range of scales commonly used in drafting:

> 3/4 in. = 1 ft. 1 in. = 1 ft. $1\frac{1}{2}$ in. = 1 ft. 3 in. = 1 ft. Half Full Scale Full Scale Double Scale

5. ENGINEERING MODELLING

5.1 BENDING DEFLECTIONS AND STRESSES

The forces applied on the shaft are kept in three distinct groups that are treated separately:

- gravitational forces caused by masses attached to the shaft;
- 2. vertical exterior forces;
- 3. horizontal forces.

They can initially be concentrated or uniformly distributed forces. The shaft's own weight is added to uniformly distributed gravitational forces. Within each of the three groups of forces, the uniformly distributed forces are replaced by a number of concentrated forces equal in size and spaced at equal intervals.

Each force is taken individually and reactions in bearings and bending moments are calculated for the force acting alone.

To calculate deflection caused by each force, use is made of the area-moment method (Reference 3) as follows:





Take first a force F situated in the span AB. For each cylindrical portion of the shaft, MN, between two adjacent discrete points specified in input data, the moment area is calculated:

$$Am = \frac{M_{m} + M_{n}}{2} (X_{n} - X_{m})$$
(5.1)

 ${\rm M}_{\rm m}$ and ${\rm M}_{\rm n}$ being bending moments in M and N caused by the force F.

The angle θ between the tangent to the deflection curve at points M and N is

$$\Theta = \frac{Am}{Elz}$$
(5.2)

E is modulus of elasticity for shafts material

 I_{Z} is the moment of inertia of shafts section between M and N

The total angle θ_{τ} between tangents to the deflection curve at the bearings is

$$\Theta_{\mathrm{T}} = \sum_{i=1}^{n_{i}} \frac{Am_{i}}{\mathrm{E}\,\mathrm{lz}_{i}} \tag{5.3}$$

n₁ is the number of discrete points between bearings.

In a point S

$$\Theta_{s} = \sum_{i=1}^{n_{s}} \frac{Am_{i}}{E |z_{i}|}$$
(5.4)

n $_{\rm S}$ is the number of discrete points from bearing A to point S.

Consider the distance \overline{BB} ' between bearing B

and the tangent to the deflection curve in A measured along the vertical. The contribution made by the deformation of the length MN to this distance is $\overline{M'N'}$.

$$\overline{M'N'} = \Theta \times C_B = \frac{A_m}{E_{lz}} \times C_B$$
(5.5)

Where ${\rm C}_{\rm B}$ is the distance between the centre of gravity of moment area Am and bearing B. Then the total distance $\overline{\rm BB}{}^{\,\rm s}$ is

$$\overline{BB}' = \sum_{i=1}^{n} \frac{Am_i}{E |z_i|} \times C_{B_i}$$
(5.6)

For any point S on the shaft

$$SS' = \sum_{i=1}^{n_s} \frac{Ami}{E|z_i} \times C_{Si}$$
(5.7)

The deflection in point S is:

$$J_{5} = \overline{55''} = \overline{55''} = \overline{55'} =$$

Take points A_1 and B_1 close to bearing A and B

$$\overline{AA}_{i} = \overline{BB}_{i} = \frac{L}{10\,000}.$$
(5.9)

The deflection in ${\rm A}_1$ and ${\rm B}_1$ is $\mathcal{J}_{{\rm A}_1}$ and $\mathcal{J}_{{\rm B}_1}$ calculated as above.

The slope in bearing A and B is:

$$\alpha_{\mu} = \frac{\int_{A_{\mu}}}{\overline{A \, \mu_{\mu}}} \tag{5.10}$$

$$\alpha_{B} = \frac{\delta_{B,}}{BB,}$$
(5.11)

The slope in the point S is:

 $\alpha_{\rm S}=\,\theta_{\rm A}-\theta_{\rm S}$

(5.12)

The deflection in a point T situated in the cantilever span is:

$$\int_{T} = (X_{T} - L) \times \alpha_{B}$$
(5.13)

For a force situated in the cantilever span, the deflections and slopes are calculated in a similar manner.

Applying the superposition principle, the reactions in bearings, moments, deflections and slopes in each point on the shaft are calculated by totalizing the reactions, moments, deflections and slopes caused by each of the gravitational forces, exterior vertical forces and horizontal forces.

The vertical reactions in bearings, moments, deflections and slopes all along the shaft are calculated by adding the effects of gravitational and vertical exterior forces.

The normal stresses produced by bending are calculated then in the vertical and horizontal planes.

$$\overline{\mathbf{v}}_{i} = \frac{\mathbf{M}_{i}}{|\mathbf{z}_{i}|} \times \frac{\mathbf{D}_{i}}{2} \tag{5.14}$$

$$\overline{U}_{H_i} = \frac{M_{H_i}}{|z_i|} \times \frac{D_i}{2}$$

(5.15)

The geometrical resultant of the reacions in bearings, moments, deflections, slopes and stresses are computed next:

$$R_{\rm H} = -\sqrt{R_{\rm AV}^2 + R_{\rm AH}^2}$$
(5.16)

$$R_B = \sqrt{R_{BV}^2 + R_{AH}^2} \qquad (5.17)$$

$$M_{i} = \sqrt{M_{V_{i}}^{2} + M_{H_{i}}^{2}}$$
(5.18)

$$J_i = \sqrt{J_{V_i}^2 + J_{H_i}^2}$$
(5.19)

$$\alpha_i = \sqrt{\alpha_{V_i}^2 + \alpha_{H_i}^2} \tag{5.20}$$

5.2 TORSIONAL DEFLECTIONS AND STRESSES

The torsional deflection at any point on the shaft is calculated as follows:

$$\varphi_{k} = \sum_{i=1}^{K} \frac{T_{i}}{G | p_{i}} (X_{i} - X_{i-i})$$
(5.21)

where

 T_i is the torsion moment in section i; G is the modulus of shear; I_{p_i} is the polar moment of inertia of section i; X_{i-1} , X_i are the co-ordinates of the beginning and end of section i;

20.

The shearing stress is calculated:

$$T_i = \frac{T_i}{1p_i} \times \frac{D_i}{2}$$
(5.22)

5.3 COMBINED STRESSES

The combined stresses are calculated according to the maximum strain theory of elastic failure suggested by St. Venant (References 3, 4, 5, 18 and 19) commonly accepted for mechanical shafting::

$$\overline{O_{c_i}} = .35 \ \overline{O_i} + .65 \ \sqrt{\overline{O_i}^2 + 4 \ \overline{U_i}^2}$$
(5.23)

5.4 INTENSIFIED STRESSES

In any point on the shaft where there is a stress concentration due to shaft shoulders, keyways, holes, grooves, etc., the intensified bending or shear stress is calculated by multiplying the stresses calculated as shown above by a stress intensification factor.

For shaft shoulders, the stress intensification factor is calculated within the program. The intensification factor for bending stresses is selected from Table 1 and the intensification factor for torsional shear from Table 2 below by linear interpolation. The tables are reproduced from Ref. (6) pages 386 and 388.

$\frac{h}{r}$ \overline{d}	.05	.10	.20	.27	. 50	1.0
•5	1.61	1.49	1.39	1.34	1.22	1.07
1.0	1.91	1.70	1.48	1.38	1.22	1.08
1.5	2.00	1.73	1.50	1.39	1.23	1.08
2.0		1.74	1.52	1.39	1.23	1.09
3.5		1.76	1.54	1.40	1.23	1.10

TABLE 5.1 - BENDING STRESS CONCENTRATION FACTORS r FOR SHAFT SHOULDERS

FUR SHAFT SHUULDERS									
$\frac{D}{d}$.005	.01	.02	.03	.04	.06	.08	.10	.12
2.00 1.33 1.20 1.09	3.0 2.20	3.0 2.7 2.5 1.88	2.25 2.16 2.00 1.53	2.00 1.91 1.75 1.40	1.82 1.76 1.62 1.30	1.65 1.60 1.50 1.20	1.51 1.48 1.40 1.16	1.44 1.40 1.34 1.15	1.39 1.35 1.30 1.15

TABLE 5.2 - TORSION STRESS CONCENTRATION FACTOR FOR SHAFT SHOULDERS

In these tables;

r = shoulder radius d = the smaller diameter size D = the greater diameter size h = (D - d)/2

For other kinds of irregularities on the shaft, the stress intensification factors should be supplied in input data. They could be selected by the user from the same Ref. (6).

5.5 CRITICAL SPEED

The angular frequency of the fundamental mode of transverse vibrations caused by weights attached to the shaft is calculated by applying the energy method suggested by Rayleigh (Refs. 8, 9 and 10).

$$P = \sqrt{\frac{g \sum_{j=1}^{n} W_{j} Y_{j}}{\sum_{j=1}^{n} W_{j} Y_{j}^{2}}}$$
(5.24)

where:

p = angular frequency in rad/sec g = gravitational acceleration in in/sec² W_j = weight attached to the shaft in a point of co-ordinate x_j y_j = deflection caused by the weights attached to the shaft in a point of co-ordinate x_j

The shaft's own weight is calculated in the program and added to weights attached to the shaft as a number of concentrated forces distributed along the shaft.

The critical speed of the shaft is then calculated:

$$RPM_{cr} = \frac{30 p}{\pi}$$
(5.25)

where RPM_{cr} = critical speed in revolutions/minute 6. <u>CONCLUSIONS</u>

The computer package developed by this work is capable of bringing a considerable support to the design of a vast majority of shafts the design engineer would meet in his practice. The engineer's capability will still play the main role in the design. The engineer will establish the geometrical configuration and the loading and will specify allowable stresses, deflections, etc., depending on application, available space, reliability required and other factors.

The main objectives achieved by this package are:

1. The design of the shaft obtained by the package, complying with user specifications, is the optimum design with minimum weight and cost.

23.

- 2. The package is specifically directed to solve the specific problem of designing a shaft. The use of a large purpose stress analysis package will not only fail to give the user the optimum design but will require user's involvement in areas not relevant to his problem while missing design aspects specific to the shaft as is the stress raisers, minimum shoulder required, etc.
- 3. User's input is practical and simple. It is limited to a minimum of data determining the design. No theoretical sophistication is required to prepare the input data or to interpret the results printed out.
- 4. The engineering time required to design a shaft with help of this package is low.
- 5. The computer time and expense is low.
- 6. The results are accurate and correct.

The applicability of the package is limited to the design of horizontal step shaft on two bearings with concentrated or uniformly distributed forces and torsional moments.

This would cover most of designer's shaft design problems. The following extensions to this work might be though useful to cover a larger area of applicability and to increase the versatility of the program in other aspects:

- 1. Design of shafts on more than two bearings;
- 2. Design of inclined or vertical shafts;
- 3. Larger loading case coverage such as:

3.1 Axial loads;

- 3.2 Moments in planes containing the axis of the shaft (only torsional moments, perpendicular to axis of shaft are handled in present stage);
- 3.3 Variable loading along the shaft or on portions of the shaft.
- 4. Design of shafts with a number of alternatives concerning the loading. The same shaft might at different times be subjected to different loading.
- 5. Design of shafts that could have sections varying continuously as might be required by application or to enable further reduction of weight.
- Calculation of natural frequency for rotational vibrations, useful especially for long shafts on several bearings.
- 7. Interpret user input less restricted to following a format pattern.
- 8. Adapt package for time sharing system.

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APPENDIX A

PROGRAM SHAFT I

DESIGN OPTIMIZATION OF A SHAFT ON TWO BEARINGS

PROGRAM LISTING
	PROGRAM SHAFT1 (INPUT, OUTPUT, TAPE5=INPUT, TAPE6=OUTPUT)	MAI	10
C		MAI	20
C		MAI	30
C	DESIGN OPTIMIZATION OF A SHAFT ON TWO BEARINGS	MAI	40
C	***************************************	MAI	50
C		MAI	60
G	THE DEADAM DETERMINES THE ADDIMIN DECIDE OF A CHAPT OF THE	MAI	20
C	INE FROGRAM DETERMINES THE OFFINDIN DESIGN OF A SHAFT ON TWO BEADINGS SHETCTED TO EVERING EORCES AND TORSIONAL MOMENTS FOR	MAI	80
č	THE MINIMUM WEIGHT	MAT	100
C		MAI	110
u.	DIMENSION	MAT	120
	*RMAX(50), RMIN(50), X(50), XSTRT(50), PHI(20), PSI(1), W1(50), W2(50),	MAI	130
	*W3(50), W4(50), RD(50), WORK1(200), WORK2(200), WORK3(200), WORK4(200),	MAI	140
	*WORKK(200), WORKL(200), WORKM(200), WORKN(200), WORKP(200),	MAI	150
	*XA(50,51), XJ(50), XH(50), XS(50), XL(50), XO(50), XP(50), XE(50), XC(50),	MAI	160
~	*STEP(50), FUN(51)	MAI	170
C		MAI	180
0	REAL L, L1, L2	MAI	190
G	COMMON (AA < DOWDD(Q) UOVDD(Z) CD(Z Q) DOVDT(11) DOVDT(G) CT(G 11)	MAI	200
	FCT1(20) FCT2(20)	MAT	210
	COMMON/BB/ BA, BB, XB(200), X2(200), D2(200), PV2(200)	MAI	230
	*, BNV(200), BMH(200), BM(200), DFLV(200), DFLH(200), SLV(200), SLH(200),	MAI	240
	*SL(200), STRV(200), STRH(200), STR(200), SCB(200), SCT(200), SCF2(200),	MAI	250
	*RAD2(200), STRINT(200), TM2(200), TETA(200), TAU(200), TAUINT(200),	MAI	260
	*STR1(200), SIGMA1(200), PH2(200), DFL(200), PW2(200), BMW(200),	MA I	270
	*DFLW(200),SLW(200),STRW(200),	MAI	280
	*WORKA(200), WORKE(200), WORKE(200), WORKE(200), WORKE(200), WORKE(200),	MAI	290
	*WORKG(200), WORKH(200), WORKI(200)	MAI	300
	CONTROLY DD/ E, G, NUO, A, B, N1, N2, N3	MA I	310
	CONTINUE LE ADIAL DE AL DE AL DE LA DE LA DEMMIN VILLOAD DILOAD NIL	MAI	320
	COMMON/CC/ VDF(20) DF(20) NDF WORKS(50)	MAT	340
C		MAT	350
č	MODULUS OF ELASTICITY	MAI	360
u	E=30000000.	MAI	370
	C=11500000.	MAI	380
	NG0=200	MAI	390
_	W=1.0	MAI	400
C		MAI	410
	CALL LUAD (NGO, ND, N1, N2, N3, A, B, W, XDIA, DIA, XR,	MAI	420
	* A2,FW2,FV2,FF2,IT2,J2,5GF2,RAD2,RD, *WORVA WORVE WORVE WORVE WORVE WORVE WORVE WORVE WORVE WORVE	MAT	430
	*WORKN WORKN WORKP WORKP, WORKS, WORKS, WORKA)	MAT	450
C	whole and the second se	MAI	460
Č	READ AND PRINT OUT THE CONSTRAINTS	MAI	470
C		MAI	480
C	ALLOWABLE STRESS	MAI	490
	READ(5, 100) STRAL	MAI	500
0	WRITE(6,101) STRAL	MAI	510
u c	ALLOWARE DEFIECTION	MAT	520
u.	BEAD 5 102) DELAL	MAT	540
	WEITE(6.103) DELAL	MAI	550
C		MAI	560
C	ALLOWABLE SLOPE IN BEARINGS	MAI	570
	READ(5,102) SLAL	MAI	580
	WRITE(6,104) SLAL	MAI	590
C	ALL OWNER BORGLOWAL DEEL COMING	MAI	600
C	ALLOWABLE TORSTONAL DEFLECTION	FIA I	610
	READ(0, 102) IEIAAL	MAT	620
C	WRITE(0,105) TETAAL	MAT	640
č	MINIMUM CRITICAL SPEED	MAI	650
-	READ(5,100) RPMMIN	MAI	660
	WRITE(6,106) RPMMIN	MAI	670
C		MAI	680
C	CONSTRAINTS DEFINING SHAFT DIAMETERS	MAI	690
C	DIAMETERS OF FIXED SIZE	MAI	700
	READ(5,107) NDF	MAI	710
	$\frac{1}{1} = 1 \text{ NDF}$	MAT	720
	READ(5, 108) $XDF(1)$, DF(1)	MAI	740

00000000000

WRITE(6,110) XDP(1), DF(1) MAI 766 C CONTINUE MAI 766 C READ(5,107) XDI MAI 766 DO 2: 1:, NDI MAI 766 READ(5,107) XDI MAI 806 WAITE(6,112) MAI 806 WAITE(6,112) MAI 806 WAITE(6,112) MAI 806 WAITE(6,112) MAI 806 C THE FROGRAM USES THE SUBROUTINE SEEKS FOR OPTIMIZATION MAI 806 C IFENTRE MAI 806 C IFE FROGRAM USES THE SUBROUTINE SEEKS FOR OPTIMIZATION MAI 806 C IFE FROGRAM USES THE SUBROUTINE SEEKS FOR OPTIMIZATION MAI 906 C DO 41 1=1.50 MAI 906 NEDUS-0 MAI 906 MAI 906 NUBN 70-0 MAI 906 MAI 906 NUBN 7D-1 MAI 1906			
1 CONTINUE M1 766 C M11 766 M1 766 C M11 766 M1 766 READ/CS (107) ND1 M1 766 ND 2 1-1, ND1 M1 161 READ/CS (106) XD1(1), D1(1) M1 1630 CONTINUE M1 1630 C CONTINUE M1 1630 C THE FROGRAM USES THE SUBROUTINE SEEKS FOR OPTIMIZATION M1 1630 C THE FROGRAM USES THE SUBROUTINE SEEKS FOR OPTIMIZATION M1 1630 C THE FROGRAM USES THE SUBROUTINE SEEKS FOR OPTIMIZATION M1 1630 C THE FROGRAM USES THE SUBROUTINE SEEKS FOR OPTIMIZATION M1 1630 C DO 41 1=1.50 M1 1960 MIXOUS=0 M1 1960 M1 1960 RHINK (1)=0.0 M1 1960 M1 1960 RHINK (1)=0.0 M1 1960 M1 1960 NUNPND-1 M1 1961 M1 1960 NUNPNND-1 M1 1961 M		WRITE(6,110) XDF(1), DF(1)	MAI 750
G HINTING DIAMETER INCREASE MAI 776 G HINTING DIAMETER INCREASE MAI 796 READ(5, 107) ND1 MAI 796 WAITE(6, 112) MAI 796 DO 2 10 1.ND1 MAI 100 WAITE(6, 112) MAI 806 CONTINUE MAI 806 C MAI 806 MAXM-20 MAI 906 MAXM-20 MAI 906 MAXM-20 MAI 906 C MAI 906 C MAI 906 MAXM-20 MAI 906 XSTRUC10-0.0 MAI 906 WINN 10-0.0 MAI 906 XCINUT 10-0.0 MAI 906 WINN 10-0.0 MAI 906 C MAI 1007 <	1	CONTINUE	MAI 760
C MININUM DIAMETER INCREASE MAI 700 READ(5,107) NDI MAI 800 D0 2 1:1,NDI MAI 800 READ(5,107) NDI MAI 800 WAITE(6,112) MAI 800 WAITE(6,112) MAI 800 WAITE(6,110),DI(1),DI(1) MAI 800 C THE FROGRAN USES THE SUBROUTINE SEEKS FOR OPTIMIZATION MAI 800 C THE FROGRAN USES THE SUBROUTINE SEEKS FOR OPTIMIZATION MAI 800 MAI 900 MAI 900 MAI 900 MAI 900 MAI 900 MAI 900 MAMP=20 MAI 900 MAI 900 MAI 900 MAI 900 MAI 900 MAI 900 MAI 900 MAI 900 MUD*ND=1 MAI 900 MAI 900 MUD*ND=1 MAI 900 MAI 900 NCONFUND MAI 900 MAI 900 NCONTINUE MAI 900 MAI 900 NUD*ND=1 MAI 900 <	C .		MAI 770
S EEAN(G, 1.07) NDT MAIL TOOL MAIL TOOL WRITE(6, 112) MAI BAIL MAIL TOOL DO 2 L=1, NDI MAIL TOOL MAIL TOOL READ(G, 1.00) XDI(L), DI(L) MAIL BAIL MAIL TOOL COUTINUE MAIL TOOL MAIL BAIL C COUTINUE MAIL BAIL C THE PROGRAM USES THE SUBROUTINE SEEKS FOR OPTIMIZATION MAIL BAIL C IPHINT=1 MAIL BAIL IBATA=1 MAIL BAIL MAIL BAIL NEEUS=0 MAIL 900 MAIL 900 MAIL POOL MAIL 900 MAIL 900 MEEUS=0 MAIL 900 MAIL 900 MEEUS=0 MAIL 900 MAIL 900 MEEUS=0 MAIL 900 MAIL 900 RMINK(1)=0.0 MAIL 900 MAIL 900 RMINK(1)=0.0 MAIL 900 MAIL 900 RMINK(1)=0.0 MAIL 900 MAIL 900 ROTITUE MAIL 900 MAIL 900 ROTITUE MAIL 900 MAIL 900 ROTITUE MAIL 900 MAIL 900<	č	MINIMUM DIAMETER INCREASE	MAI 780
$ \begin{array}{c} \mbox{iff} TR(4,112) & \mbox{iff} Mit 120 & \mbox{iff} Mit 120 & \mbox{iff} Mit 122 & \mbox{iff} Mit 122 & \mbox{iff} Mit 120 &$	4	BEAD(5 107) NDI	MAI 790
NO 2. Yel, NDJ ND 10, D1(1), D1(1) ND 10, D1(1), D1(1) READA (5, 100) XD1(1), D1(1) ND 10, D1(1), D1(1) ND 10, D1(1), D1(1) C CONTINUE ND 10, D1(1), D1(1) ND 10, D1(1), D1(1) C Continue ND 10, D1(1), D1(1) ND 10, D1(1), D1(1) C Continue ND 10, D1(1), D1(1) ND 10, D1(1), D1(1) C THE PROGRAM USES THE SUBROUTINE SEEKS FOR OPTIHIZATION ND 10, D1(1), D		$I \subseteq I \subseteq \{1, 0\}$	MAT 200
$ \begin{array}{c} 10.5 (1.5 (1.5 (1.5 (1.5 (1.5 (1.5 (1.5 (1$			MAT 010
$\begin{array}{c} \mbox{Results} (100) \mbox{AD1(1), D1(1)} \\ \mbox{WR1EV} (110) \mbox{AD1(1), D1(1)} \\ \mbox{WR1EV} (110) \mbox{Results} (100) \mbox{MR1} (100) \\ \mbox{C} \\ \mbox{C} \\ \mbox{THE PROCRAM USES THE SUBROUTINE SEEKS FOR OPTIMIZATION } \\ \mbox{MA1} \mbox{Box} (100) \mbox{MA1} (100) \mbox{MA1} (100) \\ \mbox{MA1} \mbox{Box} (100) \mbox{MA1} (100) \mbox{MA1} (100) \\ \mbox{MA1} \mbox{Box} (100) \mbox{MA1} (10$			MAL ODO
2 WRITE(0, 110) Mail 100 Mail 100 C CONTINUE Mail 200 C THE PROGRAM USES THE SUBROUTINE SEEKS FOR OPTIMIZATION Mail 200 C IPRINT=1 Mail 200 IPRINT=0 Mail 200 Mail 200 MAIS=20 Mail 900 Mail 900 DO 41 1=1,50 Mail 900 STRIX(1)=0.0 Mail 900 Mail 900 REGUESCO Mail 900 Mail 900 STRIX(1)=0.0 Mail 900 Mail 900 MIDDO 4 III 940 Mail 900 N=0 Mail 900 Mail 900 NND=RD-1 Mail 900 Mail 900 N=0 Mail 900 Mail 900 N=0 Mail 900 Mail 900 N=0 Mail 900 Mail 900 N=1 Mail 900 Mail 900 ND 0 5 1=1,N Mail 900 <t< td=""><td></td><td>$READ(5, 108) \times D1(1), D1(1)$</td><td>MAI 820</td></t<>		$READ(5, 108) \times D1(1), D1(1)$	MAI 820
2 CONTINUE IN EXPERIMENTATION IN EXPERIMENTATION IN EXAMPLE AND ALL SECONTINUES THE SUBROUTINE SEEKS FOR OPTIMIZATION IN EXAMPLE AND ALL SECONTINUES THE SUBROUTINE SEEKS FOR OPTIMIZATION IN EXAMPLE AND ALL SECONTINUES THE SUBROUTINE SEEKS FOR OPTIMIZATION IN EXAMPLE AND ALL SECONTINUES THE SUBROUTINE SEEKS FOR OPTIMIZATION IN EXAMPLE AND ALL SECONTINUES AND ALL ALL SECONTINUES AND ALL ALL SECONTINUES AND ALL ALL ALL ALL ALL ALL ALL ALL ALL AL		WRITE(6, 110) XDI(1), DI(1)	MAI 830
	2	CONTINUE	MAI 840
C THE PROGRAM USES THE SUBROUTINE SEEKS FOR OPTIMIZATION HAI 866 IPRINT=1 HAI 686 IPRINT=1 HAI 686 IPRINT=1 HAI 686 IPRINT=1 HAI 686 IPRINT=1 HAI 686 IPRINT=20 HAI 687 HEADS=20 HAI 197 C D0 41 I=1.50 HAI 197 C D0 41 I=1.50 HAI 197 RHIAK(1)=0.0 HAI 987 RHIAK(1)=0.0 HAI 987 C HIAK(1)=0.0 HAI 987 C HAI 997 C HAI 997	C		MAI 850
	C	THE PROGRAM USES THE SUBROUTINE SEEK3 FOR OPTIMIZATION	MAI 860
$\begin{tabular}{lllllllllllllllllllllllllllllllllll$	C		MAI 870
$ \begin{array}{c} \text{IDATA-1} & \text{MAI B90} \\ \text{MAXMP20} & \text{MAINP20} \\ \text{MAXMP20} & \text{MAINP20} \\ \text{MAXMP20} & \text{MAINP20} \\ \text{MAXMP20} & \text{MAINP20} \\ \text{MAINP20} & \text{MAINP20} \\ \text{MAINP20} & \text{MAINP20} \\ \text{MAINP20} & \text{MAINP20} \\ \text{MIANVELDED } & \text{MAINP20} \\ \text{MAINP2ND-1} & \text{MAINP2ND-1} \\ \text{MAINP2ND-1} $		IPRINT=1	MAI 880
$\begin{tabular}{l l l l l l l l l l l l l l l l l l l $		IDATA= 1	MAI 890
$\begin{tabular}{lllllllllllllllllllllllllllllllllll$		NEQUS=0	MAI 900
C INTERPOSED (A. 1 = 1, 50 D 4 1 = 1, 50 NSTRT (1) = 0, 0 RTANK (1) = 0, 0 RTAN		MAXM=20	MAT 910
$ \begin{array}{cccccccccccccccccccccccccccccccccccc$	C		MAT 920
$ \begin{array}{c ccccccccccccccccccccccccccccccccccc$	ů.	DO 41 I=1 50	MAI 030
$\begin{array}{c} \text{REAL} (1) = 0.0 \\ \text{REAL} (1) = 0.0 \\$			MAT 040
$ \begin{array}{cccccccccccccccccccccccccccccccccccc$			MAI OFO
$\begin{array}{c c c c c c c c c c c c c c c c c c c $		$\operatorname{RTAX}(1) = 0.0$	MAI 950
X(1)=0, 0 MAI 976 C MAI 980 N=0 MAI 1960 NND=ND-1 MAI 1000 D0 4 I=1,NND MAI 1020 N=N+1 MAI 1000 SXSTRT(N)=DIA(1) MAI 1020 D0 3 J=1,NDF MAI 1020 CONTINUE MAI 1020 IF(LOLA).EQ.XDF(J)) N=N-1 MAI 1020 4 CONTINUE MAI 1020 10 0 5 1=1,N MAI 1020 RMAX(1)=1.1*XSTRT(1) MAI 1020 RMAX(1)=0.9*XSTRT(1) MAI 1120 RMAX(1)=0.9*XSTRT(1) MAI 1120 C MAI 1120 MAI 1120 MAI 1120 MAI 1120 MAI 1120 MAI 1120 MAI 1120 RMAX(1)=0.9*XSTRT(1) MAI 1120 REDUCE=0 MAI 1120 MAI 1120 MAI 1120 MAI 121 MAI 1221 RE.00 MAI 1200 MAI 1221 MAI 1221 RE.00 MAI 1221 MAI 1221 MAI 1221 RE.00 MAI 1221 RE.00 MAI 1221 RAI		$\operatorname{RFIIN}(1) = 0.0$	MAI 960
41 CONTINUE MAI 986 N=0 MAI 1980 N=0 MAI 1010 N=0 MAI 1020 N=N+1 MAI 1020 N=0 J=1, NDF If (DIAL). EQ. XDF(J) N=N-1 MAI 1020 GONTINUE MAI 1020 If (DIAL). EQ. DIA(I-1)) N=N-1 MAI 1020 4 CONTINUE MAI 1020 C MAI 1120 MAI 1120 RIAK (DI=1.1*XSTRT(I) MAI 1120 MAI 1120 RHAK (DI=1.1*XSTRT(I) MAI 1120 MAI 1120 RUNONS=6+NDI MAI 1120 MAI 1120 C F=.02 MAI 1120 MAI 1200 HE. 05 MAI 1200 MAI 1200 MAI 1200 RAUUCE=.05 MAI 1200 MAI 1200 MAI 1200 CALL SEEK3(N, MAX, RMIN, NCONS, NEQUS, XSTRT, F, H, R, REDUCE, MAXM, INDEX, MAI 1240 MAI 1220 MAI 1220 <		X(1) = 0.0	MAI 970
	41	CONTINUE	MAI 980
	C		MAI 990
$ \begin{array}{llllllllllllllllllllllllllllllllllll$		N=Ø	MAI 1000
		NND=ND-1	MAI1010
$ \begin{array}{c} \overline{k} = N+1 & MA11036 \\ XSTRT(N) = D1A(1) & MA11046 \\ D0 3 J=1, MDF & MA11066 \\ IF (XD1A(1). EQ. XDF(J)) N=N-1 & MA11067 \\ IF (1, EQ. 1) CO TO 4 & MA11067 \\ IF (1, EQ. 1) CO TO 4 & MA11067 \\ IF (1, EQ. 1) CO TO 4 & MA11067 \\ IF (1, EQ. 1) CO TO 4 & MA11067 \\ IF (1, EQ. 1) CO TO 4 & MA11067 \\ MA11106 & MA1106 \\ C & MA11112 \\ RMAX(1)=1.1 XXSTRT(1) & MA11112 \\ RMAX(1)=0.9 XXSTRT(1) & MA11112 \\ RMAX(1)=0.9 XXSTRT(1) & MA11136 \\ C & MA11106 & MA11167 \\ C & MA1112 \\ C & MA1112 \\ RMIN(1)=0.9 XXSTRT(1) & MA11136 \\ RMIN(1)=0.9 XXSTRT(1) & MA11136 \\ RMIN(1)=0.9 XXSTRT(1) & MA11146 \\ RMA1112 \\ REDUCE=.05 & MA11167 \\ REDUCE=.05 & MA11.120 \\ REDUCE=.05 & MA11.200 \\ C & ALL SDEKS(1N, RMAX, RMIN, NCONS, NEQUS, XSTRT, F, H, R, REDUCE, MAXM, INDEX, MA11246 \\ C & MA1122 \\ REDUCE=.05 & MA11.200 \\ C & MA1122 \\ MA1$		DO 4 $I=1$, NND	MAI1020
$ \begin{array}{c} \text{issTrT}(\mathbf{N}) = \mathrm{D1A}(\mathbf{I}) & \text{MAI} 1066 \\ \text{D0} & \mathbf{J} = 1, \mathrm{NDF} & \mathrm{MAI} 1066 \\ \text{IF}(\mathbf{X} \mathrm{D1A}(\mathbf{I}) . \mathrm{EQ} . \mathrm{XDF}(\mathbf{J})) \ \mathbf{N} = \mathbb{N} - 1 & \mathrm{MAI} 1066 \\ \text{IF}(\mathbf{X} \mathrm{D1A}(\mathbf{I}) . \mathrm{EQ} . \mathrm{XDF}(\mathbf{J})) \ \mathbf{N} = \mathbb{N} - 1 & \mathrm{MAI} 1066 \\ \text{IF}(\mathbf{D1A}(\mathbf{I}) . \mathrm{EQ} . \mathrm{D1A}(\mathbf{I} - 1)) \ \mathbf{N} = \mathbb{N} - 1 & \mathrm{MAI} 1066 \\ \text{IF}(\mathbf{D1A}(\mathbf{I}) . \mathrm{EQ} . \mathrm{D1A}(\mathbf{I} - 1)) \ \mathbf{N} = \mathbb{N} - 1 & \mathrm{MAI} 1066 \\ \text{IF}(\mathbf{D1A}(\mathbf{I}) . \mathrm{EQ} . \mathrm{D1A}(\mathbf{I} - 1)) \ \mathbf{N} = \mathbb{N} - 1 & \mathrm{MAI} 1066 \\ \text{C} & \mathrm{MAI} 1106 \\ \text{RMAX}(\mathbf{I}) = 1 . 1 \times \mathrm{MSTRT}(\mathbf{I}) & \mathrm{MAI} 1136 \\ \mathrm{RMM}(\mathbf{I}) = 0 & 9 \times \mathrm{MSTRT}(\mathbf{I}) & \mathrm{MAI} 1136 \\ \text{RMMAX}(\mathbf{I}) = 0 & 9 \times \mathrm{MSTRT}(\mathbf{I}) & \mathrm{MAI} 1136 \\ \text{C} & \mathrm{MAI} 1116 \\ \text{C} & \mathrm{MCONS} = 6 + \mathrm{NDI} & \mathrm{MAI} 1166 \\ \text{F} = . 02 & \mathrm{MAI} 1166 \\ \mathrm{H} = . 65 & \mathrm{MAI} 1166 \\ \mathrm{H} = . 65 & \mathrm{MAI} 1126 \\ \mathrm{REDUCE} = . 05 & \mathrm{MAI} 1126 \\ \mathrm{REDUCE} = . 05 & \mathrm{MAI} 1126 \\ \mathrm{CALL} \ \mathrm{SEEK3}(\mathbf{N}, \mathrm{RMAX}, \mathrm{RMIN}, \mathrm{NCONS}, \mathrm{NEQUS}, \mathrm{MSTRT}, \mathbf{F}, \mathbf{H}, \mathbf{R}, \mathrm{REDUCE}, \mathrm{MAXM}, \mathrm{INDEX}, \\ \text{CALL} \ \mathrm{ANSWER}(\mathbf{U}, \mathbf{X}, \mathrm{PHI}, \mathrm{PSI}, \mathrm{N} \mathrm{NOCNS}, \mathrm{NEQUS}, \mathrm{WORK3}, \mathrm{WORK3} & \mathrm{WORK3} & \mathrm{MAI} 1236 \\ \mathrm{CALL} \ \mathrm{ANSWER}(\mathbf{U}, \mathbf{X}, \mathrm{PHI}, \mathrm{PSI}, \mathrm{N} \mathrm{NOCNS}, \mathrm{NEQUS}, \mathrm{WORK3}, \mathrm{WORK3} & \mathrm{MAI} 1246 \\ \mathrm{WORKS}(\mathbf{I}) = \mathrm{DIA}(\mathbf{I}) & \mathrm{MAI} 126 \\ \mathrm{MAI} 1270 & \mathrm{MAI} 1270 \\ \mathrm{CALL} \ \mathrm{ANSWER}(\mathbf{U}, \mathrm{X}, \mathrm{PHI}, \mathrm{PSI}, \mathrm{N} \mathrm{NOCNS}, \mathrm{NEQUS} & \mathrm{WORK3} & \mathrm{WORK3} & \mathrm{MAI} 136 \\ \mathrm{C} & \mathrm{MAI} 10.1 \\ \mathrm{ND} = \mathrm{ND} - 1 & \mathrm{MAI} 10.1 \\ \mathrm{ND} = \mathrm{ND} - 1 & \mathrm{MAI} 10.1 \\ \mathrm{ND} = \mathrm{MAI} 10.1 \\ \mathrm$		N=N+1	MAI 1030
		XSTBT(N) = DIA(I)	MAT 1040
$ \begin{array}{c} \text{IF (XD IA(1).EQ.XDF(J)) } \mathbb{N}=\mathbb{N}-1 & \text{MA 1106C} \\ \text{IF (I,EQ.1) } CO TO 4 & \text{MA 1106C} \\ \text{IF (I,EQ.1) } CO TO 4 & \text{MA 1106C} \\ \text{IF (D IA(1).EQ.DIA(I-1)) } \mathbb{N}=\mathbb{N}-1 & \text{MA 1106C} \\ \text{C} & \text{MA 11106} \\ \text{C} & \text{MA 11106} \\ \text{C} & \text{MA 11106} \\ \text{D 0 5 } I=1,\mathbb{N} & \text{MA 1106} \\ \text{RMAX(1)=1.I*XSTRT(I) } & \text{MA 11136} \\ \text{RMAX(1)=1.I*XSTRT(I) } & \text{MA 11136} \\ \text{RMAX(1)=0.9*XSTRT(I) } & \text{MA 11136} \\ \text{C} & \text{MA 11116} \\ \text{RMAX(1)=0.9*XSTRT(I) } & \text{MA 11136} \\ \text{RMA 1116} \\ \text{REDUCE = .05 } & \text{MA 11126} \\ \text{MA 11220} \\ \text{CALL SEEK3(N, RMAX, RMIN, NCONS, NEQUS, XSTRT, F, H, R, REDUCE, MAXM, INDEX, \\ *IPRINT, IDATA, U, X, PHI, PSI, N, NIOL, WORK1, WORK2, WORK3, WORK4) & \text{MA 11236} \\ \\ \text{CALL ANSWER(U, X, PHI, PSI, N, NIOL, WORK1, WORK2, WORK3, WORK4) & \text{MA 11266} \\ \\ \text{C} & \text{CALL ANSWER(U, X, PHI, PSI, N, NCONS, NEQUS) } & \text{MA 11246} \\ \\ \text{NOTEND - 1 & \text{MA 11290} \\ \text{MA 11286} \\ \text{MO 10 I = 1-1, ND & \text{MA 1136} \\ \\ \text{ND 10 I I = 1, ND & \text{MA 1136} \\ \\ \text{D 10 I I = 1, ND & \text{MA 1136} \\ \\ \text{D 10 I I = 1, ND & \text{MA 1136} \\ \\ \text{D 10 I I = 1, ND & \text{MA 1136} \\ \\ \text{MA 1136} \\ \text{MA 1136} \\ \text{MA 1136} \\ \\ \text{MA 1136} \\ \text{MA 1136} \\ \text{MA 1136} \\ \\ \text{MA 1136} \\ \text{MA 1136} \\ \text{MA 1136} \\ \text{MA 1136} \\ \\ \text{MA 1136} \\ \text{MA 1136} \\ \text{MA 1136} \\ \\ \text{MA 1136} \\ \text{MA 1136} \\ \text{MA 1136} \\ \\ \text{MA 11440} \\ \text{MA 11440} \\ \\ \text{MA 11446} \\ \\ \end{array} \end{array}$		DO 3 LE1 NDF	MAI 1050
10 (100 m) (10 m) (10 m) (10 m) (10 m) m) (10 m) 3 CONTINUE Main (10 m) 4 CONTINUE Main (10 m) 6 C Main (10 m) 7 (10 m) Main (10 m) 8 CONTINUE Main (10 m) 9 (10 m) Sign (1 m) 9 (10 m) Sign (1 m) 9 (10 m) Sign (1 m) 10 (1 m) Main (1 m) 11 (1 m) Main (1 m) <td></td> <td>$I = \{V_{n} \mid A \in V_{n} \in \{1\}\}$ N=N-1</td> <td>MAI 1060</td>		$I = \{V_{n} \mid A \in V_{n} \in \{1\}\}$ N=N-1	MAI 1060
3 CONTINUE Mailed IF(DIA(1).EQ.DIA(I-1)) N=N-1 Mailed 4 CONTINUE Mailed 6 Mailed Mailed 7 Continue Mailed 8 Continue Mailed 8 Mailed Mailed 9 Ob 5 I=1, N Mailed 8 Mailed Mailed 9 CONTINUE Mailed 6 Mailed Mailed 7 Conselet Mailed 7 Mailed Mailed 8 Continue Mailed 8 Mailed Mailed 9 Continue Mailed 9 Dialed Mailed 9 Dialed Mailed 9 Dialed Mailed 9 Dialed Mailed 9 Mailed Mailed <tr< td=""><td>0</td><td></td><td>MAI 1070</td></tr<>	0		MAI 1070
$ \begin{array}{c} \text{IF(1,EQ,1) CU 10 4} & \text{MAI1090} \\ \text{IF(1,EQ,1) CU 10 4} & \text{MAI1100} \\ \text{C} & \text{MAI1110} \\ \text{C} & \text{MAI1110} \\ \text{C} & \text{MAI1110} \\ \text{RMAK(1)=1,1*XSTRT(1)} & \text{MAI1120} \\ \text{RMAK(1)=1,1*XSTRT(1)} & \text{MAI1120} \\ \text{RMAK(1)=0,9*XSTRT(1)} & \text{MAI1120} \\ \text{RMIN(1)=0,9*XSTRT(1)} & \text{MAI1140} \\ \text{C} & \text{MAI1116} \\ \text{F}=.05 & \text{MAI1116} \\ \text{F}=.05 & \text{MAI1120} \\ \text{REDUCE=.05} & \text{MAI1120} \\ \text{CALL SEEK3(N, RMAX, RMIN, NCONS, NEQUS, XSTRT, F, H, R, REDUCE, MAXM, INDEX, MAI1226 \\ \text{CALL SEEK3(N, RMAX, RMIN, NCONS, NEQUS, XSTRT, F, H, R, REDUCE, MAXM, INDEX, MAI1226 \\ \text{CALL ANSWERU, X, PHI, PSI, NVIOL, WORK1, WORK2, WORK3, WORK4)} & \text{MAI1226} \\ \text{CALL ANSWERU, X, PHI, PSI, N, NCONS, NEQUS)} & \text{MAI1226} \\ \text{C} & \text{MAI1226} \\ \text{C} & \text{MAI1210} \\ \text{MORSS(1)=DIA(1)} & \text{MAI1226} \\ \text{MAI1226} \\ \text{CONTINUE} & \text{MAI1340} \\ \text{MAI126} \\ \text{C} & \text{MAI1340} \\ \text{MAI127} \\ \text{MORSS(1)=DIA(1)} & \text{MAI1340} \\ \text{MAI1340} \\ \text{MAI1340} \\ \text{MAI1341} \\ \text{DIA(1)=2X(K)} & \text{MAI1340} \\ \text{MAI1340} \\ \text{MAI1340} \\ \text{CO TO 9} & \text{MAI1340} \\ \text{MAI1340} \\ \text{CO TO 9} \\ \text{B} \ DIA(1)=2X(K) & \text{MAI1340} \\ MAI$	3	UNITINGE	MALIORO
		IF(1.EQ.1) GO 10 4	MAT 1080
		IF(DIA(1), EQ, DIA(1-1)) N=N-1	MAI 1090
$ \begin{array}{c} C & MA11112 \\ D0 5 I=1, N & MA1112 \\ MMAX(I)=1.1*XSTRT(I) & MA1112 \\ MA1112 & MA1112 \\ RMMAX(I)=0.9*XSTRT(I) & MA1112 \\ \\ C & MA1112 & MA1113 \\ \\ C & MA1112 & MA1113 \\ \\ C & MA1112 & MA1113 \\ \\ C & MA1112 & MA1112 \\ \\ R=05 & MA1112 & MA1112 \\ \\ R=05 & MA1122 & MA1122 \\ \\ REDUCE=.05 & MA1122 \\ \\ CALL SEEX3(N, RMAX, RMIN, NCONS, NEQUS, XSTRT, F, H, R, REDUCE, MAXM, INDEX, MA11223 \\ \\ CALL SEEX3(N, RMAX, RMIN, NCONS, NEQUS, XSTRT, F, H, R, REDUCE, MAXM, INDEX, MA11223 \\ \\ CALL ANSWER(U, X, PHI, PSI, NVIOL, WORK1, WORK2, WORK3, WORK4) & MA1223 \\ \\ CALL ANSWER(U, X, PHI, PSI, N, NCONS, NEQUS) & MA1226 \\ \\ C & MA1122 \\ CALL ANSWER(U, X, PHI, PSI, N, NCONS, NEQUS) & MA123 \\ \\ C & MA1122 \\ \\ C & MA1122 \\ \\ TO & CONTINUE & MA1132 \\ \\ NND=ND-1 & MA1132 \\ \\ R=0 & MA1132 \\ \\ C & MA1132 \\ \\ NID=ND-1 & MA1132 \\ \\ R=0 & MA1132 \\ \\ D1A(I)=DIA(I) & MA13 \\ \\ C & MA1132 \\ \\ F(XDIA(I).EQ, XDF(J)) & CO TO 8 & MA1132 \\ \\ C & MA1132 \\ \\ P(XDIA(I).EQ, XDF(J)) & CO TO 8 & MA1132 \\ \\ P(XDIA(I)=DIA(J) & MA1134 \\ \\ \\ (F(I, EQ, I) CO TO 10 & MA1134 \\ \\ (F(I, EQ, I) CO TO 10 & MA1142 \\ \\ P(WORKS(I).EQ, WORKS(I-1)) & CO TO 90 & MA1144 \\ \\ \\ (P & CONTINUE & MA1144 \\ \\ P(WORKS(I).EQ, WORKS(I-1)) & CO TO 90 & MA1144 \\ \\ P(WORKS(I).EQ, WORKS(I-1)) & CO TO 90 & MA1144 \\ \\ P(WORKS(I).EQ, WORKS(I-1)) & CO TO 90 & MA1144 \\ \\ P(WORKS(I).EQ, WORKS(I-1)) & CO TO 90 & MA1144 \\ \\ P(WORKS(I).EQ, WORKS(I-1)) & CO TO 90 & MA1144 \\ \\ P(WORKS(I).EQ, WORKS(I-1)) & CO TO 90 & MA1144 \\ \\ P(WORKS(I).EQ, WORKS(I-1)) & CO TO 90 & MA1144 \\ \\ P(WORKS(I).EQ, WORKS(I-1)) & CO TO 90 & MA1144 \\ \\ P(WORKS(I).EQ, WORKS(I-1)) & CO TO 90 & MA1144 \\ \\ P(WORKS(I).EQ, WORKS(I-1)) & CO TO 90 & MA1144 \\ \\ P(WORKS(I).EQ, WORKS(I-1)) & CO TO 90 & MA1144 \\ \\ P(WORKS(I).EQ, WORKS(I-1)) & CO TO 90 & MA1144 \\ \\ P(WORKS(I).EQ, WORKS(I-1)) & CO TO 90 & MA1144 \\ \\ P(WORKS(I).EQ, WORKS(I-1)) & CO TO 90 & MA1144 \\ \\ P(WORKS(I).EQ, WORKS(I-1)) & CO TO 90 & MA1144 \\ \\ P(WORKS(I).EQ, WORKS(I-1)) & CO TO 90 & MA1144 \\ \\ P(WORKS(I).EQ, WORKS(I-1)) & MA1144 \\ \\ P(WORKS(I).EQ, WORKS(I-1)) $	4	CONTINUE	MAI1100
$ \begin{array}{c} \text{D0 5 1=1,N} & \text{MAI 1126} \\ \text{RMAX(1)=1.1xxSTRT(1)} & \text{MAI 1136} \\ \text{RMIN(1)=0.9*XSTRT(1)} & \text{MAI 1146} \\ \text{C} & \text{MAI 1166} \\ \text{C} & \text{MAI 1166} \\ \text{C} & \text{MAI 1166} \\ \text{F}=.02 & \text{MAI 1166} \\ \text{H}=.05 & \text{MAI 1166} \\ \text{REDUCE}=.05 & \text{MAI 1122} \\ \text{REDUCE}=.05 & \text{MAI 1122} \\ \text{CALL SEEK3(N, RMAX, RMIN, NCONS, NEQUS, XSTRT, F, H, R, REDUCE, MAXM, INDEX, MAI 1236 \\ \text{CALL ANSWER(U, X, PHI, PSI, NVIOL, WORK1, WORK2, WORK3, WORK4)} & \text{MAI 1236} \\ \text{CALL ANSWER(U, X, PHI, PSI, NVIOL, WORK1, WORK2, WORK3, WORK4)} & \text{MAI 1236} \\ \text{CALL ANSWER(U, X, PHI, PSI, N, NCONS, NEQUS)} & \text{MAI 1236} \\ \text{CONTINUE} & \text{MAI 1236} \\ \text{WORKS(1)=DIA(1)} & \text{MAI 1236} \\ \text{WORKS(1)=DIA(1)} & \text{MAI 1236} \\ \text{MAI 1236} \\ \text{D0 70 I=1,ND} & \text{MAI 1236} \\ \text{MOR 1310} \\ \text{C} & \text{MAI 1336} \\ \text{D0 10 I=1,NND} & \text{MAI 1336} \\ \text{D0 10 I=1,NND} & \text{MAI 1336} \\ \text{D1A(1)=DIA(1)} & \text{CO TO B} & \text{MAI 1336} \\ \text{MAI 1336} \\ \text{MAI 1336} \\ \text{MAI 1336} \\ \text{MAI 1346} \\ \text{MAI 1346} \\ \text{MAI 1346} \\ \text{C} & \text{MAI 1346} \\ \\ \text{MAI 1346} \\ \text{MAI 1346} \\ \\ \text{MAI 1346} \\ \\ \text{MAI 1346} \\ \text{MAI 1346} \\ \\ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ $	C		MAI1110
$ \begin{array}{c} \operatorname{RMAX}(1) = 1. \ 1 \ 2 \ 3 \ 2 \ 3 \ 3 \ 3 \ 3 \ 3 \ 3 \ 3$		DO 5 I=1,N	MAI1120
$ \begin{array}{c} \mathrm{RHIN}(1) = 0.9 * \mathrm{XSTRT}(1) & \mathrm{IMI1145} \\ 5 & \mathrm{CONTINUE} & \mathrm{IMI1156} \\ \mathrm{IMI1166} & \mathrm{IMI1166} \\ \mathrm{NCONS=6+NDI} & \mathrm{IMI11166} \\ \mathrm{INOEX=6+NDI} & \mathrm{IMI11120} \\ \mathrm{IIIOEX=1} & \mathrm{IMI1120} \\ \mathrm{H=.65} & \mathrm{IMI1120} \\ \mathrm{IINDEX=1} & \mathrm{IMI1220} \\ \mathrm{REDUCE=.05} & \mathrm{IMI1230} \\ \mathrm{CALL} & \mathrm{SEK3(N, RMAX, RMIN, NCONS, NEQUS, \mathrm{XSTRT}, F, H, R, REDUCE, MAXM, INDEX, \\ \mathrm{CALL} & \mathrm{ANSWERU}, \mathrm{X, PHI, PSI, N, VIOL, WORK1, WORK2, WORK3, WORK4) & \mathrm{IMI1226} \\ \mathrm{CALL} & \mathrm{ANSWERU}, \mathrm{X, PHI, PSI, N, NCONS, NEQUS) & \mathrm{IMI1226} \\ \mathrm{CALL} & \mathrm{ANSWERU}, \mathrm{X, PHI, PSI, N, NCONS, NEQUS) & \mathrm{IMI1226} \\ \mathrm{CALL} & \mathrm{ANSWERU}, \mathrm{X, PHI, PSI, N, NCONS, NEQUS) & \mathrm{IMI1226} \\ \mathrm{CALL} & \mathrm{ANSWERU}, \mathrm{X, PHI, PSI, N, NCONS, NEQUS) & \mathrm{IMI1226} \\ \mathrm{CALL} & \mathrm{ANSWERU}, \mathrm{X, PHI, PSI, N, NCONS, NEQUS) & \mathrm{IMI1226} \\ \mathrm{CALL} & \mathrm{ANSWERU}, \mathrm{I}, \mathrm{IDIA(I)} & \mathrm{IMI1226} \\ \mathrm{CALL} & \mathrm{ANSWERU}, \mathrm{I}, \mathrm{IDIA(I)} & \mathrm{IMI1226} \\ \mathrm{IMI1226} & \mathrm{IMI1226} \\ \mathrm{IMI1226} & \mathrm{IMI1226} \\ \mathrm{COTTINUE} & \mathrm{IMI1226} \\ \mathrm{COTTINUE} & \mathrm{IMI1326} \\ \mathrm{IMI1226} & \mathrm{IMI1326} \\ \mathrm{IMI1226} & \mathrm{IMI1326} \\ \mathrm{IMI1226} & \mathrm{IMI1326} \\ \mathrm{IMI1226} & \mathrm{IMI1326} \\ \mathrm{IMI1326} \\ \mathrm{IMI1226} & \mathrm{IMI1326} \\ $		$RMAX(I) = 1.1 \times XSTRT(I)$	MAI1130
5 CONTINUE MA11156 C MA11167 NCONS=6+NDI MA11167 C MA11167 C MA11167 C MA11167 C MA11167 C MA11167 C MA11120 H=.05 MA11200 INDEX=1 MA11220 REDUCE=.05 MA11230 CALL SEEK3(N, RMAX, RMIN, NCONS, NEQUS, XSTRT, F, H, R, REDUCE, MAXM, INDEX, MA11230 CALL ANSWER(U, X, PHI, PSI, NVIOL, WORK1, WORK2, WORK3, WORK4) MA11230 CALL ANSWER(U, X, PHI, PSI, N, NCONS, NEQUS) MA11260 C CONTINUE MA11200 C MA11200 MA11200 WORKS(I)=DIA(I) MA11200 MA11200 C MA11200 MA11300 C MA11300 MA11300 C MA11300 MA11330		$RMIN(I) = 0.9 \times XSTRT(I)$	MAI1140
C MAI 1166 MAI 1167 C MAI 1166 F=.02 MAI 1196 H=.65 MAI 1120 INDEX=1 MAI 1220 REDUCE=.05 MAI 1220 CALL SEEK3(N, RMAX, RMIN, NCONS, NEQUS, XSTRT, F, H, R, REDUCE, MAXM, INDEX, *IPRINT, IDATA, U, X, PHI, PSI, NVIOL, WORK1, WORK2, WORK3, WORK4) MAI 1226 CALL ANSWER(U, X, PHI, PSI, N, NCONS, NEQUS) MAI 1226 CALL ANSWER(U, X, PHI, PSI, N, NCONS, NEQUS) MAI 1226 CALL ANSWER(U, X, PHI, PSI, N, NCONS, NEQUS) MAI 1226 C MAI 1226 CALL ANSWER(U, X, PHI, PSI, N, NCONS, NEQUS) MAI 1226 C MAI 1226 VORKS(I) = DIA(I) MAI 1226 VORKS(I) = DIA(I) MAI 1226 C MAI 1226 S MAI 1226 MAI 1326 MAI 1326 D 10 I = 1, NND MAI 1326 MAI 1326 MAI 1326 <tr< td=""><td>5</td><td>CONTINUE</td><td>MAI1150</td></tr<>	5	CONTINUE	MAI1150
NCONS=6+NDI MAII170 C MAII170 F=.02 MAII170 H=.05 MAI1120 INDEX=1 MAI1210 R=1. MAI1220 REDUCE=.05 MAI1220 CALL SEEK3(N, RMAX, RMIN, NCONS, NEQUS, XSTRT, F, H, R, REDUCE, MAXM, INDEX, MAI1220 REDUCE=.05 MAI1220 CALL ANSWER(U, X, PHI, PSI, NVIOL, WORK1, WORK2, WORK3, WORK4) MAI1220 C MAI1220 COTO I=1, ND MAI1220 WORKS(I)=DIA(I) MAI1220 70 CONTINUE MAI1280 WORD=ND-1 MAI1330 K=0 MAI1330 D0 10 I=1, NND MAI1330 K=4 MAI1330 D0 10 J=1, NDF MAI1330 K=8 MAI1330 B IA(I)=X(K) MAI1330 MAI1330 MAI1330 MAI1340 MAI1340	C		MAT1160
C MAIN OF NOT C $F = .02$ (MAI1186 H= .05 (MAI1200 INDEX=1 (MAI1200 INDEX=1 (MAI1200 INDEX=1 (MAI1220 R=1. (MAI1220 CALL SEEK3(N, RMAX, RMIN, NCONS, NEQUS, XSTRT, F, H, R, REDUCE, MAXM, INDEX, (MAI1230 CALL ANSWER(U, X, PHI, PSI, NVIOL, WORK1, WORK2, WORK3, WORK4) (MAI1230 C (MAI1220 C (MAI1220 D 70 I=1, ND (MAI1220 WORKS(I)=DIA(I) (MAI1220 70 CONTINUE (MAI1220 (MAI1220 70 CONTINUE (MAI1220 70 CONTINUE (MAI220 70 CONTINUE (MAI220 70 CONTIN	4	NCONS=6+NDI	MAT1170
$ \begin{array}{c} & & & & & & & & & & & & & & & & & & &$	C		MAT1180
$ \begin{array}{c} 1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 &$	u	F- 02	MAT1100
$ \begin{array}{c} 10^{-0.05} & \text{IMA 11216} \\ \text{INDEX=1} & \text{MA 11216} \\ \text{REDUCE=.05} & \text{MA 11226} \\ \text{REDUCE=.05} & \text{MA 11236} \\ \text{CALL SEEK3(N, RMAX, RMIN, NCONS, NEQUS, XSTRT, F, H, R, REDUCE, MAXM, INDEX, MA 11236} \\ \text{CALL ANSWER(U, X, PHI, PSI, N, NCONS, NEQUS)} & \text{MA 11236} \\ \text{CALL ANSWER(U, X, PHI, PSI, N, NCONS, NEQUS)} & \text{MA 11236} \\ \text{CALL ANSWER(U, X, PHI, PSI, N, NCONS, NEQUS)} & \text{MA 11236} \\ \text{CALL ANSWER(U, X, PHI, PSI, N, NCONS, NEQUS)} & \text{MA 11236} \\ \text{CALL ANSWER(U, X, PHI, PSI, N, NCONS, NEQUS)} & \text{MA 11236} \\ \text{CALL ANSWER(U, X, PHI, PSI, N, NCONS, NEQUS)} & \text{MA 11236} \\ \text{CALL ANSWER(U, X, PHI, PSI, N, NCONS, NEQUS)} & \text{MA 11236} \\ \text{CALL ANSWER(U, X, PHI, PSI, N, NCONS, NEQUS)} & \text{MA 11236} \\ \text{CALL ANSWER(U, X, PHI, PSI, N, NCONS, NEQUS)} & \text{MA 11236} \\ \text{CONTINUE} & \text{MA 11386} \\ \text{WORKS(1)=DIA(I)} & \text{MA 11366} \\ \text{WORKS(1)=DIA(I)} & \text{MA 11336} \\ \text{MA 11336} \\ \text{MOD=ND-1} & \text{MA 11336} \\ \text{MA 11366} \\ \text{D0 10 I=1, NND} & \text{MA 11366} \\ \text{D0 10 I=1, NND} & \text{MA 11366} \\ \text{D1A(I)=X(K)} & \text{MA 11366} \\ \text{CO TO 9} & \text{MA 11366} \\ \text{CO TO 19} & \text{MA 11366} \\ \text{MA 11426} \\ \text{IF((XDIA(I)).EQ. XDF(J)) CO TO 8} & \text{MA 11366} \\ \text{IF(WORKS(I).EQ. WORKS(I-1)) CO TO 90} & \text{MA 11426} \\ \text{IF(WORKS(I).EQ. WORKS(I-1)) CO TO 90} & \text{MA 11426} \\ \text{MA 11426} \\ \text{GO TO 10} & \text{MA 11426} \\ M$			MAT 1200
INDEA-1 MAI1220 R=1. MAI1230 CALL SEEK3(N, RMAX, RMIN, NCONS, NEQUS, XSTRT, F, H, R, REDUCE, MAXM, INDEX, MAI1230 CALL ANSWER(U, X, PHI, PSI, NVIOL, WORK1, WORK2, WORK3, WORK4) MAI1220 CALL ANSWER(U, X, PHI, PSI, N, NCONS, NEQUS) MAI1220 C MAI1220 CONTINUE MAI1220 WORKS(I)=DIA(I) MAI1220 70 CONTINUE MAI1220 C MAI1320 C MAI1320 C MAI1320 C MAI1320 C MAI1320 S MAI1320 D0 10 I=1,NDF MAI1320 D1A(I)=X(K) MAI1320 D1A(I)=DF(J) MAI1320 K=K-1 MAI14400			MAT 1210
$\begin{array}{cccc} & & & & & & & & & & & & & & & & & $		INDEX-1	MAI 1210
REDUCE ² .05 MAI 1236 CALL SEEK3(N, RMAX, RMIN, NCONS, NEQUS, XSTRT, F, H, R, REDUCE, MAXM, INDEX, MAI 1236 * IPRINT, IDATA, U, X, PHI, PSI, NVIOL, WORK1, WORK2, WORK3, WORK4) MAI 1256 CALL ANSWER(U, X, PHI, PSI, N, NCONS, NEQUS) MAI 1256 C MAI 1226 CALL SEEK3(N, RMAX, RMIN, NCONS, NEQUS) MAI 1256 C MAI 1226 DO 70 I=1, ND MAI 1226 WORKS(I)=DIA(I) MAI 1236 70 CONTINUE MAI 1236 C MAI 1236 WORKS(I)=DIA(I) MAI 1236 70 CONTINUE MAI 1236 C MAI 1336 D 10 I=1,NDD MAI 1336 C K=0 MAI 1336 D 14(I)=X(K) MAI 1336 D 14(I)=K(K) MAI 1366 B DIA(I)=DF(J) MAI 1446 K=-1 MAI 1436 90 DIA(I)=DIA(I-1) K=K-1 MAI 1446 90		R= 1.	MAI 1220
$\begin{array}{c} CALL SEEK3(N, RMAX, RMIN, NCONS, NEGUS, XSTRT, F, H, R, REDUCE, MAXM, INDEX, MAI 1236 $		REDUCE=.05	MAI 1230
$\begin{array}{c} * 1PRINT, 1DATA, U, X, PHI, PSI, NVIOL, WORK1, WORK2, WORK3, WORK4) & MA11256 \\ CALL ANSWER(U, X, PHI, PSI, N, NCONS, NEQUS) & MA11276 \\ MAI 1226 \\ MAI 1226 \\ WORKS(1) = DIA(I) & MA11286 \\ WORKS(1) = DIA(I) & MA11396 \\ C & MAI 1396 \\ DO 10 I = 1, NND & MA11326 \\ K = 0 & MA11326 \\ DIA(I) = X(K) & MA11326 \\ DIA(I) = X(K) & MA11356 \\ DO 9 J = 1, NDF & MA11356 \\ DIA(I) = DF(J) & MA11366 \\ C & MAI 1396 \\ (F \times K^{-1} & MA11366 \\ IF((I, EQ, I) CO TO 10 & MA11426 \\ IF(I, EQ, I) CO TO 10 & MA11426 \\ IF(I, EQ, I) CO TO 10 & MA11426 \\ OD DIA(I) = DIA(I^{-1}) & MAI 1456 \\ OD O IA(I) = DIA(I^{-1}) & MAI 1456 \\ MAI 1446 \\ (F \times K^{-1} & MA11426 \\ (F \times K^{-1} & MA11446 \\ (F \times K^$		CALL SEEK3(N, RMAX, RMIN, NCONS, NEQUS, XSTRT, F, H, R, REDUCE, MAXM, INDEX,	MA11240
CALL ANSWER(U, X, PHI, PSI, N, NCONS, NEQUS) MAI 1260 MAI 1270 MAI 1280 D0 70 I=1, ND MAI 1290 WORKS(I)=DIA(I) MAI 1290 70 CONTINUE MAI 1300 C MAI 1320 K=0 MAI 1320 D0 10 I=1,ND MAI 1320 D0 10 I=1,ND MAI 1320 K=4 MAI 1320 D0 10 I=1,NDF MAI 1320 D1A(I)=X(K) MAI 1330 B DIA(I)=DF(J) CO TO 8 K=K-1 MAI 1380 G O TO 9 MAI 1380 B DIA(I)=DF(J) MAI 1400 K=K-1 MAI 1420 IF(I.EQ.1) CO TO 10 MAI 1420 IF(I.EQ.1) CO TO 10 MAI 1420 IF(VORKS(I).EQ.WORKS(I-1)) CO TO 90 MAI 1420 O DIA(I)=DIA(I-1) MAI 1420 Y MAI 14400 HAI 14400 MAI 14400 HAI 14400 MAI 14400		* IPRINT, IDATA, U, X, PHI, PSI, NVIOL, WORK1, WORK2, WORK3, WORK4)	MAI 1250
C MAI12270 D0 70 I=1, ND MAI1280 WORKS(I)=DIA(I) MAI1280 70 CONTINUE MAI1290 C MAI1320 D0 10 I=1,ND MAI1320 K=0 MAI1320 D0 10 I=1,NDF MAI1320 K=K+1 MAI1320 D1A(I)=X(K) MAI1320 D0 9 J=1,NDF MAI1320 IF(XDIA(I).EQ.XDF(J)) CO TO 8 MAI1320 GO TO 9 MAI1320 8 DIA(I)=DF(J) K=K-1 MAI14400 9 CONTINUE IF(WORKS(I).EQ.WORKS(I-1)) CO TO 90 MAI1420 IF(WORKS(I).EQ.WORKS(I-1)) CO TO 90 MAI14400 MAI14400 MAI4420 IF(WORKS(I).EQ.WORKS(I-1)) CO TO 90 MAI14400 MAI14400 MAI4400 IF(WORKS(I).EQ.WORKS(I-1)) CO TO 90 MAI14400 MAI4400		CALL ANSWER(U,X,PHI,PSI,N,NCONS,NEQUS)	MAI 1260
$ \begin{array}{c} \text{DO 70 I=1, ND} & \text{MAI 1286} \\ \text{WORKS(I)=DIA(I)} & \text{MAI 1296} \\ \text{WORKS(I)=DIA(I)} & \text{MAI 1306} \\ \text{C} & \text{MAI 1306} \\ \text{C} & \text{MAI 1326} \\ \text{MAI 1326} \\ \text{MAI 1326} \\ \text{DO 10 I=1, NND} & \text{MAI 1326} \\ \text{K=60} & \text{MAI 1336} \\ \text{DO 10 I=1, NND} & \text{MAI 1326} \\ \text{K=K+1} & \text{MAI 1356} \\ \text{DI A(I)=X(K)} & \text{MAI 1366} \\ \text{DO 9 J=1, NDF} & \text{MAI 1366} \\ \text{DO 9 J=1, NDF} & \text{MAI 1376} \\ \text{IF}(XDIA(I).EQ.XDF(J)) & \text{CO TO 8} & \text{MAI 1386} \\ \text{GO TO 9} & \text{MAI 1386} \\ \text{GO TO 9} & \text{MAI 1366} \\ \text{MAI 1386} \\ \text{GO TO 9} & \text{MAI 1366} \\ \text{MAI 14406} \\ \text{K=K-1} & \text{MAI 1446} \\ \text{MAI 1446} \\ \text{IF}(WORKS(I).EQ.WORKS(I-1)) & \text{CO TO 90} & \text{MAI 1446} \\ \text{O D IA(I)=DIA(I-1)} & \text{MAI 1466} \\ \text{MAI 1446} \\ \text{MAI 1446} \\ \text{IO CONTINUE} & \text{MAI 1446} \\ \end{array}$	C		MAI 1270
WORKS(I) = DIA(I) MAI 1290 70 CONTINUE MAI 1300 C MAI 1310 NND=ND-1 MAI 1320 K=0 MAI 1320 D0 10 I=1,NND MAI 1320 K=K+1 MAI 1320 DIA(I)=X(K) MAI 1330 DIA(I)=X(K) MAI 1360 D0 9 J=1,NDF MAI 1360 IF(XDIA(I).EQ.XDF(J)) CO TO 8 MAI 1380 GO TO 9 MAI 1380 B DIA(I)=DF(J) MAI 1380 K=K-1 MAI 1400 VEKS(I).EQ.WORKS(I-1)) CO TO 90 MAI 1420 IF(WORKS(I).EQ.WORKS(I-1)) CO TO 90 MAI 1440 90 DIA(I)=DIA(I-1) MAI 1450 K=K-1 MAI 1440 VEKS(I).EQ.WORKS(I-1) MAI 1440 VEKS(I).EQ.WORKS(I-1) MAI 1440 MAI 14400 MAI 1440 IF(WORKS(I).EQ.WORKS(I-1)) MAI 1440 MAI 14400 MAI 1440 IF(WORKS(I).EQ.WORKS(I-1)) MAI 1440 MAI 14400 MAI 1440 IF(WORKS(I).EQ.WORKS(I-1)) MAI 1440 MAI 14400 MAI 1440 MAI 14400		DO 70 I=1,ND	MAI1280
70 CONTINUE MAI 1300 C MAI 1310 NND=ND-1 MAI 1320 K=0 MAI 1320 D0 10 I=1,NND MAI 1320 D0 10 I=1,NND MAI 1320 K=K+1 MAI 1340 MAI 1340 D0 9 J=1,NDF MAI 1360 B DIA(I)=X(K) MAI 1360 MAI 1360 B DIA(I)=DF(J) MAI 1380 MAI 1380 K=K-1 MAI 1440 MAI 1440 GO TO 9 MAI 1440 MAI 1440 GO TO 10 MAI 14400 MAI 14400		WORKS(I) = DIA(I)	MAI1290
C MAI 1310 NND=ND-1 MAI 1320 K=0 MAI 1330 D0 10 I=1,NND MAI 1330 K=K+1 MAI 1360 DIA(I)=X(K) MAI 1360 D0 9 J=1,NDF MAI 1360 IF(XDIA(I).EQ.XDF(J)) CO TO 8 MAI 1380 GO TO 9 MAI 1380 8 DIA(I)=DF(J) MAI 1390 K=K-1 MAI 1400 Y CONTINUE IF(VORKS(I).EQ.WORKS(I-1)) CO TO 90 MAI 1440 GO TO 10 MAI 1440 Y MAI 1440 MAI 1440 MAI 1440 MAI 1440 MAI 1440 Y MAI 1440 Y MAI 1440 Y MAI 1440 MAI 1440 MAI 1440 Y MAI 1440 Y MAI 1440 </td <td>70</td> <td>CONTINUE</td> <td>MAI1300</td>	70	CONTINUE	MAI1300
NND=ND-1 MAI 1320 K=0 MAI 1330 D0 10 I=1,NND MAI 1340 K=K+1 MAI 1360 DIA(I)=X(K) MAI 1360 DO 9 J=1,NDF MAI 1360 IF(XDIA(I).EQ.XDF(J)) CO TO 8 MAI 1380 GO TO 9 MAI 1380 8 DIA(I)=DF(J) MAI 1380 K=K-1 MAI 1440 9 CONTINUE MAI 1440 IF(I.EQ.1) CO TO 10 MAI 1420 IF(WORKS(I).EQ.WORKS(I-1)) CO TO 90 MAI 1440 90 DIA(I)=DIA(I-1) MAI 1440 K=K-1 MAI 1440 10 CONTINUE MAI 1480	C		MAI 1310
K=0 MAI 1336 $K=0$ MAI 1336 $D0 10 I=1, NND$ MAI 1346 $K=K+1$ MAI 1356 $DIA(I)=X(K)$ MAI 1366 $D0 9 J=1, NDF$ MAI 1366 $D0 9 J=1, NDF$ MAI 1386 $G0 T0 9$ MAI 1446 $K=K-1$ MAI 1426 $IF(I, EQ, 1) CO TO 10$ MAI 1426 $IF(WORKS(I), EQ, WORKS(I-1)) GO TO 90$ MAI 1446 $G0 T0 10$ MAI 1446 $F=K-1$ MAI 1466 $MAI 1446$ MAI 1466 $K=K-1$ MAI 1486 $10 CONTINUE$ MAI 1486	4	NND=ND-1	MAT1320
BO IO $I=1, NND$ MAI $II346$ BO IO $I=1, NDF$ MAI $II356$ DO 9 $J=1, NDF$ MAI $II366$ BO $IO(I) = DF(J)$ MAI MII $II366$ BO $IO(I) = DF(J)$ $MAII$ $MAII$ $II396$ $K=K-1$ $MAII406$ $MAII426$ $MAII426$ $IF(WORKS(I)) = DIA(I-1)$ IO $II41426$ $MAII4466$ GO IO $IIA(I) = DIA(I-1)$ $MAII4466$ $MAII4466$ $MAII4466$ $MAII44666$ IO $IIAII46666$ $MAII446666666666666666666666666666666666$			MAT 1330
K = K + 1 MAI 1356 $D IA(I) = X(K)$ MAI 1366 $D 0 9 J = 1, NDF$ MAI 1366 $IF(XD IA(I) . EQ. XDF(J))$ CO TO 8 MAI 1386 $GO TO 9$ MAI 1386 MAI 1386 $S DIA(I) = DF(J)$ MAI 1396 $K = K - 1$ MAI 1406 $Y = CONTINUE$ MAI 1446 $IF(VORKS(I) . EQ. WORKS(I-1))$ GO TO 90 $IIA(I) = DIA(I-1)$ MAI 1446 $Y = K - 1$ MAI 1446 $Y = K - 1$ MAI 1446 $Y = M IA(I) = DIA(I-1)$ MAI 1446 $K = K - 1$ MAI 1446 $Y = M IA(I) = DIA(I-1)$ MAI 1446 $M IA(I) = DIA(I) = DIA(I)$ MAI 1446		DO 10 I-1 NND	MAT 1940
K-K+1 MAI 1350 DIA(I) = X(K) MAI 1360 DO 9 J=1, NDF MAI 1360 IF(XDIA(I).EQ.XDF(J)) CO TO 8 MAI 1380 GO TO 9 MAI 1390 8 DIA(I) = DF(J) MAI 1400 K=K-1 MAI 1440 9 CONTINUE MAI 1420 IF(I.EQ.1) CO TO 10 MAI 1420 IF(WORKS(I).EQ.WORKS(I-1)) CO TO 90 MAI 1440 GO TO 10 MAI 1440 IF(WORKS(I).EQ.WORKS(I-1)) CO TO 90 MAI 1440 IF(VORKS(I).EQ.WORKS(I-1)) MAI 1440 IF(VORKS(I).EQ.WORKS(I-1)) MAI 1440 IF(VORKS(I).EQ.WORKS(I-1)) MAI 1440 IF(VORKS(I).EQ.WORKS(I-1)) MAI 1440 <t< td=""><td></td><td></td><td>MAT 1950</td></t<>			MAT 1950
$DIA(1) = X(K)$ $MAI1356$ $DO \ 9 \ J=1, NDF$ $MAI1376$ $IF(XDIA(1) = EQ, XDF(J))$ $CO \ TO \ 8$ $MAI1386$ $GO \ TO \ 9$ $MAI1386$ $B \ DIA(1) = DF(J)$ $MAI1386$ $K=K-1$ $MAI1386$ $9 \ CONTINUE$ $MAI14466$ $IF(I, EQ, 1) \ CO \ TO \ 10$ $MAI1426$ $IF(WORKS(1), EQ, WORKS(I-1)) \ CO \ TO \ 90$ $MAI14466$ $90 \ DIA(1) = DIA(1-1)$ $MAI14666$ $K=K-1$ $MAI14666$ $I0 \ CONTINUE$ $MAI14866$		K = KT I	MAT 1000
BO 9 $J = 1, NDF$ $MA I 1376$ $IF(XDIA(I) . EQ. XDF(J))$ CO $MA I 1386$ GO TO $MA I 1386$ BO $DIA(I) = DF(J)$ $MA I 1406$ $K = K - 1$ $MA I 1426$ 9 $CONTINUE$ $MA I 1426$ $IF(I) = DIA(I)$ CO $MA I 1426$ $IF(WORKS(I)) . EQ. WORKS(I-1))$ CO $MA I 14466$ O $DIA(I) = DIA(I-1)$ $MA I 1466$ $K = K - 1$ $MA I 1466$ IO $CONTINUE$ $MA I 1466$ $MA I 14466$ $MA I I 4466$ $MA I I 4466$ $MA I I 44666$ $MA I I 46666$ <td></td> <td>DTA(T) = X(K)</td> <td>MAT 1070</td>		DTA(T) = X(K)	MAT 1070
IF (XDIA(1), EQ. XDF(J)) GO TO 8 MAI 1386 GO TO 9 MAI 1396 8 DIA(1) = DF(J) MAI 1416 $K=K-1$ MAI 1426 9 CONTINUE MAI 1426 IF(URKS(1), EQ. WORKS(I-1)) GO TO 90 MAI 1446 90 DIA(1) = DIA(1-1) MAI 1466 K=K-1 MAI 1466 10 CONTINUE MAI 1486		DO 9 J=1,NDF	MAI 1370
GO TO 9 MAI1396 8 DIA(I)=DF(J) MAI1406 $K=K-1$ MAI1416 9 CONTINUE MAI1426 IF(I.EQ.1) CO TO 10 MAI1426 IF(WORKS(I).EQ.WORKS(I-1)) CO TO 90 MAI1446 0 DIA(I)=DIA(I-1) K=K-1 MAI1466 10 CONTINUE		IF(XDIA(I),EQ,XDF(J)) GO TO B	MAT1380
8 $DIA(I) = DF(J)$ MAI1400 K=K-1 MAI1410 9 CONTINUE MAI1420 IF(I.EQ.1) CO TO 10 MAI1430 IF(WORKS(I).EQ.WORKS(I-1)) CO TO 90 MAI1440 GO TO 10 MAI1440 90 DIA(I)=DIA(I-1) MAI1460 K=K-1 MAI1460 10 CONTINUE MAI1480		GO TO 9	MA11390
K=K-1 MAI1410 9 CONTINUE MAI1420 $IF(I, EQ, 1)$ CO TO 10 MAI1420 $IF(WORKS(I), EQ, WORKS(I-1))$ CO TO 90 MAI1440 CO TO 10 MAI1440 MAI1440 90 DIA(I)=DIA(I-1) MAI1460 K=K-1 MAI1470 10 CONTINUE MAI1480	8	DIA(I) = DF(J)	MAI1400
9 CONTINUE MAI1420 1F(1.EQ.1) CO TO 10 1F(WORKS(1).EQ.WORKS(1-1)) CO TO 90 0 DIA(1)=DIA(1-1) MAI1450 K=K-1 MAI1470 10 CONTINUE MAI1480		K= K- 1	MAI1410
IF(I.EQ.1) CO TO 10 MAI1430 IF(WORKS(I).EQ.WORKS(I-1)) CO TO 90 MAI1440 CO TO 10 MAI1440 90 DIA(I)=DIA(I-1) MAI1450 K=K-1 MAI1470 10 CONTINUE MAI1480	9	CONTINUE	MAI1420
IF (WORKS(I).EQ.WORKS(I-1)) CO TO 90 MAI 1440 GO TO 10 MAI 1450 90 DIA(I)=DIA(I-1) MAI 1460 K=K-1 MAI 1470 10 CONTINUE MAI 1480		IF(I, EQ, 1) GO TO 10	MAI1430
CO TO 10 MAI1450 90 DIA(I)=DIA(I-1) K=K-1 MAI1460 10 CONTINUE		IF(WOBKS(I), EQ, WOBKS(I-1)) GO TO 90	MAI 1440
90 DIA(I)=DIA(I-1) MAI1460 K=K-1 MAI1470 10 CONTINUE MAI1480			MAI 1450
K=K-1 MAI 1470 10 CONTINUE	90		MAT1460
10 CONTINUE MAI 1470	90	$\mathcal{D}_{\mathbf{T}}(\mathbf{x}_{1}) = \mathcal{D}_{\mathbf{T}}(\mathbf{x}_{1}) = \mathcal{D}_{\mathbf{T}}(\mathbf{x}_{1})$	MA I 1470
	10		MATIADA
	10	CONTINUE	THI 1400

	DIA(ND) = DIA(ND-1)	MAI1490
C		MAI1500
	CALL STRESS(E, G, N00, ND, N1, N2, N3, A, B, RA, RB, $XDIA$, DIA , XR , $X2$,	MAI1519
	*D2, PW2, PV2, PH2, BMW, BMV, BMH, BM, DFLW, DFLV, DFLH, DFL, SLW, SLV, SLH, SL,	MAI1520
	*STRW, STRV, STRH, STR, RPMCR, SCB, SCT, SCF2, RAD2, STRINT, TM2, TETA, TAU,	MAI1530
	*TAUINT, STR1, SIGMA1,	MAI1540
	* WORKA, WORKE, WORKC, WORKE, WORKE, WORKE, WORKE, WORKE, 1)	MAI 1550
C	,	MAI 1560
	CALL SHAFTP(XDIA, DIA, BD, A, ND, WORK1, WORK2, WORK3, WORK4)	MAI 1570
C		MAI 1580
u	STOP	MAI 1590
C	5101	MAT1600
100	FORMAT(F10, 0)	MAT1610
101	FORMAT(1H1 /////	MAT1620
101	Y 10Y AGHALLOWARLE STRESS F10 0 RH LR/SOLN /	MAI 1620
		MAI 1640
102	FORMAT(F10 5)	MAI 1650
102	FORMAT(10, 40HALLOWARD F BENDING DEFLECTION F10.5.2H IN	MAT1660
100	· (IIIAT (IOA, FORALLOWADLE DEADING DEFLECTION , IIO.0, SI III	MAI 1670
104	FORMATCION AGUALIONADIE SLOPE IN DEADINGS F10.5 AU DA	MATIGOO
104	TOWART TO A, TOTALLOWADLE SLOTE IN DEARINGS , 110.0, TI RA	MALICOO
105	$\pi_{\rm D}$, 777	MAI 1700
100	PORTATIONAL DEFLECTION , FIG. 5, 4H RA	MALITIO
100		MALITO
100	FORMATCHOX, 40HMINTHOM CRITICAL SPEED ,F10.0,4H RP	MAI 1720
105	*11,///)	MA11730
107	FORMAT(110)	MA11740
108	FORMAT(2F10.3)	MA11750
109	FORMAT(///, 10X, 23HDTAMETERS OF FIXED SIZE ,//, 10X, 29H X	MA11760
	* DIA ,//)	MA11770
110	FORMAT(10X,2F10.3,//)	MA11780
112	FORMAT(///, 10X, 34HMINIMUM DIAMETER INCREASE/DECREASE ,//, 15X, 20HX	MAI 1790
	* DIA.INCR.,//)	MAI 1800
	END	MAI1810

c	SUBROUTINE CONST(X, NCONST, PHI)	CON	10
C		CON	20
	DIMENSION X(1), PHI(1)	CON	30
C	CONSIGN (A + C DOWN (D) UOUDD(7) (D(7 C) DOUDT(1) DOUDT(6) (T(6 1))	CON	40
	(0) (10), (0)	CON	60
	COMMON/BB/ RA, RB, XR(200), X2(200), D2(200), PV2(200)	CON	70
	*, BMV(200), BMH(200), BM(200), DFLV(200), DFLH(200), SLV(200), SLH(200),	CON	80
	*SL(200), STRV(200), STRH(200), STR(200), SUB(200), SUT(200), SUF2(200), *PAD2(200), STRU(200), TEO(200), TEO(200), TAU(200), TAU(200), SUF2(200),	CON	90
	*STR1(200), SIGMA1(200), PH2(200), DFL(200), PW2(200), EMW(200),	CON	110
	*DFLW(200), SLW(200), STRW(200),	CON	120
	*WORKA(200), WORKB(200), WORKC(200), WORKD(200), WORKE(200), WORKF(200),	CON	130
	COMMON/DD/ E.G. N00, L1, L2, N1, N2, N	CON	150
	COMMON/EE/XDIA(50), DIA(50), ND	CON	160
	COMMON/FF/ STRAL, DFLAL, SLAL, TETAAL, RPMMIN, XDI(20), DI(20), NDI	CON	170
C	CUTHUN/GG/ XDF(20), DF(20), NDF, WORKS(50)	CON	180
-	DO 70 I=1, ND	CON	200
70	WORKS(I)=DIA(I)	CON	210
20	NND=ND-1	CON	220
	K=0	CON	240
	DO 3 I=1, NND	CON	250
	K = K + 1	CON	260
	DO 2 J=1, NDF	CON	280
	IF(XDIA(I).EQ.XDF(J)) GO TO 1	CON	290
1	$\frac{\text{GO TO 2}}{\text{DIA(1)-BE(1)}}$	CON	300
1	K=K-1	CON	320
2	CONTINUE	CON	330
	IF(I, EQ, 1) GO TO 3 $IF(MORVEY(I) = FO MORVEY(I = 1)) GO TO OO$	CON	340
	$ \begin{array}{c} \text{GO TO } 3 \end{array} $	CON	350
90	DIA(I) = DIA(I-1)	CON	370
3	CONTINUE	CON	380
С	DIA(ND) = DIA(ND-1)	CON	390
C		CON	410
	CALL STRESS(E, G, NOO, ND, N1, N2, N, L1, L2, RA, RB, XDIA, DIA, XR, X2,	CON	420
*	*D2, FW2, FV2, FH2, BHW, BHV, BHH, BH, DFLW, DFLW, DFLH, DFL, SLW, SLV, SLH, SL, *STBW, STBW, STBH, STB, BPMCB, SCB, SCT, SCF2, BAD2, STBINT, TM2, TETA, TAU	CON	430
	*TAUINT, STR1, SIGMA1,	CON	450
~	* WORKA, WORKB, WORKC, WORKD, WORKE, WORKF, WORKG, WORKH, WORKI, Ø)	CON	460
u	CALL MAXIM(STR1.STRMAX.N)	CON	470
	CALL MAXIM(DFL,DFLMAX,N)	CON	490
С		CON	500
	PHI(2) = DFLAL - DFLMAX	CON	510
	PHI(3) = SLAL-SL(1)	CON	530
	PHI(4) = SLAL-SL(N1)	CON	540
	PHI(6) = PPMCB-BPMMIN	CON	550
C		CON	570
	M=6	CON	580
	DO = 1, MD DO = 1, MD	CON	590
	IF(XDIA(I).EQ.XDI(J)) GO TO 4	CON	610
	CO TO 5	CON	620
4	II = II + I IF(DIA(I-1), GT, DIA(I)) GO TO 41	CON	640
	PHI(M) = DIA(I) - DIA(I-1) - DI(J)	CON	650
	GO TO 5	CON	660
41	PHI(M) = DIA(I-1) - DIA(I) - DI(J)	CON	670
5	CONTINUE	CON	690
6	CONTINUE	CON	700
u l	BETHBN	CON	710
	END	CON	730

•	SUBROUTINE UREAL(X,U)	URE	10
	DIMENSION X(1)	URE URE	$\frac{20}{30}$
3	COMMON/EE/XDIA(50), DIA(50), ND	URE URE	40 50
3	COMMON/CG/ XDF(20), DF(20), NDF, WORKS(50)	URE	60 70
70	WORKS(I) = DIA(I)	URE	90
	$\frac{1}{1}$ NND=ND-1 $K=0$	URE	110
	DO 3 I=1, NND K=K+1	URE URE	130 140
	DIA(I) = X(K) DO 2 J=1, NDF	URE URE	$150 \\ 160$
	IF(XDIA(I).EQ.XDF(J)) GO TO 1 GO TO 2	URE URE	170 180
1	DIA(I) = DF(J) $K = K - 1$	URE	190 200
2	$\begin{array}{c} \text{CONTINUE} \\ \text{IF(I.EQ.1) GO TO 3} \\ \text{IF(OPEC(I) FO WORKS(I-1)) CO TO 90} \end{array}$	URE	210
00	$\begin{array}{c} \text{GO TO 3} \\ \text{DIA}(1) = \text{DIA}(1-1) \end{array}$	URE	230 240 250
3	$\begin{array}{c} \text{CONTINUE} \\ \text{DIA(ND) = DIA(ND-1)} \end{array}$	URE	260 270
	PI=3.1415926 U=0.0	URE URE	280 290
	DO 4 I=2,ND U=U+PI*DIA(I-1)**2/4.*(XDIA(I)-XDIA(I-1))*.283	URE URE	$\frac{300}{310}$
4	CONTINUE RETURN	URE URE	320 330
	END	URE	340

- CONTINUE RETURN END 4

C

C

C

 SUBROUTINE LOAD (N00,ND,N1,N2,N,L1,L2,W,XDIA,DIA,XR, X2,PW2,PV2,PH2,TM2,D2,SCF2,RAD2,RD, (1,PW1,PV1,PH1,UNFW1,UNFV1,UNFH1,TM1,D1,SCF1,RAD1,UNFW2,UNFV2, NFH2,WORK1,WORK2,WORK3,WORK4) IMENSION XDIA(ND),DIA(ND),XR(N00),X2(N00),PV2(N00),PH2(N00), M2(N00),D2(N00),SCF2(N00),RAD2(N00),X1(N00),PV1(N00),PH1(N00), NFV1(N00),UNFH1(N00),TM1(N00),D1(N00),SCF1(N00),RAD1(N00), NFV1(N00),UNFH2(N00),WORK1(N00),WORK2(N00),WORK3(N00),WORK4(N00) D(ND),PV1(N00),PW2(N00),UNFW1(N00),UNFW2(N00) OMMON/AA/ ROVDB(8),HOVRB(7),CB(7,8),ROVDT(11),DOVDT(6),CT(6,11) CT1(20),FCT2(20) HIS SUBROUTINE READS INPUT DATA CONSISTING OF DIMENSIONS AND OADING ON THE SHAFT AND ARRANGES THEM IN WORKING ARRAYS FOR THE PTIMIZATION PROCESS EAL L,L1,L2 ATA FOR CALCULATING STRESS INTENSIFICATION ATA (ROVDB(J),J=1,8)/0.0,0.05,0.1,0.2,0.27,0.50,1.0,10000./
 UBROUTINE LOAD (N00,ND,N1,N2,N,L1,L2,W,XDIA,DIA,XR, X2,PW2,PV2,PH2,TM2,D2,SCF2,RAD2,RD, (1,PW1,PV1,PH1,UNFW1,UNFV1,UNFH1,TM1,D1,SCF1,RAD1,UNFW2,UNFV2, NFH2,WORK1,WORK2,WORK3,WORK4) IMENSION XDIA(ND),DIA(ND),XR(N00),X2(N00),PV2(N00),PH2(N00), M2(N00),D2(N00),SCF2(N00),RAD2(N00),X1(N00),PV1(N00),PH1(N00), NFV1(N00),UNFH1(N00),TM1(N00),D1(N00),SCF1(N00),RAD1(N00), NFV2(N00),UNFH2(N00),WORK1(N00),WORK2(N00),WORK3(N00),WORK4(N00) D(ND),PW1(N00),PW2(N00),UNFW1(N00),UNFW2(N00) OMMON/AA/ ROVDB(8),HOVRB(7),CB(7,8),ROVDT(11),DOVDT(6),CT(6,11) CT1(20),FCT2(20) HIS SUBROUTINE READS INPUT DATA CONSISTING OF DIMENSIONS AND OADING ON THE SHAFT AND ARRANGES THEM IN WORKING ARRAYS FOR THE PTIMIZATION PROCESS EAL L,L1,L2 ATA FOR CALCULATING STRESS INTENSIFICATION ATA (ROVDB(J),J=1,8)/0.0,0.05,0.1,0.2,0.27,0.50,1.0,10000./
<pre>MTH12, WORK1, WORK2, WORK3, WORK4) (IMENSION XDIA(ND), DIA(ND), XR(N00), X2(N00), PV2(N00), PH2(N00), M2(N00), D2(N00), SCF2(N00), RAD2(N00), X1(N00), PV1(N00), PH1(N00), NFV1(N00), UNFH1(N00), TM1(N00), D1(N00), SCF1(N00), RAD1(N00), NFV2(N00), UNFH2(N00), WORK1(N00), WORK2(N00), WORK3(N00), WORK4(N00) D(ND), PW1(N00), PW2(N00), UNFW1(N00), UNFW2(N00) OMMON/AA/ ROVDB(8), HOVRB(7), CB(7,8), ROVDT(11), DOVDT(6), CT(6,11) CT1(20), FCT2(20) HIS SUBROUTINE READS INPUT DATA CONSISTING OF DIMENSIONS AND OADING ON THE SHAFT AND ARRANGES THEM IN WORKING ARRAYS FOR THE PTIMIZATION PROCESS EAL L,L1,L2 ATA FOR CALCULATING STRESS INTENSIFICATION ATA (ROVDB(J), J=1,8)/0.0,0.05,0.1,0.2,0.27,0.50,1.0,10000./</pre>
<pre>HMENSION XDIA(ND), DIA(ND), XR(N00), X2(N00), PV2(N00), PH2(N00), M2(N00), D2(N00), SCF2(N00), RAD2(N00), X1(N00), PV1(N00), PH1(N00), NFV1(N00), UNFH1(N00), TM1(N00), D1(N00), SCF1(N00), RAD1(N00), NFV2(N00), UNFH2(N00), WORK1(N00), WORK2(N00), WORK3(N00), WORK4(N00) D(ND), PW1(N00), PW2(N00), UNFW1(N00), UNFW2(N00) OMMON/AA/ ROVDB(8), HOVRB(7), CB(7,8), ROVDT(11), DOVDT(6), CT(6,11) CT1(20), FCT2(20) HIS SUBROUTINE READS INPUT DATA CONSISTING OF DIMENSIONS AND OADING ON THE SHAFT AND ARRANGES THEM IN WORKING ARRAYS FOR THE PTIMIZATION PROCESS EAL L,L1,L2 ATA FOR CALCULATING STRESS INTENSIFICATION ATA (ROVDB(J), J=1,8)/0.0,0.05,0.1,0.2,0.27,0.50,1.0,10000./</pre>
<pre>NFV1(N00), UNFH1(N00), TM1(N00), D1(N00), SCF1(N00), RAD1(N00), NFV2(N00), UNFH2(N00), WORK1(N00), WORK2(N00), WORK3(N00), WORK4(N00) D(ND), PW1(N00), PW2(N00), UNFW1(N00), UNFW2(N00) OMMON/AA/ ROVDB(8), HOVRB(7), CB(7,8), ROVDT(11), DOVDT(6), CT(6,11) CT1(20), FCT2(20) HIS SUBROUTINE READS INPUT DATA CONSISTING OF DIMENSIONS AND OADING ON THE SHAFT AND ARRANGES THEM IN WORKING ARRAYS FOR THE PTIMIZATION PROCESS EAL L,L1,L2 ATA FOR CALCULATING STRESS INTENSIFICATION ATA (ROVDB(J), J=1,8)/0.0,0.05,0.1,0.2,0.27,0.50,1.0,10000./</pre>
COMMON/AA/ ROVDB(8), HOVRB(7), CB(7,8), ROVDT(11), DOVDT(6), CT(6,11) CT1(20), FCT2(20) HIS SUBROUTINE READS INPUT DATA CONSISTING OF DIMENSIONS AND OADING ON THE SHAFT AND ARRANGES THEM IN WORKING ARRAYS FOR THE PTIMIZATION PROCESS EAL L,L1,L2 ATA FOR CALCULATING STRESS INTENSIFICATION ATA (ROVDB(J), J=1,8)/0.0,0.05,0.1,0.2,0.27,0.50,1.0,10000./
CTI(20), FCT2(20) HIS SUBROUTINE READS INPUT DATA CONSISTING OF DIMENSIONS AND OADING ON THE SHAFT AND ARRANGES THEM IN WORKING ARRAYS FOR THE PTIMIZATION PROCESS EAL L,L1,L2 ATA FOR CALCULATING STRESS INTENSIFICATION ATA (ROVDB(J),J=1,8)/0.0,0.05,0.1,0.2,0.27,0.50,1.0,10000./
HIS SUBROUTINE READS INPUT DATA CONSISTING OF DIMENSIONS AND OADING ON THE SHAFT AND ARRANGES THEM IN WORKING ARRAYS FOR THE PTIMIZATION PROCESS EAL L,L1,L2 ATA FOR CALCULATING STRESS INTENSIFICATION ATA (ROVDB(J),J=1,8)/0.0,0.05,0.1,0.2,0.27,0.50,1.0,10000./
HIS SUBROUTINE READS INPUT DATA CONSISTING OF DIMENSIONS AND OADING ON THE SHAFT AND ARRANGES THEM IN WORKING ARRAYS FOR THE PTIMIZATION PROCESS EAL L,L1,L2 ATA FOR CALCULATING STRESS INTENSIFICATION ATA (ROVDB(J),J=1,8)/0.0,0.05,0.1,0.2,0.27,0.50,1.0,10000./
EAL L,L1,L2 ATA FOR CALCULATING STRESS INTENSIFICATION ATA (ROVDB(J),J=1,8)/0.0,0.05,0.1,0.2,0.27,0.50,1.0,10000./
ATA FOR CALCULATING STRESS INTENSIFICATION ATA (ROVDB(J),J=1,8)/0.0,0.05,0.1,0.2,0.27,0.50,1.0,10000./
ATA FOR CALCULATING STRESS INTENSIFICATION ATA (ROVDB(J), J=1,8)/0.0,0.05,0.1,0.2,0.27,0.50,1.0,10000./
ATA (ROVDB(J), J=1,8)/0.0,0.05,0.1,0.2,0.27,0.50,1.0,10000./
AIA (107bb(5),5-1,0)/0.0,0.00,0.1,0.2,0.24,0.00,1.0,10000./
ATA (HOVER(I) I=1 7)/0 0 0 5 1 0 1 5 2 0 3 5 10000 /
ATA ((OP(1 1) 1-1, 0) 1-1, 7) /
$\begin{array}{c} \text{AIA} ((100, 1, 3), 3 = 1, 3), 1 = 1, 7) \\ 1.00, 1.0$
2.00, 1.91, 1.70, 1.48, 1.38, 1.22, 1.08, 1.00, 2.00, 1.91, 1.70, 1.48, 1.38, 1.22, 1.08, 1.00,
2.00, 2.00, 1.73, 1.50, 1.39, 1.23, 1.08, 1.00, 2.00, 2.00, 1.74, 1.52, 1.39, 1.23, 1.09, 1.00,
2.00, 2.00, 1.76, 1.54, 1.40, 1.23, 1.10, 1.00, 2.00, 2.00, 2.00, 2.00, 2.00, 2.00, 2.00, 2.00, 2.00, 2.00/
ATA (ROVDT(J), J=1, 11) /0.0, 0.005, 0.01, 0.02, 0.03, 0.04, 0.06, 0.08, .: .12, 10000./
ATA(DOVDT(I), I=1,6)/10000.,2.00,1.33,1.20,1.09,1.00/
ATA((CT(I,J), J=1, 11), I=1, 6) / 3.00, 3.00, 3.00, 2.25, 2.00, 1.82, 1.65, 1.51, 1.44
1.39, 1.00, 3.00, 2.25, 2.00, 1.82, 1.65, 1.51, 1.44, 3.00
1.39, 1.00, 3.00, 2.7, 2.16, 1.91, 1.76, 1.60, 1.48, 1.40.
1.35, 1.00, 3.00, 2.50, 2.00, 1.75, 1.62, 1.50, 1.40, 1.34.
1.30, 1.00, 3.00, 2.20, 1.88, 1.53, 1.40, 1.30, 1.20, 1.16, 1.15.
1.15, 1.00, 1.00, 1.00, 1.00, 1.00, 1.00, 1.00, 1.00, 1.00.
1.00, 1.00/
ET WORKING ARRAYS TO 0 O 1 I=1, N00
1(I)=0.0 (2(I)=0.0
W1(1) = 0.0 W2(1) = 0.0
V1(1) = 0.0 V2(1) = 0.0
V2(1)-0.0
H1(I) = 0.0
H1(I)=0.0 H2(I)=0.0 NFW1(I)=0.0

	UNFV2(I)=0.0	740
	UNFH1(I) = 0.0	750
	UNFH2(1)=0.0	760
	TM1(I) = 0.0	770
	TM2(I) = 0.0	780
	$D1(\cdot I) = \mathbf{O} \cdot \mathbf{O}$	790
	$D_2(1) = 0.0$	008
	SCF1(I) = 1.0	810
	SCF2(I) = 1.0	820
	RAD1(I) = 10000.	830
	RAD2(I) = 10000.	840
	XII(I) = 0, 0	850
	WOBK1(I) = 0.0	860
	WOEK2(1) = 0.0	870
	WORK3(1) = 0.0	880
	WORK(4 1) = 0.9	890
1	CONTINUE	900
c ¹	Gontinol	910
u	PW=0 0	920
		020
		04.0
		050
		900
		900
	UNFH=0.0	970
		980
		990
	SCF=1.0	1000
	RAD=10000.	1010
_	P1=3.1415926	1020
C		1030
C	PRINT OUT THE TITLE AND INPUT DATA	1040
C		1050
	WRITE(6, 150)	1060
C		1070
C	READ INPUT DATA AND PRINT OUT	1080
C		1090
	READ(5,101) L1,L2	1100
	L = L + L 2	1110
	X1(2) = L	1120
C		1130
	WRITE(6, 151) L1, L2	1140
C		1150
-	NX=2	1160
C		1170
č	CONCENTRATED FORCES	1180
č		1190
u	READ(5. 110) NPW NPV NPH	1200
	IEINEW FO AL CO TO 60	1210
	WDITE (A 197)	1220
		1220
		1230
	READ(3,111) XFW, FW	1240
	WRITE(6,141) XPW,PW	1250
	X= XPW	1260
	CALL RANGE(X, PW, PV, PH, UNFW, UNFV, UNFH, TM, D, SCF, X1, PW1, PV1, PH1, UNFW1	1270
	*, UNFV1, UNFH1, TM1, D1, SCF1, X2, PW2, PV2, PH2, UNFW2, UNFV2, UNFH2, TM2, D2,	1280
	*SCF2, RAD, RAD1, RAD2, NX, N00)	1290
30	CONTINUE	1300
	PW=0.0	1310
69	CONTINUE	1320
C		1330
	IF(NPV.EQ.0) GO TO 70	1340
	WRITE(6, 140)	1350
	DO 2 I=1, NPV	1360
	READ(5,111) XPV, PV	1370
	WRITE(6, 141) XPV, PV	1380
	X= XPV	1390
	CALL BANGE(X, PW, PV, PH, UNFW, UNFV, UNFH, TM, D. SCF, X1, PW1, PV1, PH1, UNFW1	1400
	* INFV1. INFH1. TM1. D1. SCF1. X2. PV2. PV2. PH2. INFV2. INFV2. INFF2. INFF9. INFF9.	1410
	SCF2. RAD. BAD1. RAD2. NX. NO()	1420
2	CONTINUE	1420
-	PV=0 0	1440
C		1450
70	CONTINUE	1460
	IF(NPH FO 6) CO TO 71	1470
	A CHARLENDY OF A FE	1-160

CCC CCC

a	WRITE(6,142)	1480
L.	DO 3 I=1,NPH	1500
	READ(5,111) XPH,PH WRITE(6,141) XPH PH	1510 1520
	X= XPH	1530
	CALL RANGE(X, PW, PV, PH, UNFW, UNFV, UNFH, TM, D, SCF, X1, PW1, PV1, PH1, UNFW1 *, HNFV1, HNFH1, TM1, D1, SCF1, X2, PW2, PV2, PH2, UNFW2, HNFV2, HNFH2, TM2, D2,	1540 1550
_	*SCF2, RAD, RAD1, RAD2, NX, N00)	1560
3	CONTINUE PH=0.0	1570 1580
C		1590
C 71	CONTINUE	1600
C	UNIFORMLY DISTRIBUTED FORCES	1620 1630
L.	READ(5,110) NUNFW, NUNFV, NUNFH	1640
	IF(NUNFW.EQ.0) GO TO 31 WRITE(6, 138)	1650 1660
	DO 32 I=1, NUNFW	1670
	WRITE(6,144) X1UNFW, X2UNFW, UNFW	1680
	X=X1UNFW CALL DANCE(V DW DV DH HNEW HNEW HNEH TM D SCE V1 DW1 DV1 DH1 HNEW1	1700
	*, UNFV1, UNFH1, TM1, D1, SCF1, X2, PW2, PV2, PH2, UNFW2, UNFV2, UNFH2, TM2, D2,	1720
	*SCF2, RAD, RAD1, RAD2, NX, NOO) HNFW=-HNFW	1730
	X= X2UNFW	1750
	*, UNFV1, UNFH1, TM1, D1, SCF1, X2, PW2, PV2, PH2, UNFW2, UNFV2, UNFH2, TM2, D2,	1760
	*SCF2, RAD, RAD1, RAD2, NX, N00)	1780
32	UNFW=0.0	1800
31 C	CONTINUE	1810
u	IF(NUNFV.EQ.0) GO TO 72	1830
	WRITE(6,143) DO 4 I=1.NUNFV	1840
	READ(5, 112) X1UNFV, X2UNFV, UNFV	1860
	X=X1UNFV	1880
	CALL RANGE(X, PW, PV, PH, UNFW, UNFV, UNFH, TM, D, SCF, X1, PW1, PV1, PH1, UNFW1 # UNFV1 UNFW1 TM1 D1 SCF1 Y2 PW2 PV2 PH2 UNFW2 UNFW2 UNFW2 D2	1890
	*; OAF VI, OAF MI, HAI, DI, SOF I, AZ, I WZ, I VZ, I MZ, OAF WZ, OAF WZ, OAF MZ, HAZ, HZ, BZ, *SCF2, RAD, RAD1, RAD2, NX, N00)	1910
	UNFV=-UNFV X=X211NFV	1920 1930
	CALL RANGE(X, PW, PV, PH, UNFW, UNFW, UNFH, TM, D, SCF, X1, PW1, PV1, PH1, UNFW1	1940
	*, UNFV1, UNFH1, TM1, D1, SCF1, X2, PW2, PV2, PH2, UNFW2, UNFV2, UNFV2, TM2, D2, *SCF2, RAD, RAD1, RAD2, NX, NOO)	1950
4		1970 1980
C		1990
72	CONTINUE IF(NUNFH.EQ.0) GO TO 73	2000 2010
C		2020
	WRITE (6,145) DO 5 I=1,NUNFH	2030 2040
	READ(5,112) X1UNFH, X2UNFH, UNFH IDITE(6,144) X1UNFH X2UNFH UNFH	2050 2060
	X=X1UNFH	2070
	CALL RANGE(X, PW, PV, PH, UNFW, UNFV, UNFH, TM, D, SCF, X1, PW1, PV1, PH1, UNFW1 *. UNFV1, UNFH1, TM1, D1, SCF1, X2, PW2, PV2, PH2, UNFW2, UNFV2, UNFH2, TM2, D2.	2080 2090
	*SCF2, RAD, RAD1, RAD2, NX, N00)	2100
	X=X2VNFH	2110
	CALL RANGE(X, PW, PV, PH, UNFW, UNFV, UNFH, TM, D, SCF, X1, PW1, PV1, PH1, UNFW1 # IINFW1 IINFH1 TM1 D1 SCF1 X2 PW2 PW2 PH2 IINFW2 IINFW2 IINFW3 TM3 D2	2130 2140
	*SCF2, RAD, RAD1, RAD2, NX, N00)	2150
5	CONTINUE UNFII=0.0	2160 2170
C		2180
73 C	CONTINUE	2190 2200
C	TORSION MOMENTS	2210

C		
	READ(5,120) NTM	
	IF(NTM.EQ.0) GO TO 74	
	WRITE(6, 146)	
	READ(5, 112) X1TM, X2TM, TM	
	WRITE(6, 144) X1TM, X2TM, TM	
	X= X1 TM	
	CALL RANGE(X, PW, PV, PH, UNFW, UNFW, UNFH, TM, D, SCF, X1, PW1, PV1, PH1, UNFW1	
	*, ONF VI, ONF HI, IMI, DI, SUF I, X2, F W2, F V2, PH2, ONF W2, ONF V2, ONF H2, IM2, D2,	
	X=X2TM	
	TM = -TM	
	CALL RANGE(X, PW, PV, PH, UNFW, UNFV, UNFH, TM, D, SCF, X1, PW1, PV1, PH1, UNFW1	
	*, UNFV1, UNFH1, TM1, D1, SCF1, X2, PW2, PV2, PH2, UNFW2, UNFV2, UNFH2, TM2, D2,	
6	*SUF2, RAD, RADI, RAD2, NA, NVO) CONTINUE	
v	TM=0.0	
C		
74	CONTINUE	
	DIAMETERS	
u	WRITE(6,147)	
	READ(5, 120) ND	
	DO 7 I=1,ND	
	$\operatorname{READ}(5, 113) \mathrm{XD}, \mathrm{D}$	
	DIA(I) = D	
	WRITE(6,139) XD,D	
	X= XD	
	CALL RANGE(X, PW, PV, PH, UNFW, UNFV, UNFH, TM, D, SCF, X1, PW1, PV1, PH1, UNFW1	
	*, UNFV1, UNFH1, TM1, D1, SCF1, X2, PW2, PV2, PH2, UNFW2, UNFV2, UNFH2, TM2, D2,	
7	*SOFZ, RAD, RADI, RADZ, NA, NUU) CONTINUE	
	D=0.0	
2		
	STRESS CONCENTRATION FACTORS	
	DEAD/E 196) NOF	
	LEADUS, 1207 NUT LE(NCE, EQ. 0) CO TO 75	
	WRITE(6, 148)	
	DO 8 I=1, NCF	
	READ(5, 101) XSCF, SCF	
	WRITE(6, 139) XSCF, SCF V=VSCF	
	CALL RANGE(X, PW, PV, PH, UNFW, UNFV, UNFH, TM, D, SCF, X1, PW1, PV1, PH1, UNFW1	
	*, UNFV1, UNFH1, TM1, D1, SCF1, X2, PW2, PV2, PH2, UNFW2, UNFV2, UNFH2, TM2, D2,	
	*SCF2, RAD, RAD1, RAD2, NX, N00)	
8	CONTINUE	
•	SUP = 1.0	
75	CONTINUE	
1		
2	RADII	
	DO = 89 = 1 = 1, ND	
80	CONTINUE	
2	don'i mon	
	READ(5,120) NRAD	
	IF(NRAD.EQ.0) GO TO 76	
	WRITE(0,149) DO Q L=1 NRAD	
	READ(5, 101) XRAD, RAD	
	WRITE(6,139) XRAD, RAD	
	DO 90 J=1, ND	
0.0	IF(XRAD, EQ, XDIA(J)) RD(J) = RAD	
90	CONTINUE	
	A-ARAD CALL BANCE(X, PW, PV, PH, INFW, INFV, INFH, TM, D, SCF, X1, PW1, PV1, PU1, INFW1	
	*, UNFV1, UNFH1, TM1, D1, SCF1, X2, PW2, PV2, PH2, UNFW2, UNFV2, UNFV2, TM2, D2	
	*SCF2, RAD, RAD1, RAD2, NX, N00)	
9	CONTINUE	
76	CONTINUE	
10	CONTINUE	

EPS=0.001 2960 IF(W.LT.EPS) GO TO 78 2970 NUNFW=1 2980 2990 C ADD WEIGHT OF SHAFT TO UNIFORM DISTRIBUTED WEIGHTS C 3000 NSS=NX-1 3010 3020 DO 77 I=1.NSS UNFW2(1)=UNFW2(1)+P1*D2(1)**2/4.*.283 3030 77 CONTINUE 3040 78 CONTINUE 3050 C 3060 UNFW1(1) = UNFW2(1)3070 UNFV1(1) = UNFV2(1) 3080 TM1(NX) = TM2(NX-1)3090 UNFV1(NX) = UNFV2(NX-1) 3100 UNFH1(NX) = UNFH2(NX-1) 3110 TM2(NX) = TM1(NX)3120 UNFV2(NX) = UNFV1(NX) 3130 UNFH2(NX) = UNFH1(NX) 3140 C 3150 INCLUDE IN THE RANGE OF X DOUBLE POINTS WHERE THE DIAMETER OR C 3160 C TORSIONAL MOMENT CHANGE VALUE 3170 NXX=13180 C 3190 DO 11 I=2,NX 3200 IF(D2(I).NE.D2(I-1)) GO TO 10 3210 IF(TM2(I).NE.TM2(I-1)) GO TO 10 3220 3230 NXX=NXX+1 X1(NXX)=X2(I) 3240 PW1(NXX)=PW2(I) 3250 PV1(NXX) = PV2(I)3260 PH1(NXX) = PH2(I)3270 UNFW1(NXX) = UNFW2(I) 3280 UNFV1(NXX) = UNFV2(I) 3290 UNFH1(NXX) = UNFH2(I) 3300 TM1(NXX) = TM2(I)3310 D1(NXX) = D2(I)3320 SCF1(NXX)=SCF2(I) 3330 RAD1(NXX) = RAD2(I)3340 GO TO 11 3350 С 3360 10 NXX=NXX+1 3370 X1(NXX) = X2(I)3380 PW1(NXX)=0.0 3390 PV1(NXX)=0.0 3400 PH1(NXX) = 0.03410 UNFW1(NXX) = UNFW2(I-1) 3420 UNFV1(NXX) = UNFV2(I-1)3430 UNFH1(NXX) = UNFH2(I-1) 3440 TM1(NXX) = TM2(I-1)3450 D1(NXX) = D2(I-1)3460 SCF1(NXX) = 1.03470 RAD1(NXX)=RAD2(I) 3480 С 3490 NXX=NXX+1 3500 X1(NXX) = X2(I)3510 PW1(NXX) = PW2(I)3520 PV1(NXX)=PV2(I) 3530 PH1(NXX) = PH2(I)3540 UNFW1(NXX) = UNFW2(I) 3550 UNFV1(NXX) = UNFV2(I)3560 UNFH1(NXX) = UNFH2(I) 3570 TM1(NXX) = TM2(I)3580 D1(NXX) = D2(I)3590 SCF1(NXX) = SCF2(I)3600 RAD1(NXX) = 10000. 3610 C 3620 3630 K= I+1 ICOUNT=NXX 3640 DO 12 J=K, NX 3650 ICOUNT= ICOUNT+1 3660 X1(ICOUNT) = X2(J)3670 PW1(ICOUNT) = PW2(J) 3680 PV1(ICOUNT) = PV2(J) 3690

PH1(ICOUNT)=PH2(J) 3700 UNFW1(ICOUNT) = UNFW2(J) 3710 UNFV1(ICOUNT) = UNFV2(J) 3720 UNFH1(ICOUNT) = UNFH2(J) 3730 TM1(ICOUNT) = TM2(J) 3740 D1(ICOUNT) = D2(J)3750 SCF1(ICOUNT)=SCF2(J) 3760 RAD1(ICOUNT) = RAD2(J) 3770 12 CONTINUE 3780 C 3790 CONTINUE 3800 11 С 3810 NX= ICOUNT 3820 C 3830 WRITE(6,200) 3840 C 3850 DO 13 I=1,NXX 3860 RAD2(I)=RAD1(I) 3870 IF(RAD1(I).EQ. 10000.) RAD1(I)=0.0 3880 13 3890 CONTINUE 3900 I=1 WRITE(6,202) I, X1(I), D1(I), RAD1(I), SCF1(I), PW1(I), PV1(I), PH1(I), 3910 *UNFW1(I), UNFV1(I), UNFH1(I), TM1(I) 3920 NLAST=NXX-1 3930 DO 15 I=2, NLAST 3940 IF(X1(I).EQ.L1) GO TO 14 3950 WRITE(6,203) I,X1(I),D1(I),RAD1(I),SCF1(I),PW1(I),PV1(I),PH1(I), 3960 *UNFW1(I), UNFV1(I), UNFH1(I), TM1(I) 3970 GO TO 15 3980 WRITE(6,202) I, X1(I), D1(I), RAD1(I), SCF1(I), PW1(I), PV1(I), PH1(I), 3990 14 *UNFW1(I), UNFV1(I), UNFH1(I), TM1(I) 4000 4010 15 CONTINUE 4020 I=NXX WRITE(6,204) I, X1(I), D1(I), RAD1(I), SCF1(I), PW1(I), PV1(I), PH1(I), 4030 *UNFW1(I), UNFV1(I), UNFH1(I), TM1(I) 4040 C 4050 DO 131 I=1,NXX 4060 RAD1(I)=RAD2(I) 4070 131 CONTINUE 4080 C 4090 DO 16 I=1,NXX 4100 XR(I) = X1(I)4110 CONTINUE 16 4120 С 4130 C REPLACE UNIFORMLY DISTRIBUTED FORCES BY CONCENTRATED FORCES 4140 C 4150 N=NXX 4160 MCONC=1 4170 C 4180 KK=Ø 4190 NSS=N-1 4200 IF(NUNFW.EQ.0) GO TO 17 4210 DO 19 I=1,NSS 4220 IF(UNFW1(I).EQ.0.0) GO TO 19 4230 IF((X1(I+1)-X1(I)).EQ.0.0) GO TO 19 4240 DO 191 J=1, MCONC 4250 KK=KK+1 4260 WORK1(KK) =4270 * X1(I)+(X1(I+1)-X1(I))/FLOAT(MCONC*2)+(X1(I+1)-X1(I))/FLOAT(MCONC 4280 *)*(FLOAT(J)-1) 4290 WORK2(KK) =4300 UNFW1(I)*(X1(I+1)-X1(I))/FLOAT(MCONC) * 4310 191 CONTINUE 4320 19 CONTINUE 4330 DO 192 I=1,KK 4340 IF(UNFW1(I).EQ.0.0) GO TO 192 4350 IF((X1(I+1)-X1(I)).EQ.0.0) GO TO 192 4360 X=WORK1(I) 4370 WORK1(1) = 0.04380 PW=WORK2(I) 4390 WORK2(1) = 0.04400 CALL RANGE(X, FW, PV, PH, UNFW, UNFV, UNFH, TM, D, SCF, X1, PW1, PV1, PH1, UNFW1 4410 *, UNFV1, UNFH1, TM1, D1, SCF1, X2, PW2, PV2, PH2, UNFW2, UNFV2, UNFH2, TM2, D2, 4420 *SCF2, RAD, RAD1, RAD2, N, N00) 4430

192	CONTINUE
17	PW=0.0 CONTINUE
	KK=0
	1155=11-1 IF(NUNFV, EQ. 0) GO TO 291
	DO 20 I=1,NSS
	IF(UNFV1(I).EQ.0.0) GO TO 20
	IF((XI(1+1)-XI(1))) EQ.0.0) GO TO 20
	KK=KK+1
	WORK1(KK) =
	* X1(I)+(X1(I+1)-X1(I))/FLOAT(MCONC*2)+(X1(I+1)-X1(I))/FLOAT(MCONC
	(FLUAT(J)-1) WORK2(KK) =
	* UNFV1(I)*(X1(I+1)-X1(I))/FLOAT(MCONC)
1	CONTINUE
20	CONTINUE DO 201 I-1 KK
	10 201 1-1, KK IF(UNFV1(1), EQ. 0.0) GO TO 201
	IF((X1(I+1)-X1(I)).EQ.0.0) CO TO 201
	X=WORK1(1)
	WORK1(I) = 0.0
	V = MORZ(1) WOBK2(1) = 0.0
	CALL RANGE(X, PW, PV, PH, UNFW, UNFV, UNFH, TM, D, SCF, X1, PW1, PV1, PH1. UNFW1
	*, UNFV1, UNFH1, TM1, D1, SCF1, X2, PW2, PV2, PH2, UNFW2, UNFV2, UNFH2, TM2, D2,
01	*SCF2, RAD, RAD1, RAD2, N, NOO)
101	PV=0.0
91	CONTINUE
	177-0
	KK=0 NSS=N-1
	IF(NUNFH.EQ.0) CO TO 222
	DO 22 I=1, NSS
	IF(UNFH1(I).EQ.0.0) GO TO 22
	$\frac{11}{10} \frac{11}{10} - \frac{11}{10} \frac{11}{10} \frac{10}{10} \frac{10}{10} \frac{10}{10} \frac{12}{10} \frac{10}{10} \frac{12}{10} \frac{10}{10} $
	KK=KK+1
	WORK3 (KK) =
	* X1(I)+(X1(I+1)-X1(I))/FLOAT(MCONC*2)+(X1(I+1)-X1(I))/FLOAT(MCONC *)*(FLOAT(I)-1)
	$\pi/\pi(r_{\rm LOAI(J)}-1)$ WOBK4(KK) =
	* UNFH1(I)*(X1(I+1)-X1(I))/FLOAT(MCONC)
23	CONTINUE
2	CONTINUE
	$10 \ 221 \ 1-1, KK$ IF(INFH1(1), EQ. 0, 0) GO TO 221
	IF((X1(I+1)-X1(I)).EQ.0.0) GO TO 221
	X=WORK3(I)
	WORK3(I) = 0.0
	WORK4(1) = 0.0
	CALL RANGE(X, PW, PV, PH, UNFW, UNFV, UNFH, TM, D, SCF, X1, PW1, PV1, PH1, UNFW1
	*, UNFV1, UNFH1, TM1, D1, SCF1, X2, PW2, PV2, PH2, UNFW2, UNFV2, UNFH2, TM2, D2,
0.1	*SCF2, RAD, RAD1, RAD2, N, NO0)
21	PH=0.0
22	CONTINUE
_	
	DO 301 I=1,N00
	$\frac{A2(1) - A1(1)}{PW2(1) = PW1(1)}$
	PV2(I) = PV1(I)
	PH2(I)=PH1(I)
	TM2(I) = TM1(I)
	D2(1) = D1(1) SCF2(1) = SCF1(1)
	RAD2(I) = RAD1(I)
01	CONTINUE
	DO 24 1=1.N

24	IF(X2(I).NE. N1=I CONTINUE N2=N-N1	L1) GO TO	24					
C	RETURN							
101 C	FORMAT(2F10.	3)						
110 C	FORMAT(3110)							
<u></u>	FORMAT(F10.3	,F10.0)						
112	FORMAT(2F10.	3,F10.)						
ີ 113	FORMAT(2F10.	3)						
C 120	FORMAT(110)							
C 137	FORMAT(///, 1	OX,25HWEI	GHTS ATTA	CHED TO	SHAFT, //	, 15X, 1	6HX	WE
138	*ICHT) FORMAT(///, 1 *15X, 33HX STA	IOX, 42HUN II	FORMLY DIS	STRIBUTE WEIG	D WEIGH	rs		,11,
C	FORMATC, 102	AV COMPEN		ana		1 6 7777		EODCEN
C 140	FUMPIATC///, I	WX, 20HVER	TIGAL FOR	ULS .	,//, IƏX	, 10HX		FURCE
141 C	FORMAT(/, 10)	4,F9.3,F13	.0)					
142 C	FORMAT(///, 1	OX, 20HHOR	IZONTAL F	ORCES	,//, 15X	, 16HX		FORCE)
143	FORMAT(///, 1 *15X, 33HX STA	ØX, 44HVER ART	TICAL UNI X END	FORMLY D FORC	ISTRIBU E)	FED FOR	ICES	,11,
C 144	FORMAT(//, 6)	K,2F13.3,F	13.0)					
C 145	FORMAT(///, 1 *15X, 33HX STA	ØX,44HHOR	IZONTAL U X END	NIFORMLY FORC	DISTRI	BUTED F	ORCES	,11,
C 146	FORMAT(//, 10 * MOMENT	X, 17HTORS	IONAL MOM	ENTS,//,	10X, 35H	X SI	TART	X END
C 147	FORMAT(//, 10	X,9HDIAME	TERS//, 10	X,21H	х		DIA)	
C 148	FORMAT(//, 10 * FACTOR)	X, 28HSTRE	SS CONCEN	TRATION	FACTORS	,//, 15}	K, 19HX	
C 149	FORMAT(//, 10	X, 5HRADII	,//, 15X, 10	6HX	1	RAD)		
C 150	FORMAT(1H1, / *20X, 25HSHAF7 *20X, 25H***** *20X, 11HINPU7 *20X, 10H*****	C DESICN O ************************************	PTIMIZATI ********* ,	ON,/, **,////,				
C 151	FORMAT(10X, 2 * 10X, 2	20HLENGTH 20HLENGTH	OF FIRST S	SPAN, F10 SPAN, F10	.3,3H II .3,3H II	N,//, N,//)		
C 200	FORMAT(1H1, / *10X, 127H====	////,,10X,	22HDIMENS	IONS AND	LOADIN	G,//,		
	*=== * 123HPOINT *	XUN	DIA IF.DISTR.	RADII FORCE	STRESS TORS	s. Mom.	CONC REMA	,/,10X, .FORCE RKS ,/,
	*10X, * 123HNO				CONC.F	CT. WE	IGHT	VERT.
	* HORIZ. *10X,	WEIGHT	VERT.	HORIZ	•			,/,
	* 123H * I.B		IN LB/IN		N TI	BIN	LB	LB
	*10X, 127H====							,,,
	*===)						
C				A AVI 4 AVI				

C		5920
203	FORMAT(10X, I4, 3F9.3, F9.2, 7F10.0, 3X, /)	5930
C		5940
204	FORMAT(10X, 14, 3F9.3, F9.2, 7F10.0, 3X, 12HEND OF SHAFT, /)	5950
C		5960
	END	5970

	CONDUCTINE CONDUCTION OF NO. NO. N. L. LO. DA. DD. VOLA. DIA VO. NO.	CITD	10
C	SUBRUUTINE STRESS(E,G,N00,ND,N1,N2,N,L1,L2,RA,RB,XD1A,D1A,XR,X2,	STR	10
	*D2, PW2, PV2, PH2, BMW, BMV, BMH, BM, DFLW, DFLV, DFLH, DFL, SLW, SLV, SLH, SL,	STR	20
	*TAUINT, STRI, SIGMA1, SI, SIP, Z, ZP, WORKE, WORKF, WORKG, WORKH, WORKI, IPRT)	STR	40
С	COMMON (AA < POUNDE(R) HOURDE(T) CR(T R) POUNT(11) DOUDT(E) CT(E 11)	STR	50
	*FCT1(20), FCT2(20)	STR	70
С	DIMENSION VALAGED DIAGED VEGNAAL DOGEAAL VOGEAAL CIGEAAL	STR	80
	*SIP(N00), Z(N00), ZP(N00), PV2(N00), PH2(N00), BMV(N00), BMH(N00),	STR	100
	*BM(N00), DFLV(N00), DFLH(N00), DFL(N00), SLV(N00), SLH(N00), SL(N00), *STRV(N00), STRV(N00), STRV(N00), STRV(N00), SCR(N00),	STR	110
	*, STRINT(NO0), TAUINT(NO0), TM2(NO0), TETA(NO0), TAU(NO0), STR1(NO0),	STR	130
	*SIGMA1(N00), PW2(N00), BMW(N00), DFLW(N00), SLW(N00), STRW(N00), *VORKE(N00), WORKE(N00), WORKE(N00), WORKE(N00),	STR	140
С		STR	160
С	REAL L, L1, L2	STR	170
u	PI=3.1415926	STR	190
C	DO 10 I=1 N	STR	200
	WORKE(I) = D2(I)	STR	220
10	CONTINUE	STR	230
ŭ	D2(1) = DIA(1)	STR	250
	KK= ND-1 DO 2 J=2.N	STR	260
	DO 1 J=1, KK	STR	280
	IF(X2(1), LE, XDIA(J)) GO TO 1 IF(X2(1), GT, XDIA(J+1)) GO TO 1	STR	290
	D2(1) = DIA(J)	STR	310
	F(WORKE(1), EQ, WORKE(1-1)) = DIA(J+1)	STR	320
1	CONTINUE	STR	340
c	CONTINUE	STR	350
C	CALCULATE MOMENT OF INERTIA AND SECTION MODULUS	STR	370
	150 251-1, R IF(D2(1). EQ. 0.0) GO TO 25	STR	390
	SI(1) = PI * D2(1) * * 4/64.	STR	400
	Z(1) = SI(1) * 2. / D2(1)	STR	420
25	ZP(I) = SIP(I) * 2.7D2(I)	STR	430
C		STR	450
	CALL BEND(E, L1, L2, N1, N2, N, X2, S1, Z, PW2, BMW, DFLW, SLW, STRW, RAW, RBW, *N00, BM, DFL, SL, STR, TAU, STR1, WORKE, WORKF, WORKG, WORKH, WORKI)	STR	460
	CALL BEND(E,L1,L2,N1,N2,N,X2,SI,Z,PV2,BNV,DFLV,SLV,STRV,RAV,RBV,	STR	480
	*NOO, BM, DFL, SL, STR, TAU, STR1, WORKE, WORKF, WORKG, WORKH, WORK1) CALL BEND(E, L1, L2, N1, N2, N, X2, SL, Z, PH2, BMH, DFLH, SLH, STRH, RAH, RBH,	STR	490
	*NOO, BM, DFL, SL, STR, TAU, STR1, WORKE, WORKF, WORKG, WORKH, WORKI)	STR	510
C	CALCULATE THE RESULTANT BENDING MOMENT, DEFLECTION, SLOPE AND STRESS	STR	520 530
	RAV=RAV+RAW	STR	540
	RBV=RBV+RBW	STR	560
	RB=SQRT(RBV**2+RBH**2)	STR	570
	BO 20 I = 1, N BMV(I) = BMV(I) + BMW(I)	STR	590
	BM(I) = SQRT(BMV(I) **2 + BMH(I) **2) DFLV(I) = DFLV(I) + DFLV(I)	STR	600
	DFL(1) = SQRT(DFLV(1) **2+DFLH(1) **2)	STR	620
	SLV(1)=SLV(1)+SLW(1) SL(1)=S0BT(SLV(1)**2+SLH(1)**2)	STR	630 640
	STRV(I)=STRV(I)+STRW(I)	STR	650
26	STR(1)=SQRT(STRV(1)**2+STRH(1)**2) CONTINUE	STR	660 670
c		STR	680
	SCB(K) = SCF2(K)	STR	690 700
	SCT(K) = SCF2(K)	STR	710
	IF(D2(K+1).EQ.0.0) GO TO 60	STR	730

	IF(RAD2(K).CE.10000.) CO TO 60	STR 740
	DMIN=D2(K)	STR 750
	IF(D2(K+1), LT, D2(K)) DMIN=D2(K+1)	STR 760
C	RDX=RAD2(K)/DTHN	STR 770
u	HRX = ABS(D2(K+1) - D2(K))/2, /RAD2(K)	STR 790
С		STR 800
	IF(D2(K+1).GT.D2(K))GO TO 53	STR 810
	DDX=D2(K)/D2(K+1)	STR 820
52	GU IU 54 CONTINUE	STR 830
00	$DDX = D2(K+1) \neq D2(K)$	STR 850
54	CONTINUE	STR 860
C		STR 870
	D0 55 I=2,7	STR 880
	DO 56 I=1 8	STR 890
	FCT(J) = CB(J-1,J)	STR 910
	FCT2(J) = CB(I, J)	STR 920
56	CONTINUE	STR 930
	FCTR1=FTABLE(ROVDB, FCT1, RDX, 8)	STR 940
	FCIR2-FIABLE(ROVDB, FCI2, RDA, O) SCB(K) = ABS((HBX-HOVBB(I-1))/(HOVBB(I)-HOVBB(I-1))*(FCTB2-FCTB1)+	STR 950
	*FCTR1)	STR 970
	GO TO 551	STR 980
55	CONTINUE	STR 990
551	CONTINUE	STR1000
u	DO 57 I=2.6	STR1010
	IF(DDX.LE.DOVDT(I)) GO TO 57	STR1030
	DO 58 J=1,11	STR1040
	FCT1(J) = CT(I-1, J)	STR1050
58	FG12(J)=G1(1,J)	STRI060
00	FCTR1=FTABLE(ROVDT, FCT1, RDX, 11)	STR1080
	FCTR2=FTABLE(ROVDT, FCT2, RDX, 11)	STR1090
	SCT(K) = ABS((DDX-DOVDT(I-1))/(DOVDT(I)-DOVDT(I-1))*(FCTR2-FCTR1)+	STR1100
	*FGTR1)	STR1110
57	CONTINIE	STR1120
571	CONTINUE	STR1140
60	CONTINUE	STR1150
C	ON OUR ATTE THE INTERSTELED STREES	STRI160
G	BO 27 I=1.N	STR1180
	STRINT(I)=STR(I)*SCB(I)	STR1190
27	CONTINUE	STR1200
C	DIND THE DOTATIONS AND SHEAD STDESS DHE TO TODSION	STR1210
C	FIND THE RUTATIONS AND SHEAR STRESS DUE TO TORSTON	STR1220
ŭ	CALL TWIST(G, N, X2, SIP, ZP, TM2, TETA, TAU, N00)	STR1240
C		STR1250
С	CALCULATE INTENSIFIED SHEAR STRESSES	STR1260
	DO 28 $I=1, N$ TALLNT(I) - TALL(I) + SCT(I)	STR1270
28	CONTINUE	STR1290
C		STR1300
C	FIND COMBINED STRESSES	STR1310
	DO 30 I=1, N C = C = C = C = C = C = C = C = C = C =	STR1320
	$SIGMAI(1) = .33 \times SIR(1) + .50 \times SQRI(SIR(1) \times 2 + 4 \cdot \times IAU(1) \times 2)$ STB1(1) = .95 \STRUNT(1) + .65 \SORT(STRUNT(1) \x 2 + 4 \cdot \XIAU(1) \times 2)	STR1330
30	CONTINUE	STR1350
C		STR1360
С	CALCULATE CRITICAL SPEED	STR1370
	GRAV=385.92	STR1380
	SUM2=0 0	STR1400
	DO 3 I=1.N	STR1410
	SUM1=SUM1+PW2(I)*DFLW(I)	STR1420
0	SUM2=SUM2+PW2(1)*DFLW(1)**2	STR1430
6	CONTINUE	STR1440
č	ANGULAR FREQUENCY OF FUNDAMENTAL VIBRATIONS	STR1460
	P=SQRT(GRAV*SUM1/SUM2)	STR1470

C		CTD 1400
G	CRITICAL CREER	STR1400
L	CRITICAL SPEED	S1R1490
	RPMCR=30.*P/P1	STR1500
С		STR1510
	IF(IPRT.EQ.0) CO TO 502	STR1520
C		STR1530
C	FIND THE WEIGHT OF SHAFT	STR1540
	WE IGHT = $0, 0$	STB1550
	DO 40 I=2 N	STB1560
	$50 \pm 0.1 \pm 2.1$	STD1570
40	$\frac{1}{2} = \frac{1}{2} = \frac{1}$	OTDIEDO
C	CONTINUE	STRIDOO
u		STR1590
	XA=0.0	STR1600
	XB=L1	STR1610
C	PRINT OUT THE REACTIONS	STR1620
	WEITE(6,240) XA, RAV, RAH, RA, XB, RBV, RBH, RB	STR1630
C		STR1640
C		STR1650
-	WBITE(6, 250)	STB1660
C		STB1670
u	V-0	STD1690
		STRICOO
		STR1090
	DO 48 I=1,N	SIRI700
	D0 481 J=1,NXX	STR1710
	IF(X2(1), NE, XR(J)) GO TO 481	STR1720
	K= K+ 1	STR1730
	WRITE(6,251)K, X2(1), BMV(1), BMH(1), BM(1), TM2(1)	STR1740
	GO TO 48	STR1750
481	CONTINUE	STR1760
48	CONTINUE	STR1770
C		STB1780
ŭ	WRITE($6, 260$)	STR1790
C		STD1000
6	W- O	STRIGUU
		SIRIBIO
	10491=1,N	STR1820
	DO 491 J=1, NXX	STR1830
	IF(X2(I), NE, XR(J)) GO TO 491	STR1840
	K= K+ 1	STR1850
	WRITE(6, 261) K, X2(I), D2(I),	STR1860
	* DFLV(1), DFLH(1), DFL(1), SLV(1), SLH(1), SL(1), TE	STR1870
	*TA(I)	STR1880
	GO TO 49	STB1890
401	CONTINUE	STR 1900
40		STP1010
49	CONTINUE	STR1910
u		SIR1920
	WRITE(6,270)	STR1930
C		STR1940
	K=0	STR1950
	DO 50 I=1,N	STR1960
	DO 501 J=1,NXX	STR1970
	IF(X2(I), NE, XR(J)) GO TO 501	STR1980
	K= K+ 1	STR1990
	WBITE(6, 271)K, X2(1), STRV(1), STRH(1), STR(1), TAU(1), SIGMA1(1), SCB(1)	STR2000
	* SCT(1) STRINT(1), TAUINT(1), STR1(1)	STB2010
	CO TO 50	GTROADA
FOI		STDOADA
501		STR2000
20	CONTINUE	S1R2040
G		STR2050
C	PRINT OUT WEIGHT OF SHAFT	STR2060
	WRITE(6,280) WEIGHT	STR2070
C		STR2080
C	PRINT OUT FUNDAMENTAL FREQUENCY	STR2090
C		STR2100
	WRITE(6,281)P, RPMCR	STR2110
C		STR2120
502	CONTINUE	STR2130
C		STR2140
u	DETTIDN	STPOISA
0	iter of the	STR2100
G	PODVAW/ 111	5112160
240	FURNATE IHI,	S1R2170
	* /////, 19X, 11H0UTPUT DATA, /, 19X, 11H**********, ////, 19X,	STR2180
	*45H X VERTICAL HORIZONTAL REZULTANT, //, 10X,	STR2190
	*F9.3,3F12.0,//,10X,	STR2200
	*F9.3,3F12.0,//)	STR2210

C STR2220 250 FORMAT(////, 10X, 38H BENDING MOMENTS AND TORSIONAL MOMENTS ,//, 10X STR2230 , /, 12X, X *========= STR2250 BENDING MOMENT TORSION MOME STR2260 *64HNO *NT ,/, 12X, STR2270 *45H VERT HORIZ RES ,/, 12X, STR2280 *62H LBIN LBIN STR2290 *,/,10X, STR2300 STR2310 *========) STR2320 C STR2330 251 FORMAT(/, 10X, 14, F10.3, 2X, 4F12.0) STR2340 C STR2350 260 FORMAT(1H1. STR2360 ////, 10X, 32HDEFLECTIONS, SLOPES AND ROTATIONS , //, 10X, * STR2370 STR2380 ./. 11X. STR2390 5 ,35H STR2400 *2HNR X DIA DEFLECTION * SLOPE ROTATION ,/,22X, STR2410 ,26H VERT *45H VERT HORIZ RES HO STR2420 *RIZ RES ./. 12X. STR2430 *52H IN IN IN ,44H RAD STR2440 IN IN * RAD RAD RAD ,/, 10X, STR2450 STR2460) STR2470 C STR2480 261 FORMAT(/, 10X, 14, 2F10.3, 7F10.6) STR2490 C STR2500 270 FORMAT(1H1,////, 10X, 8HSTRESSES, //, 10X, STR2510 STR2520 *-----,/,10X, 116 STR2530 BENDING STRESSES TORSION **COMBIN STR2540** *H NR Х INT FCT INTENSIFIED STRESS *ED 118 STR2550 , /, 10X, STRESS STRES STR2560 ***H** VERT HORIZ RES 116 STR2570 *5 BEND TORS BEND TORS COMB ,/,10X, PSI PSI ***H** IN PSI PSI PSI STR2580 PSI PSI PSI ,/,10X, STR2590 * STR2610 3 C STR2620 271 FORMAT(/, 10X, 14, 11F10.3) STR2630 C STR2640 FORMAT(////, 10X, 16HWEIGHT OF SHAFT= ,F10.0,4H LBS,//) 280 STR2650 FORMAT(10X, 52HANGULAR FREQUENCY OF FUNDAMENTAL MODE OF VIBRATIONS STR2660 281 *=, F10.3, 7HRAD/SEC, //, 10X, 15HCRITICAL SPEED=, F10.3, 3HRPM) STR2670 С STR2680 END STR2690

	SUBROUTINE MAXIM(A, AMAX, M)	MAX	10
C		MAX	20
C	DIMENSION A(1)	MAX MAX	30 40
	AMAX=A(1)	MAX	50
	DO 1 I=2, M	MAX	60
	IF(A(I).GT.AMAX) AMAX=A(I)	MAX	70
1	CONTINUE	MAX	80
C		MAX	90
	RETURN	MAX	100
	END	MAX	110

	SUBROUTINE RANGE	RAN	10
C	TELESCOPERSESSES	13 A 31	00
	* (X, FW, FV, PH, UNFW, UNFV, UNFH, TH, J, SGF, XI, FWI, FVI, PHI, UNFWI • INFU1 INFH1 TM1 D1 SGF1 V9 PW9 PW9 PH9 INFW9 INFW9 INFW9 TM9 D9	RAN	20
	*, ONF V1, ONF H1, 1H1, D1, SGF 1, A2, 1 w2, 1 w2, 1 H2, ONF w2, ONF v2, ONF H2, 1H2, D2, $*SCF2$, RAD, RAD2, NX, N(0)	RAN	40
C		RAN	50
	DIMENSION X1(N00), X2(N00), PV1(N00), PV2(N00), PH1(N00), PH2(N00),	RAN	60
	*UNFV1(N00), UNFV2(N00), UNFH1(N00), UNFH2(N00), TM1(N00), TM2(N00),	RAN	70
	*PW1(N00), PW2(N00), UNFW1(N00), UNFW2(N00), D1(N00), D2(N00), SCF1(N00), *SCF2(N00), BAD1(N00), BAD2(N00)	RAN	80
С	*SUP2(100), IGD1(100), IGD2(100)	RAN	100
Ĉ	THE SUBROUTINE PLACES THE INPUT DATA IN ARRAYS IN INCREASING ORDER	RAN	110
C	OF X	RAN	120
C		RAN	130
	$\begin{array}{c} DU & 6 & I=1, NOU \\ IE(Y IE Y I(I)) & CO TO 1 \end{array}$	RAN	140
	$X_2(1) = X_1(1)$ (0) (0) (0) (0) (0) (0) (0) (0) (0) (0)	RAN	160
	PW2(I) = PW1(I)	RAN	170
	PV2(I) = PV1(I)	RAN	180
	PH2(1) = PH1(1)	RAN	190
	$\frac{1}{1000} = \frac{1}{1000} = 1$	RAN	210
	UNFH2(I)=UNFH1(I)	RAN	220
	TM2(1) = TM1(1)	RAN	230
	D2(I)=D1(I)	RAN	240
	SCF2(1) = SCF1(1) PAD2(1) = PAD1(1)	RAN	250
	GO TO 6	RAN	270
1	IF(X.LT.X1(I)) CO TO 3	RAN	280
	X2(I)=X	RAN	290
	PW2(I) = PW1(I) + PW	RAN	300
	PV2(I) = PV1(I) + PV PH2(I) = PH1(I) + PH	RAN	320
	UNFW2(I) = UNFW1(I) + UNFW	RAN	330
	UNFV2(I) = UNFV1(I) + UNFV	RAN	340
	UNFH2(I) = UNFH1(I) + UNFH	RAN	350
	$T_{\rm H2}(1) = 1 T_{\rm H1}(1) + 1 T_{\rm H1}$	RAN	360
	D2(I)=D	RAN	380
	GO TO 11	RAN	390
10	D2(1)=D1(1)	RAN	400
11	CONTINUE	RAN	410
	BAD2(I) = BAD	BAN	430
С		RAN	440
	K= I+1	RAN	450
	DO 2 J=K, NOO	RAN	460
	$PW_2(J) = PW_1(J)$ $PV_2(J) = PV_1(J)$	RAN	470
	PH2(J) = PH1(J)	RAN	490
	UNFW2(J) = UNFW1(J) + UNFW	RAN	500
	UNFV2(J) = UNFV1(J) + UNFV	RAN	510
	UNFH2(J) = UNFH1(J) + UNFH TMO(J) = TM1(J) + TM	RAN	520
	IF(D, EQ, 0, 0) G0 TO 100	RAN	540
	D2(J) = D	RAN	550
	CO TO 101	RAN	560
100	D2(J) = D1(J)	RAN	570
101	CONTINUE SCF2(D = SCF1(D	RAN	590
	RAD2(J) = RAD1(J)	RAN	600
2	CONTINUE	RAN	610
-	GO TO 7	RAN	620
C 2	V2(1) = V	RAN	640
0	PW2(I) = PW	RAN	650
	PV2(I) = PV	RAN	660
	PH2(I)=PH	RAN	670
	UNFW2(1) = UNFW1(1-1) + UNFW $UNFW2(1) = UNFV1(1-1) + UNFV$	RAN	600
	UNFH2(I) = UNFH1(I-1) + UNFH	RAN	700
	TM2(I) = TM1(I-1) + TM	RAN	710
	IF(D.EQ.0.0) GO TO 30	RAN	720
	D2(1)=D	RAN	730

30 31 C	CO TO 31 D2(I)=D1(I-1) CONTINUE SCF2(I)=SCF RAD2(I)=RAD NX=NX+1 K=I+1			RAN 740 RAN 750 RAN 760 RAN 770 RAN 780 RAN 790 RAN 800 RAN 810
	D0 4 $J=K, N00$ X2(J)=X1(J-1) PW2(J)=PW1(J-1) PV2(J)=PV1(J-1) PH2(U)=PV1(J-1)			RAN 820 RAN 830 RAN 840 RAN 850 RAN 850
	UNFW2(J) = UNFW1(J-1) + UNFW UNFW2(J) = UNFV1(J-1) + UNFW UNFW2(J) = UNFW1(J-1) + UNFW UNFH2(J) = UNFH1(J-1) + UNFH TM2(J) = TM1(J-1) + TM			RAN 870 RAN 880 RAN 890 RAN 900
200	IF(D.EQ.0.0) CO TO 300 D2(J)=D CO TO 301 D2(J)=D1(J=1)			RAN 910 RAN 920 RAN 930
301	CONTINUE SCF2(J) = SCF1(J-1) RAD2(J) = RAD1(J-1)			RAN 940 RAN 950 RAN 960 RAN 970
4 C	CONTINUE GO TO 7			RAN 980 RAN 990 RAN1000
6 7 C	CONTINUE			RAN 1010 RAN 1020 RAN 1030 BAN 1040
	X1(I)=X2(I) PW1(I)=PW2(I) PV1(I)=PV2(I)			RAN 1050 RAN 1060 RAN 1070
	PH1(I)=PH2(I) UNFW1(I)=UNFW2(I) UNFV1(I)=UNFV2(I) UNFV1(I)=UNFV2(I)			RAN 1080 RAN 1090 RAN 1100
	TM1(I) = TM2(I) D1(I) = D2(I) SCF1(I) = SCF2(I)			RAN1120 RAN1130 RAN1140
8 C	RAD1(I)=RAD2(I) CONTINUE			RAN1150 RAN1160 RAN1170 RAN1120
	END			RAN1190

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с	SUBROUTINE TWIST(G, N, X, SIP, ZP, TM, TETA, TAU, N00)	TWI	10
č		TWI	20
C	THE SUBROUTINE CALCULATES THE ANGLE OF TWIST ON A CIRCULAR SHAFT	TWI	30
C	AND SHEAR STRESS DUE TO TORSION	TWI	40
C		TWI	50
	DIM_NSION X(NOO),SIP(NOO),TM(NOO),TETA(NOO),TAU(NOO),ZP(NOO)	TWI	60
C		TWI	70
	TETA(1) = 0.0	TWI	80
	DO 1 I=2, N	TWI	90
	TETA(I) = TM(I) / (G*SIP(I)) * (X(I) - X(I-1)) + TETA(I-1)	TWI	100
1	CONTINUE	TWI	110
	DO 2 I=1,N	TWI	120
	TAU(I) = TM(I) / ZP(I)	TWI	130
2	CONTINUE	TWI	140
C		TWI	150
	RETURN	TWI	160
	END	TWI	170

BEND(E,L1,L2,N1,N2,N,X,SI,Z,P,BM,DFL,SL,STR,RA,RB, SUBROUTINE *NOO, BMOM, DEFL, SLOPE, WORKB, WORKC, WORKD, WORKE, WORKF, WORKG, WORKH, *WORKI) THE SUBROUTINE CALCULATES BENDING STRESSES IN ONE PLANE ALONG THE SHAFT REAL L1.L2.L DIMENSION X(NO0), SI(NO0), Z(NO0), P(NO0), BM(NO0), DFL(NO0), SL(NO0), *STR(N00), BMOM(N00), DEFL(N00), SLOPE(N00), WORKB(N00), WORKC(N00), *WORKD(N00), WORKE(N00), WORKF(N00), WORKG(N00), WORKH(N00), WORKI(N00) DO 1 I=1,N BM(I)=0.0 DFL(I)=0.0 SL(I)=0.0 CONTINUE RA=0.0 RB=0.0 L=L1+L2DO 6 I=1,N IF(P(I).EQ.0.0) GO TO 6 IF(X(I).GT.L1) GO TO 4 A=X(I) PA=P(I) CALL FORCE(E, L1, N1, X, PA, A, SI, BMOM, DEFL, SLOPE, RRA, RRB, N00, *STR, WORKB, WORKC, WORKD, WORKE, WORKF, WORKG, WORKH, WORKI) RA=RA+RRA

2 C

4 C

C

C

C

C

C

C

C

1

C

C

C

RB=RB+RRB DO 2 J=1,N1 BM(J) = BM(J) + BMOM(J)DFL(J)=DFL(J)+DEFL(J) SL(J) = SL(J) + SLOPE(J)CONTINUE N11=N1+1 DO 3 K=N11,N DFL(K) = (X(K) - L1) * SLOPE(N1) + DFL(K)SL(K)=SLOPE(N1)+SL(K) CONTINUE 3 GO TO 6 CONTINUE C=X(I)-L1 PC=P(I) CALL FORCEX(E,L,L1,N,N1,X,PC,C,SI,BMOM,DEFL,SLOPE,RRA,RRB,N00, *STR, WORKE, WORKC, WORKD, WORKE, WORKF, WORKG, WORKH, WORKI) RA=RA+RRA RB=RB+RRB DO 5 J=1,N BM(J) = BM(J) + BMOM(J)DFL(J) = DFL(J) + DEFL(J)

5 6 C

C

DO 7 I=1,N STR(I) = BM(I) / Z(I) 7 CONTINUE RETURN

CONTINUE

CONTINUE

SL(J) = SL(J) + SLOPE(J)

END

BEN

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BEN 130

BEN 140

BEN 170

BEN 180 BEN 190

BEN 200

BEN 210

BEN 220

BEN 230

BEN 240

BEN 250

BEN 260 BEN 270

BEN 280 BEN 290

BEN 300

BEN 310

BEN 320

BEN 330

BEN 340

BEN 350

BEN 360

BEN 370

BEN 380

BEN 390

BEN 400

BEN 410

BEN 420

BEN 430

BEN 440

BEN 450

BEN 460

BEN 470

BEN 480

BEN 490

BEN 500

BEN 510

BEN 520

BEN 530

BEN 540

BEN 550

BEN 560

BEN 570

BEN 580

BEN 590

BEN 600

BEN 610

BEN 620

BEN 630

BEN 640

BEN 650

BEN 660

c	SUBROUTINE FORCE (E,L,N,X,P,A,SI,BMOM, DEFL, SLOPE, RA, RB, N00,	FOR	10
6	* KODEA VODED VODEC VODE VODE VODEC VODEC VODECI	FOD	00
C	* WORKA, WORKE, WORKE, WORKE, WORKE, WORKE, WORKE, WORKE,	FOR	20
G	THE SUBDOILTINE ON CHI ATES MOMENTS AND DEELECTIONS OF A DEAM OF	FOR	10
G	THE SUBRUCTINE CALCULATES FOTENTS AND DEFLECTIONS OF A BEAM OF	FOR	50
G	CONCENTRATED FORCE AT ANY DOINT DETWIEN THE CURDON'S	FUR	50
G	CONCENTRATED FORCE AT ANY POINT BETWEEN THE SUPPORTS	FUR	60
C		FOR	70
	REAL L	FOR	80
	DIMENSION X(NOO), SI(NOO), BHOM(NOO), DEFL(NOO), SLOPE(NOO),	FOR	90
	* WORKA(N00), WORKB(N00), WORKB(N00), WORKD(N00),	FOR	100
~	*WORKE(N00), WORKF(N00), WORKG(N00), WORKH(N00), WORKI(N00)	FOR	110
C		FOR	120
	DO 10 1=1, N	FOR	130
	BMOM(1) = 0.0	FOR	140
	$\text{DEFL}(\mathbf{I}) = 0 \cdot 0$	FOR	150
	SLOPE(1) = 0.0	FOR	160
10	CONTINUE	FOR	170
C		FOR	180
	B=L-A	FOR	190
C	CALCULATE REACTIONS IN SUPPORT POINTS	FOR	200
	RA=P*B/L	FOR	210
	RB=P*A/L	FOR	220
C		FOR	230
C	CALCULATE THE DISTRIBUTION OF THE BENDING MOMENT ALONG THE SHAFT	FOR	240
	DO 2 I=1,N	FOR	250
	IF(X(I).GT.A) CO TO 1	FOR	260
	$BMOM(I) = RA \times X(I)$	FOR	270
	GO TO 2	FOR	280
1	$BMOM(I) = RA \times X(I) - P \times (X(I) - A)$	FOR	290
2	CONTINUE	FOR	300
C		FOR	310
C		FOR	320
	NN=N+2	FOR	330
	CALL DEFLEC(E,L,N,N00,X,SI,BMOM,DEFL,SLOPE,WORKA,WORKE,WORKC,	FOR	340
	*WORKD, WORKE, WORKF, WORKG, WORKH, WORKI, NN)	FOR	350
C		FOR	360
	RETURN	FOR	370
	END	FOR	380

SUBROUTINE FORCEX(E,L,L1,N,N1,X,PC,C,SI,BMOM,DEFL,SLOPE,RA,RB,N00,	FOR
*DD, SS, WORKC, WORKD, WORKE, WORKF, WORKG, WORKH, WORKI)	FOR
THE SUBBOILTINE CALCHIATES MOMENTS AND DEFLECTIONS OF A BEAM OF	FOR
VARIABLE MOMENT OF INERTIA, SIMPLY SUPPORTED, WITH CONCENTRATED	FOR
FORCE AT ANY POINT OUTSIDE OF SUPPORTS	FOR
REAL L.L1	FOR
DIMENSION X(N00), SI(N00), BMOM(N00), DEFL(N00), SLOPE(N00)	FOR
*, DD(NOO), SS(NOO), WORKC(NOO), WORKD(NOO), *VOBKE(NOO), WOBKF(NOO), WOBKC(NOO), WOBKH(NOO), WOBKI(NOO)	FOR
	FOR
$\begin{array}{c} \text{DO} 10 \text{I}=1, \text{N} \\ \text{DNOM}(1)=0, 0 \end{array}$	FOR
DEFL(1) = 0.0	FOR

10 C

C

C

C C C

C

C

DD(I) = 0.0

SS(I)=0.0

SLOPE(I) = 0.0

CONTINUE CALCULATE REACTIONS IN SUPPORT POINTS C RA=-PC*C/L1

RB=PC*(C+L1)/L1 FOR 230 FOR 240 С CALCULATE THE DISTRIBUTION OF THE BENDING MOMENT ALONG THE SHAFT C FOR 250 FOR 260 F=L1+CDO 2 I=1,N FOR 270 IF(X(I).GT.L1) GO TO 1 FOR 280 BMOM(I) = RA*X(I) FOR 290 GO TO 2 FOR 300 CONTINUE 1 FOR 310 IF(X(I).GT.F) GO TO 2 FOR 320 BMOM(I) = RA*X(I) + RB*(X(I) - L1) FOR 330 2 CONTINUE FOR 340 NN=N+2 FOR 350 C FOR 360 CALL DEFLEC(E,L,N,N00,X,SI,BMOM,DD,SS,DEFL,SLOPE,WORKC,WORKD, FOR 370 *WORKE, WORKF, WORKG, WORKH, WORKI, NN) FOR 380 C FOR 390 DO 3 I=1,N FOR 400 DEFL(I) = DD(I) - DD(N1) / L1 * X(I)FOR 410 SLOPE(I)=SS(I)-DD(N1)/L1 FOR 420 3 CONTINUE FOR 430 FOR 440

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C
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RETURN END

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FOR 100

FOR 110

FOR 120

FOR 130

FOR 140

FOR 150

FOR 160

FOR 170

FOR 180

FOR 190

FOR 200

FOR 210

FOR 220

FOR 450

FOR 460

C	SUBROUTINE DEFLEC(E,L,N,N00,X,SI,BMOM,DEFL,SLOPE,XX,SSI,BBMOM,TETA	DEF	10
u .	*. CG. DDEFL. XDEFL. BMOMA. SSLOPE. NN)	DEF	20
C	,,,,,,,,,,,	DEF	30
C	THE SUBROUTINE CALCULATES DEFLECTIONS AND SLOPES ALONG A BEAM WITH	DEF	40
C	KNOWN DISTRIBUTION OF BENDING MUMENT AND MOMENT OF INERITA	DEF	50
u	REAL L	DEF	70
	DIMENSION X(N00), SI(N00), BMOM(N00), DEFL(N00), SLOPE(N00),	DEF	80
	* XX(N00), SSI(N00), BBMOM(N00), TETA(N00), CG(N00), DDEFL(N00 *) VDEFL(N00), BMOMA(N00), SSI OPE(N00)	DEF	90
C	*), ADEF L(NOO), BHOHA(NOO), SSLOI E(NOO)	DEF	110
-	DO 100 I=1,NN	DEF	120
	TETA(I) = 0.0	DEF	130
	CG(1) = 0.0 DDFFL(1) = 0.0	DEF	140
	XDEFL(I) = 0.0	DEF	160
	BMOMA(I) = 0.0	DEF	170
100	SSLOPE(1) = 0.0	DEF	180
C	CONTINOE	DEF	200
C	ADD TWO STATION ON THE SHAFT CLOSE TO ENDS	DEF	210
	DO 1 I=3, N	DEF	220
	SSI(1) = SI(1-1)	DEF	230
	BBMOM(I) = BMOM(I-1)	DEF	250
1	CONTINUE	DEF	260
C	$\nabla Y(1) = V(1)$	DEF	270
	XX(2) = L/10000.	DEF	290
	XX(N+1)=L-L/10000.	DEF	300
	XX(N+2) = X(N)	DEF	310
	SSI(2) = SI(1)	DEF	330
	SSI(N+1)=SI(N-1)	DEF	340
C	SSI(N+2) = SI(N)	DEF	350
4	BBMOM(1) = BMOM(1)	DEF	370
	BBMOM(2) = (BMOM(2) - BMOM(1)) / (X(2) - X(1)) * (XX(2) - XX(1)) + BMOM(1)	DEF	380
	BBMOM(N+1) = (PMOM(N) - PMOM(N-1)) ((Y(N) - Y(N-1))) (Y(N+2) - YY(N+1)) (Y(N+2) - YY(N+2)) (Y(N+2) - YY(N+	DEF	390
	* $-(BHOH(N) - BHOH(N - 1)) / (X(N) - X(N - 1)) * (XX(N + 2) - XX(N + 1)) + *BMOM(N)$	DEF	410
	BBMOM(N+2) = BMOM(N)	DEF	420
C	DETERMENT ADDA MOMENT AND DOTATIONS FOR THE N. 1 INTERVALS	DEF	430
u	NNN=N+1	DEF	450
С		DEF	460
	DO 2 I=1, NNN	DEF	470
	BMOMA(I) = (BBMOM(I) + BBMOM(I+1))/2.*(XX(I+1) - XX(I))	DEF	490
	CO TO 4	DEF	500
3	CONTINUE	DEF	510
4	CONTINUE	DEF	520
r	$TETA(I+1) = TETA(I) + BMOMA(I) / (E \times SSI(I))$	DEF	540
2	CONTINUE	DEF	550
C	DETERMINE THE DEFLECTIONS ALONG THE SHAFT	DEF	560
U	TDEFL=0.0	DEF	580
	DO 7 I=1, NNN	DEF	590
C	CENTED OF CRAVITY OF ADEA MOMENT	DEF	600
C.	XA=XX(I)	DEF	620
	XB=XX(I+1)	DEF	630
	IF $(XB-XA)$. EQ. 0.0) GO TO 60	DEF	640
	$Y_1 = (XB - XA)/2.$	DEF	660
	A1 = BBMOM(I) * (XB-XA)	DEF	670
	Y2=(XB-XA)*2./3.	DEF	680
	$A = (DDDDT(1+1) - DDDDT(1)) \neq (XD - XA)/2.$	DEF	700
5	$Y_1 = (XB - XA)/2.$	DEF	710
	A1 = BBMOM(I+1) * (XB-XA)	DEF	720
	12-(AD-AA)/3.	DEF	130

A2=-(BBMOM(I+1)-BBMOM(I))*(XE-XA)/2. 6 CONTINUE AAA=A1+A2 IF(AAA.EQ.0.0) CO TO 60 CG(I) = (A1*Y1+A2*Y2)/(A1+A2)GO TO 61 60 CG(I)=0.0 CONTINUE 61 CGB=L-(XA+CG(I))TDEFL=BMOMA(I) *CGB/(E*SSI(I)) +TDEFL CONTINUE 7 C DO 9 I=2, NN DEFLJ=0.0 II = I - 1C DO 8 J=1, II CGI=XX(I)-(CG(J)+XX(J))DEFLJ=BMOMA(J)*CGI/(E*SSI(J))+DEFLJ 8 CONTINUE XDEFL(I) = TDEFL/L*XX(I) DDEFL(I) = XDEFL(I) - DEFLJ 9 CONTINUE C C C DETERMINE THE END SLOPES TETAA=DDEFL(2)/XX(2) TETAB=DDEFL(N+1)/(L-XX(N+1)) C C DETERMINE SLOPES ALONG THE BEAM DO 10 I=1,NN SSLOPE(I) = TETAA-TETA(I) 10 CONTINUE C ELIMINATE THE TWO POINTS ADDED C DEFL(1) = DDEFL(1)SLOPE(1)=SSLOPE(1) III=N-1DO 11 I=2, III DEFL(I) = DDEFL(I+1) SLOPE(I)=SSLOPE(I+1) 11 CONTINUE DEFL(N) = DDEFL(NN) SLOPE(N) = SSLOPE(NN) C RETURN END

DEF 740 DEF 750 DEF 760 DEF 770 DEF 780 DEF 790 DEF 800 DEF 810 DEF 820 DEF 830 DEF 840 DEF 850 DEF 860 DEF 870 DEF 880 DEF 890 DEF 900 DEF 910 DEF 920 DEF 930 DEF 940 DEF 950 DEF 960 DEF 970 DEF 980 DEF 990 DEF1000 DEF1010 DEF1020 DEF1030 DEF1040 DEF1050 DEF1060 DEF1070 DEF1080 DEF1090 DEF1100 **DEF1110 DEF1120 DEF1130 DEF1140 DEF1150 DEF1160** DEF1170 **DEF1180 DEF1190 DEF1200**

C	FUNCTION FTABLE(VAR, FUNC, XX, M)	FTA	10
C		FTA	20
	DIMENSION VAR(1), FUNC(1)	FTA	30
C		FTA	40
	NEND=M-1	FTA	50
	DO 10 I=1, NEND	FTA	60
	INT= I	FTA	70
	IF(XX.GT.VAR(I).AND.XX.LE.VAR(I+1))G0 T0 11	FTA	80
10	CONTINUE	FTA	90
C		FTA	100
11	FTABLE=FUNC(INT)+(XX-VAR(INT))*(FUNC(INT+1)-FUNC(INT))/(VAR(INT+1)	FTA	110
	*-VAR(INT))	FTA	120
C		FTA	130
	RETURN	FTA	140
	END	FTA	150

С	SUBROUTINE SHAFTP(XDIA, DIA, RAD, A, ND, XX, YY, WORK3, WORK4)	SHA	10
C	DIMENSION XDIA(ND), DIA(ND), BAD(ND), XX(1), YY(1), WOBK3(1), WOBK4(1)	SHA	20
C		SHA	40
-	CALL DATE(THEDATE)	SHA	50
	CALL LETTER(8,.24,90.,.5,1.0,6HL.POPA)	SHA	60
	CALL LETTER(10,.125,90.,.75,1.0, THEDATE)	SHA	70
_	CALL PLOT(1.5,0.0,-3)	SHA	80
C		SHA	90
	XN=18.	SHA	100
	INFI.	SHA	110
	VN=16.5	SHA	120
	XN=.75	SHA	140
	IF (XDIA(ND).GT.500.) GO TO 11	SHA	150
	IF(XDIA(ND).GT.200.) G0 TO 12	SHA	160
	IF(XDIA(ND).GT.100.) CO TO 13	SHA	170
	IF(XDIA(ND).GT. 50.) CO TO 14	SHA	180
	IF(XDIA(ND).GT. 25.) GO TO 15	SHA	190
	$16 \times 16 \times 16 \times 12.5 = 60 \times 10 \times 16 \times 10^{-10} \times 10^{-$	SHA	200
	ASUALE0	SHA	210
	CO TO 17	SHA	220
C		SHA	240
11	XSCALE=16.	SHA	250
	CALL LETTER(18,.1,0.0,XN,YN,18HSCALE 3/4IN=1FT)	SHA	260
	GO TO 17	SHA	270
12	XSCALE=12.	SHA	280
	CALL LETTER(18,.1,0.0,XN,YN,18HSCALE 1IN=1FT)	SHA	290
10		SHA	300
13	xSCALE=8.	SHA	310
	CALL LETTER 16, 1, 0.0, AN, IN, IONSCALE 1-1/21N-1F1)	SHA	320
14		SHA	340
11	CALL LETTER(181.0.0.XN, YN, 18HSCALE 3IN=1FT)	SHA	350
	GO TO 17	SHA	360
15	XSCALE=2.	SHA	370
	CALL LETTER(13,.1,0.0,XN,YN,18HSCALE HALF FULL)	SHA	380
	GO TO 17	SHA	390
16	XSCALE=1.	SHA	400
	CALL LETTER(18, 1, 0.0, XN, YN, 18HSCALE FULL)	SHA	410
C ¹⁷	CONTINUE	SHA	420
6		SHA	430
	V=-2.*XSCALE	SHA	450
	W=-7.*YSCALE	SHA	460
	XMIN=-1.8*XSCALE	SHA	470
	XMAX=60.*XSCALE	SHA	480
	YMIN=-6.5*YSCALE	SHA	490
0	YMAX=3.*YSCALE	SHA	500
G	CALL DITING VOCALE VOCALE V & WIN VMAY VMIN VMAY	SHA	510
C	CALL FLITHCASCALE, ISCALE, V, W, AMIN, AMAX, IMIN, IMAX)	SHA	520
č	PLOT THE CENTER LINE	SHA	540
u i		SHA	550
	$X^2 = XDIA(ND)$	SHA	560
	$Y_1=0.0$	SHA	570
	Y2=0.0	SHA	580
	CALL UNITTO(X1,Y1,XP1,YP1)	SHA	590
	XX(1) = XP15	SHA	600
	CALL 011110(X2, Y2, XP2, YP2)	SHA	610
	AA(2) - AP2 + 0 VV(1) = VP1	SHA	620
	YY(2) = YP2	SHA	640
	NDIM=2	SHA	650
	DASH1=1.0	SHA	660
	DASH2=.1	SHA	670
	GAP=.15	SHA	680
	UN I T=.3	SHA	690
	N= 1	SHA	700
0	CALL DDASHM(XX, YY, NDIM, DASH1, DASH2, N, GAP, UNIT, IE, WORK3, WORK4)	SHA	710
C C	DI OTI THE CHAPT	SHA	720
L.	LUI INE SHAFI	SHA	130

C X1 = XDIA(1)Y1=DIA(1)/2. X2=X1 Y2 = -Y1CALL PLTLN(X1, Y1, X2, Y2) DO 1 I=2,ND IF(I.EQ.ND) GO TO 10 IF(DIA(I).EQ.DIA(I-1)) GO TO 1 10 X1=XDIA(I) Y1=DIA(I)/2 IF(DIA(I).LT.DIA(I-1)) Y1=DIA(I-1)/2. X2=X1 Y2=-Y1 CALL PLTLN(X1, Y1, X2, Y2) 1 CONTINUE С C DRAW HORIZONTAL LINES AND QUARTER CIRCLES FOR SHOULDER RADIUS DEV=.005 NND = ND - 1DO 4 I=1, NND X1=XDIA(I) Y1=DIA(1)/2. X2=XDIA(I+1)Y2=Y1 IF(RAD(I).GE.10000.) GO TO 2 IF(DIA(I).GT.DIA(I-1)) GO TO 2 XA=XDIA(I) YA=DIA(I)/2.+RAD(I) XB=XDIA(I)+RAD(I) YB=DIA(I)/2. XC=XB YC=YA CALL PLTARC(XA, YA, XB, YB, XC, YC, DEV) CALL UNITTO(XC, YC, XCP, YCP) X3=XCP+.15 Y3=YCP+.15 X4=XC-RAD(I)/SQRT(2.) Y4=YC-RAD(I)/SQRT(2.) CALLUNITTO(X4, Y4, X4P, Y4P) CALL ARROW(X3, Y3, X4P, Y4P, 3) RADM=RAD(I) XN=X3+.03 CALL NUMBER(XN, Y3, . 100, RADM, 0.0, 6H(F5.3)) XN=X3+.55 CALL LETTER(10, . 100, 0.0, XN, Y3, 3HRAD) X1 = XBY1 = YBYA=-YA YB=-YB YC=-YC CALL PLTARC(XB, YB, XA, YA, XC, YC, DEV) C 2 CONTINUE IF(RAD(I+1).GE.10000.) GO TO 3 IF(DIA(I).GT.DIA(I+1)) GO TO 3 XA=XDIA(I+1)-RAD(I+1) YA=DIA(I)/2. XB=XDIA(I+1) YB=DIA(I)/2.+RAD(I+1) XC=XA YC=YB CALL PLTARC(XA, YA, XB, YB, XC, YC, DEV) CALL UNITTO(XC, YC, XCP, YCP) X3=XCP-.15 Y3=YCP+.15 X4=XC+RAD(I+1)/SQRT(2.) Y4=YC-RAD(I+1)/SQRT(2.) CALL UNITTO(X4, Y4, X4P, Y4P) CALL ARROW(X3, Y3, X4P, Y4P, 3) RADM=RAD(I+1) XN=X3-.85

CALL NUMBER(XN, Y3, . 100, RADM, 0.0, 6H(F5.3))

SHA 740

SHA 750

SHA 760

SHA 770

SHA 780

SHA 790

SHA 800

SHA 810

SHA 820

SHA 830

SHA 840

SHA 850

SHA 860

SHA 870

SHA 880

SHA 890

SHA 900

SHA 910 SHA 920

SHA 930

SHA 940

SHA 950

SHA 960

SHA 970

SHA 980

SHA 990

SHA1000

SHA1010

SHA1020

SHA1030

SHA1040

SHA1050

SHA1060

SHA1070

SHA1080

SHA1090

SHA1100

SHA1110

SHA1120

SHA1130

SHA1140

SHA1150

SHA1160 SHA1170

SHA1180

SHA1190

SHA1200

SHA1210

SHA1220

SHA1230

SHA1240

SHA1250

SHA1260

SHA1270

SHA1280

SHA1290

SHA1300

SHA1310

SHA1320

SHA1330

SHA1340

SHA1350

SHA1360

SHA1370

SHA1380

SHA1390

SHA1400

SHA1410

SHA1420

SHA1430

SHA1440

SHA1450

SHA1460

SHA1470

DRAW VERTICAL LINES MARKING SHAFT SHOULDERS

С

XN=X3-.32 CALL LETTER(10, . 100, 0.0, XN, Y3, 3HRAD) X2=XA Y2=YA YA=-YA YB=-YB YC=-YC CALL PLTARC(XB, YB, XA, YA, XC, YC, DEV) 3 CONTINUE CALL PLTLN(X1, Y1, X2, Y2) Y1=-Y1 Y2=-Y2 CALL PLTLN(X1, Y1, X2, Y2) 4 CONTINUE DRAW DIMENSION LINES DO 5 I=1,ND X1=XDIA(I) Y1=-DIA(1)/2. X2=X1 Y2=-DIA(1)/2.-(FLOAT(1)*.38+.2)*YSCALE IF(XDIA(1).EQ.0.0) GO TO 40 IF(XDIA(I).EQ.A) GO TO 40 CALL PLTLN(X1, Y1, X2, Y2) GO TO 5 CONTINUE 40 CALL UNITTO(X1, Y1, XP1, YP1) XX(1) = XP1YY(1) = YP1Y2=-DIA(1)/2. CALL UNITTO(X2, Y2, XP2, YP2) YP2=YP2-FLOAT(ND)*.38-.2 XX(2) = XP2YY(2) = YP2CALL DDASHM(XX, YY, NDIM, DASH1, DASH2, N, CAP, UNIT, IE, WORK3, WORK4) XN=XP1-.06 YN= YP2+1. CALL LETTER(10,.1,90., XN, YN, 10HCL. BEARING) 5 **CONTINUE** DO 6 I=1, NND X1=XDIA(1) Y1=-DIA(1)/2.-(FLOAT(1)*.38+.5)*YSCALE CALL UNITTO(X1, Y1, XP1, YP1) X2=XDIA(I+1) Y2=Y1 CALL UNITTO(X2, Y2, XP2, YP2) CALL ARROW(XP1, YP1, XP2, YP1, 1) DIST=XDIA(I+1)-XDIA(1)XN=DIST/2.5 YN=Y1+.06*YSCALE CALL UNITTO(XN, YN, XPN, YPN) CALL NUMBER(XPN, YPN, . 100, DIST, 0.0, 6H(F7.3)) X1=XDIA(I)+(XDIA(I+1)-XDIA(I))/1.8 Y1=DIA(1)/2. X2=X1 Y2=-Y1 CALL UNITTO(X1, Y1, XP1, YP1) CALL UNITTO(X2, Y2, XP2, YP2) CALL ARROW(XP1, YP1, XP2, YP2, 1) XN=X1-.06*XSCALE YN=-.4*DIA(I) DIAM=DIA(I) CALL UNITTO(XN, YN, XPN, YPN) CALL NUMBER(XPN, YPN, . 100, DIAM, 90., 6H(F7.3)) 6 CONTINUE RETURN END

SHA1480

SHA1490

SHA1500 SHA1510

SHA1520

SHA1530

SHA1540

SHA1550

SHA1560

SHA1570

SHA1580

SHA1590

SHA1600

SHA1610

SHA1620

SHA1630

SHA1640

SHA1650

SHA1660

SHA1670

SHA1680

SHA1690

SHA1700

SHA1710

SHA1720

SHA1730

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SHA1780

SHA1790

SHA1800

SHA1810

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SHA1830 SHA1840

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SHA1910

SHA1920

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SHA1940

SHA1950

SHA1960

SHA1970

SHA1980

SHA1990

SHA2000

SHA2010

SHA2020

SHA2030

SHA2040

SHA2050

SHA2060

SHA2070

SHA2080

SHA2090 SHA2100

SHA2110

SHA2120 SHA2130

SHA2140

SHA2150

C

C

C

SUBROUTINE NUMBER(X, Y, HEIGHT, ANUM, THETA, FMT)	NUM	10
DIMENSION BCD(1)	NUM	20
ENCODE(10, FMT, BCD) ANUM	NUM	30
CALL SYMBOL(X, Y, HEIGHT, BCD, THETA, 10)	NUM	40
RETURN	NUM	50
END	NUM	60

C

APPENDIX B

USERS' MANUAL

PROGRAM SHAFT 1 McMaster University Mechanical Engineering Dept.

> Laurentiu Popa Prof. James N. Siddall

USERS' MANUAL

DESIGN OPTIMIZATION OF A SHAFT ON TWO BEARINGS

1. PURPOSE

Given a shaft of known geometrical configuration and loading, this program will determine diameter sizes along the shaft for which the weight of the shaft will be minimum and the following constraints will be satisfied:

- the stress at any point along the shaft will be below a user set allowable value:
- the maximum deflection will be less than an allowable deflection specified by user;
- the slope of the shaft in bearings will be below an admissible value;
- the torsional deflection will be less than the allowable value;
- the critical speed will be greater than a user specified value;
- the shoulder size at specified points along the shaft will be greater than a specified value (for shoulders adjacent to gear hubs, couplings, bearings, etc.).

Certain diameters will remain of fixed size specified by user (as it may be required by the bearing size, standard parts on shaft, etc.).

2. GEOMETRICAL CONFIGURATION

The shaft is supported on two bearings and can have a cantilever extension (see the example shown on Fig. 1).

The bearings permit slopes of the shaft at bearing point and one of them is free to translate along the axis of the shaft. The location of the bearings and the points where diameter changes size have to be specified by user. Shoulder radius should also be specified by user.

The user can further restrict the configuration of the shaft by specifying a diameter increase or decrease of a minimum value at any point along the shaft. (e.g. He may wish to specify a minimum shoulder size adjacent to bearing, a gear, coupling, etc.)

3. LOADING

The program can take any concentrated or uniformly distributed forces perpendicular to axis or shaft projected in the vertical and horizontal planes and any torsional moments (torques). Gravitational forces attached to the shaft shall be specified separately, these forces being the only ones considered in calculating of the critical speed.

4. METHOD

The input data consisting of information describing geometrical configuration, loading, allowable stresses, deflections, etc. are read and information pertaining to different points of the shaft is arranged in arrays in an order following the axis of the shaft.

The optimization process begins with starting diameter sizes supplied by the user in input data. Deflections and stresses are calculated in all the points along the shaft that are specified in input data. The natural frequency is also calculated.

An unconstrained artificial objective function is calculated. It is defined as follows:

$$P(d_1, d_2...d_n, r) = W(d_1, d_2...d_n) + r \sum_{k=1}^{p} \frac{1}{\Phi_k(d_1, d_2...d_n)}$$
where

 $d_1, d_2 \dots d_n$ are the unknown diameters W $(d_1, d_2 \dots d_n)$ is the weight at the shaft $\Phi_k(d_1, d_2 \dots d_n) \ge 0$ $(k = 1, 2 \dots p)$ are inequality constraints limiting stresses, slopes, critical speed and diameter increase or decrease

r is a positive parameter that is 1.0 at the beginning of the optimization and decreases after each cycle.

A series of steps are taken with varying diameter size following a direct search method and the objective function is minimized until no further improvement can be found.

When calculating deflections, stresses and natural frequencies, the following procedure is applied:

Using the superposition principle, each force is taken alone and reactions in bearings and moments along the shaft are calculated.

The area-moment method is applied to calculate deflections in all required points along the shaft.

The effects of individual forces are totalized in all specified points for all gravitational forces, exterior vertical forces and horizontal forces.

Using the deflections caused by gravitational forces attached to the shaft, the frequency of fundamental mode is calculated for transverse vibrations following Rayleigh's method.

Stresses are calculated in the horizontal and vertical planes and then the geometrical resultant of moments, deflections and stresses are calculated all along the shaft. The torsional deflection and the shear stress caused by torsion is calculated next and then the combined stress is calculated using the maximum strain theory:

$$\overline{U_{c}} = .35 \ \overline{U} + .65 \sqrt{U^{2} + T^{2}}$$

where:

 \widetilde{U} = normal stress (bending) \widetilde{l} = shear stress (torsion) $\widetilde{U_c}$ = combined stress

The intensified stress that appears in some points due to shaft shoulders, keyways, grooves, etc. is calculated by multiplying the stresses calculated as shown above by a stress concentration factor. The stress concentration factor at shaft shoulders is selected by this program from Tables in (6), pages 386 and 388, making use of linear interpolation. Other stress concentration factors are supplied by user. They could also be selected from (6).

The optimum design of the shaft is plotted on a Benson-Lehner Plotter at a suitable scale.

5. INPUT DATA

It is useful to draw a sketch as in the example in Fig. 1 showing the geometrical configuration supports and loading.

Table 1 shows the data cards used to run the program Shaft 1 for the optimization of the shaft shown in Fig. 1. Only the first 40 columns on the cards are shown, their being the only ones used. On the side of the cards is described what the figures represent.

All data fields are 10 columns long. The data should be right justified in their fields. Put the decimal point of real numbers in same field as in example. Put integers right justified without decimal point.



Fig. 1 SHAFT SKETCH FOR SAMPLE RUN

(Beginning Sh 1 10 226.375	RDS own Only) 20 61.000 2	30	DESCRIPTION OF DATA Length of first span and length of
<u>1</u> 10 226.375	61.000 20	30	DESCRIPTION OF DATA
226.375	61.000		Length of first span and length of
Contraction of the second s	2	And the second designed in the second designe	second span
2		2	Number of readings for weights attached to shaft, vertical and horizontal forces
125.125 287.375 60.625 147.125	26500. 24900. 41160. 12000.		Co-ordinate, Force
0	1	0	Number of readings for uniformly distributed weights attached to shaft, vertical and horizontal uniformly distributed forces
170.625	198.625	1286.	Co-ordinate of beginning, co-ordinate of end uniformly distributed force
2	т.		Number of readings for torsional moments
60.625 147.125	147.125 287.375	2619000. 1899000.	Co-ordinate of beginning, co-ordinate of the end, torsional moment
0.000 16.875 50.125 125.125 147.125 147.125 198.625 226.375 272.875 287.375	$ \begin{array}{r} 16.000\\ 20.000\\ 24.000\\ 26.000\\ 24.000\\ 20.000\\ 16.000\\ 16.000\\ 14.000\\ 14.000\\ 14.000\\ \end{array} $		Co-ordinate of point where given diameter starts, diameter size
1			Number of readings for stress concentration factor
181.625	1.300		Co-ordinate, stress concentration factor
7			Number of readings for shoulder radii
16.875 50.125 125.125 147.125 170.625 198.625 272.875	1.000 1.500 0.500 0.500 2.000 1.000 1.000		Co-ordinate, Radius

TABLE 1 - INPUT DATA FOR SAMPLE RUN (SHAFT SHOWN IN FIG. 1)

0.05000	Allowable bending deflection					
0.00100	Allowable slope in bearings					
0.01000	Allowable torsional deflection					
60.	Minimum critical speed					
3	Number of readings for diameters of fixed size					
0.000 16.000 198.625 16.000 272.875 14.000	Co-ordinate, Diameter					
1	Number of readings for minimum diameter increase/decrease					
16.875 1.000	Co-ordinate of shoulder, minimum diameter increase/decrease					

All X co-ordinates of points on shaft are measured from the first bearing (bearing A in our example). Within each group of data, e.g. weights attached to the shaft, vertical forces, etc. keep the cards in a sequence following the X co-ordinates of points of the shaft in an increasing order. Below is shown the complete set of input data and their sequence:

- Length of first span and length of second span (in.).
- 2. Number of weights attached to shaft, number of vertical forces and number of horizontal forces.
- 3. X co-ordinate (in.) and weight attached to shaft (lbs.). Do not show own weight of shaft. This is going to be calculated internally by the program.
- 4. X co-ordinate and exterior vertical force.
- 5. X co-ordinate and horizontal force.
- 6. Number of uniformly distributed weights attached to shaft, number of exterior vertical uniformly distributed forces and number of horizontal uniformly distributed forces.
- 7. X co-ordinate for beginning of uniformly distributed weight, X co-ordinate for end of uniformly distributed weight and uniformly distributed weight (lbs./in.).
- 8. Same as 7 but for exterior vertical uniformly distributed forces.
- 9. Same as 7 but for horizontal uniformly distributed forces.
- 10. Number of torsion moments.
- 11. X co-ordinate for beginning of torsion moment, X co-ordinate for end of torsion moment and torsion moment in lbs./in.

- 12. Number of diameter readings.
- 13. X co-ordinate where diameter of given size starts and diameter size (ins.).
- 14. Number of readings for stress concentration factor.
- 15. X co-ordinate and stress concentration factor. Do not give stress concentration factor for shoulder. This will be calculated internally.
- 16. Number of readings for radii.
- 17. X co-ordinate and shoulder radius.
- 18. Allowable stress (lbs./sq. in.).
- 19. Allowable bending deflection (in.).
- 20. Allowable slope in bearings (rad.).
- 21. Allowable torsional deflection (rad.).
- 22. Minimum critical speed (rpm.).
- 23. Number of diameters of fixed size.
- 24. X co-ordinate and diameter size for sections where diameter must remain of given value.
- 25. Number of readings for diameter increase or decrease.
- 26. X co-ordinate and minimum diameter increase, or decrease.

6. OUTPUT DATA

The following data are printed out:

- input data as supplied by the user;
- data supplied to the direct search optimization Subroutine SEEK3;

- the objective function and the independent variables (unknown diameter sizes) after each optimization cycle;
- the optimum solution consisting of the independent variables and inequality constraints;
- reactions in bearings;
- bending moments and torsional moments;
- diameters;
- bending deflections, slopes and torsional deflections;
- bending stresses, torsion stresses, combined stresses, intensification factors and intensified stresses;
- weight of shaft;
- critical speed.

7. COMMENTS

If a feasible solution is not found during the first minimization cycle, an error message is printed out. In this case, another set of starting diameters should be tried.

If the method has not converged, the current solution is printed out. A new run should be tried with these current diameters as start diameters.

8. SAMPLE RUN

The program has been run for a shaft of geometrical configuration and loading as shown on Sketch in Fig. 1.

Below is the computer print-out for this run and the plot of the optimum design (F(g,2))

SHAFT DESIGN OPTIMIZATION

INPUT DATA

LENGTH	0F	FIRST	SPAN	226.375	IN
LENGTH	0F	SC≠ND	SPAN	61.000	IN

WEIGHTS ATTA	CHED TO SHAFT
×	WEIGHT
125.125	26590.
287.375	24900.

VERTICAL FORCES	
X	FORCE
60.625	43650.
147.125	29190.

HORIZONTAL FORCES

x	FORCE
60.625	41160.
147.125	12000.

VERTICAL UNIFO	RMLY DISTRIB	NTED FORCES
X START	X END	FORCE
179.625	198.625	1286.
TORSIONAL MOME	NTS	
X START	X END	MOMENT
60.625	147.125	2619000.

147.125 237.375 1899000.

DIAMETERS

X	DEA
0.000	16.000
16.875	20.000
50. 425	25.000
125,125	26.000
147.125	24.000
170.625	20.000
198.625	16.000
226. 375	16.000
272.875	14.000
287 . 375	14.000

STRESS CONCENTRATION FACTORS

Х	FACTOR		
181.625	1.300		

RADII

х	RAD
16.875	1.000
50.125	1.500
125.125	• 500
147.125	.510
170.625	2.000
198.625	1.000
272.875	1.000

CIMENSIONS AND LOACING

	=========											
NC	<u>^</u>	CIP	RADII	CONC.FCT.	WEIGHT	VERT.	HORIZ	WEIGHT	VEPT	HORIZ	IURS. FUF.	REPARKS
=====	IN	IN	IN		LB	LB	LB	LEVIN	L8/IN	LB/IN	LBIN	
1	0.000	16.000	0.000	1.00	0.	0.	9.	57.	3.	G .	0.	SUPPORT POINT
2	16.875	16.000	1.000	1.30	0.	0.	0.	57.	0.	0.	0.	
3	16.875	23.000	0.00.0	1.00	0.	3.	с.	89.	0.	0.	С.	
4	50.125	20.000	1.500	1.00	٥.	8.	0.	89.	з.	0.	С.	
5	50.125	25.000	0.000	1.00	0.	0.	0.	139.	0.	0.	с.	
6	60.625	25.000	0.000	1.30	8.	0.	٥.	139.	٥.	0.	с.	
7	60.625	25.000	.3:300	1.00	0.	43650.	41160.	139.	0.	0.	2619000.	
8	125.125	25.000	.500	1.00	0.	0.	G.	139.	Ο.	С.	2619000.	
9	125.125	26.000	0.000	1.00	26500.	Ο.	3.	150.	0.	۵.	2619000.	
10	147.125	26.000	.500	1.00	9.	С.	0.	150.	0.	0.	2619000.	
11	147.125	24.000	0.300	1.90	е.	29190.	12000.	128.	0.	ũ.	1899000.	
12	170.625	24.000	2.000	1.00	0.	9.	0.	128.	0.	0.	1899000.	
13	170.625	20.000	0.000	1.30	0.	0.	0.	89.	1286.	0.	1899000.	
14	181.625	20.000	0.000	1.30	0.	٥.	0.	89.	1286.	Ο.	1899000.	
15	198.625	20.000	1.300	1.90	0.	0.	0.	89.	1286.	٥.	1899000.	
16	198.625	16.000	9.000	1.00	C.	0.	0.	57.	0.	3.	1899000.	
17	226.375	16.000	1.000	1.00	0.		0.	57.	0.	٥.	1899000.	SUPFORT PCINT
18	272.875	16.000	1.000	1.00	0.	0.	ο.	57.	0.	0.	1899000.	
19	272.875	14.000	0.000	1.00	0.	0.	0.	440	0.	٥.	1899000.	
20	287.375	14.000	0.300	1.00	24900.	з.	2.	0.	Э.	٥.	1899000.	END OF SHAFT

ć

ALLOWABLE	STRESS	8000.	LB/SOIN
ALLOWABLE	BENDING BEFLECTION	• 05000	IN
ALL OWA BLE	SLOPE IN BEARINGS	.00100	RAD
ALLOWABLE	TORSIONAL DEFLECTION	.01000	RAD
MINIMUM CR	ITICAL SPEED	60.	RPM

DIAMETERS OF FIXED SIZE X DIA

0.000	16.000
198.625	16.000
272.875	14.000

MINIMUM DIAMETER INCREASE/DECREASE

Х	DIA.INCR.
16.875	1.000

OPTIMIZATION USING DIRECT SEARCH METHOD SEEK3

NUMBER OF INDEPENDENT VARIABLES N = 5 INTERMEDIATE OUTPUT EVERY IFRINT(TH) CYCLE. . . IPRINT = 1 INPUT DATA IS PRINTED OUT FOR IDATA=1 ONLY. . . . TDATA = 1 NUMBER OF INEQUALITY (.GF.) CONSTRAINTS NCOMS = 7 NEQUS = Ω .18000000E+02 .22500000E+02 .23400000E+02 .216999995+92 -180000F+02•22000000E+02 .22000000E+02 .27500000E+02 .28600000E+02 .26400000E+02 .20000009E+92 .25000009E+02 .26000009E+92 .24000000E+02 .2000000E+02 FRACTION OF RANGE USED AS STEP SIZE F = - 2000000F-01 STEP SIZE FRACTION USED AS CONVERGENCE CRITERION. 6 = 1000000E+00 MAXIMUM NUMBER OF MOVES PERMITTED 20 MAXM = PENALTY MULTIPLIER USED IN SEEK3.10000000E+01 R = REDUCTION FACTOR FOR (R) AFTER EACH MINIMIZATION. REDUCE = .50000000E-01

INDEPENDENT VARIABLES X(I)

/

R = U = •10000000E+01 •276343255+05 ·23120000E+02 -24918750E+02 -2392000F+02 .221700005+02 1148500005+02 R = U = .50000000E-01 ·253595669E+05 .20160000E+02 ·24118750E+02 .240500005+02 -22074909E+92 -17790000F+02 R = .25000000E-02 25723025F+05 .19830000E+02 •24918750E+02 ·24154009E+02 ·22026000E+02 179100007+02 .125000005-03 R = ii = 257076845+05 19830000E+02 .24018750E+02 .241995005+02 .22014000E+02 .17805009E+02 .62500000E-05 R = **H** = 257032895+05 .19815000E+02 +24018750E+02 -24199500E+02 .22014000E+02 .17805000E+02 .312500C0E-06 R = 11 = -25701925E+05 19810000E+02 .24018750E+02 -24199500E+02 .220140005+02 17805000E+02 R = 156250 COE-07 $\dot{v} =$.19810000E+02 .24139500E+02 ·25701825E+05 .240137505+02 22014000E+02 178950005+02

OPTEMUM SOLUTION FOUND .25701825E+05 MINIMUM U = 123) .19810000E+02 .24018750E+02 .24199500E+02 .24199500E+02 .22014000E+02 X(X(X(1 14 - 100 4) -X(5) =.17805000E+02 • 5 86 5 15 2 2E + 02 • 26 1 06 7 35E = 05 • 1 00 9 46 9 2E = 03 • 41 7 2 99 4 0E = 03 • 6 22 4 1 7 8 2E = 02 • 1 05 1 8 5 7 0E + 04 • 2 8 1 0 0 0 9 E + 01 4) = 5) = 6) = 7) =

OUTPUT DATA

REACTIONS

X	VERTICAL	HORIZONTAL	REZULTANT		
0.000	57409.	34338.	66395.		
226. 375	88216.	18822.	90201.		

BENDING MOMENTS AND TORSIONAL MOMENTS

= = = = = N 0	×=====================================	BENDING	MOMENT	DES	TORSION MOMEN		
	LBIN		n#J	LBIN			
	A 300						
1	0.000) e	1.	Je	5.0		
2	16.875	960678.	579454.	1121904.	9 e		
3	16.875	960673.	579454.	1121904.	0		
14	50.125	2788459.	1721193.	3276891.	. D.		
5	50.125	2788459.	1721193.	3276891.	0.		
6	61.625	3350134.	2081743.	3944242.	0.		
7	60.625	3350134.	2081743.	3944242.	2619000.		
3	125.125	3696029.	1641725.	4044242.	2619000.		
Э	125.125	3696029.	1641725.	4044242.	2619000.		
1 0	147.125	1096085.	1491542.	3436676.	2619000.		
11	147.125	3096085.	1491642.	3436676.	1899000.		
12	170.625	1730431.	1049325.	2023728.	1899000.		
13	170.625	1730431.	1049325.	2023723.	1899000.		
14	161.625	1085810.	842283.	1374200.	139900.		
15	198.625	81265.	522310.	523594.	1899000.		
16	198.625	81265.	522310.	528594.	1899000.		
17	226.375	-1580417.	- () .	1530417.	1899000.		
18	272.875	-351051.	0.	361050.	1899000.		
19	272.875	-351050.	η.	361050.	1899000.		
21	287.375	- () •	0.	1.	1899100.		

CEFLECTIC'S, SLOPES AND ROTATIONS

===== G	X CIA			DEFLECTION		SLOPE		ROTATION		
	Iŀ.	IN	IN	HCRIZIN	RES IN	RAD	RAD	PAD	R A D	
	the manual over the states and and states and the	an and some the set of the some page-day		94 ang ook an ant ma ma an on an	aan aa aan an an an an an an an an a	an can can can can anti sudo -uso nta san uga sa		anga wana anga dish nang anga anga wana anga anga	146 5.7 118 op 201 1981 201 400 age 201 age	
1	0.000	16.000	0.00000	0,00000	0.00000	• 0 0 0 7 7 6	.000454	.001899	0.000000	
2	16.875	16.000	.012617	.007380	. 014617	. 000692	.000404	.000801	0.00000	
3	15.875	19.810	.012617	• 0 0 7 38 0	. 114617	.003692	.000404	.000801	0.00000	
'a	50.125	19.810	. 031754	.018459	. 036729	.000415	.000235	.000477	0.000000	
5	50.125	24.013	.031754	. 118459	. 1367 ? 9	.000415	.000235	. 00 9477	0.00000	
5	59.525	24.013	. 135776	.020719	• 041342	.000349	.000194	. (00400	0.000000	
7	50.525	24.019	.035776	.020719	• 041342	.000349	.000194	. 000400	0.000000	
3	125.125	24.019	. 143280	.025031	. 049997	000124	000051	.000134	.000450	
9	125.125	24.200	.043280	. [25031	. 049997	000124	000051	.000134	.000450	
10	147.125	24.200	.038872	023151	.045244	003272	000119	.000297	. 000593	
11	147.125	22.014	.038872	. 023151	.045244	000272	000119	.000297	. 0.0 3 5 9 8	
12	170.625	22.014	.030363	. 01 9279	.035967	000436	000205	.000482	.000767	
1 3	170.625	17.505	. 930363	.01 \$279	.035967	001436	000205	.000492	. 000757	
14	151.625	17.605	. 124943	.018619	. 023973	000541	000276	. 000607	.000951	
15	198.525	17.815	.015012	.011214	.0187 38	000608	30 0354	.011704	. 001235	
.15	198.625	16.000	.015012	.011214	.018738	000603	000354	. 030704	.001235	
17	226.375	16.000	00 00 0	000000	. 00 00 00	000394	000429	.000583	.001948	
18	272.875	16.000	10 53 50	01956	.020660	.000066	000429	. 000434	. 103141	
13	272.875	14.000	005350	019956	.020660	.000066	000429	. (00434	. 003141	
20	297.375	14.000	003944	026178	.026474	.000112	000429	• 03 9444	. 103776	

α.

STRESSES

=====					===========						
NR	x	NERT	ENDING STR	ESSES	TORSION	COMEINED	INT FOT	TOPS	INTE	NSIFIED ST	RESS
	IN	PSI	PSI	PSI	PSI	PSI			PSI	PSI	PSI
1	0.000	0.000	0.000	0.000	0.000	0.000	1.000	1.000	0.000	0.000	0.000
2	16.875	2389.010	1440.984	2789.947	0.000	2789.947	1.935	1.516	5397.222	0.000	5397.222
3	16.875	1258.706	759.217	1469.950	0.000	1469.950	1.000	1.000	1469.950	0.000	1469.950
4	50.125	3653.516	2255.155	4293.472	0.000	4293.472	1.850	1.429	7941.348	0.000	7941.348
5	50.125	2049.808	1265.257	2408.856	0.000	2408.856	1.000	1.000	2408.856	0.000	2408.856
6	60.625	2462.697	1530.298	2899.429	0.000	2899.429	1.000	1.000	2899.429	0.000	2899.429
7	60.625	2462.697	1530.298	2899.429	962.619	3277.065	1.000	1.000	2899.429	962.619	3277.065
8	125.125	2716:966	1296.839	2972.939	962.619	3342.750	1.303	1.043	3873.151	1004.423	4191.627
9	125.125	2656.539	1179.998	2906.819	941.210	3268.405	1.000	1.000	2906.819	941.210	3268.405
10	147.125	2225.327	1072.125	2470.128	941.210	2883.215	2.000	1.532	4940.256	1441.584	5447.112
11	147.125	2956.080	1424.189	3281.269	906.563	3585.220	1.000	1.000	3281.269	906.563	3585.220
12	170.625	1652.181	1001.875	1932.215	906.563	2398.577	1.676	1.330	3238.169	1206.106	3757.984
13	170.625	3122.688	1893.583	3651.963	1713.441	4533.406	1.000	1.000	3651.963	1713.441	4533.406
14	181.625	1959.423	1519.951	2479.842	1713.441	3617.463	1.300	1.300	3223.795	2227.473	4702.702
15	198.625	146.648	942.546	953.886	1713.441	2646.017	1.803	1.256	1720.226	2151.500	3614.251
16	198.625	202.089	1298.878	1314.505	2361.213	3646.352	1.000	1.000	1314.505	2361.213	3646.352
17	226.375	-3930.174	000	3930.174	2361.213	5369.099	1.000	1.000	3930.174	2361.213	5369.099
18	272.875	-897-858	0.000	897.858	2361.213	3438.814	1.820	1.305	1634.101	3080.967	4715.639
19	272.875	-1340.242	0.000	1340.242	3524.609	5133.157	1.000	1.000	1340.242	3524.609	5133.157
20	287.375	000	0.000	.000	3524.609	4581.992	1.000	1.000	.000	3524.609	4581.992

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WEIGHT OF SHAFT= 25702. LBS

ANGULAR FREQUENCY OF FUNDAMENTAL MODE OF VIBRATICNS= 116.433RAD/SEC CRITICAL SPEED= 1111.857RPM





Fig. 2 PLOT OF THE SHAFT (Reduced Plot Size)