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The Behaviour And Design Of Mineshaft Steelwork And Conveyances

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4.4.5 Effect of bunton spacing

Neither measurements nor parametric studies using DISCS have shown that bunton spacing is an important variable, although most of the measurements were in shafts with the same bunton spacing, i.e. 4,57 m. Only two sets of measurements were in shafts with 6,10 m bunton spacing, two with 3,68 m bunton spacing, and two with 4,0 m bunton spacing which are probably insufficient to be very conclusive. However, the time between buntons increases as bunton spacing increases and for a given misalignment the off-vertical angle of the guides reduces. The magnitude of misalignment should thus be related to bunton spacing to give:

$$K_m = \frac{\Delta}{0{,}010 \times \frac{A}{4{,}57}} \quad K_D$$

$$= \frac{450\ \Delta}{A} \quad K_D$$

where A = bunton spacing.

4.4.6 Effect of guide and bunton stiffness

The only noticeable effect of differing stiffness was in shafts where the buntons on one side were stiffer than on the other side of the conveyance. As shown in Table 4.1, for Hartebeestfontein No. 8 shaft the peak wheel loads on the side with the stiff buntons were very much higher than on the other side. The layout of buntons in this shaft is shown in Figure 4.13.

The stiffnesses of the buntons as numbered on Figure 4.13 is:-

Skip				Bunton/guide stiffness ratio
1	-	50 000	kN.m	39,5
2	-	14 286	kN.m	11,9
Cage				
2	-	11 111	kN.m	9,4
3	-	7 692	kN.m	6,8

The maximum wheel loads measured at 15 m/s on these buntons were:

Skip		
1	19,4	kN
2	8,1	kN
Cage		
2	12,7	kN
3	7,6	kN

In both cases the ratio of wheel loads to the bunton stiffness is similar on both sides, indicating that the maximum wheel loads are directly related to the bunton stiffness, and the relative bunton stiffnesses on opposite sides of the compartment. The figures above show no absolute relationship between wheel load and bunton stiffness, but this ratio seems to increase as the relative bunton stiffness increases. One way of dealing with this would be to consider the wheel loads as being above and below an average value, the amount above or below being determined by the bunton stiffness ratio as shown in Figure 4.14 below.

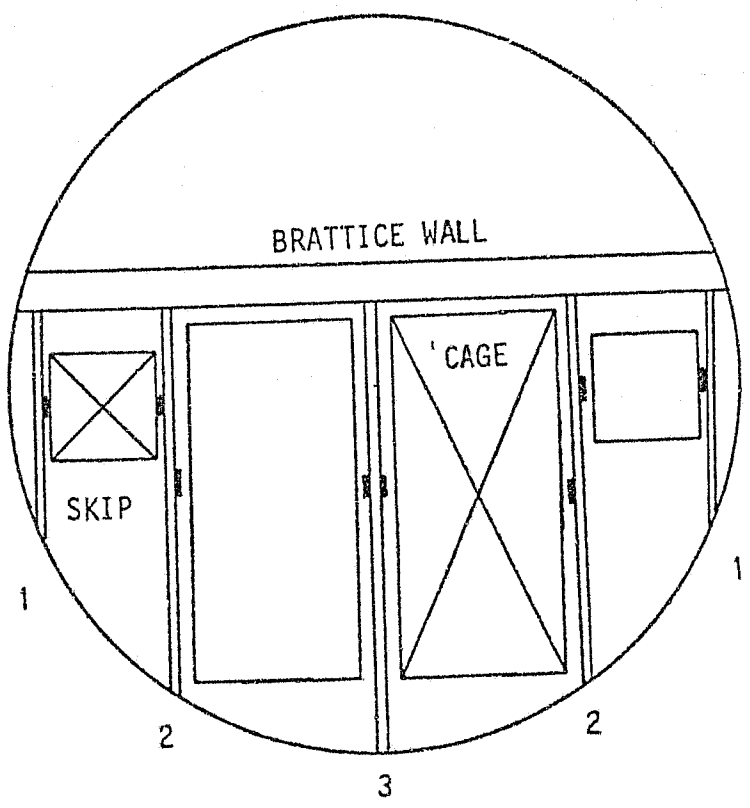


FIGURE 4.13 : Hartebeestfontein No. 8 shaft layout

It is also recommended in Chapter 6 that more severe deflection limitations should be applied as the bunton stiffness ratio increases, to limit the effects of this phenomenon.

In this shaft the practice is to use a fairly high pre-load (0,5 tonnes). In the absence of such preload there may well not be this relationship because the maximum wheel loads relate to dynamic behaviour of the conveyance to a greater degree, except that where the guide gauge reduces a stiff bunton will lead to a high wheel load.

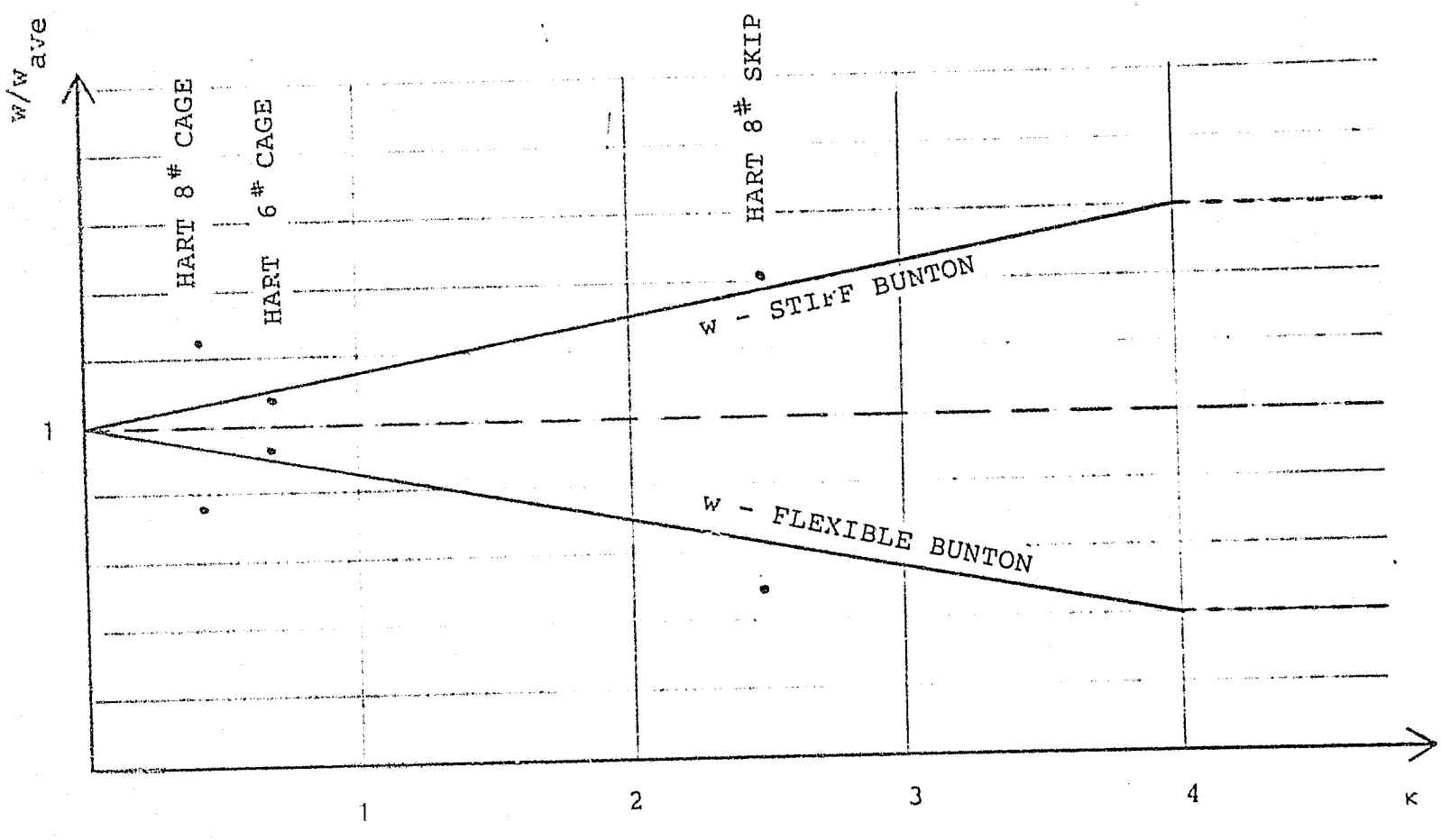


FIGURE 4.14 : Wheel load variation with bunton stiffness ratio

The factor K_p x PRELOAD above should thus be taken as:-

$$K_p \text{ X PRELOAD} = \left(\frac{\bar{K}_{Bunt}}{K_{Bank}} \text{ PRELOAD} + \tfrac{1}{2}\ \delta\ .\bar{K}_{Bunt}\right)\ (1\pm 0{,}15\kappa)$$

where $\bar{K}_{Bunt}$ = average equivalent wheel spring stiffness at a bunton

K_{Bank} = average equivalent wheel spring stiffness at bank where wheel preload is set.

δ = maximum guide gauge reduction (in m).

κ = ratio of stiffer bunton stiffness to more flexible bunton stiffness - 1.

This can then be rewritten as:

$$\bar{K}_{Bunt}\ \left(\frac{\text{PRELOAD}}{K_{Bank}} + \frac{\delta}{2}\right)\ (\ 1\pm 0{,}15\kappa)$$

4.4.7 Effect of wheel preload

All the measurements and DISCS predictions show that wheel preload acts only as a fixed preset displacement on the wheels, giving a wheel load which varies with varying guide stiffness. In no case was there clear evidence of a higher or lower preload either increasing or decreasing the dynamic behaviour of the conveyance.

4.4.8 Effect of spring stiffness

In practice there is not a very wide variation of spring stiffness of guide wheels and it was never possible to alter this with all other parameters unchanged. Parametric studies using DISCS and work done by McKechnie[18] show that a more flexible spring on the wheels leads to lower wheel loads. However, for this to operate a larger deflection is required, so that a greater clearance between guide and slipper is required. If slipper/guide

contact occurs because a more flexible spring is used the consequent maximum wheel loads may well be more severe than with a stiffer spring which prevents such contact. McKechnie[18] thus uses a double spring, a flexible spring for normal operation and a much stiffer spring to prevent slipper/guide contact. Spring stiffness has also been shown to be the cause of wheel resonance in the case of President Steyn. This is a difficult problem to predict, so that it should be catered for, not by adjusting the design wheel load, but by using wheelsets where the spring stiffness can easily be varied on site if a problem arises.

4.4.9 Maximum wheel load equation

Combining the relevant effects discussed above gives the equation for maximum wheel load as:

$$P=W_E(0,16V\frac{30\Delta}{A}) + \bar{K}_{Bunt}(\frac{PRELOAD}{K_{Bank}} + \frac{\delta}{2})(1\pm0,15\kappa) \text{ for skips}$$

$$P=W_E(0,20V\frac{30\Delta}{A}) + \bar{K}_{Bunt}(\frac{PRELOAD}{K_{Bank}} + \frac{\delta}{2})(1\pm0,15\kappa) \text{ for cages}$$

This can be rewritten as:

$$P = F.W_E(\frac{V\Delta}{A}) + \bar{K}_{Bunt}(\frac{PRELOAD}{K_{Bank}} + \frac{\delta}{2})(1\pm0,15\kappa)$$

where F is a "conveyance factor" equal to:

4,8	for skips
6,0	for cages

There may be some justification in specifying different F factors for good, acceptable and non-acceptable shafts as described in Chapter 6. However, this is to some

extent covered by the term Δ in the equation, so this will not be done, as a single factor for each type of conveyance is easier to work with.

For koepe winders there is some indication that the above F factor may be divided by 2, by virtue of the damping effect of the tailropes, so the Western Deep Levels have been doubled in calculating the averages in table 4.8. This needs verification by further tests however. It should be noted that the above equations deal only with cases where there is no dynamic magnification. Section 5.5 deals with wheel loads in the presence of magnification.

4.5 RELATIONSHIP OF WHEEL LOADS TO ACCELERATIONS

In trying to find some way of relating lateral accelerations to wheel loads, several transfer functions between wheel loads and accelerations were calculated from the relevant power spectra. This did not however give useful results, probably because all the wheel loads and all the accelerations are interrelated, so that no one acceleration is directly related to one wheel load, and also because of the presence of noise. A low (noise) power spectrum value divided by a lower (noise) value can give a large result at random.

An alternative means of achieving an averaged relationship is described below:

The expected acceleration value is equal to a factor, T, multiplied by the square root of the sum of the power spectrum values, and the expected value of wheel load is equal to the same factor, T, multiplied by the sum of its power spectrum values. The relationship

between the force and acceleration values is thus given by:

$$R = \frac{T.\ \sqrt{\Sigma \text{Power Spectrum of Wheel Load}}}{T.\ \sqrt{\Sigma \text{Power Spectrum of Acceleration}}}$$

$$= \frac{\sqrt{\Sigma \text{Power Spectrum of Wheel Load}}}{\sqrt{\Sigma \text{Power Spectrum of Acceleration}}}$$

This value, R, is given in Table 4. 9 below for all the shafts in which wheel load measurements were made. Omitting the values at Blyvooruitsig No. 4 shaft, which was not felt to be a good wheel load measurement, the means of these values is 1,30 with a standard deviation of 0,47. The same analysis was carried out for the DISCS runs with similar, although somewhat higher results. These are also shown on Table 4.12.

TABLE 4. 9 : R VALUES

SHAFT	R - value		DISCS	R - value
	Top Wheel	Bottom Wheel	Top Wheel	Bottom Wheel
Pres. Steyn 4#				
19t skip	0,76	1,78	-	-
10t skip	1,03	1,42	-	-
Western Deep Levels 2*18t skip	0,67	-	2,64	2,58
Western Holdings 1# 10t skip	1,06	1,13	0,87	1,63
Blyvooruitsig 4# Skip	0,33	0,22	-	-
Hartebeestfontein 8#				
Skip	-	0,68 (R) 1,34 (L)		
Cage	1,31	1,58	2,02	1,73
Hartebeestfontein 6#Cage	1,00	2,39	-	-
Deelkraal 1# 21t skip	1,55	1,78	2,91	2,55

Assuming a normal distribution for R, a 1% probability of exceedence, and zero preload, the expected wheel load is then given by:-

WHEEL LOAD = Acceleration (1,30 + 2,4 x 0,47)
= 2,4 x ACCELERATION

Including preload the expected wheel load is:

WHEEL LOAD = PRELOAD + 2,4 x ACCELERATION

This serves to confirm the above statement that no problems or damage should be expected below accelerations of about 7 m/sec², because this gives:-

WHEEL LOAD = PRELOAD + 16,8

Typically, preload values are not greater than 3 kN, i.e.

WHEEL LOAD = 19,8 kN at 7 m/sec²

Many modern conveyances fully loaded weigh 20 tonnes or more, so that the W/10 design load is 20 kN or more. No problems should be expected until this design load is significantly exceeded.

CHAPTER 5 : DYNAMIC MAGNIFICATION

The dynamic magnification of wheel loads and accelerations due to the interaction of natural frequencies and exciting frequencies is a phenomenon which must be avoided in a mineshaft. Instances of high dynamic magnification have been known,[6,7] and have had serious consequences for the shaft and conveyances. The following is an assessment of this problem and how it may be avoided.

Initially, the recommendations of two major reports, i.e. that of Reinke[8] and one from the CSIR[9] are considered, and this is followed by discussion of parametric studies carried out using DISCS. These are followed by some comments relating to actual instances of dynamic magnification which has been experienced in various shafts. General conclusions regarding the problem of dynamic magnification are drawn and finally recommended methods for avoiding dynamic magnification and for assessing the level of wheel load when it does occur, are described.

5.1 Literature survey

The CSIR[9], and Reinke[8], both deal at some length with dynamic magnification.

5.1.1 CSIR report[9]

This report assesses the magnification of displacements in three dimensions and then calculates the wheel loads from the displacements. All the translational and rotational modes are considered as being uncoupled. Thus in the X-Z plane, i.e. the plane between the guides, the force amplitudes are:-

$$F_V = KU\sqrt{A^2+B^2-2A\cos\alpha/2 - 2B\sin\alpha/2 + 1}$$

For the top and bottom wheels, where:-

$$A = \frac{\sqrt{2(1+\cos\alpha)}}{2(1-\eta^2)}$$

$$B = \frac{Z^2\sqrt{2(1-\cos\alpha)}}{\rho^2\ 2(Z^2/\rho^2-\eta^2)}$$

$$\eta^2 = \Omega^2/P_x^{\ 2}$$

$$\rho = R_{I/M}$$

α = $2\pi(2Z-a)/a$ for $0<2Z<2a$

$2\pi(2Z-na)/a$ for $na<2Z<(n+1)a$

a = bunton spacing

Z = half the conveyance overall length

$$P_x = \sqrt{4K/_M} = 2\sqrt{K/_M}$$

K = individual wheel spring stiffness

$$\Omega = \frac{2\pi\nu}{a}$$

U = the amplitude of misalignment, assumed to be a sine curve.

In this equation, K and U are constants. Thus:-

$$F \propto \sqrt{A^2 + B^2 - 2\ A\cos\alpha/2 - 2\ B\sin\alpha/2 + 1}$$

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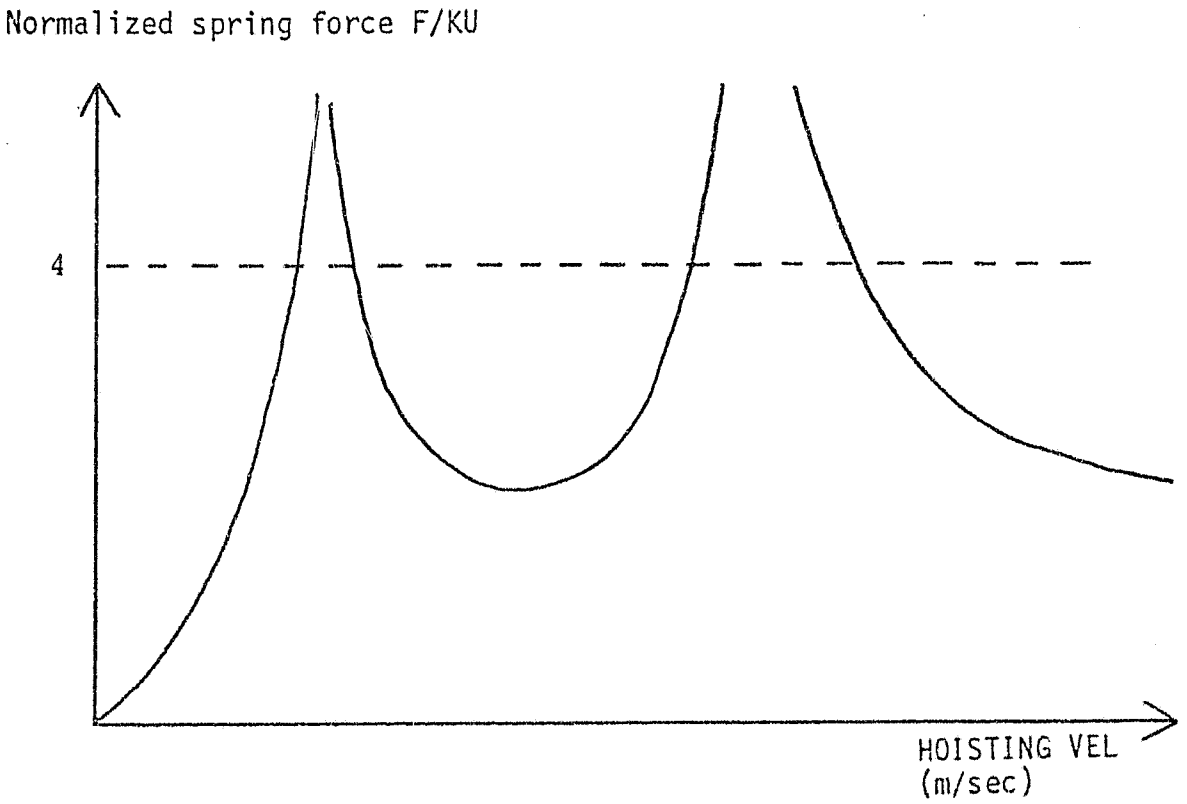


FIGURE 5.1 : Dynamic Magnification According to CSIR Report[9]

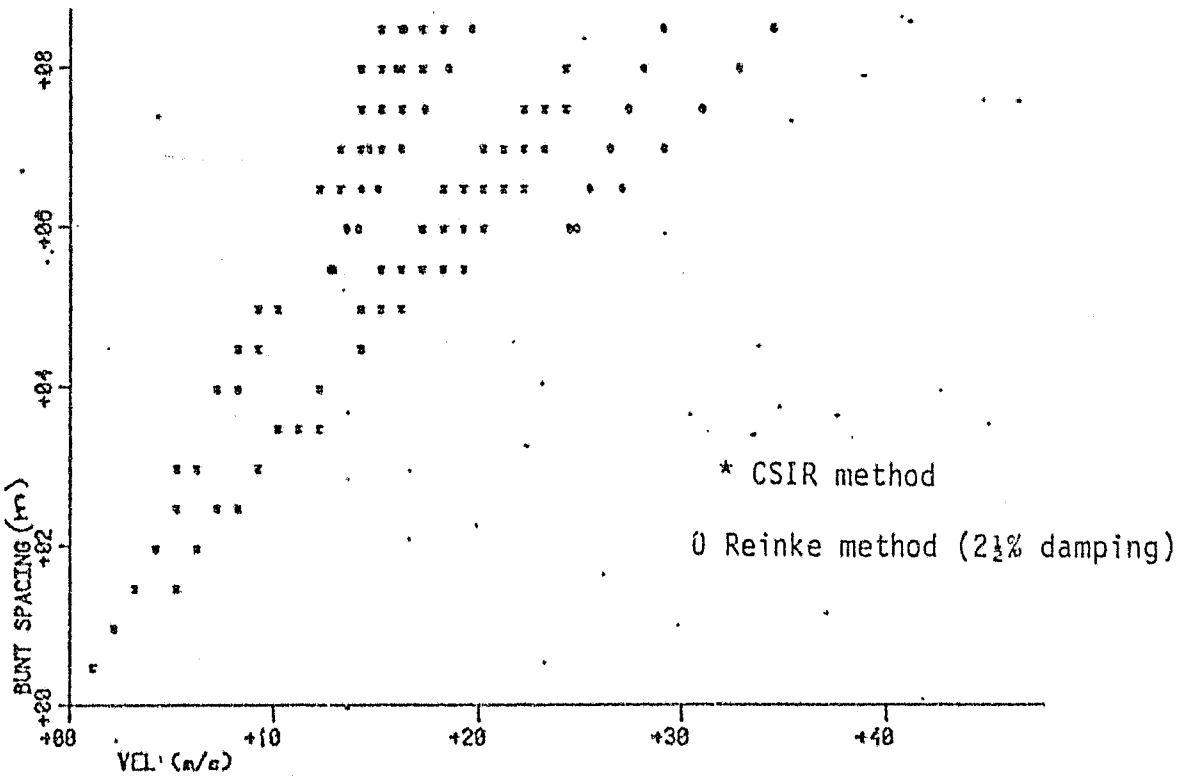


FIGURE 5.2 : Areas of High Dynamic Magnification

Plotting F against hoisting velocity typically gives a graph as shown in figure 5.1. In order to draw a more useful graph, and the one used by Reinke[8] (see below), of areas of high magnification on a plot of bunton spacing against hoisting velocity, it is considered, arbitrarily, that a high magnifier is where:

$$\sqrt{A^2 + B^2 - 2\,A \cos \alpha/2 - 2\,B \sin \alpha/2 + 1} \geq 4$$

Because of the very high slope of the curve for F, see Figure 5.1, this arbitrary selection of the limits of areas of high magnification is felt to be acceptable. This then results in the area shown by the crosses in Figure 5.2, for a typical cage.

5.1.2 German approach

The approach used by Reinke[8] in studying dynamic magnification is to model the conveyance in two dimensions as a single rigid body with two degrees of freedom, supported by elastic springs onto an elastically supported continuous beam. By solving the equations of motion of the system, natural frequencies are obtained which are then related to the frequency of passing buntons:-

$$\omega_e = \frac{2\pi v}{a}$$

This result can then be plotted on a graph of bunton spacing against hoisting velocity, to show areas of high magnification of forces. A typical plot is shown by the circles on figure 5.2.

A computer programme, DYNMAG, which is listed and described in appendix E, was written to calculate these areas of high magnification following both the above methods.

The output from this programme is a graph in the form of figure 5.2.

There are always two main natural frequencies, the frequencies of translation and rotation. For the very simplified conveyances considered by the CSIR report[9], these frequencies are:-

$$\omega_T = \sqrt{\frac{4K}{M}} \qquad \text{for translation}$$

$$\omega_R = \sqrt{\frac{4Ka^2}{\theta}} \qquad \text{for rotation}$$

where:-

K = spring stiffness
M = conveyance mass
θ = conveyance rotational inertia
a = half the conveyance length.

However it is known that for this case with centre of mass and geometric centre coinciding

$$\theta = \frac{M}{12} (4a^2 + b^2)$$

where:-

b = conveyance width

Thus:-

$$\omega_T = \sqrt{\frac{4K}{M}}$$

$$\omega_R = \sqrt{\frac{4Ka^2}{\frac{M}{12}(4a^2 + b^2)}}$$

$$= \sqrt{\frac{4K}{M}} \sqrt{\frac{12}{4 + b^2/a^2}}$$

$$= \sqrt{\frac{12}{4 + b^2/a^2}} \cdot \omega_T$$

In all practical cases a is larger than b, thus

$$4 < 4 + b^2/a^2 < 5$$

and $1,55 < \sqrt{\frac{12}{4 + b^2/a^2}} < 1,73$

The rotational frequency is thus always the higher one, with a value approximately 1,6 times the translational frequency.

Clearly these two methods give very similar results, except that the CSIR areas of high magnification always start from the origin because damping is neglected. The German curves are thus more useful in practice. Only the German method is thus referred to below.

5.2 Prediction by DISCS of dynamic magnification

In order to study this phenomenon of dynamic magnification using DISCS, various hypothetical models, covering a wide range of possible shaft layouts, were run. In all cases the misalignment of the guides was as shown on Figure 5.3.

These models were run using bunton spacing of 4 m and 8 m and various hoisting velocities, both inside and outside areas of dynamic magnification. Figure 5.4 shows a typical result.

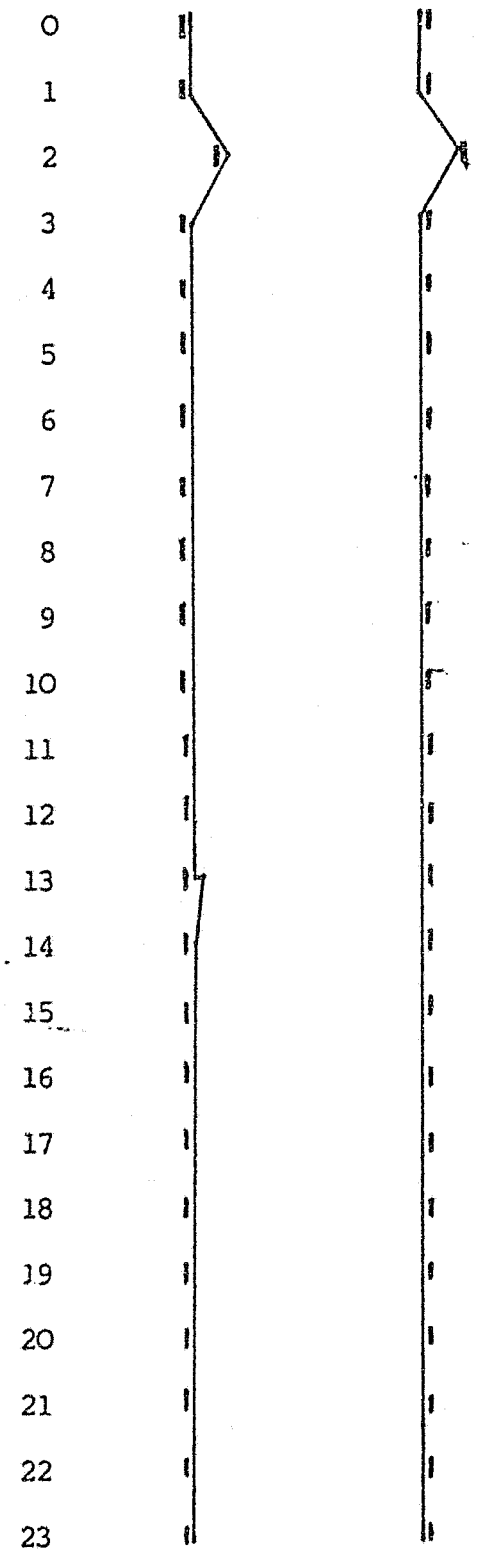


FIGURE 5.3 : Guide Misalignment

From these runs, it is clear that DISCS predicts dynamic magnification in similar conditions to Reinke's predictions, although areas of high magnification do not exactly coincide. DISCS shows a greater tendency towards magnification and a higher level of magnification in the translational mode than in the rotational mode. DISCS also in some cases predicts magnification between the two modes given by Reinke's method.

Returning to the simplified CSIR approach, using uncoupled translation and rotation, Warburton[19] shows that for a single-degree-of-freedom system, excited by a sinusoidally varying force, the magnification is:-

$$\frac{1}{\left[(1 - \omega^2/\omega_N^2)^2 + (C\omega/K)^2\right]^{1/2}}$$

High magnification occurs where:-

$$\omega = \omega_N$$

and its value is given by:-

$$\frac{1}{\left[(1 - \omega_N^2/\omega_N^2)^2 + (C\omega N/K)^2\right]^{1/2}}$$

$$= \frac{K}{C\omega_N}$$

For constant damping, C, and stiffness, K, it is clear that this magnification reduces for higher natural frequencies.

It would thus be expected that in general, high magnification is less manifest in the rotational mode, which is the higher natural frequency, than in the translational mode.

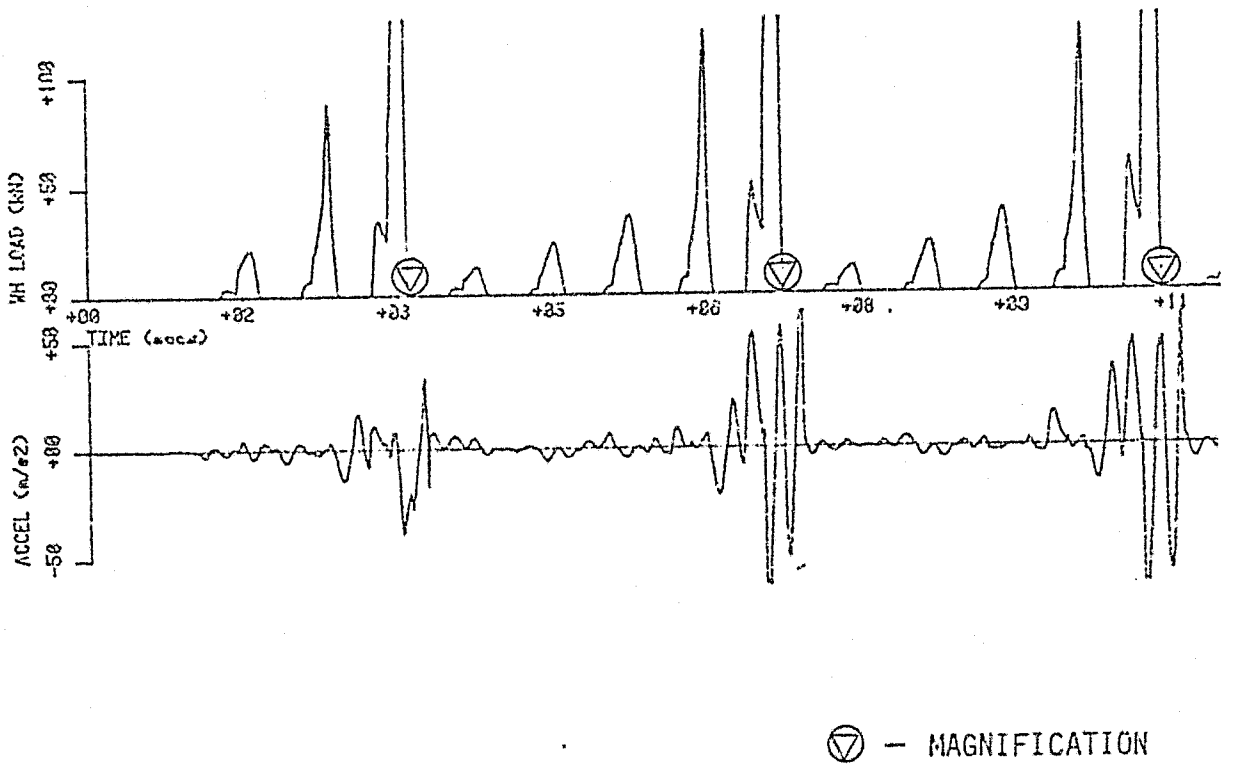


FIGURE 5.4 : Dynamic Magnification Predicted by DISCS

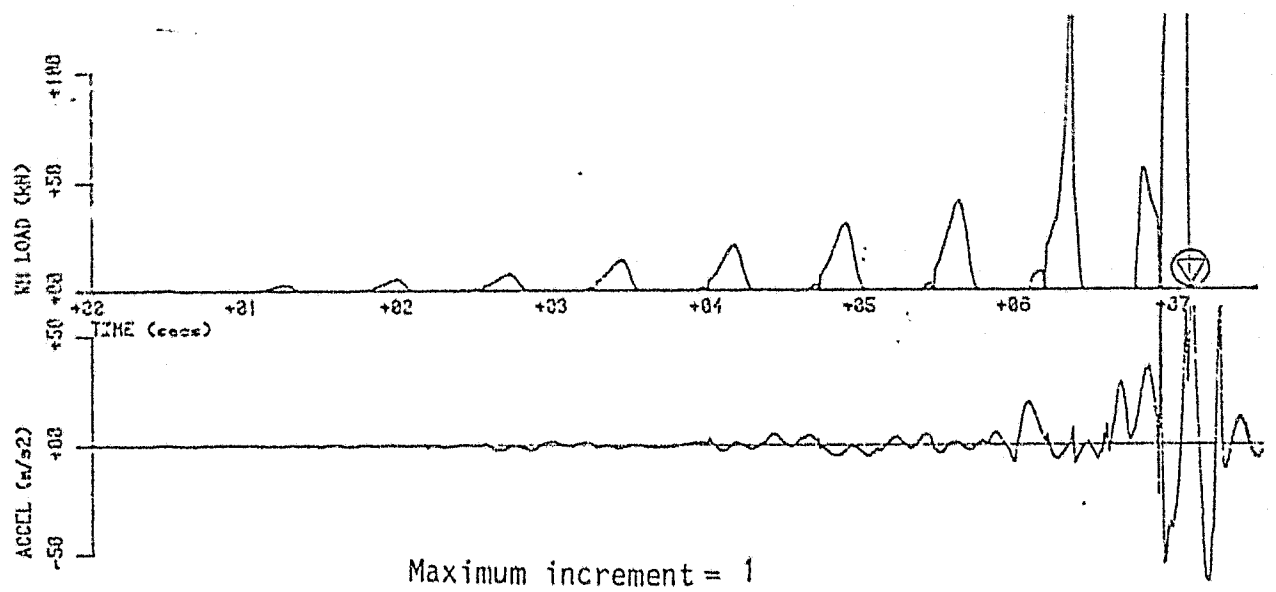


FIGURE 5.5 : Decreasing Dynamic Magnification with Increasing Misalignment

DISCS can thus be used to predict dynamic magnification as well as wheel loads and accelerations with random misalignment. Reinke's finding that dynamic magnification reduces with increasing magnitude of guide misalignment was also confirmed by running DISCS with the specified misalignment and also with random misalignment, as shown in Figure 5.5.

5.3 Measured Dynamic Magnification

High dynamic magnification has been measured at some shafts such as Deelkraal No. 2 shaft. On this shaft it occurred at about 15 m/sec hoisting speed, but not during every hoist.

The maximum hoisting speed was reduced to 11,5 m/s and this dynamic magnification was thus not recorded by measurements taken for the present study. Measurements showed natural frequencies of the cage in this shaft to be 1,2 hz, 2,3 hz, 3,3 hz and 18,5 hz. At 15 m/sec with a bunton spacing of 4,0 m, the frequency of passing buntons is 3,75 hz, which does not coincide with any of the natural frequencies. At 9 m/sec however, the frequency of passing buntons is 2,3 hz which does coincide with the second natural frequency and at 5 m/sec the frequency of passing buntons is 1,25 hz which coincides with the fundamental natural frequency. At 9 m/sec hoisting speed, the magnitude of the peak at 2,3 hz is slightly increased by virtue of the coincidence of a natural and an exciting frequency, but not to the extent that it could be considered a dynamic magnification problem. Apart from this, the power spectra did not show the frequency of passing buntons at all.

The fundamental flexural frequency of the cage is given approximately by:-

$$f_1 = \frac{\pi}{2\ell^2} \left(\frac{EI}{pA}\right)^{1/2}$$

For this cage:

ℓ = 7,8 m (the length of the cage)
I ≅ 1050 x 10^6 m^4 (the second moment of area about the vertical axis of the cage)
pA ≅ 0,5 t/m excluding top and bottom transoms (the mass per metre length of the cage)

Thus:

f_1 = 17,1 hz

This is probably the 18,5 hz natural frequency shown by measurement. This vibration mode is shown schematically in Figure 5.6

This coincides with the frequency of rotation of the guide wheels at a hoisting speed of 14,5 m/sec. At lower hoisting speeds, the frequency of revolution of the wheels is clearly shown as a very significant frequency, leading to the conclusion that this is probably the cause of the dynamic magnification.

Another shaft where severe problems have been experienced is President Steyn No. 4 shaft. The wheel load measurements on both the 19 tonne and 10 tonne skips, sections of which are shown in Figure 5.7 and the power spectra of these measurements, clearly show the problem frequency to be in the region of 20 hz. Again this is the

frequency of revolution of the wheels at 15 m/sec hoisting speed, and it is also likely to be the fundamental natural frequency of the wheel itself.

The Structural Dynamic Research Corporation[20] (SDRC) have carried out tests on the wheels used on the skips in this shaft and have found that at a low preload their natural frequency is 17 hz, increasing to about 29 hz at a high preload. At a certain level of preload, the natural frequency of the wheels can thus coincide exactly with their frequency of revolution. Although SDRC[20] found the wheels to have high damping (about 40% of critical) this is not sufficient to prevent magnification of the dynamic effects.

It seems likely that the cause of the problem in this shaft is resonance between the wheel revolution and its own natural frequency.

Another shaft in which problems have occurred is the Deelkraal No. 1 shaft on the 21 tonne skips. Dimitriou[21] has studied this problem, and concludes that, although this problem occurs at a lower frequency, it is due to severe misalignment rather than dynamic magnification.

Measurements in this shaft bear out this finding. Between the time of the work carried out by Dimitriou[21] and the time of taking measurements for the present work, extensive realignment of the shaft steel work has taken place. The measurements showed a short section with very high wheel loads and accelerations in a few runs only (see Figure 5.8). These measurements do not show any tendency for increasing wheel loads or accelerations as would be expected if dynamic magnification were a severe problem. Rather it appears that the cause of these very high wheel loads is a short badly aligned section of the guides or perhaps it is only at one

bunton where the guide is badly aligned and is struck by the skip only if it is orientated in a certain way as it approaches that section.

It is however interesting that for this shaft, the engineer stated that dynamic magnification occurs at 12,5 m/sec hoisting speed. Reinke's[8] method when applied to this skip running empty, indicates that dynamic magnification in the translational mode should be expected at hoisting speeds between 12,5 m/sec and 12,9 m/sec as shown in figure 5.9.

Significantly, the magnitude of wheel loads measured at 10 m/sec was higher than those measured at 12,5 m/sec. This reducing magnitude probably indicates some dynamic magnification at approximately 10 m/sec. This is not a severe problem here, the magnified wheel loads still being less than those at 15 m/sec and faster, but it does occur at a hoisting speed which is fairly close to the speed at which dynamic magnification was predicted.

5.4 Avoiding Dynamic Magnification

There are two different frequency ranges in which dynamic magnification should be considered, i.e. the higher frequencies relating to wheel rotation, and the lower frequencies relating to bunton spacing.

5.4.1 High Frequency Problems

These are related to the frequency of revolution of the wheels, and appear to occur at the higher hoisting speeds, where the frequency is in the region of 18 hz to 21 hz. In considering the elimination of this problem, it is necessary to study the behaviour of conveyances in more detail. DISCS does not model the wheels as individual units, nor does it make allowance for the higher frequency modes of vibration of the conveyance. What is

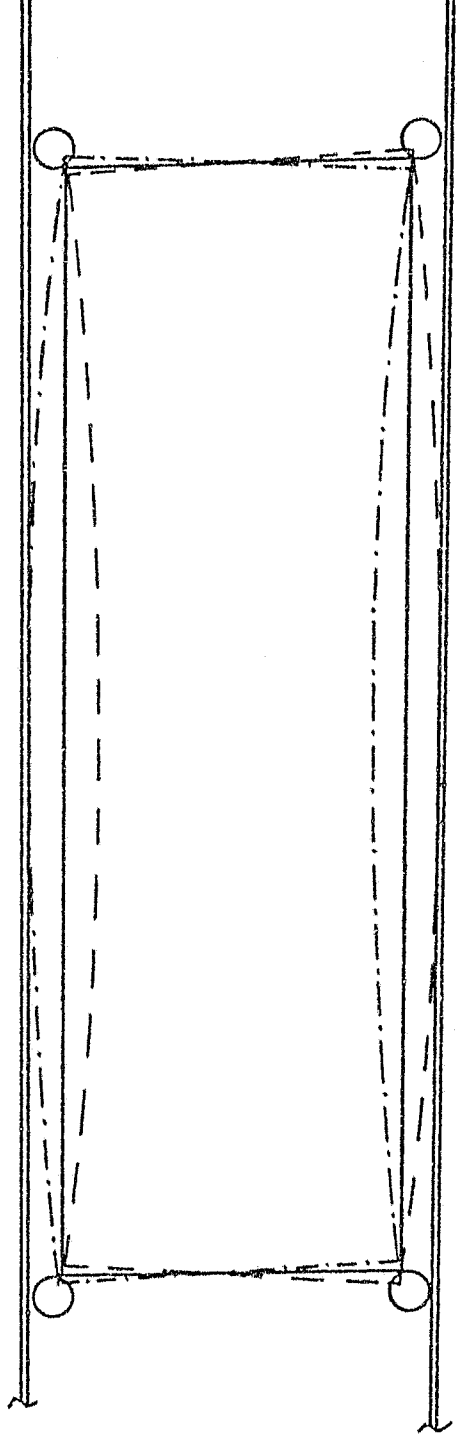
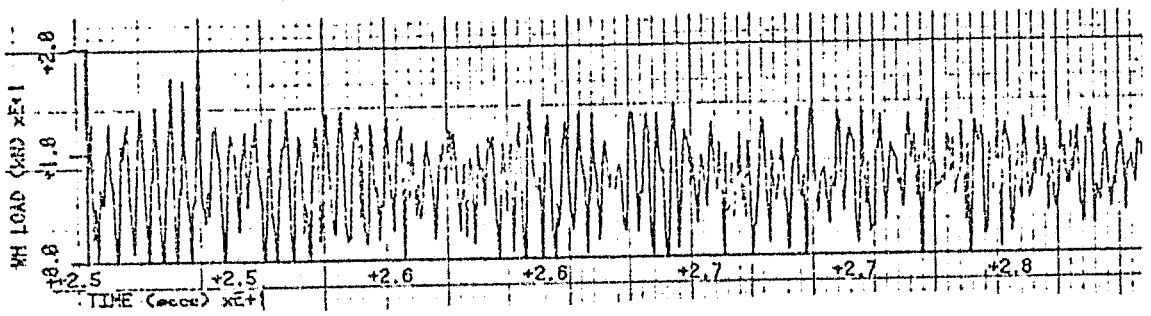
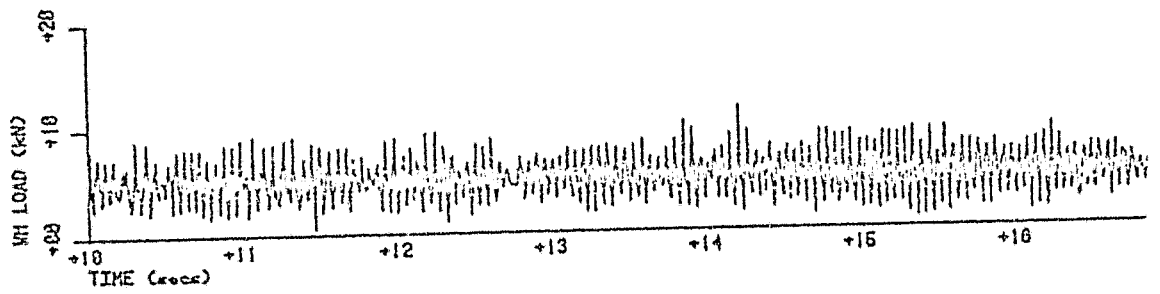


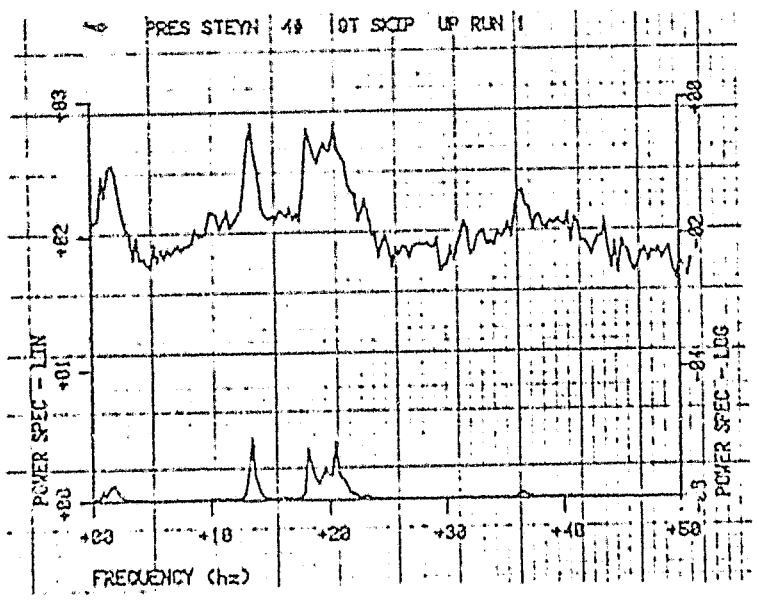
FIGURE 5.6 : Flexural Vibration Mode of Deelkraal No. 2 Shaft Cage.



(a) Wheel loads on 19 tonne skip

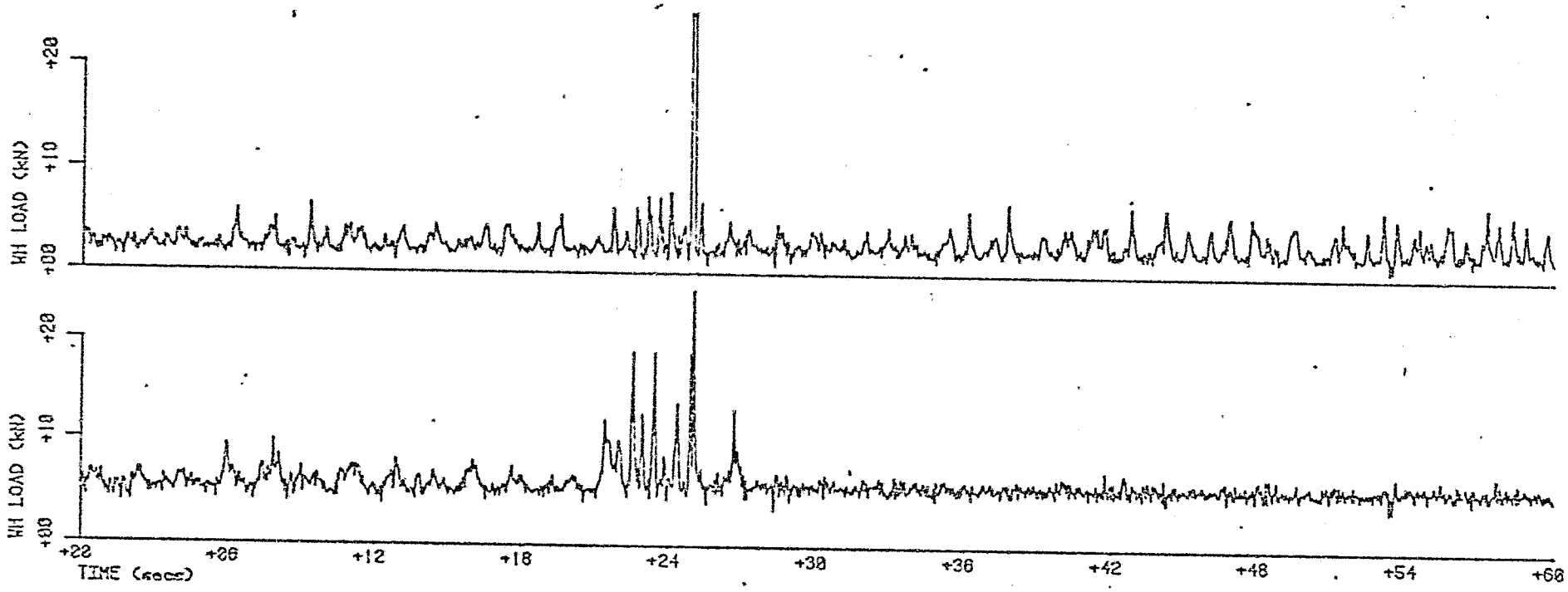


(b) Wheel loads on 10 tonne skip



(c) Typical power spectrum of wheel loads

FIGURE 5.7 : Wheel loads at President Steyn No. 4 Shaft



DEELKRAAL 1# UP 16.56T 17.8M/S

FIGURE 5.8 : Wheel loads in bad section of the Deelkraal No. 1 shaft

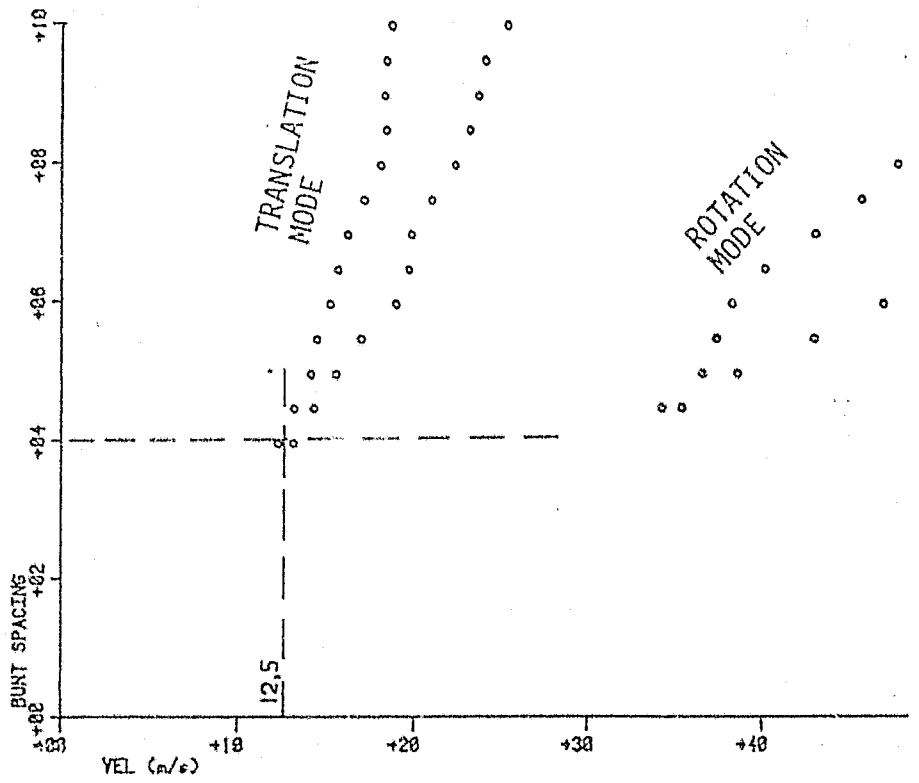
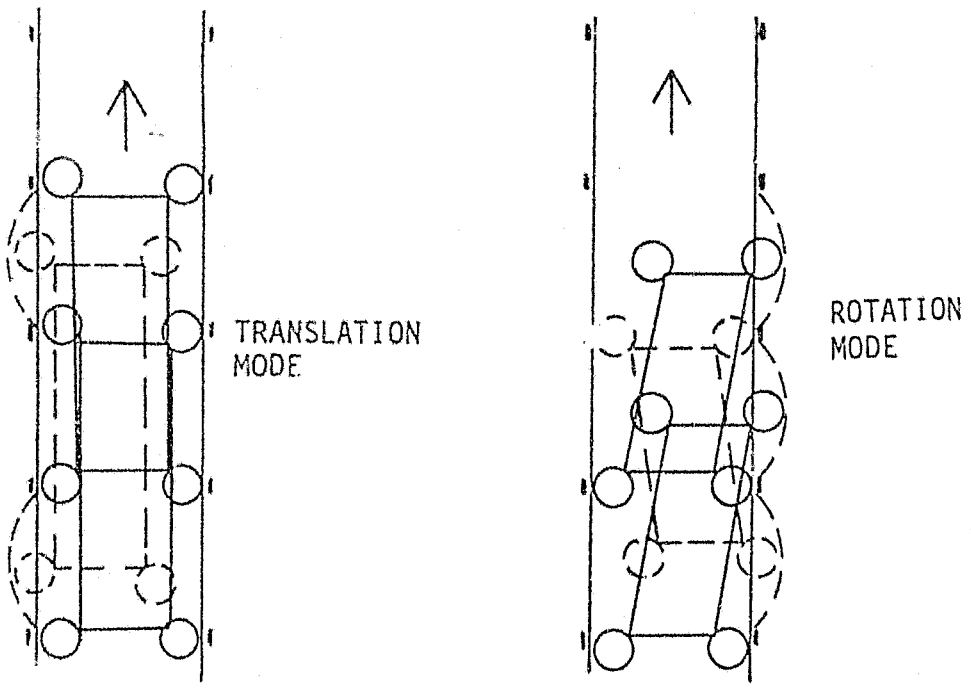


Figure 5.9 : Dynamic Magnification on Deelkraal No. 1 Shaft, 21 Tonne Skip.



(a) LENGTH=(N) BUNTON SPACES (b) LENGTH=(N+½)BUNTON SPACES

Figure 5.10 : Conveyance Movement in a Shaft

required is a finite element model of the conveyance, including the wheels as separate masses, in order to establish the higher order natural frequencies. Alternatively, once a conveyance is in service, there are methods available whereby these higher frequencies can be measured. One such method is the use of the cyclical exciter described in section 3.1.5. The wheelsets must then be designed in such a way that there is no coincidence between wheel revolution frequency and any natural frequencies, or if this cannot be avoided some form of dampers should be fitted.

5.4.2 Low Frequency Problems

Although only one case of dynamic magnification has been specifically measured at low frequencies during the present work, it should not be ignored. The one example quoted above shows that it may well be a problem in other cases as well. Two modes of behaviour may develop at lower frequencies, translation or rotation. As discussed in section 5.2 above, translation is always the lower frequency and is likely to produce the higher magnification if this occurs. Studying the motion of the conveyance, as shown in Figure 5.10, where the overall conveyance length is equal to an integer multiple of the bunton space the stiffness of the guide at the top and bottom wheels is increasing or decreasing at the same time. This will tend to excite translation rather than rotation. On the other hand where the overall conveyance length is equal to an integer-plus-half multiple of the bunton space the stiffness of the guide at the top wheel increases while that at the bottom wheel decreases, which will tend to excite rotation rather than translation.

In avoiding the more likely and severe problem of dynamic magnification at the translation frequency, an overall conveyance length of an integer-plus-half multiple of bunton spacing should be used. In addition, some assessment of possible dynamic magnification using DISCS or a method such as that proposed by Reinke[8] should be made. If possible problems are predicted, than some suitable adjustment should be made to bunton spacing, guide stiffness or conveyance geometry.

5.5 Maximum Wheel Load with Magnification

From the measurements it was observed that the increase of wheel load with velocity was usually linear, but that where dynamic magnification occurred it became exponential. This exponential increase above a linear increase is also shown by DISCS, and can be shown schematically as in figure 5.11 to have two components - the basic linear increase and a magnification 'hump' above it. In practice, hoisting speeds were seldom high enough to measure the decrease beyond the hump, but this is predicted by DISCS, and measured at Deelkraal No. 1 shaft.

The total wheel load where dynamic magnification occurs can be split into two components as shown by figure 5.11, giving:

$$W = W_1 + W_2$$

$$= W_1 \left(1 + \frac{W_2}{W_1}\right)$$

$$= W_1 \left(\frac{W}{W_1}\right)$$

The factor W/W_1 is referred to as the dynamic magnification factor, and it is given by Warburton[19] for a single degree of freedom system as:

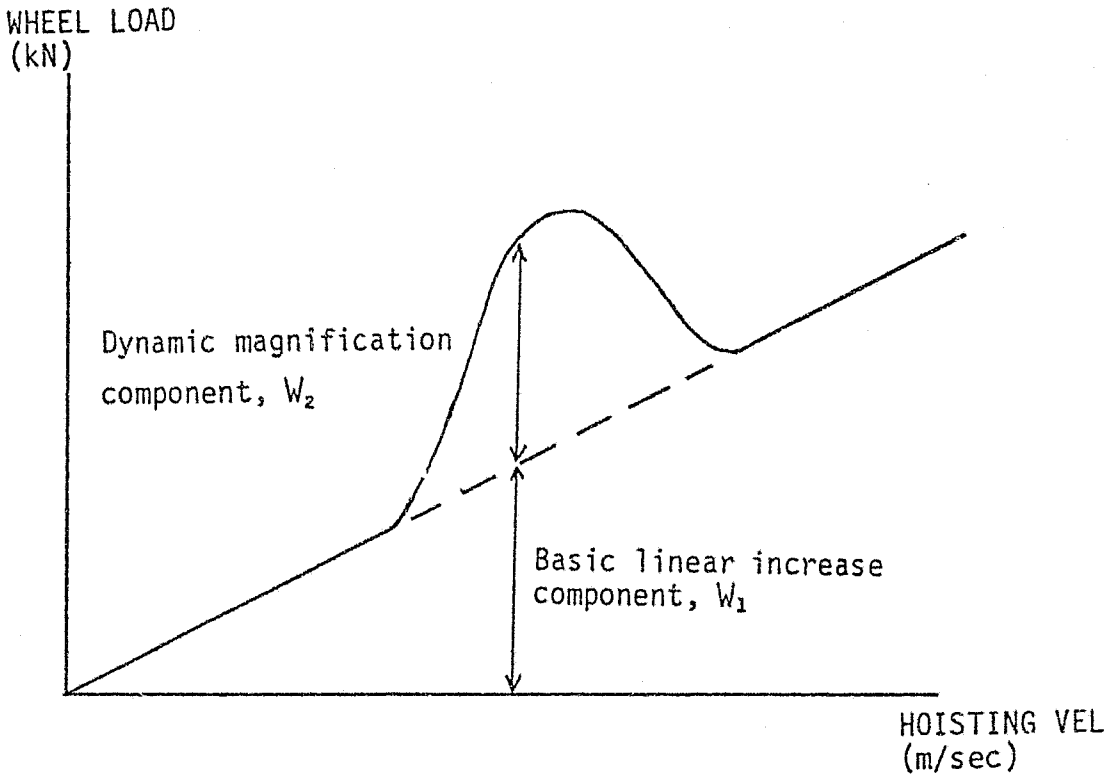


FIGURE 5.11: Dynamic Magnification Hump

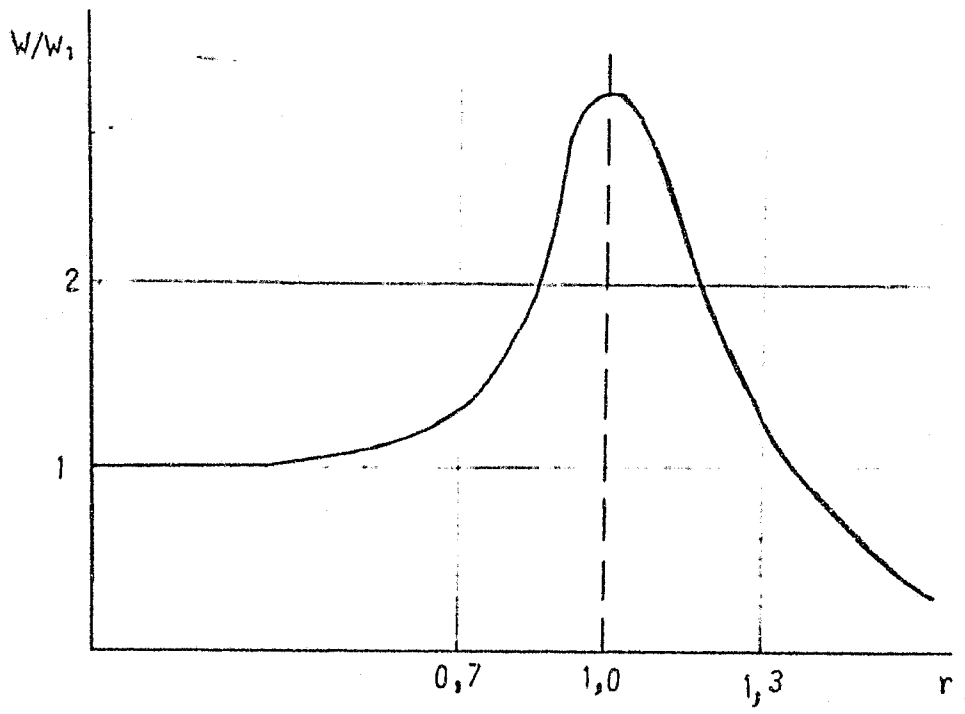


FIGURE 5.12 : Magnification Factor

$$\frac{W}{W_1} = \frac{1}{\left|(1-r^2)^2 + (2\ \gamma\ r)^2\right|^{1/2}}$$

Where γ = damping ratio

r = ratio of the exciting frequency to the natural frequency.

The exciting frequencies are proportional to the speed, so r could equally well be defined as

r = ratio of hoisting speed to speed at which the exciting frequency equals the natural frequency.

This magnification factor has a value significantly above one only for $0,7 < r < 1,3$ as shown on Figure 5.12. It has also been noted in chapters 4 and 5 that in practice severe dynamic magnification appears usually, but not always to relate to the frequency of revolution of the wheels.

In order to establish dynamic magnification of wheel loads at high frequencies the following procedure is suggested.

(a) Establish whether there is a higher order (deformation mode or wheel set) natural frequency, ω_o, in the range of wheel revolution frequency at speeds of 10 m/sec and faster. With the standard 0,25 m diameter wheels used at present this is a frequency range of $10/_{0,25\pi} = 12,5$ hz and higher.

(b) If there is not, ignore dynamic magnification. If there is such a frequency, calculate the speed, Vo, at which it equals the wheel revolution frequency.

$$Vo = \omega_o \times 0,25\pi$$
$$= 0,785\ \omega_o$$

(c) For speeds in the range

$$0,7\ V_o < V < 1,3\ V_o$$

the maximum wheel load is then given by

$$W = \frac{W_1}{\left|(1-r^2)^2 + (2\gamma r)^2\right|^{\frac{1}{2}}}$$

Where W_1 = maximum wheel load calculated from linear increase.

For low damping ratios, a good approximation to this is:

$$W = \frac{W_1}{1-r^2}$$

but with a maximum value determined by the damping ratio. Warburton[19] shows a maximum magnification of five for a damping ratio of 0,1, but the complexity of the practical shaft appears to restrict the magnification more severely. A good semi-empirical approach thus seems to be:-

For $0,7\ Vo < V < 1,3\ Vo$

$$W = \frac{W_1}{1-\left(\frac{V}{Vo}\right)^2}$$

but $W \neq 3\ W_1$

At low frequencies, if magnification is predicted in the translation mode, the conveyance length should be made equal to an integer-plus-half multiple of bunton spacing. If magnification is predicted in the rotation mode, then the conveyance length should be an integer multiple of the bunton spacing.

CHAPTER 6

DESIGN LOAD RECOMMENDATIONS

It has already been stated in the introduction that shaft steelwork practice has developed, by necessity, with the historical development of mines to greater depths and greater production requirements. Shaft steelwork design methods, also developing historically or empirically, have at no stage reflected the dynamic character of the loads imposed by conveyances on the guides. This is clearly shown by Devy[22], in an interesting survey of shaft steelwork design methods. All but the most recent Anglo American design method are based very simply on a static load equal to some percentage of the conveyance mass. The latest Anglo American design method still assumes a static load, but this is now related to the square of hoisting speed and certain limitations are imposed on the relative stiffnesses of buntons and guides.

The design of conveyances, both skips and cages has tended to follow prototype testing methods. Suppliers have, by experience, based new designs on what they know has operated well in the past. This has led to uncertainities regarding factors of safety, fatigue life and discomfort to passengers. The mining houses are at present beginning to require more satisfactory design procedures, but there is not a great deal of value in a properly executed design which is based on unknown magnitudes of loading.

The following recommendations form an attemt to remedy this situation, by providing easy to use yet acceptably

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The following recommendations form an attemt to remedy this situation, by providing easy to use yet acceptably

accurate methods of predicting design loads for conveyances and shaft steelwork. The work on which these recommendations is based represents only a small sample of measurements. Thus, although the format of these recommendations and the way in which the important variables are included is unlikely to alter, further measurements may well indicate that the absolute values proposed need adjustment.

6.1 SUGGESTED BASIC OPERATING LIMITS

In order for the conveyances in a shaft to operate safely and reliably, and to carry out routine maintenance to an acceptable standard, limits should be placed on certain variables. The two suggested "control variables" are guide misalignment for quality control which should be specified for shaft equipping and lateral acceleration which can be used in an existing shaft to determine the necessity of maintenance. Following similar categories to those suggested by Gotzman[23], these will be defined for good, acceptable and unacceptable conditions of shafts.

6.1.1 Misalignment of the guides

There should be four basic values defined as components of the overall misalignment. These are:

(a) overall distance of the guide from the true vertical position. This does not have any noticeable effect on the conveyance behaviour, but it should be limited to ensure that the conveyance is basically running vertically, and to limit the horizontal component of rope pull. It is thus specified as a ratio of distance from surface. See Table 6.1.

(b) the increment of the guide position from true vertical, from one bunton to the next. This is an important factor in determining the dynamic behaviour, so it should be carefully controlled. Discussion with engineers at various mines as well as parametric studies using DISCS has led to the recommendations shown in Table 6.1, where a good shaft should not have wheel loads greater than half the maximum design value, and an acceptable shaft should not have wheel loads exceeding the design loads.

(c) the guide gauge error can reasonably easily be controlled accurately by the use of a template, and it is also of significant importance in dynamic behaviour. Guide gauge reduction could lead to jamming of conveyances, so it should not be permitted. Guide gauge increase can lead to wheels coming away from the guides which leads to increased wheel loads and severe tyre wear, so that it is limited to a small amount.

(d) guide mismatch leads to high shock loads and should thus be minimised, either by some system whereby it can be ensured that guides of very nearly equal height are placed consecutively down the shaft, or by grinding joints where there is mismatch to a maximum slope of 1:20.

These misalignments are shown schematically in Figure 6.1 and suggested maximum permissable values are given in Table 6.1.

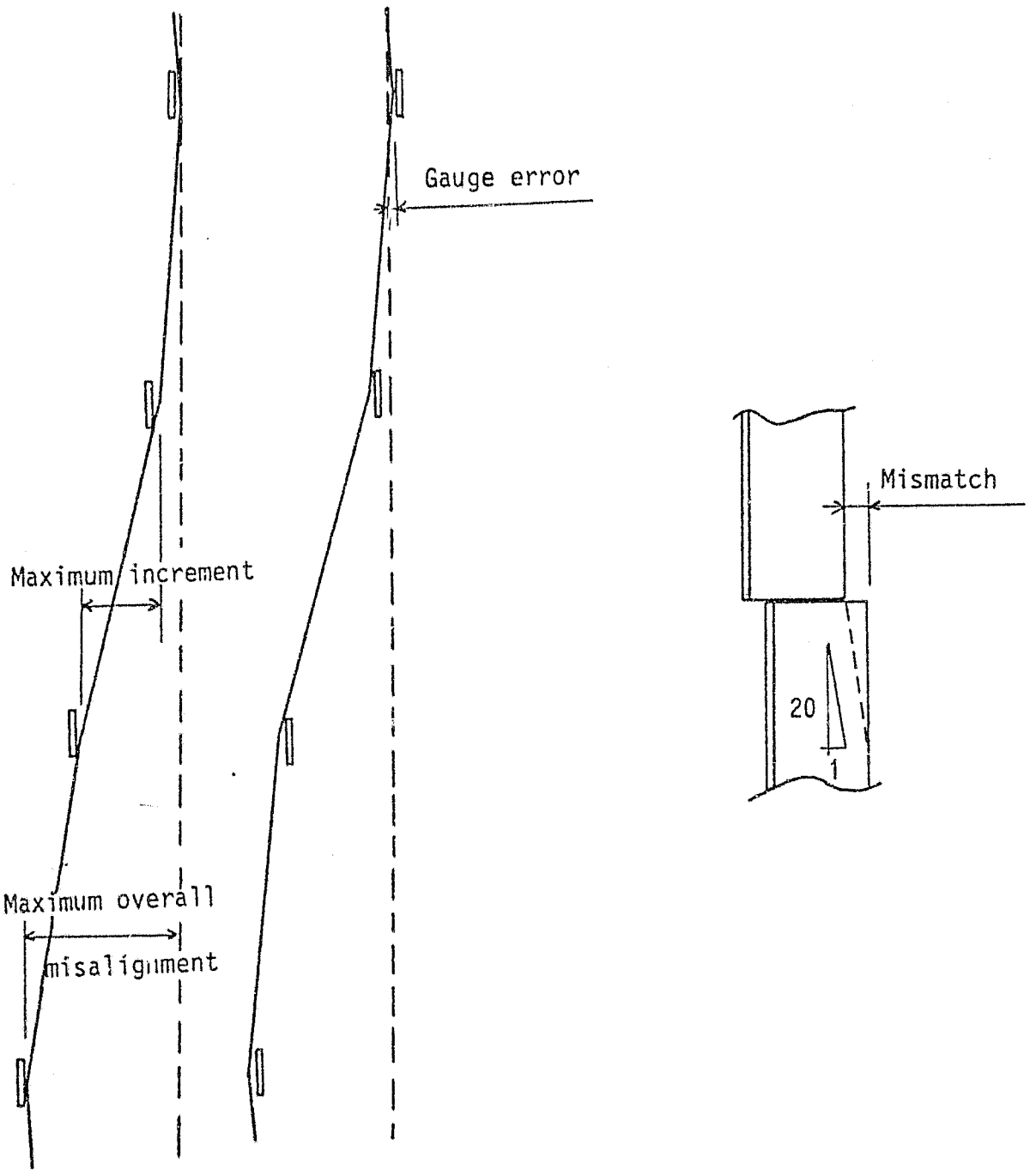


FIGURE 6.1 : Misalignments of guides

6.1.2 Lateral acceleration

As shown in section 4.5 above the design loads of W/10 which have previously been used are, in general, equivalent to lateral acceleration of about 7 m/sec².

A good shaft in the assessment of most engineers has accelerations below about 3 m/sec², so that these are suggested as the basic limits for a good shaft and an acceptable shaft. The reason for using lateral acceleration as the control variable here is that it does have a definite relationship to shaft condition and some bearing on maximum wheel loads, and it is also easy to measure with equipment which is readily available to all mines.

TABLE 6.1 : BASIC OPERATING LIMITS

	Control variable	Good shaft	Acceptable shaft
quality control	overall off-vertical misalignment	D/2000 ≯ 0,5 m	D/1000 ≯ 0,5 m
	Off-vertical increment misalignment	± 5 mm	± 8 mm
	Gauge error	−0 mm +2 mm	−0 mm +4 mm
	Mismatch (maximum value without grinding)	0,3 mm	0,6 mm
maintenance	Lateral acceleration	3 m/sec²	7 m/sec²

D = depth below sheaves

6.2 DESIGN RULES

Based on the measurements obtained as described above, on personal discussions with many engineers and on some parametric studies using DISCS, the following rules are proposed for establishing the design loading for conveyances running between two guides in vertical mineshafts. From two sets of measurements in conveyances with a different guide configuration, similar rules probably apply to other guide configurations, but too few measurements were obtained to extend these proposals to such cases.

6.2.1 Assesmment of wheel loads and their point of application

The design procedure should be based on an assessment of the wheel loads as given in section 4.4.9 and 5.5 above, i.e.

$$P = F.W_E \left(\frac{V\Delta}{A}\right) + \bar{K}_{Bunt} \left(\frac{PRELOAD}{K_{Bank}} + \frac{\delta}{2}\right)(1 \pm 0,15\kappa) \quad \ldots 6.1$$

The results of this equation, together with measured maximum wheel loads and DISCS predictions are shown in Table 6.2

TABLE 6.2 DESIGN, MEASURED AND DISCS WHEEL LOADS AT 15 m/sec

SHAFT	Shaft condition	Design load (kN)	Measured load (kN)	DISCS load (kN)
Pres. Steyn* 4# skip	Non-acceptable	21,4	16,8 22,8	11,3 31,4
Western Deep Levels 2# skip +	Good	6,6	6,8	7,8
Western Holdings 1# skip	Good Acceptable	4,3 6,9	7,8	10,5
Harties 8# cage	Acceptable Non-acceptable	13,3 17,9	15,6	15,3
Deelkraal 1# skip	Acceptable	21,1	14,7	17,5

* Values given for top and bottom wheels

\+ Koepe winder, F = F/2

The values for "good", "acceptable" and "non-acceptable" shafts in this Table 6.2 are obtained by putting the value of A equal to 0,005, 0,008 and 0,012 respectively.

In designing conveyances, these wheel loads should be applied at any one wheel and resisted at the level of the centre of gravity of the conveyance, i.e. by the inertia of the conveyance.

To design the guides, the first section only of equation 6.1 should be used. This arises by virtue of the dynamic behaviour of the conveyance and can occur anywhere along the guide. At the buntons, the preload may also have a high value, so that the buntons should be designed considering the entire equation 6.1 for the wheel loads. In both cases P should be considered as acting at one wheel only. These design loads are shown schematically in Figure 6.2.

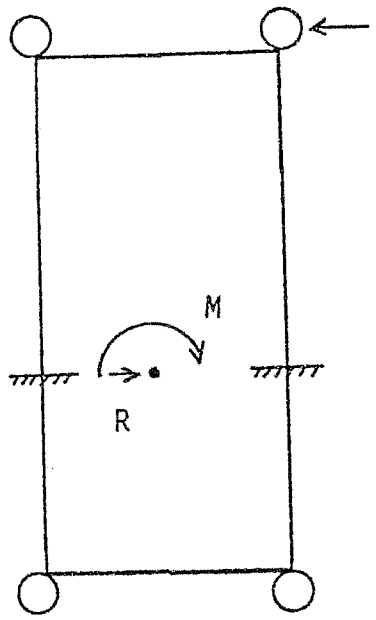
6.2.2 Guide and Bunton Stiffnesses

As discussed above, the guide and bunton stiffness can play an important part in increasing wheel loads where there is a significant preload, where the guide guage descreases, or if the bunton stiffness is not the same on both sides. One or other of these applies in almost all mines, so certain limitations need to be placed on guide and bunton stiffness. As the maximum wheel load and the preload increases, the bunton deflection should increase under the design load, but the guide deflection should not increase, but rather decrease. Also, as the ratio of the bunton stiffness of the stiffer bunton to the more flexible one increases above one, the guide deflection should decrease to prevent the high change in wheel load on the side of the stiffer bunton. The set of curves in Figure 6.3 represent the recommended deflection limits for bunton deflection (minimum limit, i.e. deflection should not be less than this value) and for guide deflection (maximum limit, i.e. deflection should not be greater than this value).

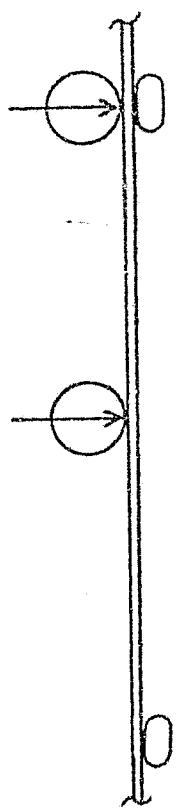
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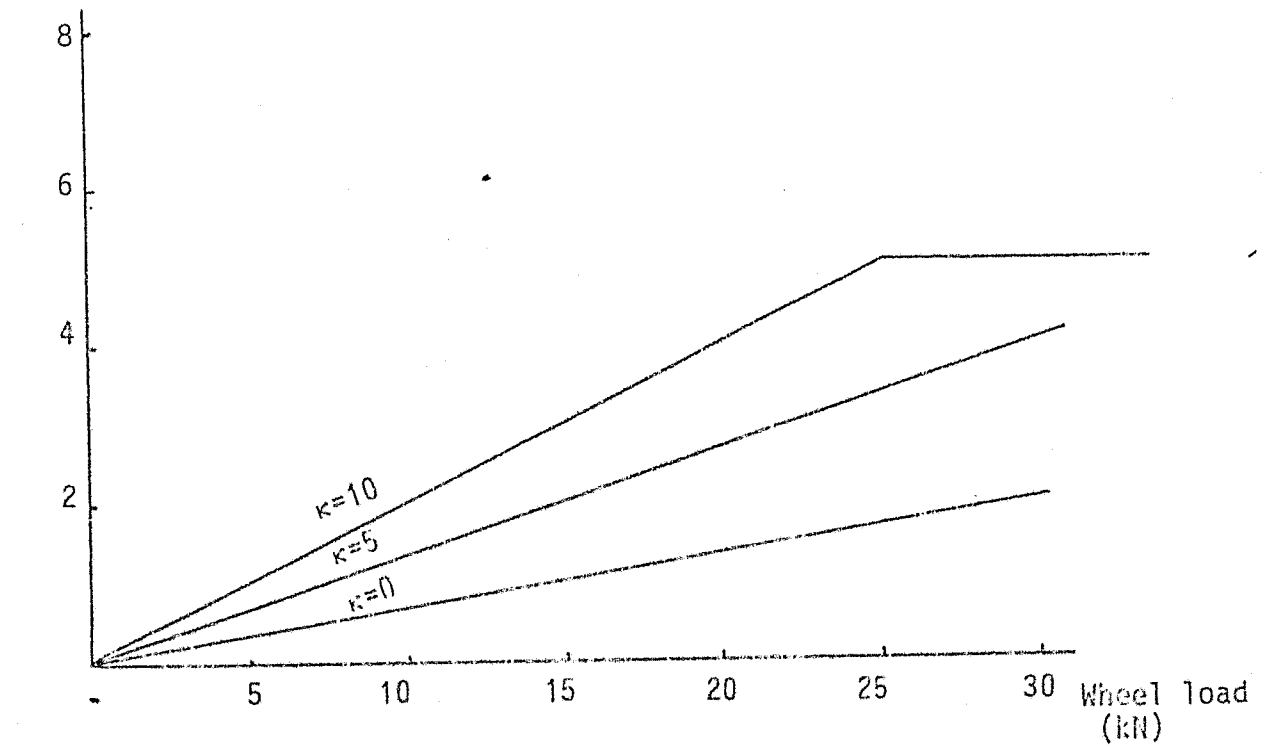
$$P = F.W_e\left(\frac{V\Delta}{A}\right) + \bar{K}_{Bunt}\left(\frac{PRELOAD}{K_{Bank}} + \delta\right)(1 \pm 0{,}15k)$$



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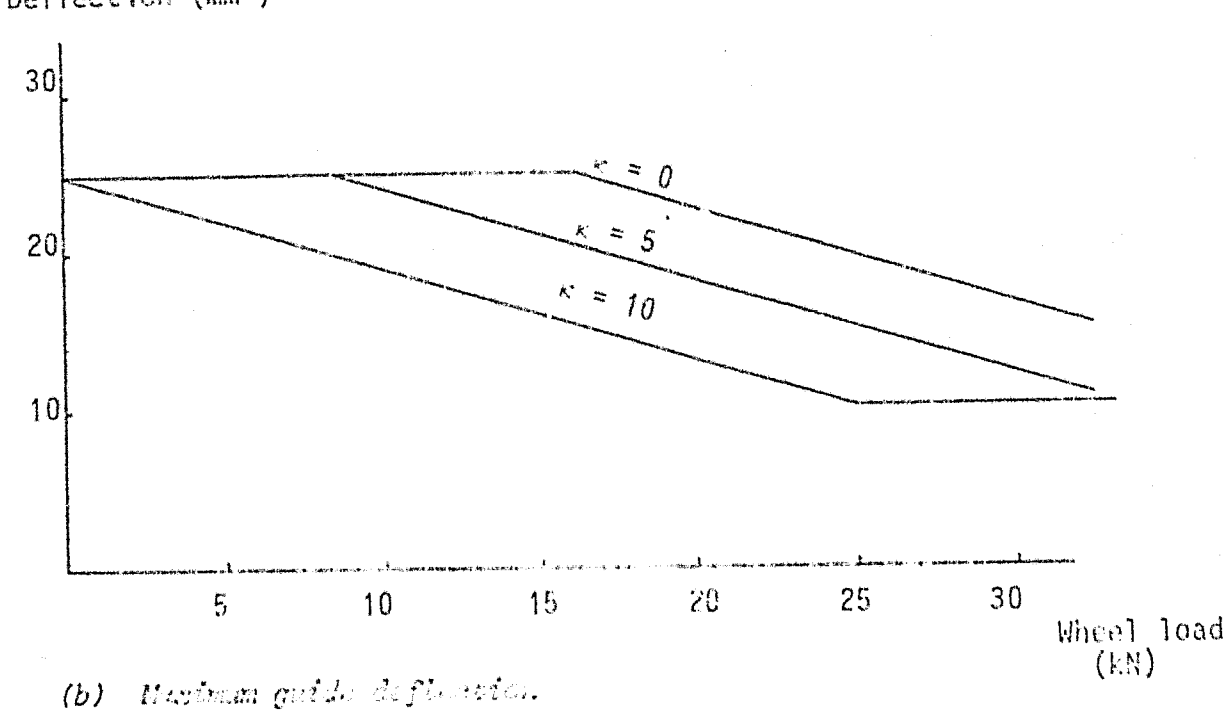
$$P = F.W_e\left(\frac{V\Delta}{A}\right)$$

FIGURE 6.2 : Design wheel loads



(a) minimum bunton deflection

$$\kappa = \left(\frac{\text{Stiffness of stiffer bunton}}{\text{Stiffness of less stiff bunton}} - 1\right)$$



(b) Maximum guide deflection.

FIGURE 5.3 Deflection limits

6.2.3 Basic permissable stresses

The basic permissable stresses in shaft steelwork should be those given in SABS 0162 divided by 2 to allow for the much greater uncertainties of loading and steelwork condition after some years in the shaft. For conveyances the same loads apply, but these should then be factored in accordance with the rope strength factors specified by the Mines and Work Act, divided by the ratio of ultimate strength to maximum working stress and the stresses as given in SABS 0162 should be used.

6.2.4 Fatigue life

The fatigue life should be calculated in accordance with BS 5400 or SABS 0162 Appendix F, using the fatigue load of 5 kN applied the number of times which will be recommended by Fotopoulos[15] .

6.2.5 Preventing dynamic magnification

This problem relates to the frequency of revolution of the wheels. If this frequency is within 30% of a natural frequency of deformation of the conveyance, one of the frequencies should be altered. The simplest alteration would be to change the diameter of the wheel, preferably to a larger diameter so that the frequency of revolution decreases for a given hoisting speed. To achieve this, it would be very valuable if the wheel suppliers could offer wheels of different diameter. Alternatively, some alteration should be made to the conveyance, to alter its natural frequencies of deformation.

6.3 DESIGN METHOD

6.3.1 Applying the rules

In applying the recommended design rules above, the following design procedure should be used.

(a) establish the shaft layout and conveyance size and mass from normal shaft design criteria.

(b) make some assumption regarding bunton stiffness and hence with a standard, or specified preload, assess the maximum wheel loads, including dynamic magnification

(c) check that deflections are within the limits specified in 6.2.2. In calculating guide deflections use only that component of the wheel load applicable to dynamic behaviour, and in calculating the bunton deflection the full wheel load should be used.

(d) Check that stresses do not exceed the relevant values, again using only the dynamic component of wheel load for the guides in bending, and the full wheel loads for the guides in shear and the buntons.

6.3.2 Example of design

Devy[22] has shown the application of several existing design methods, to the shaft layout in the Free State Geduld No. 5 shaft, shown in Figure 6.4. These design methods, together with the maximum horizontal loads and resulting bunton sections are shown in Table 6.3. This shaft layout is used for a design example which illustrates the design method proposed in this thesis.

TABLE 6.3 : DESIGN COMPARISONS

Design method	Maximum horizontal force as % of full conveyance weight	Bunton size 0
Old A A C	12,5	300 x 100 x 8
New A A C	10	300 x 150 x 8
German	8,33	200 x 100 x 6
DISCS predictions	11	-----
Krige (method proposed in this thesis)	6	300 x 100 x 8

The shaft layout at Free State Gedule No. 5 shaft is shown in Figure 6.4. Figure 6.5 shows the results of checking for dynamic magnification using DYNMAG. It is clear from this figure that no dynamic magnification should be expected with a bunton spacing of less than 6,0 m and a hoisting velocity of less than 20 m/sec. Dynamic magnification is thus not a problem in this instance.

It is assumed that the wheel preload will be 2 kN and that the bunton stiffness will be 15000 kN.m. The design wheel load for the skip is thus:

$$P = 4,8\ W_E\left(\frac{V\Delta}{A}\right) + \bar{K}_{Bunt}\left(\frac{PRELOAD}{K_{Bank}} + \frac{\delta}{2}\right)(1\pm 0,15\kappa)$$

Looking initially at the skip compartment marked with a cross, the buntons on each side of it will be assumed to have equal stiffness. The empty weight of the skip is 89 kN,

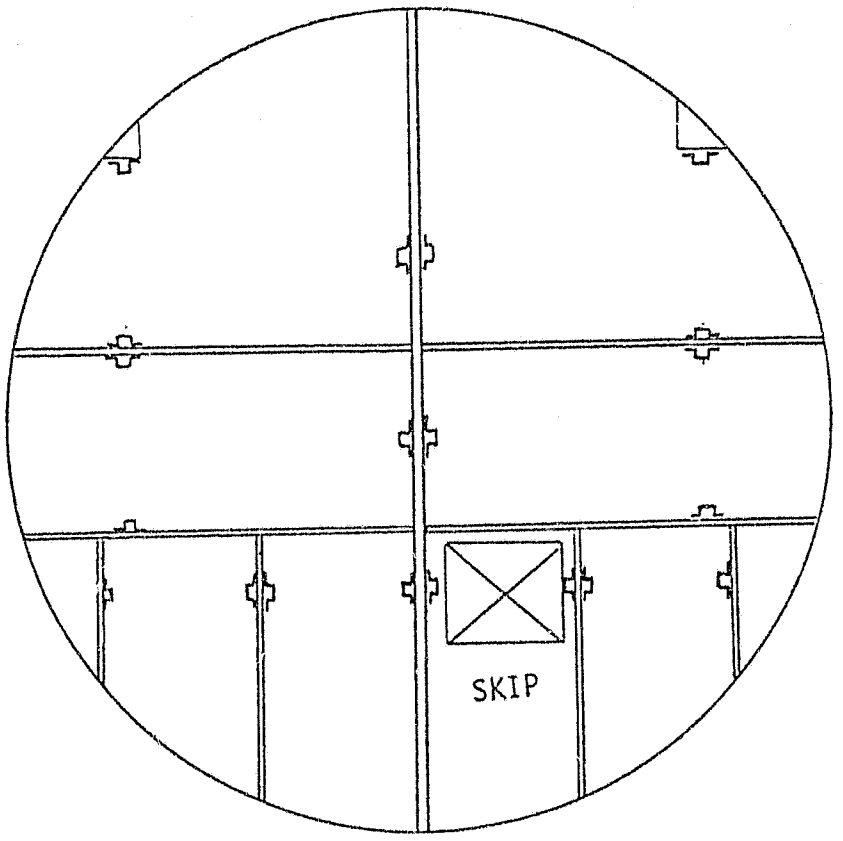


FIGURE 6.4 : Layout of Free State Geduld No. 5 Shaft

FIGURE 6.5 : DYNMAG dynamic predictions for F.S.G No. 5 shaft

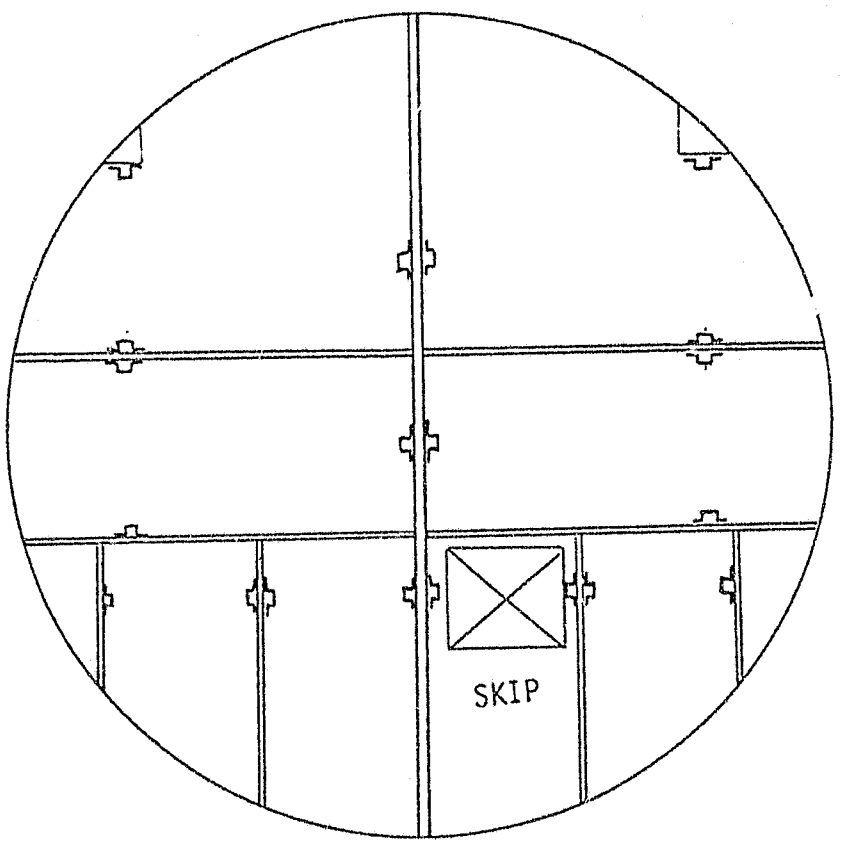


FIGURE 6.4 : Layout of Free State Geduld No. 5 Shaft

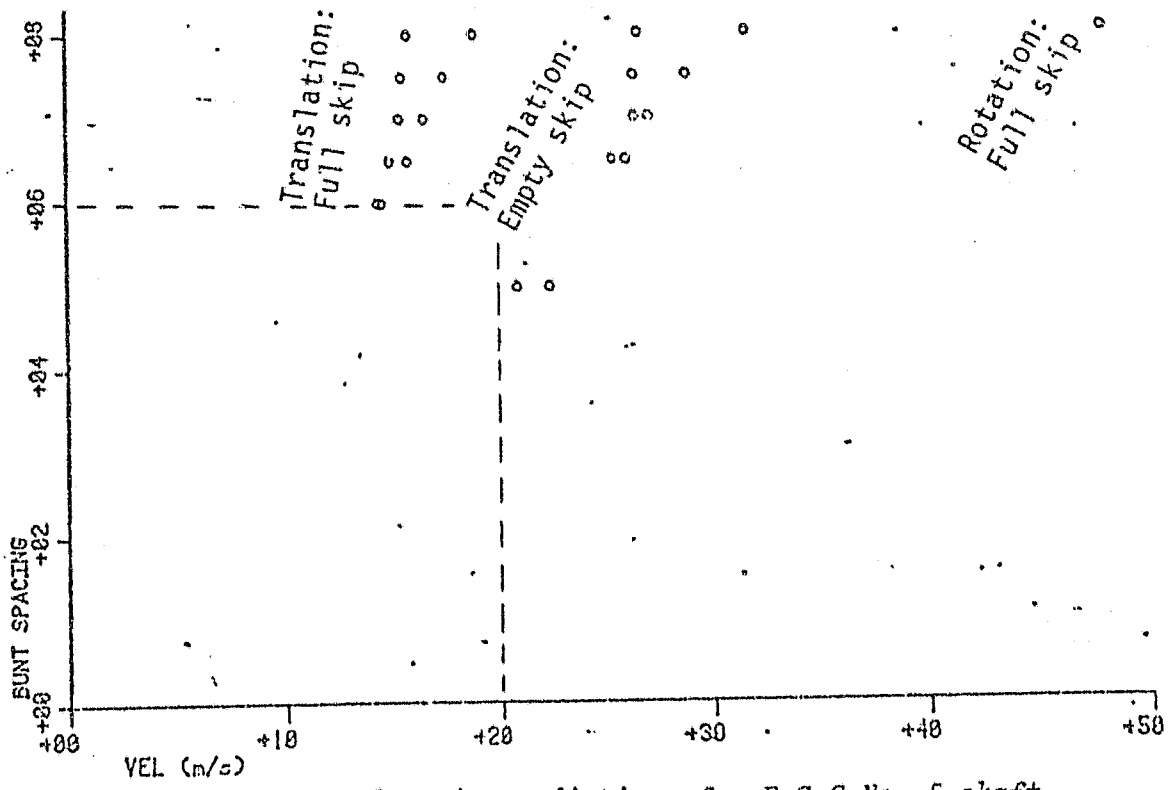


FIGURE 6.5 : DYNMAG dynamic predictions for F.S.G No. 5 shaft

the hoisting velocity is 15 m/sec and it will be assumed that specified alignment errors are in the acceptable classification, i.e. $\Delta = 0{,}008$. Assuming that the wheel spring stiffness is 1000 kN m, we have:

$$W = 4{,}8 \times 89 \left(\frac{15.0{,}008}{4{,}57}\right) + \frac{15000 \times 1000}{15000+1000}\left(\frac{2}{K_{Bank}} + 0\right).$$

$$(1 \pm 0{,}15.0)$$

$$= 11{,}2 + 937{,}5 \left(\frac{2}{K_{Bank}}\right) \text{ kN}$$

Assuming that the wheels are adjusted where the stiffness of the guides is 8000 kN m,

$$K_{Bank} = \frac{8000 \times 1000}{8000 + 1000} = 888{,}9 \text{ kN.m}$$

Thus

$$W = 11{,}2 + \frac{937{,}5.2}{888{,}9} = 13{,}3 \text{ kN}$$

The bunton length is 3,39 m and this force is applied 1,02 m from the end. Assume that it is fixed ended.

Thus the maximum bending moment is

$$B.M = 13{,}5 \text{ kN.m}$$

The required modulus is thus

$$Z_{req'd} = \frac{13{,}5 \times 10^3}{165/2} = 163{,}6 \times 10^{6} \text{ m}^3$$

This requires the use of a

300 x 100 x 8 ▯ bunton.

The stiffness of this bunton can be calculated as:

16864 kN/m.

The stiffness of the other bunton a 610 x 230 x 140 UB, can be calculated as :

23566 kN/m

These are not similar, so that $\kappa = \frac{23566}{16864} - 1$
$= 0,4$

This bunton stiffness gives a design wheel load of:

$$W = 11,2 + \frac{16864 \times 1000}{16864 + 1000} \left(\frac{2}{889}\right) (1-0,15x0,4) \text{ kN}$$

$= 11,2 + 2,0$ kN

$= 13,2$ kN

Check deflections:

$\kappa = 0,4$

Bunton deflection $= \frac{13,2}{16864} = 0,0008$ m $\cong$ 1 mm

Guide deflection $= \frac{13,2}{1057} = 0,0125$ m = 12,5 mm

The 300 x 100 x 8 ▯ is thus acceptable.

CHAPTER 7

CONCLUSION AND FURTHER RESEARCH NEEDED

Previous design practice for shaft steelwork has been based on assumed or "historically extrapolated" conveyance wheel loads. There has not previously been any comprehensive measurement of these wheel loads, or use of theoretically derived methods in predicting them. The research described in this report addresses this problem.

7.1 CONCLUSIONS

A computer model, DISCS, has been set up, based on a simplified mathematical model of a conveyance running between two guides of equal stiffness. In addition, a method of measuring the lateral accelerations and the wheel loads on a conveyance under normal operating conditions has been developed.

An assessment of the validity of the computer model, by comparison of its predictions with actual measurements, has shown that once some adjustments have been made to certain input variables, the wheel loads are predicted with reasonable accuracy. Such adjustments could in all cases be explained - as relating to one or other of the simplifying assumptions made in setting up the model. This gives an acceptable degree of confidence that the model can be altered to predict design values.

Several important conclusions can be drawn from the measurements which were obtained.

(a) The wheel load, W/10, which is the normal current design value, is usually a good maximum design value, although in many cases it is too high. The major exceptions to this, where the actual wheel loads exceed this value are cases where there is dynamic magnification, where the hoisting speed exceeds 15 m/sec, or where the guide misalignment is significantly worse than the acceptable limit proposed in Chapter 6. An empirical method is proposed whereby these factors are taken into account, to give a more accurate assessment of the design wheel load value.

(b) There is no direct relationship between wheel loads and the associated accelerations, so that measurements of acceleration only will not necessarily indicate the wheel load magnitude. It was however found that in general, high levels of acceleration are linked to high levels of wheel loads. Thus, although the commonly used "decelerometer traces" do not yield the exact location or magnitude of high wheel loads, they do give a good general indication of the shaft condition.

(c) The condition of the wheels and their revolution frequency are very important to the determination of the dynamic behaviour of a conveyance.

(d) Dynamic magnification was found to relate to the natural frequencies of the wheelsets or of deformation of the conveyance coinciding with the frequency of revolution of the wheels, rather than to the coincidence of the natural frequencies of overall displacement of the conveyance and the bunton passing frequency. This latter possibility cannot be ruled out however. A method is proposed for assessing and avoiding, or allowing for, possible dynamic magnification.

7.2 FURTHER RESEARCH NEEDED

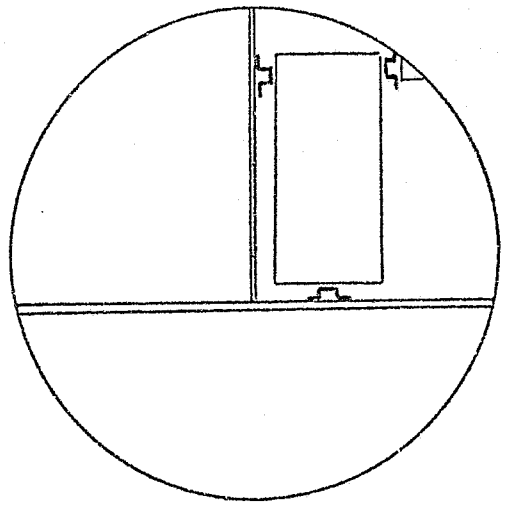
As has been mentioned in this thesis, it was necessary to limit the scope of the work undertaken, thus excluding aspects which may be of significant importance. Further research in these areas, listed below, is required.

7.2.1 Geometric factors

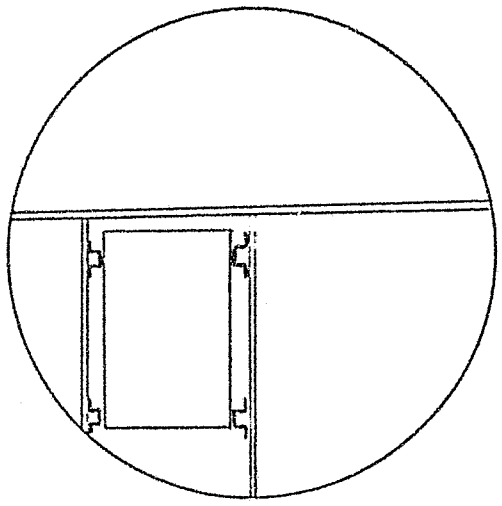
(a) Three dimensional study. The measurements which were taken in the direction perpendicular to the plane between the guides show that accelerations in this direction are often higher than in the plane between the guides. No analysis of these measurements was undertaken, and it is not certain whether it would follow that the wheel loads on the sides of the guides are thus also higher than the face wheel load. Buntons are usually very stiff in this direction, being loaded axially rather than flexurally, which may be a contributary factor to this higher acceleration, and the mass moment of inertia about the vertical axis is much lower than about other axes, so that high accelerations relating to rotation may not lead to high wheel loads.

(b) Guide Layout. Linked to the three dimensional study, is an assessment of the contribution to dynamic behaviour of different guide layouts. The one set of measurements taken on a cage with two guides on one side only, as shown in figure 7.1(a), when compared with the DISCS prediction showed similar results to those expected with one guide each side, but this is by no means an indication of the behaviour with other layouts, some of which are shown in Figure 7.1.

(a)



(b)



(c)

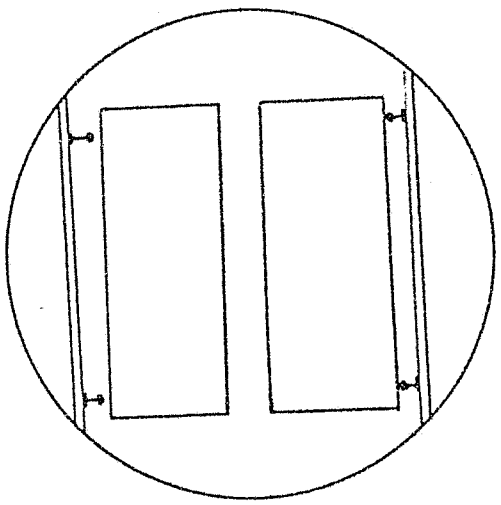


FIGURE 7.1 : Other guide layouts

(c) Other Factors. There may well also be merit in investigating other factors such as aerodynamic behaviour of skip and cage shapes, and the effects of two conveyances travelling the same direction, next to each other in adjacent compartments.

7.2.2 Specific problem areas

During the course of this study, several specific problem areas were identified, which need a more detailed investigation.

The first of these was the behaviour of the wheels. A more detailed study, both theoretically and experimentally of variables relating directly to the wheel, should be undertaken. These variables should include the lever arm between wheel and pivot, the age and condition of the rubber tyre, the inertia of the wheel about its pivot, and the effect of damping the wheel.

The second of these was the higher order natural frequencies. Local factors such as connection stiffness and slip between bridle and skip or cage played a significant part in determining the natural frequencies relating to deformation of the conveyance. More measurements should be undertaken to enable an empirical or theoretical assessment of these frequencies to give more accurate results.

A third problem was that slipper contact forces could not be measured. A more complete picture of the dynamic behaviour would be obtained if this could be done, even if it is only to measure forces which are seldom applied.

7.2.3 Economic and Maintenance Aspects

A study such as outlined in this thesis could well be followed up with a detailed study of the relation between initial capital expenditure in equipping a new shaft, and subsequent expected maintenance and down-time costs. Such a study would probably require measurements repeated in one or more selected shafts over an extended time period, or at least an examination of decelerometer trace records where they are available over the past few years.

7.4 DESIGN RECOMMENDATIONS

While this project has identified many important factors which determine the dynamic response, the absolute levels of the design recommendations specified in Chapter 6 should be assessed in a wide range of good and acceptable shafts as well as shafts which are not acceptable, in order to improve the confidence with which these recommendations can be applied.

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MAJOR NOTATION

A	-	bunton spacing
A_1 to A_{23}	-	constants used in the equations of motion in DISCS
B_1 to B_4	-	constants used to calculate the natural frequencies in DISCS
C_B	-	damping (percentage of critical) of conveyance body and bridle
C_S	-	damping (percentage of critical)
C_{S_1} to C_{S_6}	-	effective damping of steelwork and wheel
d_1 to d_6	-	conveyance dimensions
$E\{x\}$	-	expected value of x
F	-	"conveyance factor"
F_N	-	upper frequency limit
F_1 to F_6	-	forces on three rigid bodies in DISCS
f_n or f	-	natural frequencies
I_R and I_{R_1} to I_{R_3}	-	mass moments of inertia
K_{Bank}	-	effective wheel spring stiffness at bank level where preload is adjusted
$\bar{K}_{Bunt}$	-	average effective wheel spring stiffness at a bunton
K_{C_3} to K_{C_4}	-	connection stiffness between conveyance body and transoms
K_{e_1} to K_{e_6}	-	effective wheel spring stiffness
K_G	-	guide stiffness
K_W	-	wheel spring stiffness
K_W', K_P, K_M', K_D	-	various constants used in deriving wheel load equation
ℓ	-	overall conveyance length
M_1 to M_3	-	masses

OWE	-	other wheel effect, i.e. the displacement at one wheel due to the other wheel on the same guide
P	-	the design wheel load
r	-	ratio of frequencies
R	-	ratio of sum of power spectra for wheel loads and accelerations
$S_{yy}(\omega)$	-	power spectrum of y(t)
V	-	hoisting velocity
W	-	wheel load
W_1 to W_6	-	specific wheel loads calculated by DISCS
W_E	-	empty weight of conveyance
w_{xx}	-	spring travel, or clearance between guide and guide shoe
w_{01} to w_{04}	-	guide position off true vertical
y(t)	-	function of time (either acceleration or wheel load)
Δ	-	maximum misalignment increment
σ	-	minimum guage error
γ	-	damping ratio
κ	-	(ratio of stiffness of stiffer bunton to more flexible bunton)-1
v_1 to v_3	-	lateral displacements of rigid bodies in DISCS
ω	-	cyclical frequencies
ϕ	-	rotation of rigid bodies in DISCS

APPENDIX A : DERIVATION OF THE EQUATIONS OF MOTION

Rotation Equation:-

For simplicity of writing equations use :-

$\phi = \phi\ (t)$

$\nu_1 = \nu_1 (t)$

$\nu_2 = \nu_2 (t)$

$\nu_3 = \nu_3 (t)$

$I_R = I_{R1} + I_{R2} + I_{R3}$

$\dot{\phi} = \frac{d\phi(t)}{dt}$

$\dot{\nu}_1 =$ as above

$\dot{\nu}_2 =$ as above

$\dot{\nu}_3 =$ as above

$\ddot{\phi} = \frac{d^2\phi(t)}{dt^2}$

$w_1 = w_1\ (x,\ t)$

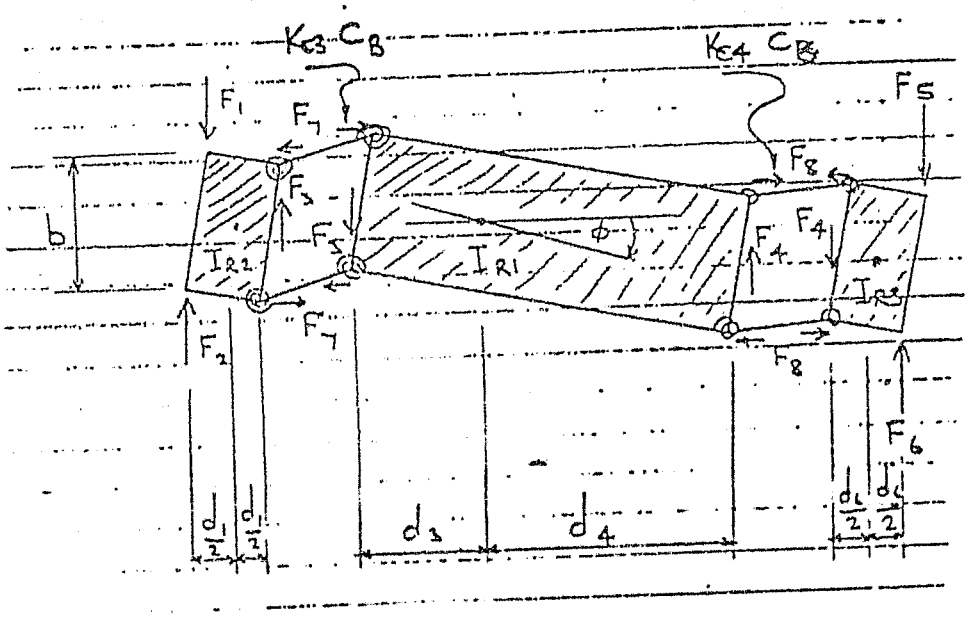
$w_2 = w_2\ (x,\ t)$

$w_3 = w_1\ (x + \ell,\ t)$

$w_4 = w_2\ (x + \ell,\ t)$

Assumptions

Angular rotation of transoms is the same as body of the skip - i.e. bridle legs are taken as inextensible.



$$w_{01} = w_{01}(x)$$

$$w_{02} = w_{02}(x)$$

ϕ is small, so that:-

$$\cos\phi \cong 1 \qquad \sin\phi \cong \phi$$

$$\sin\phi\,\frac{d_1}{2} \cong \sin\phi\,\frac{d_6}{2} \cong \sin\phi\,\frac{b}{2} \cong 0$$

Equation of Motion is :-

$$I_{R1}\ddot{\phi} + I_{R2}\ddot{\phi} + I_{R3}\ddot{\phi} = (-F_1+F_2-F_3)\frac{d_1}{2} - F_7 b - F_3 d_3 - F_4 d_4 + F_7 b + F_8 b + (F_5-F_6-F_4)\frac{d_6}{2} - F_8 b$$

$$\therefore\ I_R\ddot{\phi} + (F_1-F_2+F_3)\frac{d_1}{2} + F_3 d_3 + F_4 d_4 + (-F_5+F_6+F_4)\frac{d_6}{2} = 0 \quad \ldots\ldots(1)$$

$$F_1 = (v_2 - w_1 - w_{01})K_{e1} + (\dot{v}_2 - \dot{w}_1 - \dot{w}_{01})C_{s1}$$

$$F_2 = (-v_2 - w_2 - w_{02})K_{e2} - (\dot{v}_2 + \dot{w}_2 + \dot{w}_{02})C_{s2}$$

$$F_5 = (v_3 - w_3 - w_{03})K_{e5} + (\dot{v}_3 - \dot{w}_3 - \dot{w}_{03})C_{s5}$$

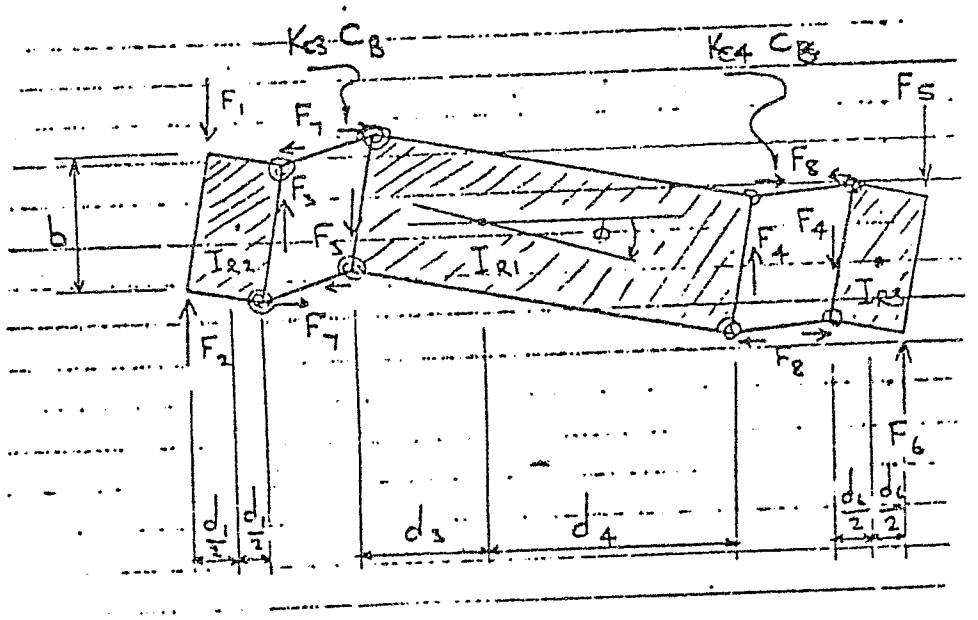
$$F_6 = (-v_3 - w_4 - w_{04})K_{e6} - (\dot{v}_3 + \dot{w}_4 + \dot{w}_{04})C_{s6}$$

$$F_3 = (v_1 + d_3\phi - v_2)K_{c3} + (\dot{v}_1 + d_3\dot{\phi} - \dot{v}_2)C_{b3}$$

$$F_4 = (-v_1 + d_4\phi + v_3)K_{c4} + (-\dot{v}_1 + d_4\dot{\phi} + \dot{v}_3)C_{b4}$$

K_i are spring stiffnesses
C_i are damping values.

Note: F_1, F_2, F_5 & F_6 are zero if deflection causes wheels to leave the rails.



$$w_{01} = w_{01}(x)$$

$$w_{02} = w_{02}(x)$$

ϕ is small, so that:-

$$\cos\phi \cong 1 \qquad \sin\phi \cong \phi$$

$$\sin\phi\,\frac{d_1}{2} \cong \sin\phi\,\frac{d_6}{2} \cong \sin\phi\,\frac{b}{2} \cong 0$$

Equation of Motion is :-

$$I_{R1}\ddot{\phi} + I_{R2}\ddot{\phi} + I_{R3}\ddot{\phi} = (-F_1+F_2-F_3)\frac{d_1}{2} - F_7 b - F_3 d_3 - F_4 d_4 + F_7 b + F_8 b + (F_5-F_6-F_4)\frac{d_6}{2} - F_8 b$$

$$\therefore\ I_R\ddot{\phi} + (F_1-F_2+F_3)\frac{d_1}{2} + F_3 d_3 + F_4 d_4 + (-F_5+F_6+F_4)\frac{d_6}{2} = 0 \quad \ldots\ldots\ldots (1)$$

$$F_1 = (v_2 - w_1 - w_{01})K_{e1} + (\dot{v}_2 - \dot{w}_1 - \dot{w}_{01})C_{s1}$$

$$F_2 = (-v_2 - w_2 - w_{02})K_{e2} - (\dot{v}_2 + \dot{w}_2 + \dot{w}_{02})C_{s2}$$

$$F_5 = (v_3 - w_3 - w_{03})K_{e5} + (\dot{v}_3 - \dot{w}_3 - \dot{w}_{03})C_{s5}$$

$$F_6 = (-v_3 - w_4 - w_{04})K_{e6} - (\dot{v}_3 + \dot{w}_4 + \dot{w}_{04})C_{s6}$$

$$F_3 = (v_1 + d_3\phi - v_2)K_{c3} + (\dot{v}_1 + d_3\dot{\phi} - \dot{v}_2)C_{b3}$$

$$F_4 = (-v_1 + d_4\phi + v_3)K_{c4} + (-\dot{v}_1 + d_4\dot{\phi} + \dot{v}_3)C_{b4}$$

K_i are spring stiffnesses

C_i are damping values.

Note: F_1, F_2, F_5 & F_6 are zero if deflection causes wheels to leave the rails.

Horizontal Motion of Mass M_1

$$M_1\ddot{\nu}_1 = -F_3 + F_4$$

$$\therefore \quad M_1\ddot{\nu}_1 + F_3 - F_4 = 0 \qquad (2)$$

Horizontal Motion of Mass M_2

$$M_2\ddot{\nu}_2 = -F_1 + F_2 + F_3$$

$$\therefore \quad M_2\ddot{\nu}_2 + F_1 - F_2 - F_3 = 0 \qquad (3)$$

Horizontal Motion of Mass M_3

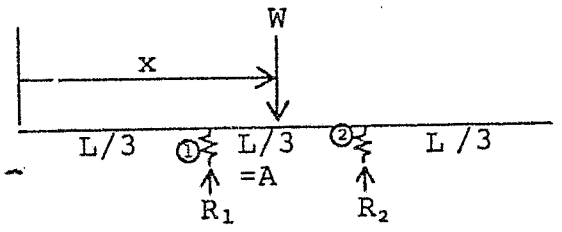
$$M_3\ddot{\nu}_3 = -F_5 + F_6 - F_4$$

$$\therefore \quad M_3\ddot{\nu}_3 + F_5 - F_6 + F_4 = 0 \qquad (4)$$

APPENDIX B : DERIVATION OF GUIDE STIFFNESS EQUATION

Derivation of Varying Guide Stiffness

Considering the 3 - span beam shown, the stiffness can be evaluated for load moving across the centre span. This stiffness repeated along the guide gives the varying guide stiffness.



Using standard structural deflection theory it can be shown that:-

(N.B. - Applies for $L/3 \leq x \leq 2L/3$ only)

[1] For $R_1 = R_2 = 0$

$$\Delta_1 = \frac{WL^3}{162EI}(-1+19a-27a^2+9a^3)$$

$$\Delta_2 = \frac{WL^3}{162EI}(8a - 9a^3)$$

where $a = \frac{x}{L}$

Δ_1, Δ_2 are the deflections at [1] and [2] resp.

[2] For $W = 0$

$$-\Delta_1 = \frac{(8R_1+7R_2)L^3}{486\ EI} \qquad -\Delta_2 = \frac{(7R_1+8R_2)L^3}{486\ EI}$$

The deflections under the action of W, resisted by spring supports are thus:-

$$\Delta_1 = \frac{L^3}{162EI}\left[W(-1+19a-27a^2+9a^3) - \tfrac{1}{3}(8R_1 + 7R_2)\right] = \frac{R_1}{K_B}$$

$$\Delta_2 = \frac{L^3}{162EI}\left[W(8a-9a^3) - \tfrac{1}{3}(7R_1+8R_2)\right] = \frac{R_2}{K_B}$$

where K_B is the bunton stiffness.

Solving these two equations for R_1 and R_2 gives:-

$$R_1 = W\left[B_1(-1+19a-27a^2+9a^3)+B_2(-1+11a-27a^2+18a^3)\right]$$

$$R_2 = W\left[B_1(8a-9a^3)-B_2(-1+11a-27a^2+18a^3)\right]$$

where $B_1 = \frac{1}{B_3/K_B+5}$ $\quad B_2 = B\left(\frac{7/3}{B_3/K_B+1/3}\right)$ $\quad B_3 = \frac{162EI}{L^3}$

It can then be shown that the deflection under W is:-

$$\Delta_x = \frac{W}{B_3}\left[54a^2(1-a)^2-B_1(-1+19a-27a^2+9a^3)^2-B_1(8a-9a^3)^2 - B_2(-1+11a-27a^2+18a^3)^2\right]$$

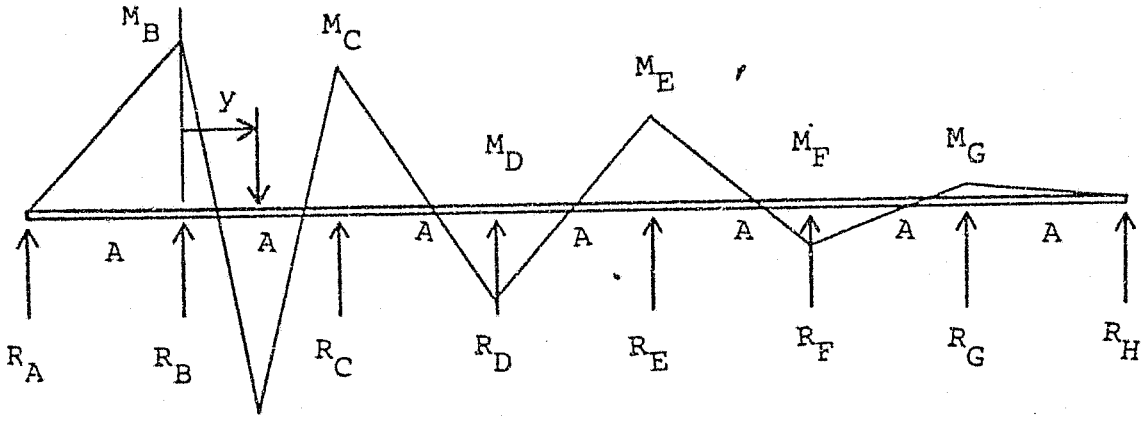
The guide stiffness, K_G, is thus given by:-

$$1/K_G = 1/B_3\left[(-B_1-B_2)+(38B_1+22B_2)a+(54-479B_1-175B_2)a^2 -(108-1044B_1-630B_2)a^3+(54-927B_1-1125B_2)a^4 +(486B_1+972B_2)a^5-(162B_1+324B_2)a^6\right]$$

APPENDIX C : CALCULATION OF GUIDE DISPLACEMENT DUE TO OTHER WHEEL LOAD

The effect at each wheel due to the other wheel on the same guide is calculated as below. Due to symmetry and laws of reciprocity, the unit load effect at each of the four wheels is the same.

Consider the beam shown below:



The guide is simplified as a continuous beam over elastic supports having reactions R_A to R_H and support moments of M_B to M_G. Initially, the moments and reactions due to a unit load, as shown, are calculated.

Putting : $K = \frac{6EI}{a^2}$ $\quad Y_1 = \frac{y(a-y)^2}{a^2}$ $\quad Y_2 = \frac{y^2(a-y)}{a^2}$ Fixed end moments

$M_B = -M_{BA} = M_{BC}$ $\quad M_C = -M_{CB} = M_{CD}$ $\quad M_D = -M_{DC} = M_{DE}$

$M_E = -M_{ED} = M_{EF}$ $\quad M_F = -M_{FE} = M_{FG}$ $\quad M_G = -M_{GF} = M_{GH}$

we can write the slope-defection equations for the beam as:

$$-M_B = -\frac{3EI}{a}\theta_B + \frac{K}{2}(\delta_B - \delta_A)$$

$$M_B = Y_1 - \frac{4EI}{a}\theta_B - \frac{2EI}{a}\theta_C + K(\delta_C - \delta_B)$$

$$-M_C = Y_2 - \frac{4EI}{a}\theta_C - \frac{2EI}{a}\theta_B + K(\delta_C-\delta_B)$$

$$M_C = -\frac{4EI}{a}\theta_C - \frac{2EI}{a}\theta_D + K(\delta_D-\delta_C)$$

$$-M_D = -\frac{4EI}{a}\theta_D - \frac{2EI}{a}\theta_C + K(\delta_D-\delta_C)$$

$$M_D = -\frac{4EI}{a}\theta_D - \frac{2EI}{a}\theta_E + K(\delta_E-\delta_D)$$

$$-M_E = -\frac{4EI}{a}\theta_E - \frac{2EI}{a}\theta_D + K(\delta_E-\delta_D)$$

$$M_E = -\frac{4EI}{a}\theta_E - \frac{2EI}{a}\theta_F + K(\delta_F-\delta_E)$$

$$-M_F = -\frac{4EI}{a}\theta_F - \frac{2EI}{a}\theta_E + K(\delta_F-\delta_E)$$

$$M_F = -\frac{4EI}{a}\theta_F - \frac{2EI}{a}\theta_G + K(\delta_G-\delta_F)$$

$$-M_G = -\frac{4EI}{a}\theta_C - \frac{2EI}{a}\theta_F + K(\delta_G-\delta_F)$$

$$M_G = -\frac{3EI}{a}\theta_G + \frac{K}{2}(\delta_H-\delta_G)$$

where θ and δ are the rotation (clockwise +ve) and deflection (down +ve) respectively at the support points.

Eliminating all θ's from these equations we have:

$$4M_B + M_C = 2Y_1 - Y_2 + K\delta_A - 2K\delta_B + K\delta_C$$

$$M_B + 4M_C + M_D = Y_1 - 2Y_2 + K\delta_B - 2K\delta_C + K\delta_D$$

$$M_C + 4M_D + M_E = K\delta_C - 2K\delta_D + K\delta_E$$

$$M_E + 4M_F + M_G = K\delta_E - 2K\delta_F + K\delta_G$$

$$-M_E - 3M_F + 3M_G = -K\delta_E + 3K\delta_F - 3K\delta_G + K\delta_H$$

$$-M_C - 2M_D + 6M_E + 7M_G = -K\delta_C + 4K\delta_D - 6K\delta_E + 6K\delta_F - 5K\delta_G + 2K\delta_H$$

Equilibrium equations are:

$$\text{Vertical} : aR_A + aR_B + aR_C + aR_D + aR_E + aR_F + aR_G + aR_H = a$$

$$\text{Moment} : aR_H = -M_G$$

$$2aR_H + aR_G = -M_F$$

$$3aR_H + 2aR_G + aR_F = -M_E$$

$$4aR_H + 3aR_G + 2aR_F + aR_E = -M_D$$

$$5aR_H + 4aR_G + 3aR_F + 2aR_E + aR_D = -M_C$$

$$aR_A = -M_B$$

$$2aR_A + aR_B - (a-y) = -M_C$$

We also have:

$$a\delta_i K_B = aR_i \quad \text{where } K_B \text{ is bunton stiffness.}$$

$$K\delta_i = \frac{KaR_i}{aK_B} = K_1 aRi \text{ where } K_1 = \frac{K}{aK_B}.$$

substitute for M_i and $K\delta_i$ above, and include vert. equil and equate the two expressions for Mc, dividing through by a, to give:-

$$-6R_A - R_B + 1 - \frac{Y}{a} = \frac{2Y_1 - Y_2}{a} + K_1R_A - 2K_1R_B + K_1R_C$$

$$-2R_A - R_B - 4R_E - 9R_F - 14R_G - 19R_H + 1 - \frac{Y}{a} = K_1R_C - 2K_1R_D + K_1R_E$$

$$-9R_A - 4R_B - R_E - 2R_F - 3R_G - 4R_H + 4 - 4\frac{Y}{a} = \frac{Y_1 - 2Y_2}{a} + K_1R_B - 2K_1R_C + K_1R_D$$

$$-R_F - 6R_G - 12R_H = K_1R_E - 2K_1R_F + K_1R_G$$

$$R_F + 5R_G + 6R_H = -K_1R_E + 3K_1R_F - 3K_1R_G + K_1R_H$$

$$2R_A + R_B + 2R_E - 2R_F - 6R_G - 17R_H - 1 + \frac{Y}{a} = -K_1R_C + 4K_1R_D - 6K_1R_E + 6K_1R_F - 5K_1R_G + 2K_1R_H$$

$$R_A + R_B + R_C + R_D + R_E + R_F + R_G + R_H = 1$$

$$-2R_A - R_B + R_D + 2R_E + 3R_F + 4R_G + 5R_h = -1 + \frac{Y}{a}$$

Eliminating R_A and then R_B and rearranging equations gives:-

$$-R_F - 6R_G - 12R_H = K_1R_E - 2K_1R_F + K_1R_G$$

$$-R_D - 6R_E - 12R_F - 18R_G - 24R_H = K_1R_C - 2K_1R_D + K_1R_E$$

$$-R_C - 6R_D - 12R_E - 18R_F - 24R_G - 30R_H = X_1 - 5X_3 + K_1X_3 - 4K_1R_C - 2K_1R_D - 4K_1R_E - 5K_1R_F - 6K_1R_G - 7K_1R_H$$

$$R_D + 4R_E + R_F - 2R_G - 12R_H = -K_1R_C + 4K_1R_D - 6K_1R_E + 6K_1R_F - 5K_1R_G + 2K_1R_H$$

$$-4R_C - 9R_D - 14R_E - 19R_F - 24R_G - 29R_H = X_2 - 5X_3 - 3K_1X_3 + 6K_1R_C + 8K_1R_D + 11K_1R_E + 14K_1R_F + 17K_1R_G + 20K_1R_H$$

$$R_F = -8R_G - 24R_H - K_1R_E + 3K_1R_G - 2K_1R_H$$

where $X_1 = \frac{Y_1 - 2Y_2}{a} + 5 + 4\frac{Y}{a}$ $\quad X_2 = \frac{2Y_1 - Y_2}{a} + K_1 + 5 + \frac{Y}{a}$

$$X_3 = 1 + \frac{Y}{a}$$

Put $X_4 = X_1 - 5X_3 + K_1X_3$ $\qquad X_5 = X_2 - 5X_3 - 3K_1X_3$

Substitute for R_F to give :-

$$R_G+6R_H-10K_1R_G-23K_1R_H-K_1^2R_E+3K_1^2R_G-2K_1^2R_H=0$$

$$-R_C-6R_D-12R_E+120R_G+402R_H+4K_1R_C+2K_1R_D+22K_1R_E-88K_1R_G-77K_1R_H$$
$$-5K_1^2R_E+15K_1^2R_G-10K_1^2R_H=X_4$$

$$R_D+4R_E-10R_G-36R_H+K_1R_C-4K_1RD+5K_1R_E+56K_1R_G+140K_1R_H+6K_1^2R_E$$
$$-18K_1^2R_G+12K_1^2R_H=0$$

$$-4R_C-9R_D-14R_E+128R_G+427R_H-6K_1R_C-8K_1R_D+8K_1R_E+38K_1R_G+354K_1R_H$$
$$+14K_1^2R_E-42K_1^2R_G+28K_1^2R_H = X_5$$

$$R_C=-\frac{1}{K_1}R_D-\frac{6}{K_1}R_E+\frac{78}{K_1}R_G+\frac{264}{K_1}R_H+2R_D+11R_E-36R_G+24R_H$$

Substitute for R_C to give:-

$$R_G+6R_H-10K_1R_G-23K_1R_H-K_1^2R_E+3K_1^2R_G-2K_1^2R_H=0$$

$$\frac{1}{K_1}R_D+\frac{6}{K_1}R_E-\frac{78}{K_1}R_G-\frac{264}{K_1}R_H-12R_D-47R_E+468R_G+1434R_H+10K_1R_D$$
$$+66K_1R_E-232K_1R_G+19K_1R_H-5K_1^2R_E+15K_1^2R_G-10K_1^2R_H=X_4$$

$$\frac{4}{K_1}R_D+\frac{24}{K_1}R_E-\frac{312}{K_1}R_G-\frac{1056}{K_1}R_H-11R_D-22R_E-196R_G-1253R_H-20K_1R_D$$
$$-58K_1R_E+254K_1R_G+210K_1R_H+14K_1^2R_E-42K_1^2R_G+28K_1^2R_H = X_5$$

$$R_D=-\frac{1}{K_1}R_E+\frac{34}{K_1}R_G+\frac{114}{K_1}R_H+8R_E+10R_G+82R_H+3K_1R_E-9K_1R_G+6K_1R_H$$

Substitute for R_D and regroup the equations to give:-

$$(-K_1^2)R_E + (1-10K_1+3K_1^2)R_G + (6-23K_1-2K_1^2)R_H = 0$$

$$(-\frac{1}{K_1^2} + \frac{26}{K_1} - 150+110K_1+25K_1^2)R_E + (\frac{34}{K_1^2} - \frac{476}{K_1} +679 - 24K_1-75K_1^2)R_G$$
$$+(\frac{114}{K_1^2} - \frac{1550}{K_1} + 1596+767K_1+50K_1^2)R_H = X_4$$

$$(-\frac{4}{K_1^2} + \frac{67}{K_1} - 78-251K_1-46K_1^2)R_E + (\frac{136}{K_1^2} - \frac{646}{K_1} -1022+153K_1+138K_1^2)_{RG}$$
$$+(\frac{456}{K_1^2} - \frac{1982}{K_1} -4411 - 1496K_1-92K_1^2)R_H = X_5$$

Put: $$Z_1 = \frac{1-10K_1+3K_1^2}{K_1^2}$$

$$Z_2 = \frac{6-23K_1-2K_1^2}{K_1^2}$$

$$Z_3 = -\frac{1}{K_1^2} + \frac{26}{K_1} - 150+110K_1+25K_1^2$$

$$Z_4 = \frac{34}{K_1^2} - \frac{476}{K_1} + 679 - 24K_1-75K_1^2$$

$$Z_5 = \frac{114}{K_1^2} - \frac{1550}{K_1} + 1596 + 767K_1+50K_1^2$$

$$Z_6 = -\frac{4}{K_1^2} + \frac{67}{K_1} - 78 - 251K_1-46K_1^2$$

$$Z_7 = \frac{136}{K_1^2} - \frac{646}{K_1} - 1022 + 153K_1+138K_1^2$$

$$Z_8 = \frac{456}{K_1^2} - \frac{1982}{K_1} - 4411 - 1496K_1-92K_1^2$$

The equations can then be written as:-

$$R_E = Z_1R_G + Z_2R_H$$

$$Z_3R_E+Z_4R_G + Z_5R_H = X_4$$

$$Z_6R_E + Z_7R_G + Z_8R_H = X_5$$

Substituting for R_E:

$$(Z_1Z_3+Z_4)R_G + (Z_2Z_3+Z_5)R_H = X_4$$

$$(Z_1Z_6+Z_7)R_G + (Z_2Z_6+Z_8)R_H = X_5$$

$$(Z_1Z_6+Z_7)(Z_1Z_3+Z_4)R_G + (Z_1Z_6+Z_7)(Z_2Z_3+Z_5)R_H = (Z_1Z_6+Z_7)X_4$$

$$(Z_1Z_3+Z_4)(Z_1Z_6+Z_7)R_G + (Z_1Z_3+Z_4)(Z_2Z_6+Z_8)R_H = (Z_1Z_3+Z_4)X_5$$

Thus:
$$R_H = \frac{(Z_1Z_6+Z_7)X_4 - (Z_1Z_3+Z_4)X_5}{(Z_1Z_6+Z_7)(Z_2Z_3+Z_5) - (Z_1Z_3+Z_4)(Z_2Z_6+Z_8)}$$

$$R_G = \frac{X_4 - (Z_2Z_3+Z_5)R_H}{(Z_1Z_3+Z_4)}$$

Having established the reactions, the effect in the other spans is determined as follows:-

$$\frac{d\nu^2}{dx^2} = \frac{M}{EI} = \frac{BM - \frac{BM-EM}{a}x}{EI} = \frac{1}{EI}\left(BM - \frac{BMx}{a} + \frac{EMx}{a}\right)$$

$$\frac{d\nu}{dx} = \frac{1}{EI}\int\left(BM - \frac{BMx}{a} + \frac{EMx}{a}\right)dx$$

$$= \frac{1}{EI}\left(BMx - \frac{BMx^2}{2a} + \frac{EMx^2}{2a} + C\right)$$

$$\nu = \frac{1}{EI} \int \left(BMx - \frac{BMx^2}{2a} + \frac{EMx^2}{2a} + C\right) dx$$

$$\nu = \frac{1}{EI} \left(\frac{BMx^2}{2} - \frac{BMx^3}{6a} + \frac{EMx^3}{6a} + Cx + D\right)$$

At $x = 0$, $\nu = B\delta$ Thus $D = EIB\delta$

At $x = a$ $\nu = E\delta$

$$EI.E\delta = \frac{BMa^2}{2} - \frac{BMa^2}{6} + \frac{EMa^2}{6} + Ca + EI.B\delta$$

$$Ca = EI.E\delta - EI.B\delta - \frac{BMa^2}{3} + \frac{EMa^2}{6}$$

$$C = \frac{EI}{a}(E\delta - B\delta) - \frac{BMa}{3} + \frac{EMa}{6}$$

Thus:

$$\nu = \frac{1}{EI}\left(\frac{BMx^2}{2} - \frac{BMx^3}{6a} + \frac{EMx^3}{6a} - \frac{BMax}{3} + \frac{EMax}{6}\right) - \frac{B\delta}{a}x + \frac{E\delta}{a}x + B\delta$$

This is then multiplied by the value of the relevant wheel load at the previous time step and added to the guide position.

APPENDIX D : DERIVATION OF EQUATIONS TO CALCULATE NATURAL FREQUENCIES

(a) EQUATIONS OF MOTION

The full equations of motion can be written as:-

$$I_R\ddot{\phi}+(K_{e1}\nu_2-K_{e1}w_{01}+C_{S1}\dot{\nu}_2-C_{S1}\dot{w}_{01}+K_{e2}\nu_2+K_{e2}w_{02}+C_{S2}\dot{w}_{02}$$
$$+C_{S2}\dot{\nu}_2+K_{C3}\nu_1+K_{C3}d_3\phi-K_{C3}\nu_2+C_{B3}\dot{\nu}_1+C_{B3}d_3\dot{\phi}-C_{B4}\dot{\nu}_2)\frac{d_1}{2}$$
$$+(K_{C3}\nu_1+K_{C3}d_3\phi-K_{C3}\nu_2+C_{B3}\dot{\nu}_1+C_{B3}d_3\dot{\phi}-C_{B3}\dot{\nu}_2)d_3+(K_{C4}\nu_3-K_{C4}\nu_1$$
$$+K_{C4}d_4\phi-C_{B4}\dot{\nu}_1+C_{B4}d_4\dot{\phi}+C_{B4}\dot{\nu}_3)d_4+(K_{C4}\nu_3-K_{C4}\nu_1+K_{C4}d_4\phi$$
$$-C_{B4}\dot{\nu}_1+C_{B4}d_4\dot{\phi}+C_{B4}\dot{\nu}_3-K_{e5}\nu_3+K_{e5}w_{03}+C_{S5}\dot{w}_{03}-C_{S5}\dot{\nu}_3-K_{e6}\nu_3$$
$$-K_{e6}w_{04}-C_{S6}\dot{w}_{04}-C_{S5}\dot{\nu}_3)\frac{d_5}{2}=0$$

$$I_R\ddot{\phi}+(C_{B3}\frac{d_1}{2}+C_{B3}d_3-C_{B4}d_4-C_{B4}\frac{d_6}{2})\dot{\nu}_1+(C_{S1}\frac{d_1}{2}+C_{S2}\frac{d_1}{2}-C_{B3}\frac{d_1}{2}-C_{B3}d_3)\dot{\nu}_2+$$
$$(C_{B4}d_4+C_{B4}\frac{d_6}{2}-C_{S5}\frac{d_6}{2}-C_{S6}\frac{d_6}{2})\dot{\nu}_3+(C_{B3}d_3\frac{d_1}{2}+C_{B3}d_3{}^2+C_{B4}d_4{}^2+C_{B4}d_4\frac{d_6}{2})\ddot{\phi}$$
$$+(K_{C3}\frac{d_1}{2}+K_{C3}d_3-K_{C4}d_4-K_{C4}\frac{d_6}{2})\nu_1+(K_{e1}\frac{d_1}{2}+K_{e2}\frac{d_1}{2}-K_{C3}\frac{d_1}{2}-K_{C3}d_3)\nu_2$$
$$+(K_{C4}d_4+K_{C4}\frac{d_6}{2}-K_{e5}\frac{d_6}{2}-K_{e6}\frac{d_6}{2})\nu_3+(K_{C3}d_3\frac{d_1}{2}+K_{C3}d_3{}^2+K_{C4}d_4{}^2+K_{C4}d_4\frac{d_6}{2})\phi$$
$$+(K_{e2}\frac{d_1}{2}w_{02}-K_{e1}\frac{d_1}{2}w_{01}+K_{e5}\frac{d_6}{2}w_{03}-K_{e6}\frac{d_6}{2}w_{04}+C_{S2}\dot{w}_{02}\frac{d_1}{2}$$
$$-C_{S1}\dot{w}_{01}\frac{d_1}{2}+C_{S5}\dot{w}_{03}\frac{d_6}{2}-C_{S6}\dot{w}_{04}\frac{d_6}{2})=0$$

Putting:-

$$A_1 = C_{B_3}\frac{d_1}{2} + C_{B_3}d_3 - C_{B_4}d_4 - C_{B_4}\frac{d_6}{2}$$

$$A_2 = C_{S_1}\frac{d_1}{2} - C_{B_3}\frac{d_1}{2} - C_{B_3}d_3 + C_{S_2}\frac{d_1}{2}$$

$$A_3 = C_{B_4}d_4 + C_{B_4}\frac{d_6}{2} - C_{S_6}\frac{d_6}{2} - C_{S_5}\frac{d_6}{2}$$

$$A_4 = C_{B_3}d_3\frac{d_1}{2} + C_{B_3}d_3^2 + C_{B_4}d_4^2 + C_{B_4}d_4\frac{d_6}{2}$$

$$A_5 = K_{C_3}\frac{d_1}{2} + K_{C_3}d_3 - K_{C_4}d_4 - K_{C_4}\frac{d_6}{2}$$

$$A_6 = K_{e_1}\frac{d_1}{2} + K_{e_2}\frac{d_1}{2} - K_{C_3}\frac{d_1}{2} - K_{C_3}d_3$$

$$A_7 = K_{C_4}d_4 + K_{C_4}\frac{d_6}{2} - K_{e_5}\frac{d_6}{2} - K_{e_6}\frac{d_6}{2}$$

$$A_8 = K_{C_3}d_3\frac{d_1}{2} + K_{C_3}d_3^2 + K_{C_4}d_4^2 + K_{C_4}d_4\frac{d_6}{2}$$

$$A_9 = K_{e_2}\frac{d_1}{2}w_{02} - K_{e_1}\frac{d_1}{2}w_{01} + K_{e_5}\frac{d_6}{2}w_{03} - K_{e_6}\frac{d_6}{2}w_{04}$$

$$+ C_{S_1}\frac{d_1}{2}\dot{w}_{01} - C_{S_2}\frac{d_1}{2}\dot{w}_{02} + C_{S_5}\frac{d_6}{2}\dot{w}_{03} - C_{S_6}\frac{d_6}{2}\dot{w}_{04}$$

We thus have:

$$I_R\ddot{\phi} + A_1\dot{\nu}_1 + A_2\dot{\nu}_2 + A_3\dot{\nu}_3 + A_4\dot{\phi} + A_5\nu_1 + A_6\nu_2 + A_7\nu_3 + A_8\phi + A_9 = 0 \quad \ldots\ldots (1)$$

$$M_1\ddot{\nu}_1 + K_{C_3}\nu_1 + K_{C_3}d_3\phi - K_{C_3}\nu_2 + C_{B_3}\dot{\nu}_1 + C_{B_3}d_3\dot{\phi} - C_{B_3}\dot{\nu}_2 + K_{C_4}\nu_1$$

$$- K_{C_4}d_4\phi - K_{C_4}\nu_3 + C_{B_4}\dot{\nu}_1 - C_{B_4}d_4\dot{\phi} - C_{B_4}\dot{\nu}_3 = 0$$

$$M\ddot{\nu}_1 + (C_{B_3} + C_{B_4})\dot{\nu}_1 + (-C_{B_3})\dot{\nu}_2 + (-C_{B_4})\dot{\nu}_3 + (C_{B_3}d_3 - C_{B_4}d_4)\dot{\phi} + (K_{C_3} + K_{C_4})\nu_1$$

$$+ (-K_{C_3})\nu_2 + (-K_{C_4})\nu_3 + (K_{C_3}d_3 - K_{C_4}d_4)\phi = 0$$

Putting:- $A_{10} = C_{B_3} + C_{B_4}$

$A_{11} = C_{B_3} d_3 - C_{B_4} d_4$

$A_{12} = K_{C_3} + K_{C_4}$

$A_{13} = K_{C_3} d_3 - K_{C_4} d_4$

We thus have:-

$$M_1 \ddot{\nu}_1 + A_{10} \dot{\nu}_1 - C_{B_3} \dot{\nu}_2 - C_{B_4} \dot{\nu}_3 + A_{11} \dot{\phi} + A_{12} \nu_1 - K_{C_3} \nu_2 - K_{C_4} \nu_3 + A_{13} \phi = 0 \quad \ldots (2)$$

$$M_2 \ddot{\nu}_2 + K_{e_1} \nu_2 - K_{e_1} w_{01} + C_{S_1} \dot{\nu}_2 - C_{S_1} \dot{w}_{01} + K_{e_2} \nu_2 + K_{e_2} w_{02} + C_{S_2} \dot{\nu}_2 + C_{S_2} \dot{w}_{02}$$

$$K_{C_3} \nu_1 - K_{C_3} d_3 \phi + K_{C_3} \nu_2 - C_{B_3} \dot{\nu}_1 - C_{B_3} d_3 \dot{\phi} + C_{B_3} \dot{\nu}_2 = 0$$

$$M_2 \ddot{\nu}_2 + (-C_{B_3}) \dot{\nu}_1 + (C_{S_1} + C_{S_2} + C_{B_3}) \dot{\nu}_2 + (-C_{B_3} d_3) \dot{\phi} + (-K_{C_3}) \nu_1 + (K_{e_1} + K_{e_2} + K_{C_3}) \nu_2$$

$$+ (-K_{C_3} d_3) \phi + (K_{e_2} w_{02} - K_{e_1} w_{01} + C_{S_2} \dot{w}_{02} - C_{S_1} \dot{w}_{01}) = 0$$

Putting:- $A_{14} = C_{S_1} + C_{B_3} + C_{S_2}$

$A_{15} = -C_{B_3} d_3$

$A_{16} = K_{e_1} + K_{e_2} + K_{C_3}$

$A_{17} = -K_{C_3} d_3$

$A_{18} = K_{e_2} w_{02} - K_{e_1} w_{01} + C_{S_2} \dot{w}_{02} - C_{S_1} \dot{w}_{01}$

We thus have:-

$$M_2 \ddot{\nu}_2 - C_{B_3} \dot{\nu}_1 + A_{14} \dot{\nu}_2 + A_{15} \dot{\phi} - K_{C_3} \nu_1 + A_{16} \nu_2 + A_{17} \phi + A_{18} = 0 \quad \ldots\ldots (3)$$

$$M_3\ddot{\nu}_3+K_{e_5}\nu_3-K_{e_5}w_{03}+C_{S_5}\dot{\nu}_3-C_{S_5}\dot{w}_{03}+K_{e_6}\nu_3+K_{e_6}w_{04}+C_{S_6}\dot{\nu}_3+C_{S_6}\dot{w}_{04}$$

$$-K_{C_4}\nu_1+K_{C_4}d_4\phi+K_{C_4}\nu_3-C_{B_4}\dot{\nu}_1+C_{B_4}d_4\dot{\phi}+C_{B_4}\dot{\nu}_3 = 0$$

$$M_3\ddot{\nu}_3+(-C_{B_4})\dot{\nu}_1+(C_{S_5}+C_{S_6}+C_{B_4})\dot{\nu}_3+(C_{B_4}d_4)\dot{\phi}+(-K_{C_4})\nu_1+(K_{e_5}+K_{e_6}+K_{C_4})\nu_3$$

$$+(K_{C_4}d_4)\phi+(K_{e_6}w_{04}-K_{e_5}w_{03}-C_{S_5}\dot{w}_{03}+C_{S_6}\dot{w}_{04}) = 0$$

Putting:-

$$A_{19} = C_{B_4}d_4$$

$$A_{20} = K_{C_4}+K_{e_5}+K_{e_6}$$

$$A_{21} = K_{C_4}d_4$$

$$A_{22} = K_{e_6}w_{04}-K_{e_5}w_{03}+C_{S_6}\dot{w}_{04}-C_{S_5}\dot{w}_{03}$$

$$A_{23} = C_{S_5}+C_{S_6}+C_{B_4}$$

We thus have:-

$$M_3\ddot{\nu}_3-C_{B_4}\dot{\nu}_1+A_{23}\dot{\nu}_3+A_{19}\dot{\phi}-K_{C_4}\nu_1+A_{20}\nu_3+A_{21}\phi+A_{22} = 0 \quad \ldots\ldots \quad (4)$$

(b) Expansion of Determinant

To obtain a non-trivial solution the determinant must be non-zero,

ie:

$$\begin{vmatrix} A_{12}-M_1\omega^2 & -K_{C_3} & -K_{C_4} & A_{13} \\ -K_{C_3} & A_{16}-M_2\omega^2 & 0 & A_{17} \\ -K_{C_4} & 0 & A_{20}-M_3\omega^2 & A_{21} \\ A_5 & A_6 & A_7 & A_8-I_R\omega^2 \end{vmatrix} = 0$$

Expanding this determinant by the second row gives:-

$$K_{C_3}\begin{vmatrix} -K_{C_3} & -K_{C_4} & A_{13} \\ 0 & A_{20}-M_3\omega^2 & A_{21} \\ A_6 & A_7 & A_8-I_R\omega^2 \end{vmatrix} + (A_{16}-M_2\omega^2)\begin{vmatrix} A_{12}-M_1\omega^2 & -K_{C_4} & A_{13} \\ -K_{C_4} & A_{20}-M_3\omega^2 & A_{21} \\ A_5 & A_7 & A_8-I_R\omega^2 \end{vmatrix} - 0$$

$$+A_{17}\begin{vmatrix} A_{12}-M_1\omega^2 & -K_{C_3} & -K_{C_4} \\ -K_{C_4} & 0 & A_{20}-M_3\omega^2 \\ A_5 & A_6 & A_7 \end{vmatrix} = 0$$

Expanding these determinants by the second row in each case gives:-

$$K_{C_3}\left|-0+\{A_{20}-M_3\omega^2\}\{-K_{C_3}(A_8-I_R\omega^2)-A_6A_{13}\}-A_{21}\{-K_{C_3}A_7+K_{C_4}A_6\}\right|$$

$$+\left|A_{16}-M_2\omega^2\right|\left|K_{C_4}\{-K_{C_4}(A_8-I_R\omega^2)-A_7A_{13}\}+\{A_{20}-M_3\omega^2\}\{(A_{12}-M_1\omega^2)\right.$$

$$\left.(A_8-I_R\omega^2)-A_5A_{13}\}-A_{21}\{(A_{12}-M_1\omega^2)A_7+K_{C_4}A_5\}\right|+A_{17}\left|K_{C_4}\{-K_{C_3}A_7+K_{C_4}A_6\}\right.$$

$$\left.-\{A_{20}-M_3\omega^2\}\{(A_{12}-M_1\omega^2)A_6+K_{C_3}A_5\}\right| = 0$$

$$K_{C_3}\left|(A_{20}-M_3\omega^2)(-K_{C_3}A_8+K_{C_3}I_R\omega^2-A_6A_{13})+K_{C_3}A_7A_{21}-K_{C_4}A_6A_{21}\right|$$

$$+\left|A_{16}-M_2\omega^2\right|\left|K_{C_4}(-K_{C_4}A_8+K_{C_4}I_R\omega^2-A_7A_{13})+(A_{20}-M_3\omega^2)\right.$$

$$\left.(A_8A_{12}-A_{12}I_R\omega^2-A_8M_1\omega^2+M_1I_R\omega^4-A_5A_{13})-A_{21}(A_7A_{12}-A_7M_1\omega^2+K_{C_4}A_5)\right|$$

$$+A_{17}\left|-K_{C_3}K_{C_4}A_7+K_{C_4}^2A_6-(A_{20}-M_3\omega^2)(A_6A_{12}-A_6M_1\omega^2+K_{C_3}A_5)\right. = 0$$

$$\omega^8 (M_1M_2M_3 I_R) - \omega^6 (A_{16} M_1M_3 I_R + A_{12} M_2M_3 I_R + A_{20} M_1M_2 I_R + A_8 M_1M_2M_3)$$

$$+ \omega^4 (-K_{C_3}{}^2 M_3 I_R + A_{12} A_{16} M_3 I_R + A_{16} A_{20} M_1 I_R + A_8 A_{16} M_1M_3 + A_{12} A_{20} M_2 I_R$$

$$+ A_8 A_{12} M_2M_3 - K_{C_4}{}^2 M_2 I_R - A_5 A_{13} M_2M_3 + A_8 A_{20} M_1M_2 - A_7 A_{21} M_1M_2 - A_6 A_{17} M_1M_3)$$

$$+ \omega^2 (K_{C_3}{}^2 A_{20} I_R + K_{C_3}{}^2 A_8 M_3 + K_{C_3} A_6 A_{13} M_3 - A_{12} A_{16} A_{20} I_R - A_8 A_{12} A_{16} M_3$$

$$+ K_{C_4}{}^2 A_{16} I_R + A_5 A_{13} A_{16} M_3 - A_8 A_{16} A_{20} M_1 + A_7 A_{16} A_{21} M_1 - A_8 A_{12} A_{20} M_2$$

$$+ A_7 A_{12} A_{21} M_2 + K_{C_4}{}^2 A_8 M_2 + K_{C_4} A_7 A_{13} M_2 + K_{C_4} A_5 A_{21} M_2 + A_5 A_{13} A_{20} M_2$$

$$+ K_{C_3} A_5 A_{17} M_3 + A_6 A_{12} A_{17} M_3 + A_6 A_{17} A_{20} M_1) + (-K_{C_3}{}^2 A_8 A_{20} + K_{C_3}{}^2 A_7 A_{21}$$

$$- K_{C_3} K_{C_4} A_6 A_{21} - K_{C_3} A_6 A_{13} A_{20} + A_8 A_{12} A_{16} A_{20} - A_7 A_{12} A_{16} A_{21} - K_{C_4}{}^2 A_8 A_{16}$$

$$- K_{C_4} A_7 A_{13} A_{16} - K_{C_4} A_5 A_{16} A_{21} - A_5 A_{13} A_{16} A_{20} - K_{C_3} K_{C_4} A_7 A_{17} - K_{C_3} A_5 A_{17} A_{20}$$

$$- A_6 A_{12} A_{17} A_{20} + K_{C_4}{}^2 A_6 A_{17}) = 0$$

Dividing through by $M_1 M_2 M_3 I_R$ and putting:-

$$B_1 = A_{16}/M_2 + A_{12}/M_1 + A_{20}/M_3 + A_8/I_R$$

$$B_2 = -K_{C_3}{}^2/(M_1M_2) + A_{12} A_{16}/(M_1M_2) + A_{16} A_{20}/(M_2M_3) + A_8 A_{16}/(M_2 I_R)$$

$$+ A_{12} A_{20}/(M_1M_3) + A_8 A_{12}/(M_1 I_R) - K_{C_4}{}^2/(M_1M_3) - A_5 A_{13}/(M_1 I_R)$$

$$+ A_8 A_{20}/(M_3 I_R) - A_7 A_{21}/(M_3 I_R) - A_6 A_{17}/(M_2 I_R)$$

$$B_3 = (K_{C_3}{}^2 A_{20}\, I_R + K_{C_3}{}^2 A_8 M_3 + K_{C_3} A_6 A_{13}\, M_3 - A_{12}\, A_{16}\, A_{20}\, I_R - A_8 A_{12} A_{16}\, M_3$$

$$+ K_{C_4}{}^2 A_{16}\, I_R + A_5 A_{13}\, A_{16}\, M_3 - A_8 A_{16}\, A_{20}\, M_1 + A_7 A_{16}\, A_{21}\, M_1 - A_8 A_{12}\, A_{20}\, M_2$$

$$+ A_7 A_{12}\, A_{21}\, M_2 + K_{C_4}{}^2 A_8 M_2 + K_{C_4} A_7 A_{13}\, M_2 + K_{C_4} A_5 A_{21}\, M_2 + A_5 A_{13}\, A_{20}\, M_2$$

$$+ K_{C_3} A_5 A_{17}\, M_3 + A_6 A_{12}\, A_{17}\, M_3 + A_6 A_{17}\, A_{20}\, M_1) / (M_1 M_2 M_3 I_R)$$

$$B_4 = (-K_{C_3}{}^2 A_8 A_{20} + K_{C_3}{}^2 A_7 A_{21} - K_{C_3} K_{C_4} A_6 A_{21} - K_{C_3} A_6 A_{13}\, A_{20} + A_8 A_{12}\, A_{16}\, A_{20}$$

$$- A_7 A_{12}\, A_{16}\, A_{21} - K_{C_4}{}^2 A_8 A_{16} - K_{C_4} A_7 A_{13}\, A_{16} - K_{C_4} A_5 A_{16}\, A_{21} - A_5 A_{13}\, A_{16}\, A_{20}$$

$$- K_{C_3} K_{C_4} A_7 A_{17} - K_{C_3} A_5 A_{17}\, A_{20} - A_6 A_{12}\, A_{17}\, A_{20} + K_{C_4}{}^2 A_6 A_{17}) / (M_1 M_2 M_3 I_R)$$

We then have:

$$\omega^8 - B_1 \omega^6 + B_2 \omega^4 + B_3 \omega^2 + B_4 = 0$$

(The slope w.r.t ω^2 is $4\omega^6 - 3B_1 \omega^4 + 2B_2 \omega^2 + B_3$)

APPENDIX E : COMPUTER PROGRAMMES

E.1 DISDAT

The input for DISDAT is all in free format in response to questions.

(i) A title up to 80 characters long

(ii) A filename of 6 characters

(iii) The conveyance rotational inertia in t.m.^{2} (RI)

(iv) Masses, in t, of the body, the top transom and the bottom transom in that order. (AM1, AM2, AM3).

(v) Depths, in m, of the top and bottom transoms, in that order. (D1, D6).

(vi) Distances, in m, from the conveyance centre of gravity to the top of the body and then to the bottom of the body (D3, D4)

(vii) The overall length of the conveyance, or the distance between top and bottom guide wheels, in m. (AOL)

(viii) The bunton spacing, in m. (A)

(ix) The damping constants, as percentage of critical damping, for the shaft steelwork/wheel combination and for the conveyance. (CS, CB)

(x) The guide inertia in units of 10^{-6} m^4 and the bunton stiffness in kN/m. The bunton stiffness is calculated in accordance with normal structural theory, making allowance for end compliance as described by Laubsher and Bull[14]. (CK1, CK2)

(xi) Spring stiffness of wheels in kN/m, and wheel diameter. For the stiffness an average value, based on the spring curve supplied by the manufacturers, is used. (AK, DIAM)

(xii) Stiffness, in kN/m, of connection between top transom and conveyance body, and of the connection between the bottom transom and body. This stiffness divided by the mass of the relevant transom should not exceed about 25000, or ill-conditioning of the equations of motion results. The stiffness is calculated in accordance with standard structural methods. (CEK3, CEK4)

(xiii) The velocity of conveyance travel, in m/sec, the preload applied to the wheels in KN, and the wheel clearance from the guides. One of these last two must be zero, as both relate to the positioning of the wheels relative to the guides. (VEL, PREL, CLEAR)

(xiv) Spring travel, in m. This is the distance the wheel can move back before hard contact occurs. (WXX)

(xv) Wheel irregularity (in m) and four phase angles for the initial wheel positions (AMP, PH1, PH2, PH3, PH4).

(xvi) Number of buntons for the run. A typical deep shaft has 300 to 500 buntons, but for DISCS to give good predictions for analysis 50 buntons are probably sufficient. (NOB)

(xvii) A number to determine how the misalignment is input. (MISAL)

1 - Misalignment is calculated randomly between specified limits.

2 - All misalignment values must be specified

xviii) Number of buntons, from start, which have non-zero misalignment. This is usually equal to the number of buntons. (IBUNT)

If MISAL = 1 :-

(xix) The maximum values, in m, of misalignment increment, gauge error and overall misalignment (WL(1), WL(2))

(xx) The variance of the mismatch, in m, and six random seed numbers, which should be any numbers between 0 and 199017 (WL(3), XWX(1) to XWX(6)).

If MISAL = 2 :-

(xxi) The misalignment, in m, of the two guides and the mismatch, also in m, of both guides. (WO(1), WO(2), WM(1), WM(2)). This input is repeated for each bunton, including 7 buntons prior to the initial bunton, number 0, which allow for initiallising. For specified misalignment the first seven input lines should thus be zeros in most cases.

The output from DISDAT is:-

(i) Heading in 20A4 format.

(ii) RI, AM1, AM2, AM3 in 4F12.4 format.

(iii) D1, D3, D4, D6, A, AOL in 6F12.4 format

(iv) CB, CS, CK1, CK2, AK in 5F12.4 format

(v) CEK3, CEK4 in 2F12.4 format

(vi) VEL, PREL, CLEAR, WXX in 4F12.4 format

(vii) AMP, DIAM in 2F12.4 format

(viii) PH1, PH2, PH3, PH4 in 4F12.4 format

(ix) NOB, MISAL in 2I7 format

(x) WO(1), WO(2), WM(1), WM(2) in 4F12.4 format, for each bunton.

DISDAT : Flowchart

Specify dimensions
and read variable types
Read input interactively
Specify full filename
of output as:

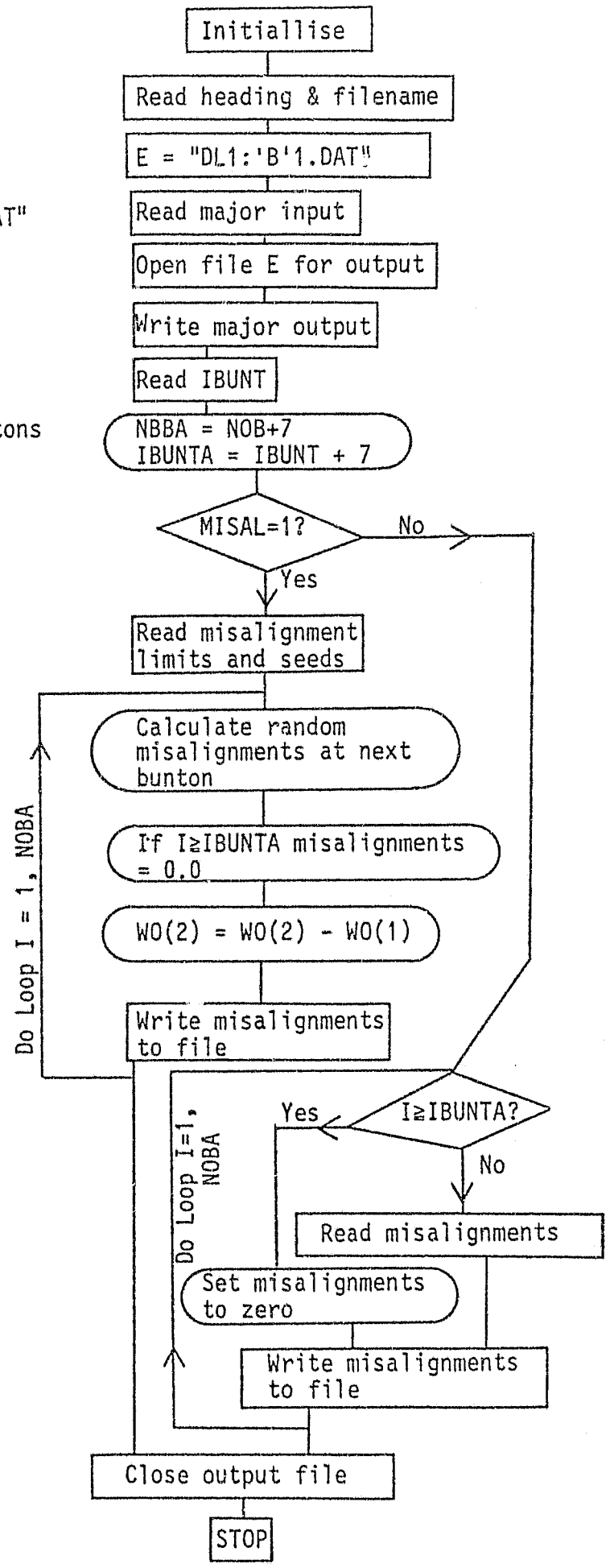
Filename ="DL1:"filename"1. DAT"

Logical unit 1 is assigned to
file E

Calculate total number of buntons
considered

Guide 2 misalignment
is gauge error less
guide 1 misalignment

This section reads
specified misalignment



PROGRAMME DISDAT : Listing

```
 C
C  THIS PROGRAMME GENERATES THE INPUT FOR DISCS INTERACTIVELY
C
      INTEGER*2 B(3),D(3),E(8),F(2)
      DIMENSION WO(2),WL(3),WM(2),C(20)
      REAL*8 YWY,XWX(6)
      TYPE 300
300   FORMAT(' ENTER RUN TITLE ( < 80 CHARS BEGINNING WITH A BLANK )')
      READ(5,301)(C(I),I=1,20)
301   FORMAT(20A4)
      TYPE 302
302   FORMAT('  ENTER DATA FILE NAME ( 6 CHARS )')
      READ(5,303)(B(I),I=1,3)
303   FORMAT(3A2)
      DATA D /'1.','DA','T'/
      DATA F /'DL','1:'/
      DO 29 I=1,2
29    E(I)=F(I)
      DO 30 I=1,3
30    E(I+2)=B(I)
      DO 31 I=1,3
31    E(I+5)=D(I)
      TYPE 1
1     FORMAT('  ENTER ROTATIONAL INERTIA')
      ACCEPT *,RI
      TYPE 2
2     FORMAT(' ENTER MASSES OF : BODY, TOP TRANSOM, BOTTOM TRANSOM')
      ACCEPT *,AM1,AM2,AM3
      TYPE 3
3     FORMAT('  ENTER DEPTHS OF TOP AND BOTTOM TRANSOMS')
      ACCEPT *,D1,D6
      TYPE 4
4     FORMAT('  ENTER DISTANCE FROM C.G. TO TOP & BOTTOM OF BODY')
      ACCEPT *,D3,D4
      TYPE 5
5     FORMAT('  ENTER OVERALL CONVEYANCE LENGTH')
      ACCEPT *,AOL
      TYPE 6
6     FORMAT('  ENTER BUNTON SPACING')
      ACCEPT *,A
      TYPE 7
7     FORMAT('  ENTER % DAMPING OF STEELWORK & CONVEYANCE')
      ACCEPT *,CS,CB
      TYPE 8
8     FORMAT('  ENTER GUIDE INERTIA & BUNTON STIFFNESS')
      ACCEPT *,CK1,CK2
```

```
      TYPE 9
9     FORMAT(' ENTER WHEEL SPRING STIFFNESS & WHEEL DIAMETER')
      ACCEPT *,AK,DIAM
      TYPE 10
10    FORMAT(' ENTER CONNECTION STIFFNESS TO TOP & BOTTOM TRANSOMS')
      ACCEPT *,CEK3,CEK4
      TYPE 11
11    FORMAT(' ENTER VELOCITY, WHEEL PRELOAD & WHEEL CLEARANCE')
      ACCEPT *,VEL,PREL,CLEAR
      TYPE 12
12    FORMAT(' ENTER SPRING TRAVEL BEFORE HARD SLIPPER CONTACT')
      ACCEPT *,WXX
      TYPE 18
18    FORMAT(' ENTER WHEEL IRREGULARITY & 4 PHASE ANGLES(degrees)')
      ACCEPT *,AMP,PH1,PH2,PH3,PH4
      TYPE 13
13    FORMAT(' ENTER NUMBER OF BUNTONS FOR RUN')
      ACCEPT *,NOB
      TYPE 14
14    FORMAT(' ENTER 1 FOR RANDOM MISALIGNMENT, 2 FOR SPECIFIED MISAL
     @GNMENT')
      ACCEPT *,MISAL
      CALL ASSIGN(1,E,15)
      WRITE(1,304)(C(I),I=1,20)
304   FORMAT(20A4)
      WRITE(1,100)RI,AM1,AM2,AM3
100   FORMAT(4F12.4)
      WRITE(1,110)D1,D3,D4,D6,A,AOL
110   FORMAT(6F12.4)
      WRITE(1,120)CB,CS,CK1,CK2,AK
120   FORMAT(5F12.4)
      WRITE(1,130)CEK3,CEK4
130   FORMAT(2F12.4)
      WRITE(1,100)VEL,PREL,CLEAR,WXX
      WRITE(1,130)AMP,DIAM
      WRITE(1,100)PH1,PH2,PH3,PH4
      WRITE(1,140)NOB,MISAL
140   FORMAT(2I7)
      TYPE 17
17    FORMAT(' ENTER NUMBER OF BUNTONS WITH NON-ZERO MISALIGNMENT')
      ACCEPT *,IBUNT
      NOBA=NOB+7
      IBUNTA=IBUNT+7
      IF(MISAL.NE.1)GOTO 50
      TYPE 15
15    FORMAT(' MAX MISALIGNMENT CHANGE, GAUGE ERROR & MAX MISALIGNMENT')
      ACCEPT *,WL(1),WL(2),WLMAX
```

```
      TYPE 9
9     FORMAT(' ENTER WHEEL SPRING STIFFNESS & WHEEL DIAMETER')
      ACCEPT *,AK,DIAM
      TYPE 10
10    FORMAT(' ENTER CONNECTION STIFFNESS TO TOP & BOTTOM TRANSOMS')
      ACCEPT *,CEK3,CEK4
      TYPE 11
11    FORMAT(' ENTER VELOCITY, WHEEL PRELOAD & WHEEL CLEARANCE')
      ACCEPT *,VEL,PREL,CLEAR
      TYPE 12
12    FORMAT(' ENTER SPRING TRAVEL BEFORE HARD SLIPPER CONTACT')
      ACCEPT *,WXX
      TYPE 18
18    FORMAT(' ENTER WHEEL IRREGULARITY & 4 PHASE ANGLES(degrees)')
      ACCEPT *,AMP,PH1,PH2,PH3,PH4
      TYPE 13
13    FORMAT(' ENTER NUMBER OF BUNTONS FOR RUN')
      ACCEPT *,NOB
      TYPE 14
14    FORMAT(' ENTER 1 FOR RANDOM MISALIGNMENT, 2 FOR SPECIFIED MISA
     @GNMENT')
      ACCEPT *,MISAL
      CALL ASSIGN(1,E,15)
      WRITE(1,304)(C(I),I=1,20)
304   FORMAT(20A4)
      WRITE(1,100)RI,AM1,AM2,AM3
100   FORMAT(4F12.4)
      WRITE(1,110)D1,D3,D4,D6,A,AOL
110   FORMAT(6F12.4)
      WRITE(1,120)CB,CS,CK1,CK2,AK
120   FORMAT(5F12.4)
      WRITE(1,130)CEK3,CEK4
130   FORMAT(2F12.4)
      WRITE(1,100)VEL,PREL,CLEAR,WXX
      WRITE(1,130)AMP,DIAM
      WRITE(1,100)PH1,PH2,PH3,PH4
      WRITE(1,140)NOB,MISAL
140   FORMAT(2I7)
      TYPE 17
17    FORMAT(' ENTER NUMBER OF BUNTONS WITH NON-ZERO MISALIGNMENT')
      ACCEPT *,IBUNT
      NOBA=NOB+7
      IBUNTA=IBUNT+7
      IF(MISAL.NE.1)GOTO 50
      TYPE 15
15    FORMAT(' MAX MISALIGNMENT CHANGE, GAUGE ERROR & MAX MISALIGNMENT')
      ACCEPT *,WL(1),WL(2),WLMAX
```

```
      TYPE 16
16    FORMAT(' ENTER MISMATCH VARIANCE & 6 SEEDS')
      ACCEPT *,WL(3),XWX(1),XWX(2),XWX(3),XWX(4),XWX(5),XWX(6)
      DO 20 I=1,NOBA
      DO 21 J=1,6
      YWY=(24298.*XWX(J)+99991.)/199017.
      XWX(J)=(YWY-DINT(YWY))*199017.
      IF(J.LE.2)WO(J)=XWX(J)/199017.*2.*WL(J)-WL(J)-(J-2)*WO(J)
      IF(J.EQ.4.OR.J.EQ.6)YWY=XWX(J-1)/199017.
      IF(J.EQ.4.OR.J.EQ.6)WM(J/3)=WL(3)*SQRT(DLOG(YWY)*(0.-2.))*DCOS(6
     @ .2832*XWX(J)/199017.)
21    CONTINUE
      NWM=(I/2)*2
      DO 22 J=1,2
      IF(I.GT.IBUNTA)WM(J)=0.000
      IF(I.GT.IBUNTA)WO(J)=0.000
      IF(NWM.EQ.I)WM(J)=0.000
22    CONTINUE
      IF(WO(1).GT.WLMAX)WO(1)=WLMAX-WL(1)
      IF(WO(1).LT.-WLMAX)WO(1)=-WLMAX+WL(1)
      WO(2)=WO(2)-WO(1)
20    WRITE(1,200)WO(1),WO(2),WM(1),WM(2)
200   FORMAT(4F12.4)
      GOTO 70
50    DO 51 I=1,NOBA
      IF(I.GT.IBUNTA)GOTO 52
      TYPE 19
19    FORMAT(' ENTER MISALIGNMENT AT BOTH GUIDES & MISMATCH AT BOTH')
      ACCEPT *,WO(1),WO(2),WM(1),WM(2)
      GOTO 53
52    WO(1)=0.0
      WO(2)=0.0
      WM(1)=0.0
      WM(2)=0.0
53    WRITE(1,200)WO(1),WO(2),WM(1),WM(2)
51    CONTINUE
70    CALL CLOSE(1)
      STOP
      END
```

```
      TYPE 16
16    FORMAT('  ENTER MISMATCH VARIANCE & 6 SEEDS')
      ACCEPT *,WL(3),XWX(1),XWX(2),XWX(3),XWX(4),XWX(5),XWX(6)
      DO 20 I=1,NOBA
      DO 21 J=1,6
      YWY=(24298.*XWX(J)+99991.)/199017.
      XWX(J)=(YWY-DINT(YWY))*199017.
      IF(J.LE.2)WO(J)=XWX(J)/199017.*2.*WL(J)-WL(J)-(J-2)*WO(J)
      IF(J.EQ.4.OR.J.EQ.6)YWY=XWX(J-1)/199017.
      IF(J.EQ.4.OR.J.EQ.6)WM(J/3)=WL(3)*SQRT(DLOG(YWY)*(0.,-2.))*DCOS(6
     @ .2832*XWX(J)/199017.)
21    CONTINUE
      NWM=(I/2)*2
      DO 22 J=1,2
      IF(I.GT.IBUNTA)WM(J)=0.000
      IF(I.GT.IBUNTA)WO(J)=0.000
      IF(NWM.EQ.I)WM(J)=0.000
22    CONTINUE
      IF(WO(1).GT.WLMAX)WO(1)=WLMAX-WL(1)
      IF(WO(1).LT.-WLMAX)WO(1)=-WLMAX+WL(1)
      WO(2)=WO(2)-WO(1)
20    WRITE(1,200)WO(1),WO(2),WM(1),WM(2)
200   FORMAT(4F12.4)
      GOTO 70
50    DO 51 I=1,NOBA
      IF(I.GT.IBUNTA)GOTO 52
      TYPE 19
19    FORMAT('  ENTER MISALIGNMENT AT BOTH GUIDES & MISMATCH AT BOTH')
      ACCEPT *,WO(1),WO(2),WM(1),WM(2)
      GOTO 53
52    WO(1)=0.0
      WO(2)=0.0
      WM(1)=0.0
      WM(2)=0.0
53    WRITE(1,200)WO(1),WO(2),WM(1),WM(2)
51    CONTINUE
70    CALL CLOSE(1)
      STOP
      END
```

E.2 Programme DISCS

This is the main programme for predicting the dynamic behaviour of the conveyances.

The input is an interactive request for the filename, and all other input is then from the data file created by DISDAT.

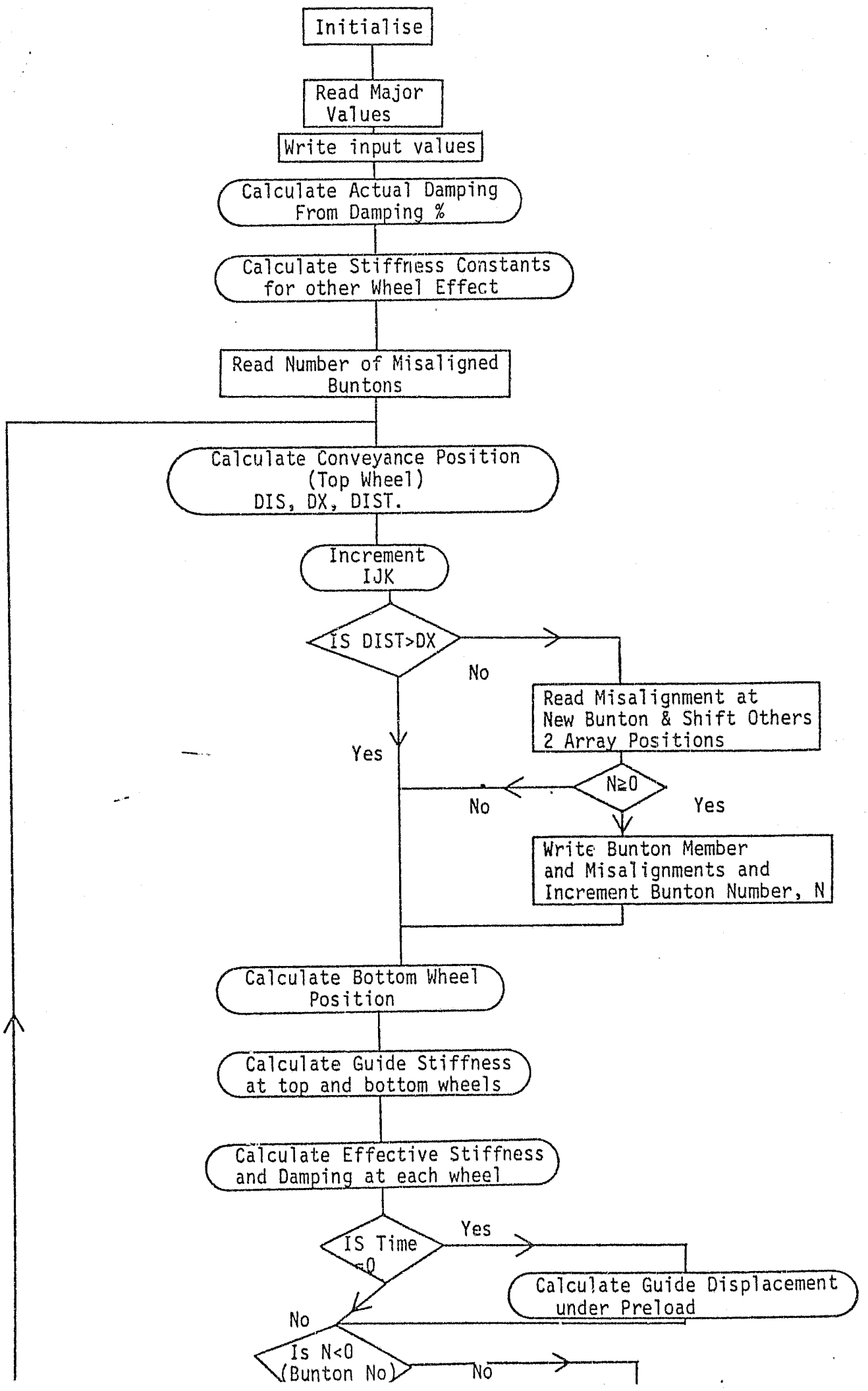
The output is:-

(i) A data file giving the wheel load and acceleration information and time at each data point.

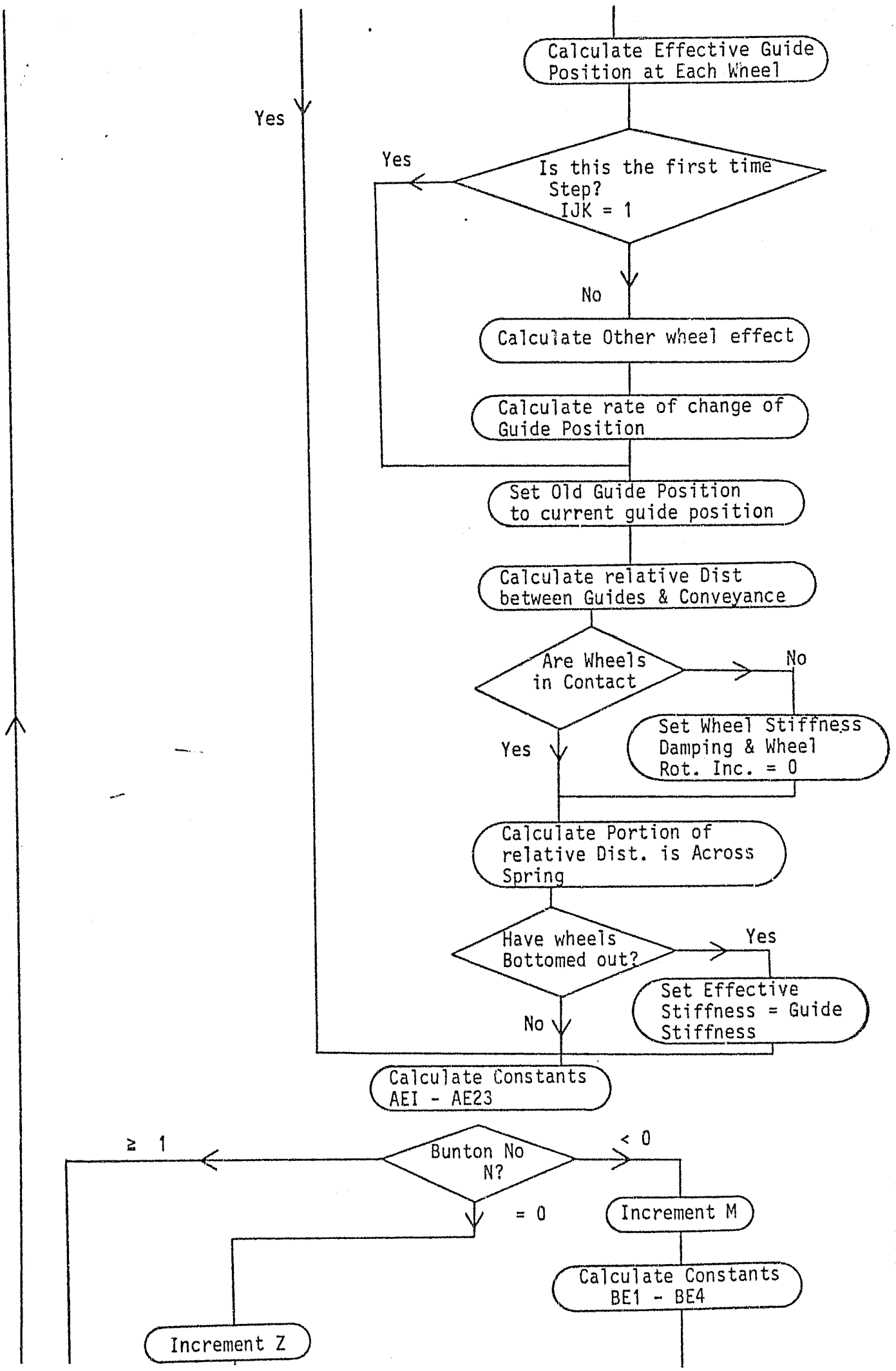
(ii) A data file giving basic information, such as time step and total number of samples, which is required by the analysis programmes.

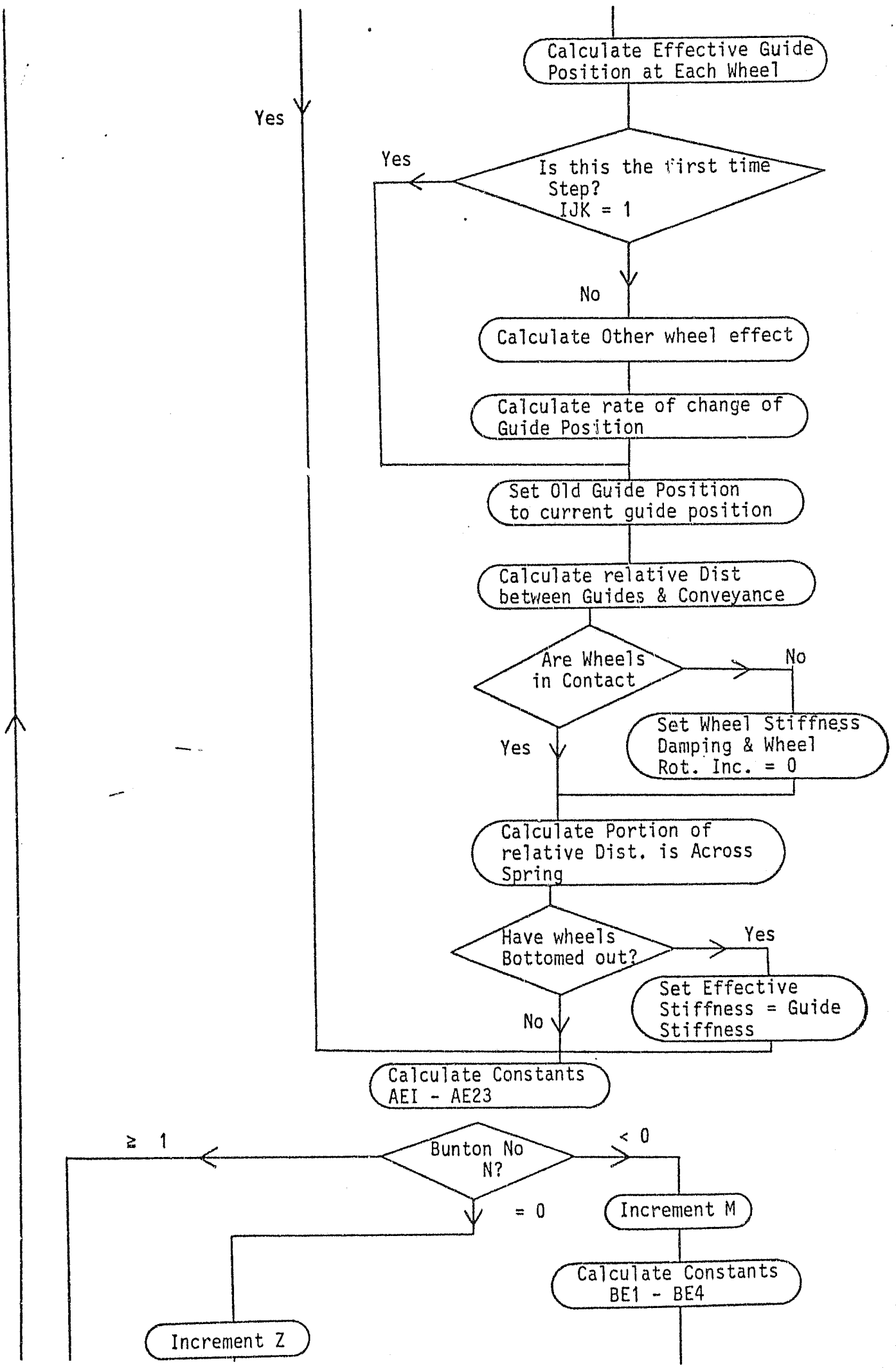
(iii) Printout of the input parameters, then the calculated natural frequencies over one guide span, and finally the guide misalignment is listed at each bunton. If there is instability, this is printed, with the time at which it occurred, between the relevant buntons listed above.

Flowchart for DISCS

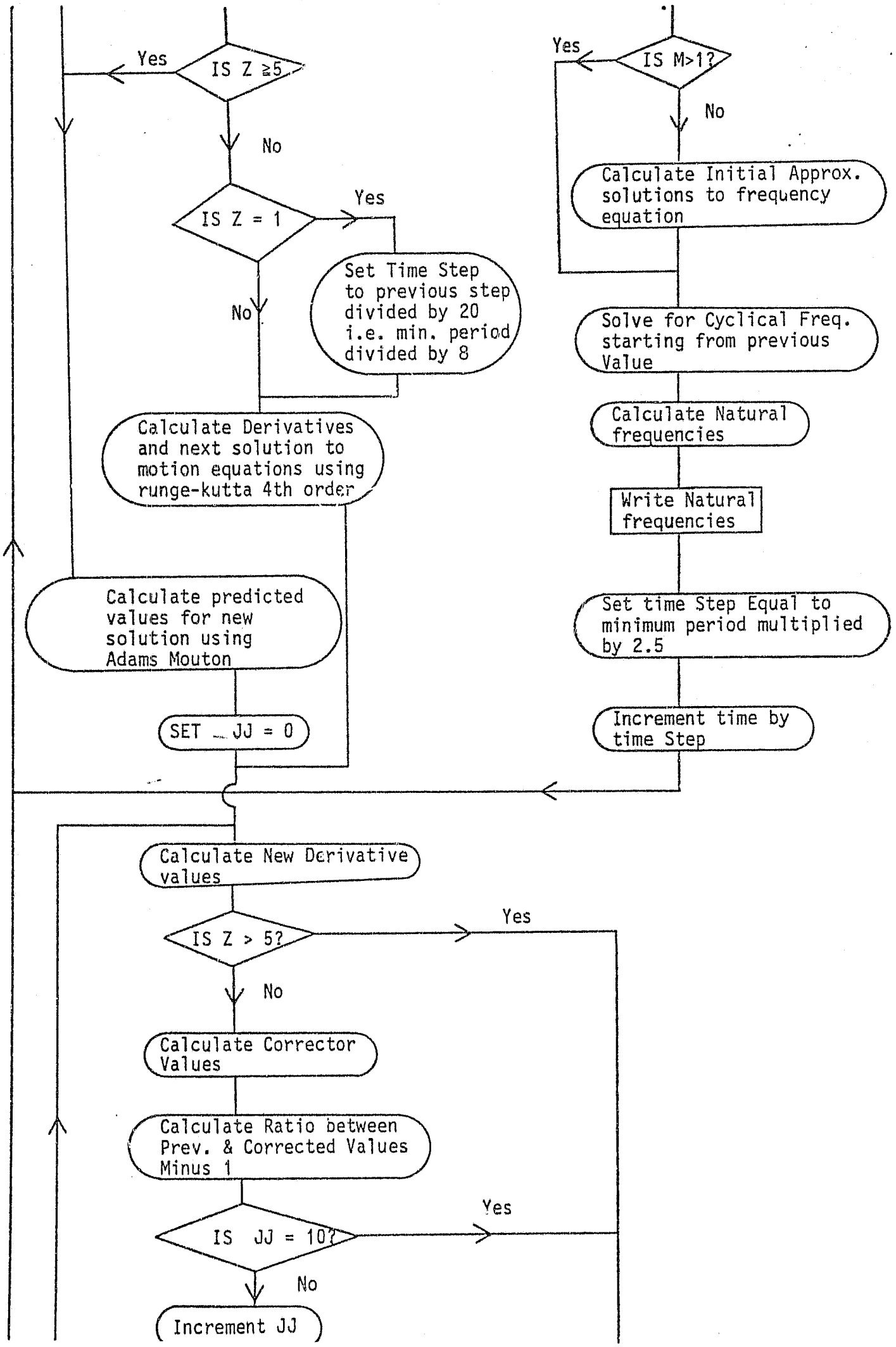


Flowchart for DISCS (cont'd)

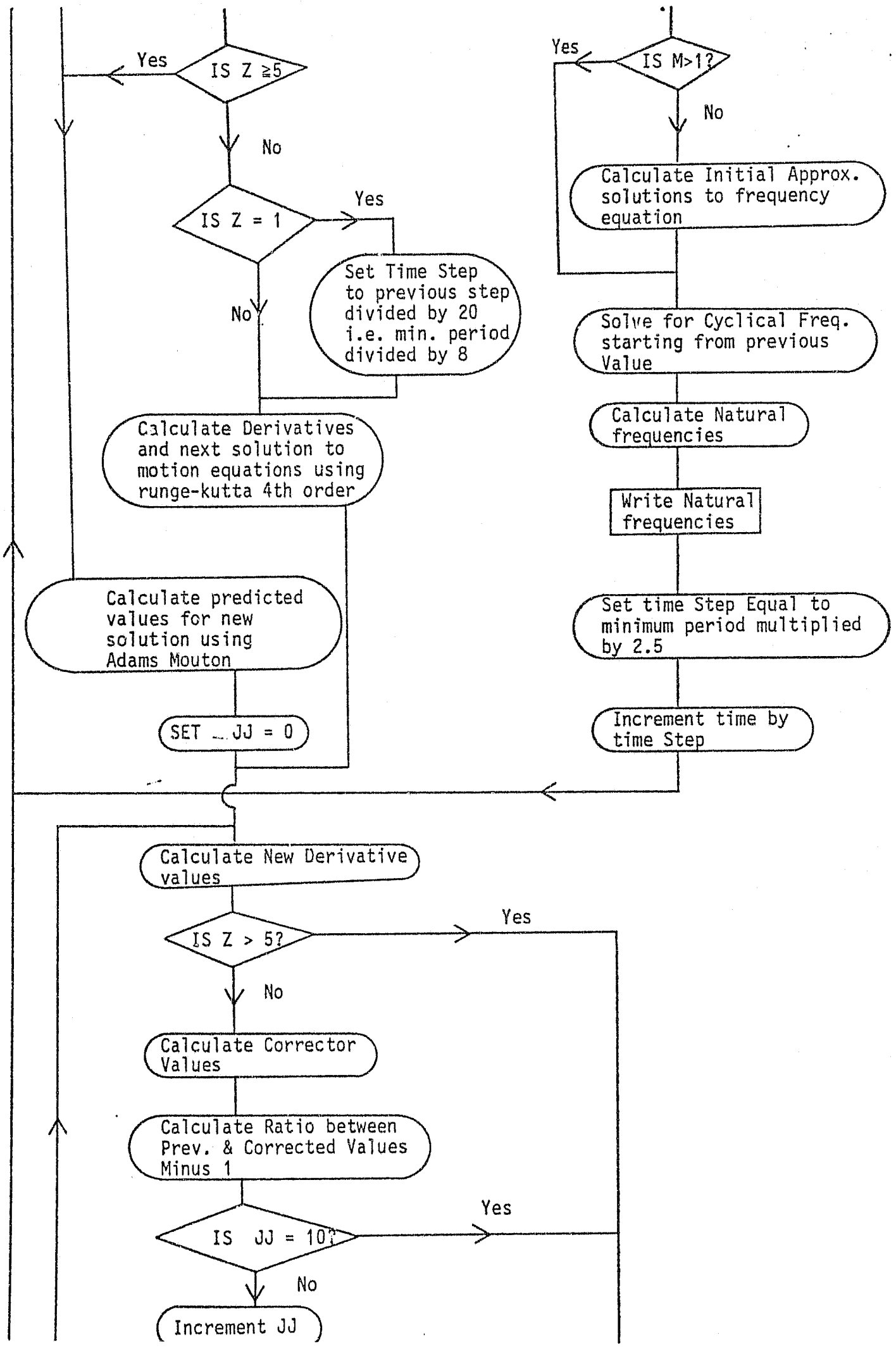



Yes
Calculate Effective Guide Position at Each Wheel
Yes
Is this the first time Step? IJK = 1
No
Calculate Other wheel effect
Calculate rate of change of Guide Position
Set Old Guide Position to current guide position
Calculate relative Dist between Guides & Conveyance
Are Wheels in Contact
No
Yes
Set Wheel Stiffness Damping & Wheel Rot. Inc. = 0
Calculate Portion of relative Dist. is Across Spring
Have wheels Bottomed out?
Yes
No
Set Effective Stiffness = Guide Stiffness
Calculate Constants AEI - AE23
≥ 1
Bunton No N?
< 0
= 0
Increment M
Calculate Constants BE1 - BE4
Increment Z

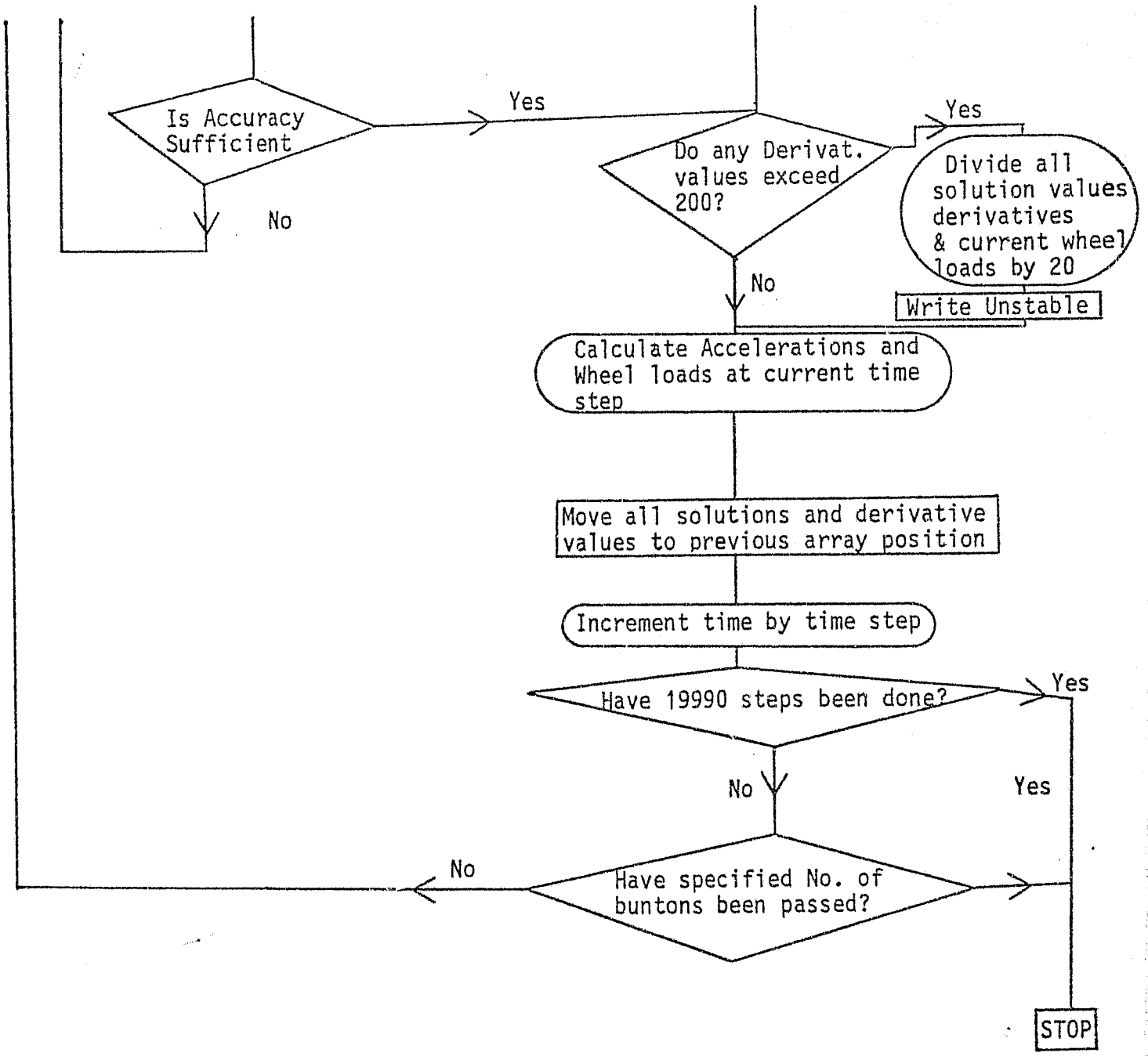
Flowchart for DISCS (Cont'd)



Flowchart for DISCS (Cont'd)



Flowchart for DISCS (cont'd)



```
C
C  ***************************************************************************
C
C  THIS PROGRAM GENERATES THE DYNAMIC WHEEL LOADS AND ACCELERATIONS OF
C  MINESHAFT CONVEYANCES FROM INPUT OF RANDOM OR SPECIFIED GUIDE
C  MISALIGNMENT AND MISMATCH.
C
C  ********** ************************************************************
C
      DIMENSION XT(8,6),DT(8,6),ZT(8,5),ZK(8,4),ET(8,4),FREQ(4,30)
      DIMENSION CHECK(8),AA(2),ETEST(4),BK(2)
      DIMENSION WO(12),WL(3),WM(12),GAP(12),C(20)
      REAL*8 Z1,Z2,Z3,Z4,Z5,Z6,Z7,Z8,Z9,RC,RD,RE,RF,RG,RH
      INTEGER*2 B(8),D(8),E(8),F(3),G(3),HH(3),FF(3),DL(2)
C
C  INITIALISE ALL NECESSARY VALUES
C
      TYPE 1
1     FORMAT('  INPUT FILE NAME (6 CHARS)')
      READ(5,2)(F(I),I=1,3)
2     FORMAT(3A2)
      DO 4 I=1,3
      B(I+2)=F(I)
      D(I+2)=F(I)
4     E(I+2)=F(I)
      DATA DL /'DL','1:'/
      DATA G /'1.','DA','T'/
      DATA HH /'2.','DA','T'/
      DATA FF /'3.','DA','T'/
      DO 6 I=1,2
      B(I)=DL(I)
      D(I)=DL(I)
6     E(I)=DL(I)
      DO 5 I=1,3
      B(I+5)=G(I)
      D(I+5)=HH(I)
5     E(I+5)=FF(I)
      DATA WL(1),WL(2),WL(3)/0.,0.,0./
      DATA OW01,OW02,OW03,OW04,W01,W02,W03,W04/0.,0.,0.,0.,0.,0.,0.,0
     @  ./
7     TIME=0.
      DIST=1.
      N=-2
      M=0
      KK=0
      JJ=0
```

```
      IJK=0
      Z=0.
      ARY=1.
      DO 110 I=1,6
      DO 110 J=1,8
      XT(J,I)=0.0
110   DT(J,I)=0.0
      DO 130 I=1,10
      WO(I)=0.0
      WM(I)=0.0
130   GAP(I)=0.005
C
C  INPUT AND WRITE SPECIFIED VARIABLES
C
      CALL ASSIGN(2,B,15)
      CALL ASSIGN(1,D,15)
      CALL ASSIGN(3,E,15)
      CALL ASSIGN(4,'DATAFILE.DAT',12)
      READ(2,3)(C(I),I=1,20)
3     FORMAT(20A4)
      READ(2,11000)RI,AM1,AM2,AM3
      READ(2,11100)D1,D3,D4,D6,A,AOL
      READ(2,11400)CB,CS,CK1,CK2,AK
      READ(2,11300)CEK3,CEK4
      READ(2,11000)VEL,PREL,CLEAR,WXX
      READ(2,11300)AMP,DIAM
      READ(2,11000)PH1,PH2,PH3,PH4
      PER=2.*VEL/DIAM
      TIW1=PH1/PER
      TIW2=PH2/PER
      TIW3=PH3/PER
      TIW4=PH4/PER
      READ(2,11200)NOB,MISAL
      RAT=AOL/A
      ANOB=NOB*1.0
      WRITE(1,3)(C(I),I=1,20)
      WRITE(3,3)(C(I),I=1,20)
      WRITE(4,50000)(C(I),I=1,20)
      WRITE(4,12100)
      WRITE(4,12500)
      WRITE(4,12600)RI
      WRITE(4,12700)AM1,AM2,AM3
      WRITE(4,13000)CS,CB
      WRITE(4,13700)
      WRITE(4,13200)AK,CEK3,CEK4
      WRITE(4,13100)CK1,CK2
      WRITE(4,13600)
```

```
      WRITE(4,12800)A,AOL
      WRITE(4,12900)D1,D3,D4,D6
      WRITE(4,14100)CLEAR,WXX
      WRITE(4,13800)DIAM,AMP
      WRITE(4,13300)VEL
      WRITE(4,13400)PREL
      WRITE(4,12100)
      WRITE(4,12200)
      CST=CS/50.*SQRT(AM2*AK/2.)
      CSB=CS/50.*SQRT(AM3*AK/2.)
      CBT=CB/50.*SQRT(AM2*CEK3)
      CBB=CB/50.*SQRT(AM3*CEK4)
      CK1=CK1*208.*162./A**3/27.
C
C  CALCULATE CONSTANTS FOR EQUATIONS FOR OTHER WHEEL EFFECT,IE WHEEL
C  INTERACTION
C
      EI=CK1*A**3/162.*27.
      XXK=6.*EI/A**2
      XXK1=XXK/A/CK2
      Z1=(1.-10.*XXK1+3.*XXK1**2)/(XXK1**2)
      Z2=(6.-23.*XXK1-2.*XXK1**2)/(XXK1**2)
      Z3=26./XXK1-1./XXK1**2-150.+110.*XXK1+25.*XXK1**2
      Z4=34./XXK1**2-476./XXK1+679.-24.*XXK1-75.*XXK1**2
      Z5=114./XXK1**2-1550./XXK1+1596.+767.*XXK1+50.*XXK1**2
      Z6=67./XXK1-4./XXK1**2-78.-251.*XXK1-46.*XXK1**2
      Z7=136./XXK1**2-646./XXK1-1022.+153.*XXK1+138.*XXK1**2
      Z8=456./XXK1**2-1982./XXK1-4411.-1496.*XXK1-92.*XXK1**2
      Z9=(Z1*Z6+Z7)*(Z2*Z3+Z5)-(Z1*Z3+Z4)*(Z2*Z6+Z8)
C
C  INITIALISE NEW TIME STEP
C
120   DIS=AINT((TIME*VEL)/A)
      IJK=IJK+1
      DX=DIST
      DIST=TIME*VEL-DIS*A
      IF(DIST.GT.DX)GOTO 210
C
C  CALCULATE GUIDE MISALIGNMENT AND MISMATCH
C
140   DO 200 I=1,2
      WO(I+10)=WO(I+8)
      WO(I+8)=WO(I+6)
      WO(I+6)=WO(I+4)
      WO(I+4)=WO(I+2)
      WO(I+2)=WO(I)
      WO(I)=WO(I)+CLEAR
```

```
      IF(WM(I).GT.0.0)GAP(I)=GAP(I)*3.0
200   CONTINUE
      DO 205 I=1,9,2
      WM(13-I)=WM(11-I)
      WM(12-I)=WM(10-I)
      GAP(13-I)=GAP(11-I)
205   GAP(12-I)=GAP(10-I)
      GAP(1)=0.005
      GAP(2)=0.005
      READ(2,11000)WO(1),WO(2),WM(1),WM(2)
      KK=KK+1
      IF(KK.LT.5)GOTO 140
      GMA=WO(3)*1000.
      GMB=WO(4)*1000.
      GMC=WM(3)*1000.
      GMD=WM(4)*1000.
      IF(N.EQ.0)GOTO 113
      GOTO 115
113   WRITE(4,12100)
      TIME=TIME-A/VEL*2.
      IJK=1
115   IF(N.GE.0)WRITE(4,11500)N,GMB,GMA,GMD,GMC
      IF(N.GE.0)WRITE(4,13500)
      N=N+1
      IF(N.LE.0)GOTO 210
C
C  CALCULATE RELEVANT DAMPING RATIOS - BASIC DAMPING IS ASSUMED CONSTANT
C  CALCULATE RELEVANT STIFFNESS VALUES - WHEEL STIFFNESS IS CONSTANT
C  FIRST CALCULATE GUIDE STIFFNESS.
C
210   ARAT=(AOL-DIST)/A
      AA(1)=DIST/A/3.+1/3.
      IF(ARAT.GT.3.0)AA(2)=(ARAT-2.)/3.
      IF(ARAT.GT.2.0.AND.ARAT.LE.3.0)AA(2)=(ARAT-1.)/3.
      IF(ARAT.GT.1.0.AND.ARAT.LE  .0)AA(2)=ARAT/3.
      IF(ARAT.LE.1.0)AA(2)=(ARAT+1.)/3.
      COA=1./(CK1/CK2+5.)
      COB=7./3./(CK1/CK2+1./3.)*COA
      DO 300 I=1,2
      BK(I)=(162.*COA+324.*COB)*AA(I)
      BK(I)=(486.*COA+972.*COB-BK(I))*AA(I)
      BK(I)=(BK(I)+54.-927.*COA-1125.*COB)*AA(I)
      BK(I)=(BK(I)-108.+1044.*COA+630.*COB)*AA(I)
      BK(I)=(BK(I)+54.-479.*COA-175.*COB)*AA(I)
      BK(I)=(BK(I)+38.*COA+22.*COB)*AA(I)
      BK(I)=CK1/(BK(I)-COA-COB)
300   CONTINUE
```

```
C
C  CALCULATE COMBINED STIFFNESSES,CEK
C
      CEK1=AK*BK(1)/(AK+BK(1))
      CEK2=CEK1
      CEK5=AK*BK(2)/(AK+BK(2))
      CEK6=CEK5
      CS1=CST
      CS2=CST
      CS5=CSB
      CS6=CSB
      IF(TIME.EQ.0.0)PR=PREL/CEK1
      IF(N.LT.0)GOTO 340
C
C  CALCULATE WO VALUES AT THE WHEELS FROM VALUES AT THE BUNTONS
C  PR ARE EFFECTIVE DISPLACEMENTS DUE TO PRELOAD SPECIFIED,CALCULATED
C  AT THE FIRST BUNTON
C
305   WO1=(WO(3)+WM(3))+(WO(1)-(WO(3)+WM(3)))*DIST/A-PR
      WO2=(WO(4)+WM(4))+(WO(2)-(WO(4)+WM(4)))*DIST/A-PR
      IF(ARAT.GT.3.0)GOTO 240
      IF(ARAT.GT.2.0)GOTO 230
      IF(ARAT.GT.1.0)GOTO 220
      WO3=WO(3)+((WO(5)+WM(5))-WO(3))*ARAT-PR
      WO4=WO(4)+((WO(6)+WM(6))-WO(4))*ARAT-PR
      GOTO 250
220   WO3=WO(5)+((WO(7)+WM(7))-WO(5))*(ARAT-1.)-PR
      WO4=WO(6)+((WO(8)+WM(8))-WO(6))*(ARAT-1.)-PR
      GOTO 250
230   WO3=WO(7)+((WO(9)+WM(9))-WO(7))*(ARAT-2.)-PR
      WO4=WO(8)+((WO(10)+WM(10))-WO(8))*(ARAT-2.)-PR
      GOTO 250
240   WO3=WO(9)+((WO(11)+WM(11))-WO(9))*(ARAT-3.)-PR
      WO4=WO(10)+((WO(12)+WM(12))-WO(10))*(ARAT-3.)-PR
C
C  CALCULATE WO VARIATION DUE TO EFFECT OF THE OTHER WHEEL ON SAME GUIDE
C
250   IF(IJK.EQ.1)GOTO 295
      ARX=ARY
      IF(ARAT.GE.0.0)ARY=(1.-ARAT)
      IF(ARAT.GT.1.0)ARY=(2.-ARAT)
      IF(ARAT.GT.2.0)ARY=(3.-ARAT)
      IF(ARAT.GT.3.0)ARY=(4.-ARAT)
      YONE=ARY*(1.-ARY)**2
      YTWO=ARY**2*(ARY-1.)
      XONE=YONE-2.*YTWO+5.+4.*ARY
      XTWO=2.*YONE-YTWO+XXK1+5.+ARY
```

```
C
C   CALCULATE COMBINED STIFFNESSES,CEK
C
          CEK1=AK*BK(1)/(AK+BK(1))
          CEK2=CEK1
          CEK5=AK*BK(2)/(AK+BK(2))
          CEK6=CEK5
          CS1=CST
          CS2=CST
          CS5=CSB
          CS6=CSB
          IF(TIME.EQ.0.0)PR=PREL/CEK1
          IF(N.LT.0)GOTO 340
C
C   CALCULATE WO VALUES AT THE WHEELS FROM VALUES AT THE BUNTONS
C   PR ARE EFFECTIVE DISPLACEMENTS DUE TO PRELOAD SPECIFIED,CALCULATED
C   AT THE FIRST BUNTON
C
305       WO1=(WO(3)+WM(3))+(WO(1)-(WO(3)+WM(3)))*DIST/A-PR
          WO2=(WO(4)+WM(4))+(WO(2)-(WO(4)+WM(4)))*DIST/A-PR
          IF(ARAT.GT.3.0)GOTO 240
          IF(ARAT.GT.2.0)GOTO 230
          IF(ARAT.GT.1.0)GOTO 220
          WO3=WO(3)+((WO(5)+WM(5))-WO(3))*ARAT-PR
          WO4=WO(4)+((WO(6)+WM(6))-WO(4))*ARAT-PR
          GOTO 250
220       WO3=WO(5)+((WO(7)+WM(7))-WO(5))*(ARAT-1.)-PR
          WO4=WO(6)+((WO(8)+WM(8))-WO(6))*(ARAT-1.)-PR
          GOTO 250
230       WO3=WO(7)+((WO(9)+WM(9))-WO(7))*(ARAT-2.)-PR
          WO4=WO(8)+((WO(10)+WM(10))-WO(8))*(ARAT-2.)-PR
          GOTO 250
240       WO3=WO(9)+((WO(11)+WM(11))-WO(9))*(ARAT-3.)-PR
          WO4=WO(10)+((WO(12)+WM(12))-WO(10))*(ARAT-3.)-PR
C
C   CALCULATE WO VARIATION DUE TO EFFECT OF THE OTHER WHEEL ON SAME GUIDE
C
250       IF(IJK.EQ.1)GOTO 295
          ARX=ARY
          IF(ARAT.GE.0.0)ARY=(1.-ARAT)
          IF(ARAT.GT.1.0)ARY=(2.-ARAT)
          IF(ARAT.GT.2.0)ARY=(3.-ARAT)
          IF(ARAT.GT.3.0)ARY=(4.-ARAT)
          YONE=ARY*(1.-ARY)**2
          YTWO=ARY**2*(ARY-1.)
          XONE=YONE-2.*YTWO+5.+4.*ARY
          XTWO=2.*YONE-YTWO+XXK1+5.+ARY
```

```
      XTHR=1.+ARY
      XFOU=XONE-5.*XTHR+XXK1*XTHR
      XFIV=XTWO-5.*XTHR-3.*XXK1*XTHR
      RH=((Z1*Z6+Z7)*XFOU-(Z1*Z3+Z4)*XFIV)/Z9
      RG=(XFOU-(Z2*Z3+Z5)*RH)/(Z1*Z3+Z4)
      RE=Z1*RG+Z2*RH
      RD=(34.*RG+114.*RH-RE)/XXK1+8.*RE+10.*RG+80.5*RH+(3.*RE-9.*RG+6.
     @ *RH)*XXK1
      RC=(78.*RG+264.*RH-RD-6.*RE)/XXK1+2.*RD+11.*RE-36.*RG+24.*RH
      RF=0.-8.*RG-24.*RH-XXK1*RE+3.*XXK1*RG-2.*XXK1*RH
      IF(ARAT.GT.3.0)GOTO 280
      IF(ARAT.GT.2.0)GOTO 270
      IF(ARAT.GT.1.0)GOTO 260
      BEGM=0.-A*(RD+2.*RE+3.*RF+4.*RG+5.*RH)
      ENDM=0.-A*(RE+2.*RF+3.*RG+4.*RH)
      BDEL=RC/CK2
      EDEL=RD/CK2
      GOTO 290
260   BEGM=0.-A*(RE+2.*RF+3.*RG+4.*RH)
      ENDM=0.-A*(RF+2.*RG+3.*RH)
      BDEL=RD/CK2
      EDEL=RE/CK2
      GOTO 290
270   BEGM=0.-A*(RF+2.*RG+3.*RH)
      ENDM=0.-A*(RG+2.*RH)
      BDEL=RE/CK2
      EDEL=RF/CK2
      GOTO 290
280   BEGM=0.-A*(RG+2.*RH)
      ENDM=0.-A*RH
      BDEL=RF/CK2
      EDEL=RG/CK2
290   OWE=BDEL+(EDEL-BDEL)*DIST/A+(ENDM-2.*BEGM)/6.*A*DIST/EI+DIST**2/
     @ EI*((ENDM-BEGM)/6./A*DIST+BEGM/2.)
      WO1=WO1+CX*OWE
      WO2=WO2+DX*OWE
      WO3=WO3+AX*OWE
      WO4=WO4+BX*OWE
C
C  CALCULATE WO VARIATION DUE TO WHEEL IRREGULARITIES . THIS VARIATION
C  IS ASSUMED TO BE A SINE WAVE .
C
      WO1=WO1+AMP*SIN(TIW1*PER)
      WO2=WO2+AMP*SIN(TIW2*PER)
      WO3=WO3+AMP*SIN(TIW3*PER)
      WO4=WO4+AMP*SIN(TIW4*PER)
C
```

```
C  CALCULATE WVO VALUES;IE RATE OF CHANGE OF GUIDE POSITION
C
        WV01=(W01-OW01)/DELT
        WV02=(W02-OW02)/DELT
        WV03=(W03-OW03)/DELT
        WV04=(W04-OW04)/DELT
        IF(DIST.GT.DX)GOTO 293
        WV01=WV01+WM(3)/GAP(3)
        WV02=WV02+WM(4)/GAP(4)
293     IF(ARY.GT.ARX)GOTO 295
        IF(RAT.LT.1.0)MIM=3
        IF(RAT.GE.1.0.AND.RAT.LT.2.0)MIM=5
        IF(RAT.GE.2.0.AND.RAT.LT.3.0)MIM=7
        IF(RAT.GE.3.0.AND.RAT.LT.4.0)MIM=9
        IF(RAT.GE.4.0)MIM=11
        WV03=WV03+WM(MIM)/GAP(MIM)
        WV04=WV04+WM(MIM+1)/GAP(MIM+1)
295     OW01=W01
        OW02=W02
        OW03=W03
        OW04=W04
C
C  CHECK WHETHER WHEELS ARE IN CONTACT WITH THE GUIDES AND PUT DAMPING
C  AND STIFFNESS OF RELEVANT WHEEL EQUAL TO 0 IF THEY ARE NOT
C
        WD1=XT(5,5)-W01
        WD2=XT(5,5)+W02
        WD3=XT(6,5)-W03
        WD4=XT(6,5)+W04
        IF(WD1.GT.0.0)GOTO 310
        CEK1=0.0
        CS1=0.0
310     IF(WD2.LT.0.0)GOTO 320
        CEK2=0.0
        CS2=0.0
320     IF(WD3.GT.0.0)GOTO 330
        CEK5=0.0
        CS5=0.0
330     IF(WD4.LT.0.0)GOTO 331
        CEK6=0.0
        CS6=0.0
C
C  CHECK FOR BOTTOMING OUT AND PUT WHEEL STIFFNESS EQUAL TO GUIDE
C  STIFFNESS IF IT HAPPENS
C
331     AKE1=BK(1)/(BK(1)+AK)
        AKE3=BK(2)/(BK(2)+AK)
```

```
      WD1X=WD1*AKE1
      WD2X=0.-WD2*AKE1
      WD3X=WD3*AKE3
      WD4X=0.-WD4*AKE3
      IF(WD1X.LT.WXX)GOTO 332
      CEK1=BK(1)
      WO1=WO1+WXX
332   IF(WD2X.LT.WXX)GOTO 333
      CEK2=BK(1)
      WO2=WO2+WXX
333   IF(WD3X.LT.WXX)GOTO 334
      CEK5=BK(2)
      WO3=WO3+WXX
334   IF(WD4X.LT.WXX)GOTO 340
      CEK6=BK(2)
      WO4=WO4+WXX
C
C  CALCULATE CONSTANTS,AE FOR USE IN EQUATIONS OF MOTION
C
340   AE1=0.-CBB*(D4+D6/2.)+CBT*(D3+D1/2.)
      AE2=CS1*D1/2.+CS2*D1/2.-CBT*(D3+D1/2.)
      AE3=CBB*(D4+D6/2.)-CS5*D6/2.-CS6*D6/2.
      AE4=CBT*(D3*D1/2.+D3**2)+CBB*(D4**2+D4*D6/2.)
      AE5=CEK3*(D1/2.+D3)-CEK4*(D4+D6/2.)
      AE6=(CEK1+CEK2-CEK3)*D1/2.-CEK3*D3
      AE7=CEK4*D4-(CEK5+CEK6-CEK4)*D6/2.
      AE8=CEK3*(D3*D1/2.+D3**2)+CEK4*(D4**2+D4*D6/2.)
      AE9=D1/2.*(CEK2*WO2-CEK1*WO1+CS1*WV01-CS2*WV02)+D6/2.*(CEK5*WO3-
     @ CEK6*WO4+CS5*WV03-CS6*WV04)
      AE10=CBT+CBB
      AE11=CBT*D3-CBB*D4
      AE12=CEK3+CEK4
      AE13=CEK3*D3-CEK4*D4
      AE14=CS1+CS2+CBT
      AE15=0.-CBT*D3
      AE16=CEK1+CEK2+CEK3
      AE17=0.-CEK3*D3
      AE18=CEK2*WO2-CEK1*WO1+CS2*WV02-CS1*WV01
      AE19=CBB*D4
      AE20=CEK4+CEK5+CEK6
      AE21=CEK4*D4
      AE22=CEK6*WO4-CEK5*WO3+CS6*WV04-CS5*WV03
      AE23=CS5+CS6+CBB
      IF(N.GE.1)GOTO 395
      IF(N.GE.0)GOTO 393
C
C  CALCULATE NATURAL UNDAMPED FREQUENCIES FROM THE EXPANDED DETERMINANT
```

```
C  OF THE EQUATIONS OF MOTION
C
348      M=M+1
         BE1=AE16/AM2+AE12/AM1+AE20/AM3+AE8/RI
         BE2=(AE12*AE16-CEK3**2)/AM1/AM2+AE16*AE20/AM2/AM3+AE8*AE16/AM2/R
        @I+AE12*AE20/AM1/AM3+AE8*AE12/AM1/RI-CEK4**2/AM1/AM3-(AE5*AE13/AM
        @1-AE8*AE20/AM3+AE7*AE21/AM3+AE6*AE17/AM2)/RI
         BE3=(CEK3**2*(AE20*RI+AE8*AM3)+CEK3*AE6*AE13*AM3-AE12*AE16*AE20*
        @RI-AE8*AE12*AE16*AM3+CEK4**2*AE16*RI+AE5*AE13*AE16*AM3-AE8*AE16*
        @AE20*AM1+AE7*AE16*AE21*AM1-AE8*AE12*AE20*AM2+AE7*AE12*AE21*AM2+C
        @EK4**2*AE8*AM2+CEK4*AE7*AE13*AM2+CEK4*AE5*AE21*AM2+AE5*AE13*AE20
        @*AM2+CEK3*AE5*AE17*AM3+AE6*AE12*AE17*AM3+AE6*AE17*AE20*AM1)/AM1/
        @AM2/AM3/RI
         BE4=(CEK3**2*(AE7*AE21-AE8*AE20)-CEK3*AE6*(CEK4*AE21+AE13*AE20)+
        @AE8*AE12*AE16*AE20-AE7*AE12*AE16*AE21-CEK4**2*AE8*AE16-CEK4*AE7*
        @AE13*AE16-CEK4*AE5*AE16*AE21-AE5*AE13*AE16*AE20-CEK3*CEK4*AE7*AE
        @17-CEK3*AE5*AE17*AE20-AE6*AE12*AE17*AE20+CEK4**2*AE6*AE17)/AM1/A
        @M2/AM3/RI
         IF(M.GT.1)GOTO 370
         FUNC=BE4
         SSS=1.0
         I=1
350      FUNF=(((SSS-BE1)*SSS+BE2)*SSS+BE3)*SSS+BE4
         FUNR=FUNC/FUNF
         FUNC=FUNF
         SSS=SSS*1.05
         IF(SSS.GT.1000000.0)GOTO 360
         IF(FUNR.LT.0.0)GOTO 360
         GOTO 350
360      FREQ(I,M)=SSS
         ETEST(I)=0.01*FREQ(I,M)
         IF(I.EQ.4)GOTO 370
         I=I+1
         GOTO 350
37       DO 390 I=1,4
         IF(M.GT.1)FREQ(I,M)=(FREQ(I,(M-1))*6.2832)**2
         IF(FREQ(I,M).GE.1000000.0)GOTO 385
380      DFQ=(((FREQ(I,M)-BE1)*FREQ(I,M)+BE2)*FREQ(I,M)+BE3)*FREQ(I,M)+BE
        @4
         SLOPE=((4.*FREQ(I,M)-3.*BE1)*FREQ(I,M)+2.*BE2)*FREQ(I,M)+BE3
         CHFR=FREQ(I,M)
         FREQ(I,M)=FREQ(I,M)-DFQ/SLOPE
         ESC=ABS(CHFR-FREQ(I,M))
         IF(ESC.GT.ETEST(I))GOTO 380
385      FREQ(I,M)=SQRT(FREQ(I,M))/6.2832
390      CONTINUE
         WRITE(4,12300)FREQ(1,M),FREQ(2,M),FREQ(3,M),FREQ(4,M)
```

```
      DELT=2.5/FREQ(4,1)
      OVER=DELT*VEL/A
      IF(OVER.GT.0.3)TIME=TIME+DELT/3.
      IF(OVER.LE.0.3.AND.OVER.GT.0.06)TIME=TIME+DELT
      IF(OVER.LE.0.06)TIME=TIME+DELT*3.
      GOTO 120
C
C  USE RUNGE-KUTTA FOURTH ORDER METHOD TO SOLVE EQUATIONS OF MOTION IN
C  FIRST FOUR TIME STEPS
C  CALCULATE K VALUES
C
393   Z=Z+1
      IF(Z.GE.5.0)GOTO 395
      IF(Z.EQ.1.0)DELT=DELT/20.
      Q=DELT/24.
      DO 705 I=1,8
      ZT(I,1)=XT(I,5)
705   CONTINUE
      DO 700 J=1,4
      ET(1,J)=(CEK3*ZT(5,J)+CEK4*ZT(6,J)-AE13*ZT(7,J)-AE10*ZT(1,J)+CBT
     @ *ZT(2,J)+CBB*ZT(3,J)-AE11*ZT(8,J)-AE12*ZT(4,J))/AM1
      ET(2,J)=(CEK3*ZT(4,J)-AE16*ZT(5,J)-AE17*ZT(7,J)-AE18+CBT*ZT(1,J)
     @ -AE14*ZT(2,J)-AE15*ZT(8,J))/AM2
      ET(3,J)=(CEK4*ZT(4,J)-AE20*ZT(6,J)-AE21*ZT(7,J)-AE22+CBB*ZT(1,J)
     @ -AE23*ZT(3,J)-AE19*ZT(8,J))/AM3
      ET(4,J)=ZT(1,J)
      ET(5,J)=ZT(2,J)
      ET(6,J)=ZT(3,J)
      ET(7,J)=ZT(8,J)
      ET(8,J)=(0.-AE1*ZT(1,J)-AE2*ZT(2,J)-AE3*ZT(3,J)-AE4*ZT(8,J)-AE5*
     @ ZT(4,J)-AE6*ZT(5,J)-AE7*ZT(6,J)-AE8*ZT(7,J)-AE9)/RI
      DO 700 I=1,8
      ZK(I,J)=DELT*ET(I,J)
      ZT(I,(J+1))=XT(I,5)+ZK(I,J)/2.
      IF(J.EQ.3)ZT(I,(J+1))=ZT(I,(J+1))+ZK(I,J)/2.
700   CONTINUE
C
C  CALCULATE NEW XT VALUES USING K VALUES
C
      DO 710 I=1,8
      XT(I,6)=XT(I,5)+(ZK(I,1)+2.*ZK(I,2)+2.*ZK(I,3)+ZK(I,4))/6.
710   CONTINUE
      GOTO 410
C
C  USE ADAMS-MOULTON PREDICTOR-CORRECTOR STEP-BY-STEP SOLUTION AFTER
C  FOURTH TIME STEP
C  PREDICTED NEW XT VALUES
```

```
C
395      DO 400 I=1,8
         XT(I,6)=XT(I,5)+Q*(55.*DT(I,5)-59.*DT(I,4)+37.*DT(I,3)-9.*DT(I,2
     @   ))
400      CONTINUE
C
C  CALCULATE NEW DERIVATIVE VALUES FROM SIMULTANEOUS EQUATIONS
C
         JJ=0
410      DT(1,6)=(CEK3*XT(5,6)+CEK4*XT(6,6)-AE13*XT(7,6)-AE10*XT(1,6)+CBT
     @   *XT(2,6)+CBB*XT(3,6)-AE11*XT(8,6)-AE12*XT(4,6))/AM1
         DT(2,6)=(CEK3*XT(4,6)-AE16*XT(5,6)-AE17*XT(7,6)-AE18+CBT*XT(1,6)
     @   -AE14*XT(2,6)-AE15*XT(8,6))/AM2
         DT(3,6)=(CEK4*XT(4,6)-AE20*XT(6,6)-AE21*XT(7,6)-AE22+CBB*XT(1,6)
     @   -AE23*XT(3,6)-AE19*XT(8,6))/AM3
         DT(4,6)=XT(1,6)
         DT(5,6)=XT(2,6)
         DT(6,6)=XT(3,6)
         DT(7,6)=XT(8,6)
         DT(8,6)=(0.-AE1*XT(1,6)-AE2*XT(2,6)-AE3*XT(3,6)-AE4*XT(8,6)-AE5*
     @   XT(4,6)-AE6*XT(5,6)-AE7*XT(6,6)-AE8*XT(7,6)-AE9)/RI
C
C CALCULATE CORRECTOR VALUES
C
         IF(Z.LT.5)GOTO 600
         DO 420 I=1,8
         XT(I,1)=XT(I,5)+Q*(9.*DT(I,6)+19.*DT(I,5)-5.*DT(I,4)+DT(I,3))
420      CONTINUE
C
C  CHECK ACCURACY OF CORRECTED VALUES
C
         DO 430 I=1,8
         CHECK(I)=ABS((ABS(XT(I,6))+0.001)/(ABS(XT(I,1))+0.001)-1.)
         XT(I,6)=XT(I,1)
430      CONTINUE
         IF(JJ.EQ.10)GOTO 600
         JJ=JJ+1
         DO 440 I=1,8
         IF(CHECK(I).GT.0.001)GOTO 410
440      CONTINUE
C
C  CALCULATE WHEEL LOADS AND ACCELERATIONS
C
600      DO 640 I=1,8
         IF(DT(I,6).GT.200.0)GOTO 810
640      CONTINUE
630      AX=CEK1*(XT(5,6)-WO1)+CS1*(XT(2,6)-WVO1)
```

```
      BX=0.-CS2*(XT(2,6)+WV02)-CEK2*(XT(5,6)+W02)
      CX=CEK5*(XT(6,6)-W03)+CS5*(XT(3,6)-WV03)
      DX=0.-CS6*(XT(3,6)+WV04)-CEK6*(XT(6,6)+W04)
      PX=DT(3,6)
      HX=DT(1,6)-D4*DT(8,6)
      GX=DT(1,6)
      FX=DT(1,6)+D3*DT(8,6)
      EX=DT(2,6)
      YR=TIME
      JWR=32
      IF(DELT.GT.0.0007)JWR=16
      IF(DELT.GT.0.0015)JWR=8
      IF(DELT.GT.0.003)JWR=4
      IF(DELT.GT.0.0075)JWR=2
      IF(DELT.GT.0.015)JWR=1
      IWR=(IJK/JWR)*JWR
      IF(IJK.EQ.1)NPTS=0
      IF(N.GE.1.AND.IJK.EQ.IWR)WRITE(1,14400)AX,BX,CX,DX,EX,FX,GX,HX,
     @PX,YR
      IF(N.GE.1.AND.IJK.EQ.IWR)NPTS=NPTS+1
C
C  MOVE ALL XT AND DT VALUES TO NEXT ARRAY POSITION FOR NEXT TIME STEP
C
      DO 620 I=1,8
      DO 620 J=2,5
      XT(I,J)=XT(I,(J+1))
      DT(I,J)=DT(I,(J+1))
620   CONTINUE
      TIME=TIME+DELT
      IF(CS1.NE.0.)TIW1=TIW1+DELT
      IF(CS2.NE.0.)TIW2=TIW2+DELT
      IF(CS5.NE.0.)TIW3=TIW3+DELT
      IF(CS6.NE.0.)TIW4=TIW4+DELT
      IF(N.LE.NOB)GOTO 120
      GOTO 800
C
C  IF ACCELERATION VALUES EXCEED 200 REDUCE ALL ACCELERATION,VELOCITY
C  AND DISPLACEMENT VALUES BY A FACTOR OF 20 AND WRITE WARNING MESSAGE
C
810   DO 820 I=1,8
      XT(I,6)=XT(I,6)/20.
      DT(I,6)=DT(I,6)/20.
      DO 820 J=1,4
      ET(I,J)=ET(I,J)/20.
820   CONTINUE
      W01=W01/20.
      W02=W02/20.
```

```
      WO3=WO3/20.
      WO4=WO4/20.
      WRITE(4,14200)
      WRITE(4,14300)TIME
      WRITE(4,14200)
      GOTO 630
C
C  END OF LOAD AND ACCELERATION GENERATION
C
800   CALL CLOSE(1)
      DELT=DELT*JWR
      WRITE(3,12345)DELT,VEL,NOB
      WRITE(3,11111)NPTS
      CALL CLOSE(3)
      READ(2,801,END=803)(F(I),I=1,3)
801   FORMAT(3A2)
      DO 802 J=3,5
      B(J)=F(J-2)
      D(J)=F(J-2)
802   E(J)=F(J-2)
      CALL CLOSE(2)
      CALL CLOSE(4)
      GOTO 7
803   STOP
11000 FORMAT(4F12.4)
11100 FORMAT(6F12.4)
11111 FORMAT(I7)
11200 FORMAT(2I7)
11300 FORMAT(2F12.4)
11400 FORMAT(5F12.4)
11500 FORMAT(/,'   BUNTON NO.',I6,8X,'GUIDE MISALIGNMENT (IN mms) ',2F
     @8.2,'  GUIDE MISMATCH (IN mms) ',2F8.2)
12100 FORMAT(//,12('**********'),//)
12200 FORMAT(17X,'UNDAMPED NATURAL FREQUENCIES'/)
12300 FORMAT(9X,4F11.2)
12345 FORMAT(F12.8,F12.4,I6)
12500 FORMAT(5X,'*',48X,'INPUT VALUES',48X,'*',/,5X,'*',48X,'*********
     @***',48X,'*',/,5X,'*',108X,'*')
12600 FORMAT(5X,'*',108X,'*',/,5X,'*',5X,'MASS MOMENT OF INERTIA :  RI
     @ =',F8.2,65X,'*')
12700 FORMAT(5X,'*',108X,'*',/,5X,'*',5X,'MASSES : CONVEYANCE BODY,AM1
     @ =',F8.2,'     TOP TRANSOM,AM2 =',F8.2,'   BOTTOM TRANSOM,AM3 = ',
     @F8.2,3X,'*')
12800 FORMAT(5X,'*',19X,'BUNTON SPACING =',F6.3,'   OVERALL CONVEYANCE
     @ LENGTH =',F7.3,29X,'*')
12900 FORMAT(5X,'*',16X,'TOP TRANSOM DEPTH =',F7.3,'   BODY TOP TO C.G
     @. =',F7.3,'   BODY BOTTOM TO C.G. =',F7.3,7X,'*',/,5X,'*',11X,'  B
```

```
     @OTTOM TRANSOM DEPTH =',F7.3,66X,'*')
13000   FORMAT(5X,'*',108X,'*',/,5X,'*',5X,'DAMPING : STEELWORK & WHEELS
     @ =',F7.2,' %',14X,'BRIDLE =',F7.2,' %',33X,'*')
13100   FORMAT(5X,'*',8X,'STEELWORK : GUIDE INERTIA =',F8.2,9X,'BUNTONS
     @=',F12.2,35X,'*')
13200   FORMAT(5X,'*',21X,'WHEEL SPRING =',F12.2,'  BRIDLE TOP =',F12.2,
     @'  BRIDLE BOTTOM =',F12.2,6X,'*')
13300   FORMAT(5X,'*',108X,'*',/,5X,'*',5X,'HOISTING SPEED :          VEL
     @ =',F5.1,68X,'*')
13400   FORMAT(5X,'*',108X,'*',/,5X,'*',5X,'WHEEL PRELOAD :          PREL
     @ =',F6.1,67X,'*')
13500   FORMAT(26X,'(+VE IS OUTWARD DISPLACEMENT)',/)
13600   FORMAT(5X,'*',108X,'*',/,5X,'*',5X,'LINEAR DIMENSIONS :',84X,'*'
     @)
13700   FORMAT(5X,'*',108X,'*',/,5X,'*',5X,'STIFFNESS VALUES :',85X,'*')
13800   FORMAT(5X,'*',108X,'*',/,5X,'*',5X,'WHEEL DIAMETER = ',F5.3,20X,
     @'WHEEL IRREGULARITY AMPLITUDE = ',F6.4,24X,'*')
14100   FORMAT(5X,'*',108X,'*',/,5X,'*',5X,'WHEEL CLEARANCE :       CLEAR
     @ =',F5.3,10X,'SPRING TRAVEL :   WXX =',F6.3,29X,'*')
14200   FORMAT(50X,'UNSTABLE SYSTEM!!!')
14300   FORMAT(40X,'ACCELERATIONS, VELOCITIES & DISPLACEMENTS DIVIDED BY
     @ 20.0    TIME=',F8.2)
14400   FORMAT(10F11.3)
50000   FORMAT(//,T20,80('='),/,T20,20A4,/,T20,80('='),/)
        END
```

E. 3 Programme DATAPL

This programme plots DISCS or measured results. The input to this programme is initially interactive, being free format in response to questions.

(i) Filename to plot. This is the six letter file-name specified for DISTAT and DISCS as well (A)

(ii) Total number of channels and highest wheel load channel. For plotting a DISCS run these are 9 and 4, and for plotting measurements, the response is any number up to 9 for the total channels sampled and up to four for the sampled wheel loads. (NOCHN, IWH)

(iii) Number of channels to be plotted. This is up to four channels on one page (NPL)

(iv) Value to plot and number of plot on the page. This gives the channel number and the position on the page, which is 1 at the top to 4 at the bottom. (JB, JC). This is repeated for each channel to be plotted.

(v) Start time and time scale. This gives the section of the record which is plotted. (TIME, SCALE)

(vi) Vertical scale and minimum value. This is half the peak to peak value to be plotted and the minimum value on the plot. If the scale is given as zero, a scale is calculated by the programme. These values are given for each channel plotted. (SCALE, VMIN)

The two output files from DISCS or CALIB are also read as input to this programme.

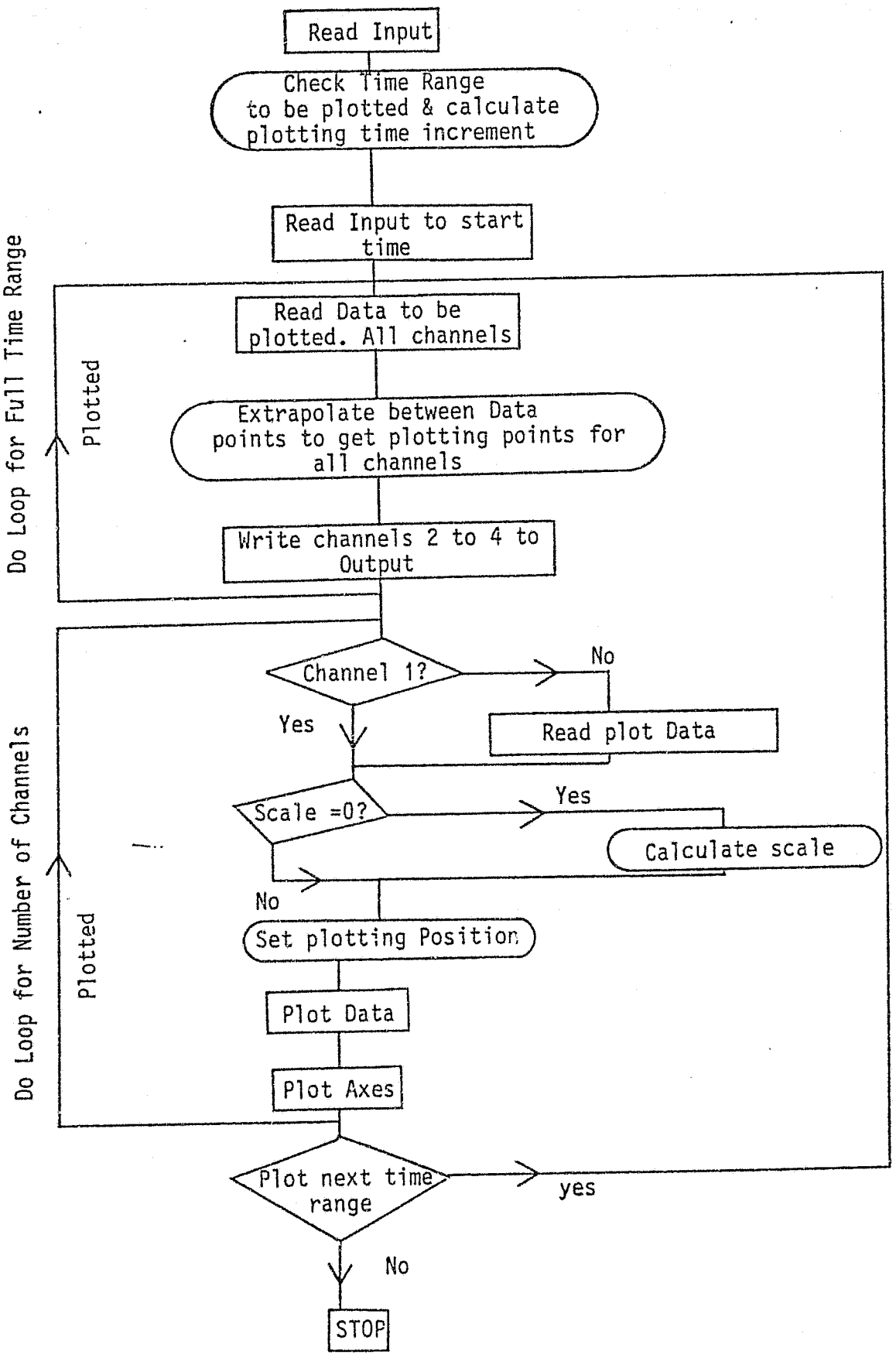
After plotting each channel the computer will pause, and RES must be typed to resume plotting.

Once all channels have been plotted more interactive input is required to either stop or continue plotting.

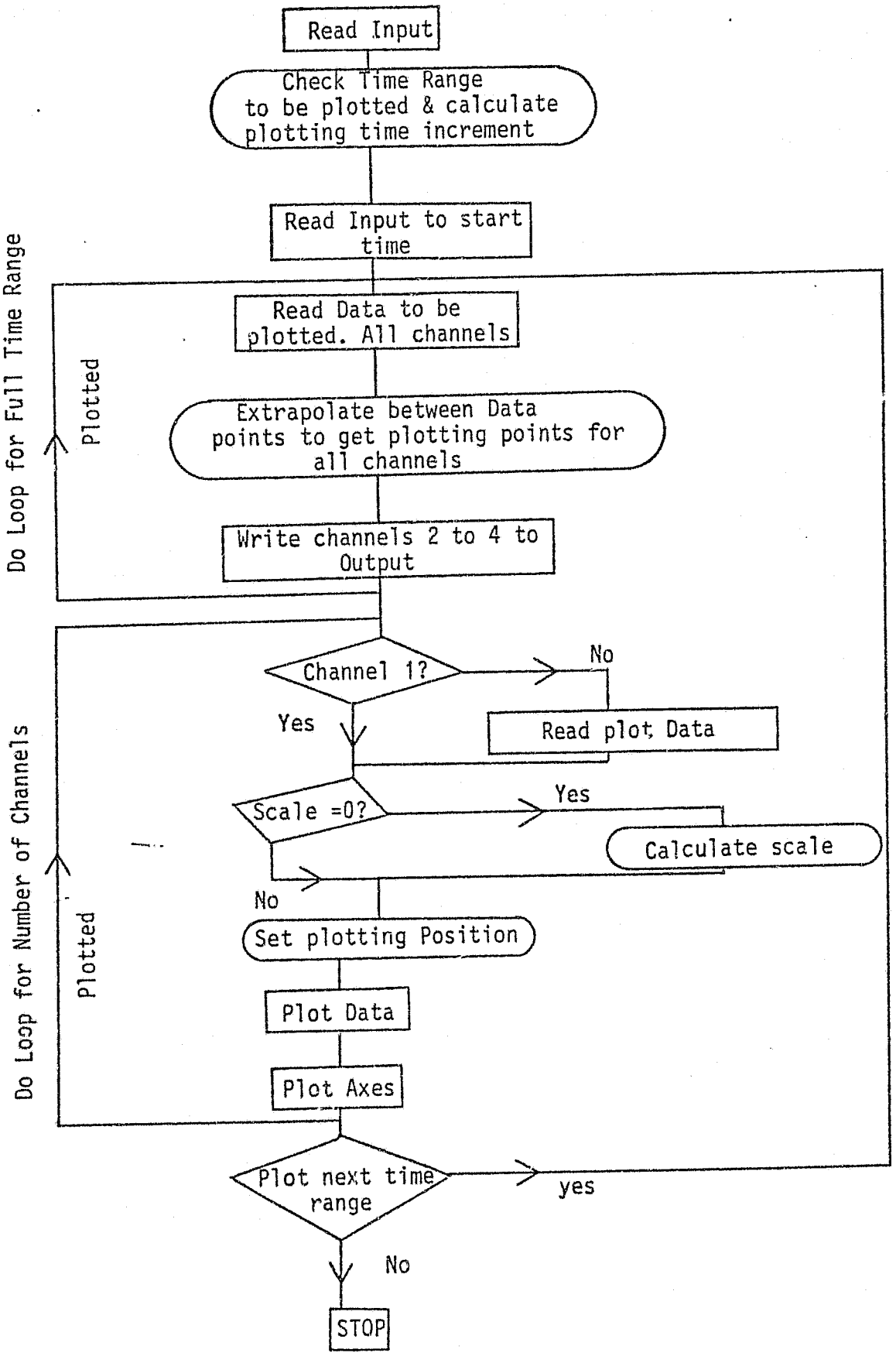
(vii) More Plots. Response is:

1 - for more plots, return to (vi) above, with same time scale, and start time set to end time of previous plot.
0 - to stop.

Flowchart for DATAPL



Flowchart for DATAPL



PROGRAMME DATAPL : Listing

```
C
C  THIS PROGRAMME PLOTS VALUES OF WHEEL LOADS AND/OR ACCELERATION
C  GENERATED BY DISCS OR MEASURED.
C  N.B. : EXTRA BUFFERS ARE NEEDED TO RUN THIS PROGRAMME, THUS:
C       1 - $F4PC (TO COMPILE)
C       2 - >TKB
C           TKB>DATAPL/CP/FP=DATAPL,LINE,AXIS,LB:[101,1]PLOTEX/LB,
C                                        LB:[11,37]F4POTS/LB
C           TKB>/
C           ENTER OPTIONS:
C           TKB>ACTFIL=6
C           TKB>//
C           >    (LINKING COMPLETED)
C
      DIMENSION VAL(2,14),X(1270),Y(1270),SCALE(4),VMIN(4)
      LOGICAL*1 A(13),B(15)
      INTEGER*4 ISAMP,J,ISA,L
      INTEGER C(80),JB(4),JC(4)
C
C  INTERACTIVE INPUT AND INPUT FROM FILES CREATED BY DISCS OR CALIB
C
      TYPE 1
1     FORMAT(' FILENAME TO PLOT ?')
      READ(5,2)(A(I),I=5,10)
2     FORMAT(6A1)
      TYPE 18
18    FORMAT(' TOTAL NO OF CHANNELS & HIGHEST WHEEL LOAD CHANNEL ?')
      ACCEPT *,NOCHN,IWH
      NOCHN1=NOCHN+1
      TYPE 8
8     FORMAT(' NO OF CHANNELS TO PLOT (MAX 4) ?')
      ACCEPT *,NPL
      TYPE 3
3     FORMAT(' VALUE TO PLOT & NUMBER OF PLOT ON PAGE ?')
      DO 9 IPL=1,NPL
9     ACCEPT *,JB(IPL),JC(IPL)
      DATA A(1),A(2),A(3),A(4)/'D','L','1',':'/
      DO 4 I=1,10
4     B(I)=A(I)
      DATA A(11),A(12),A(13),A(14),A(15)/'2',',','D','A','T'/
      DATA B(11),B(12),B(13),B(14),B(15)/'3',',','D','A','T'/
      CALL ASSIGN(1,B,15)
      READ(1,5)(C(I),I=1,80)
5     FORMAT(80A1)
      TYPE 6
6     FORMAT(' START TIME & TIME SCALE (1/10 OF RANGE) ?')
```

```
      ACCEPT *,TIME,TSCALE
      READ(1,1000)DELT,Q,MM
      READ(1,1200)ISAMP
      CALL CLOSE(1)
      MORPL=0
      CALL ASSIGN(1,A,15)
502   TYPE 7
7     FORMAT(' VERT SCALE & MIN VALUE? (SCALE=0. FOR AUTO SCALING)')
      DO 10 IPL=1,NPL
10    ACCEPT *,SCALE(IPL),VMIN(IPL)
      TIME1=0.0
      DT=33.*TSCALE/3800.
      JA=1
      CALL ASSIGN(2,'DL0:PLOT2.DAT;1',15)
      CALL ASSIGN(3,'DL0:PLOT3.DAT;1',15)
      CALL ASSIGN(4,'DL0:PLOT4.DAT;1',15)
      IF(MORPL.EQ.0)READ(1,5)(C(I),I=1,80)
      IF(DT.LT.DELT)DT=DELT
      IF(MORPL.EQ.0)J=TIME/DELT
      ISA=10*TSCALE/DELT
      IF(ISA.GT.ISAMP)ISA=ISAMP
      K=ISA-1
      IF(J.GT.50)K=K+50
      IF(J.GT.50)J=J-50
C
C  READ MAIN DATA FILE, INTERPOLATING TO ACHIEVE A GOOD TIME STEP FOR
C  PLOTTING, AND WRITE NEW VALUES TO FILES FOR LATER PLOTTING
C
      DO 130 L=1,J
130   READ(1,1100)VALDUM
      DO 110 L=1,K
      READ(1,1100)(VAL(2,M),M=1,NOCHN1)
      DT1=VAL(2,NOCHN1)-TIME1-TIME
      IF(DT1.LT.0.)GOTO 120
      Y(JA)=TIME1+TIME
      X(JA)=VAL(2,JB(1))-(VAL(2,JB(1))-VAL(1,JB(1)))/DELT*DT1
      IF(NPL.LE.1)GOTO 203
      IF(NPL.LE.2)GOTO 202
      IF(NPL.LE.3)GOTO 201
      XPL=VAL(2,JB(4))-(VAL(2,JB(4))-VAL(1,JB(4)))/DELT*DT1
      WRITE(2,1111)XPL
201   XPL=VAL(2,JB(3))-(VAL(2,JB(3))-VAL(1,JB(3)))/DELT*DT1
      WRITE(3,1111)XPL
202   XPL=VAL(2,JB(2))-(VAL(2,JB(2))-VAL(1,JB(2)))/DELT*DT1
      WRITE(4,1111)XPL
203   TIME1=TIME1+DT
      JA=JA+1
```

```
120     DO 110 II=1,NOCHN1
        VAL(1,II)=VAL(2,II)
110     CONTINUE
        JA=JA-1
        CALL CLOSE(2)
        CALL CLOSE(3)
        CALL CLOSE(4)
        CALL ASSIGN(4,'PL:',3)
        CALL PLINIT(1)
        CALL PLON
C
C  THE FOLLOWING LOOP PLOTS THE CURVES INDIVIDUALLY - ONE CURVE IS
C  PLOTTED EACH TIME THE LOOP IS COMPLETED.
C
        DO 300 IPL=1,NPL
        IF(IPL.EQ.1)GOTO 301
        IF(IPL.EQ.2)CALL ASSIGN(2,'DL0:PLOT4.DAT;1',15)
        IF(IPL.EQ.3)CALL ASSIGN(2,'DL0:PLOT3.DAT;1',15)
        IF(IPL.EQ.4)CALL ASSIGN(2,'DL0:PLOT2.DAT;1',15)
        DO 302 IJA=1,JA
302     READ(2,1111)X(IJA)
301     Z2=VMIN(IPL)
        Z1=Z2+2.*SCALE(IPL)
        IF(SCALE(IPL).NE.0.0)GOTO 303
        CALL MINVAL(X,JA,Z2)
        CALL MAXVAL(X,JA,Z1)
        Z3=ABS(Z2)
        DO 200 L=1,13
        AK=7.-L
        Z1Z=Z1/10.**AK
        Z3Z=Z3/10.**AK
        IF(Z1Z.GE.1.)GOTO 210
        IF(Z3Z.GE.1.)GOTO 210
200     CONTINUE
210     IZ1Z=(Z1Z/2+1)
        Z1=2.*IZ1Z*10.**AK
        IF(Z3.EQ.0.0)Z3=0.00001
        IZ3Z=(Z3Z/2-1*(Z2/Z3))
        Z2=2.*IZ3Z*10.**AK*Z2/Z3
303     IF(Z1.GE.0.0)Z1A=Z1*1.25
        IF(Z1.LT.0.0)Z1A=Z1*0.75
        IF(Z2.LT.0.0)Z2A=Z2*1.25
        IF(Z2.GE.0.0)Z2A=Z2*0.75
        IF(IPL.GT.1)PAUSE '! WHEN PLOTTER STOPS TYPE "RES" TO RESUME'
        CALL DWINDO(TIME-TSCALE,10.*TSCALE+TIME,Z2A,Z1A)
        IF(JC(IPL).EQ.1)CALL TWINDO(200,4000,2140,2755)
        IF(JC(IPL).EQ.2)CALL TWINDO(200,4000,1485,2100)
```

```
      IF(JC(IPL).EQ.3)CALL TWINDO(200,4000,830,1445)
      IF(JC(IPL).EQ.4)CALL TWINDO(200,4000,175,790)
      CALL LINE(Y,X,JA)
      CALL MOVEA(Y(JA),0.0)
      CALL DRAWA(TIME,0.0)
      SCALE(IPL)=(Z2-Z1)/2.
      IF(IPL.EQ.2.OR.NPL.EQ.1)CALL AXIS(TIME,Z2,0.,'T I M E   ( s e c
     @s ) ',11,TSCALE,SCALE(IPL),10)
      IF(JB(IPL).LE.IWH)CALL AXIS(TIME,Z2,90.,'W H   L O A D   ( k N )
     @ ',12,SCALE(IPL),TSCALE,2)
      IF(JB(IPL).GT.IWH)CALL AXIS(TIME,Z2,90.,'A C C E L   ( m / s 2 )
     @ ',12,SCALE(IPL),TSCALE,2)
      CALL CLOSE(2)
300   CONTINUE
      CALL PLCHAR(35,60)
      CALL DWINDO(0.,10.,0.,10.)
      CALL TWINDO(200,4000,50,120)
      CALL MOVEA(1.,-4.)
      CALL A1OUT(80,C)
      TYPE 501
501   FORMAT(' IF MORE PLOTS ENTER 1 OTHERWISE 0')
      ACCEPT *,MORPL
      J=1
      ISAMP=ISAMP-JA
      TIME=VAL(2,NOCHN1)+DELT
      CALL CLOSE(4)
      IF(MORPL.EQ.1)GOTO 502
      CALL CLOSE(1)
      CALL PLOFF
1000  FORMAT(3X,F12.4,F12.4,I6)
1100  FORMAT(<NOCHN1>F11.3)
1200  FORMAT(I7)
1111  FORMAT(1X,F11.3)
      END
C
C  THIS SUBROUTINE CALCULATES THE MAXIMUM VALUE ON THE CURVE
C
      SUBROUTINE MAXVAL(X,I,A)
      DIMENSION X(I)
      A=X(1)
      K=I-20
      DO 100 J=1,K,10
100   A=AMAX1(A,X(J),X(J+1),X(J+2),X(J+3),X(J+4),X(J+5),X(J+6),X(J+7),
     @  X(J+8),X(J+9))
      RETURN
      END
C
```

```
C   THIS SUBROUTINE CALCULATES THE MINIMUM VALUE ON THE CURVE
C
          SUBROUTINE MINVAL(X,I,A)
          DIMENSION X(I)
          A=X(1)
          K=I-20
          DO 100 J=1,K,10
100       A=AMIN1(A,X(J),X(J+1),X(J+2),X(J+3),X(J+4),X(J+5),X(J+6),X(J+7),
       @  X(J+8),X(J+9))
          RETURN
          END
```

```
      SUBROUTINE LINE(X,Y,I)
      DIMENSION X(I),Y(I)
      CALL MOVEA(X(1),Y(1))
      DO 100 J=1,I
100   CALL DRAWA(X(J),Y(J))
      RETURN
      END
```

```
      SUBROUTINE AXIS(XA,YA,DEG,TITLE,ITLEN,SCALEB,SCALEA,J)
C
C  XA -----  X CO-ORDINATE OF THE START OF THE AXIS
C  YA -----  Y
C  DEG ----  ANGLE OF THE AXIS ANTICLOCKWISE FROM THE HORIZONTAL.
C            CAN ONLY BE  0., 90., 180.
C  TITLE --  OUTPUT HEADING (MAX LENGTH 72)
C            LETTERS MUST BE SEPARATED BY BLANKS
C  ITLEN --  NO OF LETTERS IN TITLE
C  SCALEB -  INCREMENTS ON THE AXIS
C            IF NEGATIVE HEADING IS PLOTTED ANTI-CLOCKWISE FROM THE AXIS
C               POSITIVE    .          .        CLOCKWISE    .    .    .
C  SCALEA -  LENGTH OF THE INCREMENT LINE
C            RELATES TO THE SCALE OF THE OTHER AXIS
C  J ------  NO OF INCREMENTS ON THE AXIS
C
C
      INTEGER TITLE(72),REF(4),RAF(5),NUM(13),DOT
      DATA DOT,RAF(1),RAF(2),RAF(3)/'.',',',' ','x','E'/
      DATA NUM/'0','1','2','3','4','5','6','7','8','9','+','-',' '/
      AA=0.
      X=XA
      Y=YA
      A=ABS(SCALEA)
      IF(SCALEB.GT.0.)A=0.-A
      IF(SCALEB.GT.0.)AA=A/2.
      SCALE=ABS(SCALEB)
      CALL RROTAT(DEG)
      CALL LINROT(DEG)
      CALL MOVEA(X,Y)
      IF(DEG.GT.-1.0.AND.DEG.LT.1.0)G=AMAX1(J*SCALE+X,ABS(X))
      IF(DEG.GT.89.0.AND.DEG.LT.91.0)G=AMAX1(J*SCALE+Y,ABS(Y))
      IF(DEG.GT.179.0.AND.DEG.LT.181.0)G=AMAX1(J*SCALE+X,ABS(X))
      DO 10 K=1,13
      AK=K-7.
      GK=G/10.**AK
      IF(GK.LT.10.)GOTO 11
10    CONTINUE
11    MIH=ABS(AK)+1
      IREF=0
      IF(G.GE.2..AND.G.LE.100.)IREF=1
      IF(IREF.EQ.0)REF(3)=DOT
      RAF(5)=NUM(MIH)
      IF(AK.LT.0.0)RAF(4)=NUM(12)
      IF(AK.GE.0.0)RAF(4)=NUM(11)
      IF(DEG.GT.-1.0.AND.DEG.LT.1.0)AX=X/10.**AK
```

```
      IF(DEG.GT.89.0.AND.DEG.LT.91.0)AX=Y/10.**AK
      IF(DEG.GT.179.0.AND.DEG.LT.181.0)AX=X/10.**AK
      XSC=SCALE/10.**AK
      XDR=AX-XSC
      CALL DRAWR(SCALE*J,0.)
      CALL MOVER(-SCALE*J,0.)
      CALL PLCHAR(25,48)
      J1=J+1
      IF(DEG.GT.-1.0.AND.DEG.LT.1.0)X=X-SCALE
      IF(DEG.GT.89.0.AND.DEG.LT.91.0)Y=Y-SCALE
      IF(DEG.GT.179.0.AND.DEG.LT.181.0)X=X+SCALE
      DO 100 JI=1,J1
      REF(1)=NUM(11)
      IF(DEG.GT.-1.0.AND.DEG.LT.1.0)X=X+SCALE
      IF(DEG.GT.89.0.AND.DEG.LT.91.0)Y=Y+SCALE
      IF(DEG.GT.179.0.AND.DEG.LT.181.0)X=X-SCALE
      CALL MOVEA(X,Y)
      CALL DRAWR(0.0,A)
      CALL MOVER(-0.2*SCALE,A+AA)
      XDR=XDR+XSC
      IF(XDR.LT.0)REF(1)=NUM(12)
      IXA=(ABS(XDR)+0.05)
      IF(XDR.EQ.0.0)IX=0
      IF(XDR.NE.0.0)IX=IXA*(XDR/ABS(XDR))
      IF(IREF.EQ.0)REF(2)=NUM(IXA+1)
      IXA=(ABS((XDR-IX)*10)+0.5)
      IF(IREF.EQ.0)REF(4)=NUM(IXA+1)
      IF(IREF.EQ.1)CALL REFER(REF,XDR,AK,NUM)
      CALL A1OUT(4,REF)
100   CONTINUE
      CALL MOVEA(XA,YA)
      CALL MOVER(0.,A*4.)
      CALL A1OUT(ITLEN,TITLE)
      IF(IREF.EQ.0)CALL A1OUT(5,RAF)
      CALL RROTAT(0.)
      CALL LINROT(0.)
      RETURN
      END
      SUBROUTINE REFER(REF,XDR,AK,NUM)
      INTEGER REF(4),NUM(13)
      X=ABS(XDR)*10.**AK+0.5
      I=X/100
      REF(2)=NUM(I+1)
      IF(I.EQ.0)REF(2)=REF(1)
      IF(I.EQ.0)REF(1)=NUM(13)
      X=X-100.*I
      I=X/10
```

```
REF(3)=NUM(I+1)
X=X-10.*I
I=X
REF(4)=NUM(I+1)
RETURN
END
```

E.4 Programme SAMPLER

This programme is used to sample measured data from the tape recorder at a rate of up to 200 hz. Up to 14 channels can be sampled almost simultaneously.

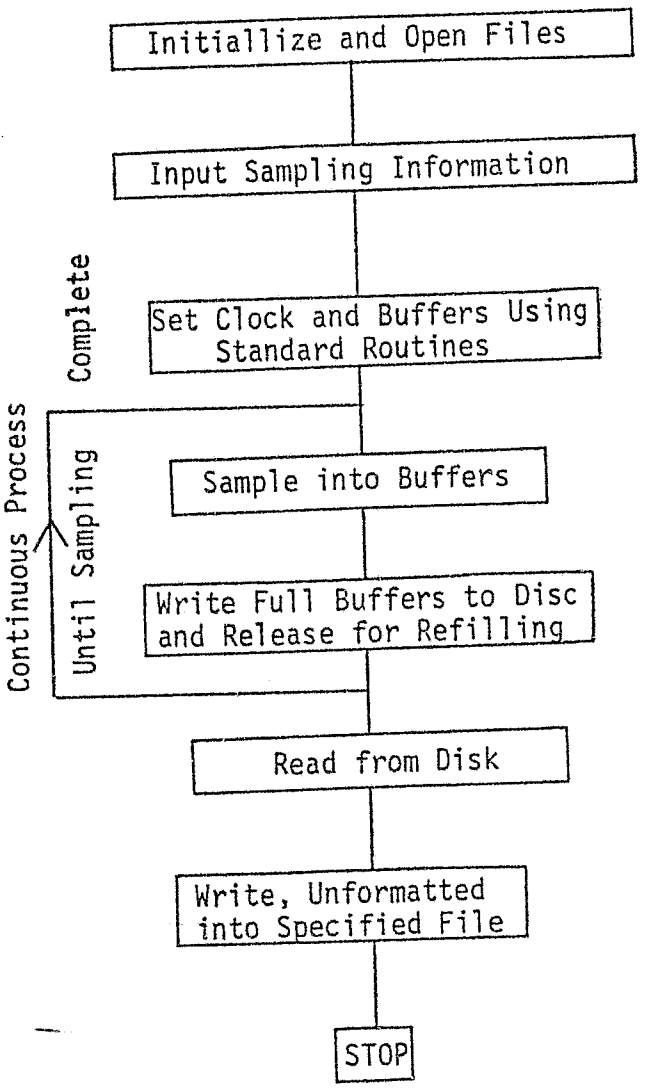
The input for this programme is interactive and analogue signals.

(i) Data filename. This is a six letter filename which will be used for all analysis or this data. (AA)

ii) Number of samples per channel and number of channels. (ISAMP, NCHN)

iii) Sampling rate. This is given in hz. (RATE) Sampling starts immediately this rate is accepted and continues for the specified number of samples.

Flowchart for SAMPLER



PROGRAMME SAMPLER : Listing

```
      IMPLICIT INTEGER (A-W)
      INTEGER*4 ISAMP
      REAL*4 ADWELL,RATE,DWELL
      DIMENSION BUF(1024,8), IBUF (40), IOSB(2)
      LOGICAL*1 AA(15),BB(5),CC(4)
      EQUIVALENCE (IBUF(1),IOSB(1))
C
C     INITIALIZE THE IBUF ARRAY FOR THE A/D SWEEP
C
      CALL SETIBF (IBUF,IND, , BUF(1,1), BUF(1,2), BUF(1,3),
     *  BUF(1,4), BUF(1,5), BUF(1,6), BUF(1,7), BUF(1,8))
     @ INITIALSIZE=2500,TYPE='UNKNOWN',FORM='UNFORMATTED')
      TYPE 1
    1 FORMAT(' DATA FILENAME ?')
      READ(5,2)(AA(I),I=5,10)
    2 FORMAT(6A1)
      DATA BB /'4',',',',','D','A','T'/
      DATA CC /'D','L','1',':'/
      DO 3 I=1,5
    3 AA(I+10)=BB(I)
      DO 7 I=1,4
    7 AA(I)=CC(I)
      TYPE 4
    4 FORMAT(' NO OF SAMPLES PER CHANNEL AND NO OF CHANNELS ?')
      ACCEPT *,ISAMP,NCHN
      NBUF=FLOAT(ISAMP)/1024.*FLOAT(NCHN)+1.
C
C     SET THE CLOCK RATE AND PRESET FOR THE SWEEP
C
      TYPE 5
    5 FORMAT(' SAMPLING RATE ?')
      ACCEPT *,RATE
      DWELL=1./RATE
      CALL XRATE(DWELL,IRATE,IPRSET,0)
      CALL CLOCKA (IRATE, IPRSET,IND)
      ADWELL=XRATE(DWELL,IRATE,IPRSET,0)
      WRITE(5,6)ADWELL,IRATE,IPRSET
    6 FORMAT(5X,'ACTUAL SAMPLING TIME',F13.5,' secs',2I8)
C
C     THIS IS INPUT,SO RELEASE ALL BUFFERS TO SERVICE
C     ROUTINE
C
      CALL RLSBUF (IBUF,IND, 0,1,2,3,4,5,6,7)
C
C     START THE SWEEP.USE 1024 WORD BUFFERS, SAMPLE FOREVER
```

```
C       EVENT FLAG 30, NCHN CHANNELS (0).
C
        CALL ADSWP (IBUF, 1024, -1, 0, IPRSET,
     * 30, 0, 0, NCHN)
C
C       HERE WE COULD CHECK THE I/O STATUS BLOCK TO ENSURE
C       THAT THE SWEEP IS ACTUALLY RUNNING
C
        WRITE (5, 910) IOSB(1)

        IBFCNT=0
C
C       THIS IS THE TOP OF THE DATA PROCESSING LOOP.WE
C       WAIT FOR A BUFFER TO BE COMPLETED,AND THEN WRITE
C       THE BUFFER INTO A DATA FILE - UNFORMATTED
C
 10     IBUFNO = IWTBUF(IBUF, 30)+1
C
C       IWTBUF WILL RETURN A POSITIVE NUMBER
C       AS LONG AS THERE IS A BUFFER OF DATA AVAILABLE
C       IF RESULT IS -1,WE PROBABLY HAD DATA OVERRUN, SO STOP
C
        IF (IBUFNO .LE. 0) GOTO 100
        IBFCNT=IBFCNT+1
        WRITE (1) (BUF(I,IBUFNO), I=1,1024)
        IF(IBFCNT.GE.NBUF)GOTO 200
C
C       RELEASE BUFFER FOR SERVICE ROUTINE TO REFILL
C
        CALL    RLSBUF(IBUF,IND,IBUFNO-1)
        IF (IND .NE. 1) GOTO 400
        GOTO 10
100     WRITE (5, 904)
        WRITE(5,900)IOSB(1),IBFCNT
        GOTO 500
200     CALL STPSWP(IBUF,0,IND)
        IF(IND.NE.1)GOTO 300
        WRITE(5,901)
        WRITE(5,900)IOSB(1),IBFCNT
        GOTO 500
300     WRITE(5,902)
        WRITE(5,900)IOSB(1),IBFCNT
        GOTO 500
400     WRITE (5, 903) IBUFNO-1, IBFCNT
500     CLOSE(UNIT=1)
        CALL ASSIGN(1,AA,15)
        CALL ASSIGN(2,'DL1:[2,4]SAMPLER.DAT;1',22)
```

```
510     READ(2,END=600)(BUF(I,1),I=1,1024)
        WRITE(1)(BUF(I,1),I=1,1024)
        GOTO 510
600     WRITE(1)(BUF(I,1),I=1,1024)
        CALL CLOSE(1)
        CALL CLOSE(2)
900     FORMAT(5X,'OPERATION COMPLETE WITH STATUS',I4,'  AFTER WRITING',
    @I7,' BUFFERS')
901     FORMAT(5X,'OPERATION COMPLETED SUCCESSFULLY')
902     FORMAT(5X,'SWEEP STOP ERROR')
903     FORMAT(5X,'BUFFER ',I2,' NOT RELEASED AFTER FILLING',I7,' BUFFE'
    @,'RS')
904     FORMAT(5X,'NO MORE BUFFERS TO BE EMPTIED')
910     FORMAT (' SWEEP STARTED WITH STATUS =', I4)
930     FORMAT (32I4)
        END
```

E.5 Programme CALIB

This programme reads the unformatted output from SAMPLER, applies the correct scale factor and zero, and writes, in engineering units into a properly formatted file.

The output is initially interactive, requesting the following:

(i) Number of files to be converted. This is simply the number of data files created in sampling one set of tests. (IFIL)

(ii) Heading. This is the first line of all subsequent files to identify them, and is used on all outputs. (HEAD)

(iii) Data filename. This is the basic filename used on all analysis. (A)

(iv) Number of channels, samples each, buntons, time step and velocity. These are the number of channels sampled, the number of samples in each channel, the number of buntons passed in the section sampled, the time step between samples, and the hoisting velocity (NCHN, ISAMP, IBUNT, DWELL, VEL)

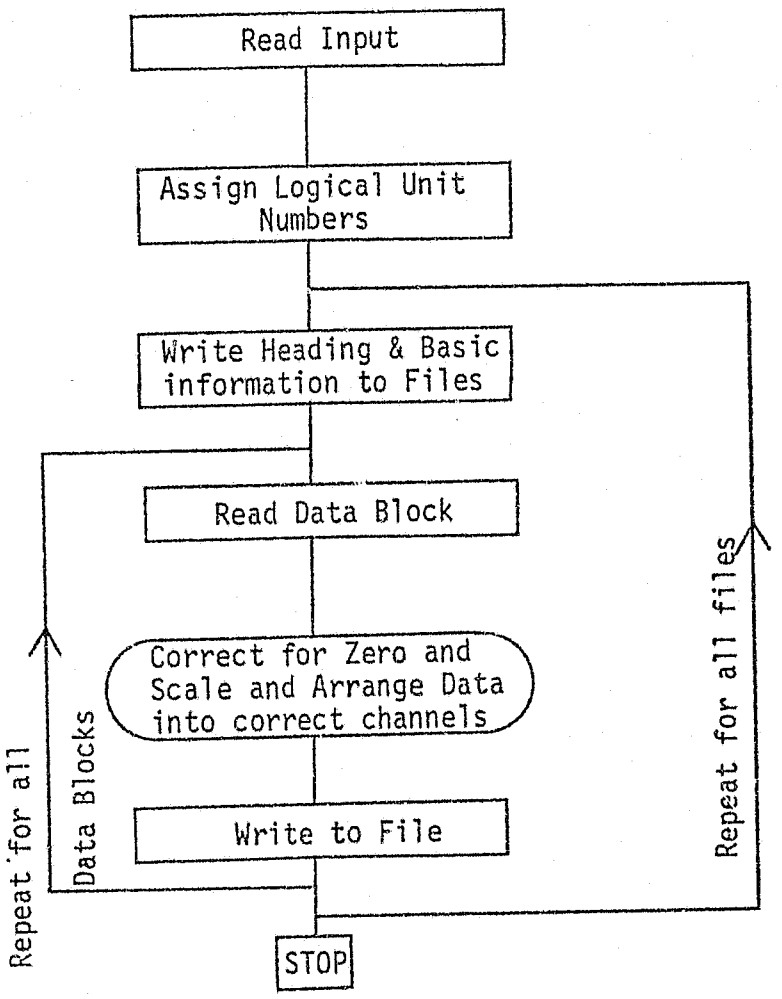
(v) Zero values and scale for each channel. These must be given in A/D convertor units i.e.:

4096 = +5 volts
2048 = 0 volts
0 = -5 volts

The values used here can be calculated, or obtained from the programme INIT.

The programme then reads the output file from SAMPLER, scales it and corrects for zero and then writes two new datafiles in the same format as the DISCS output files.

Flowchart for CALIB



PROGRAMME CALIB : Listing

```
      DIMENSION DATAA(15),DATAB(15),IDAT(15),JDAT(1100),ZERO(14)
      DIMENSION SCALE(14)
      INTEGER*4 ISAMP,HEAD(20,20),JSAMP
      LOGICAL*1 A(20,15),B(15),P(15),D(5),E(5),G(5),H(15),AZ(4)
      TYPE 15
15    FORMAT(' NUMBER OF FILES TO CONVERT ?')
      ACCEPT *,IFIL
      DO 16 JI=1,IFIL
      TYPE 13
13    FORMAT(' ENTER HEADING (80 CHARS)')
      READ(5,14)(HEAD(JI,IH),IH=1,20)
14    FORMAT(20A4)
      TYPE 1
1     FORMAT(' DATA FILENAME ?')
16    READ(5,2)(A(JI,I),I=5,10)
2     FORMAT(6A1)
      DATA AZ /'D','L','1',':'/
      DATA D /'4','.','D','A','T'/
      DATA E /'2','.','D','A','T'/
      DATA G /'3','.','D','A','T'/
      DO 25 KL=1,4
      B(KL)=AZ(KL)
      H(KL)=AZ(KL)
25    P(KL)=AZ(KL)
      TYPE 4
4     FORMAT(' NO: CHANNELS,SAMPLES EACH,BUNTONS & TIME STEP,VEL ?')
      ACCEPT *,NCHN,ISAMP,IBUNT,DWELL,VEL
      NCHN1=NCHN+1
      TYPE 7
7     FORMAT(' ZERO VALUES AND SCALES FOR EACH CHANNEL ?')
      DO 8 I=1,NCHN
8     ACCEPT *,ZERO(I),SCALE(I)
      JI=1
17    DO 3 I=5,10
      B(I)=A(JI,I)
      H(I)=A(JI,I)
      P(I)=A(JI,I)
      IF(I.EQ.10)GOTO 3
      P(I+6)=D(I-4)
      B(I+6)=E(I-4)
      H(I+6)=G(I-4)
3     CONTINUE
      CALL ASSIGN(1,P,15)
      CALL ASSIGN(2,B,15)
      CALL ASSIGN(3,H,15)
      WRITE(2,14)(HEAD(JI,IH),IH=1,20)
```

```
      WRITE(3,14)(HEAD(JI,IH),IH=1,20)
      WRITE(3,1400)DWELL,VEL,IBUNT
      DATAA(NCHN1)=0.0
      IA=1
      IB=1024
      JSAMP=1
100   READ(1,ERR=200)(JDAT(I),I=IA,IB)
      ICHN=IB/NCHN
      DO 10 I=1,ICHN
      K=(I-1)*NCHN
      DO 9 J=1,NCHN
      ADAT=(FLT16(JDAT(K+J))-ZERO(J))/SCALE(J)
9     DATAA(J)=ADAT
      WRITE(2,1100)(DATAA(II),II=1,NCHN1)
      DATAA(NCHN1)=DATAA(NCHN1)+DWELL
      JSAMP=JSAMP+1
      IF(JSAMP.GT.ISAMP)GOTO 110
10    CONTINUE
      IC=ICHN*NCHN
      IA=IB-IC
      DO 11 I=1,IA
11    JDAT(I)=JDAT(IC+I)
      IA=IA+1
      IB=IA+1023
      GOTO 100
110   CALL CLOSE(1)
      CALL CLOSE(2)
      JSAMP=JSAMP-1
      WRITE(3,1500)JSAMP
      CALL CLOSE(3)
      JI=JI+1
      IF(JI.LE.IFIL)GOTO 17
      STOP
200   WRITE(5,1200)JSAMP
      GOTO 110
1000  FORMAT(32I4)
1100  FORMAT(<NCHN1>F11.3)
1200  FORMAT(5X,'READ ERROR AT SAMPLE NO ',I7)
1400  FORMAT(F12.8,F12.4,I6)
1500  FORMAT(I7)
      END
```

E.6 Programme INIT

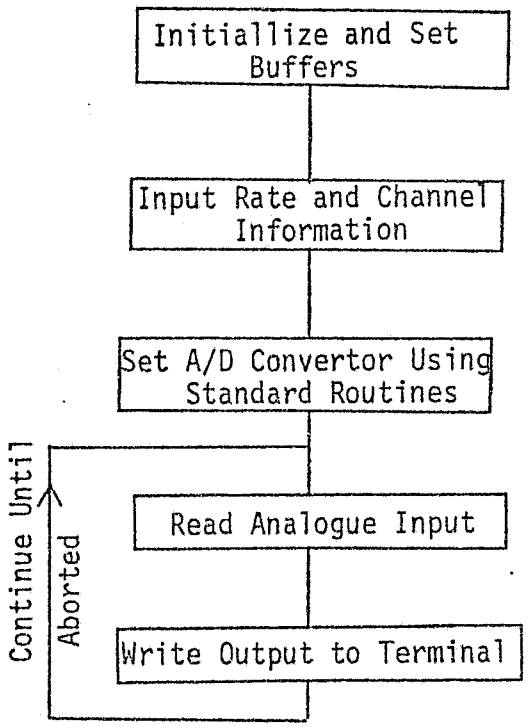
This programme samples slowly, any specified channels. It is used to calculate zero correction and scale factors for sampled data.

The input is:

(i) Sampling time and number of channels. The sampling time should be 0,3 to 0,7 seconds usually. (ZDWELL, NCHN)

The A/D convertor then reads the specified channels and the values are displayed on the terminal for as long as desired.

Flowchart for INIT



PROGRAMME INIT : Listing

```
      IMPLICIT INTEGER (A-W)
      DIMENSION BUF(308,8), IBUF (40), IOSB(2)
      EQUIVALENCE (IBUF(1),IOSB(1))
C
C     INITI  ZE THE IBUF ARRAY FOR THE A/D SWEEP
C
      CALL SETIBF (IBUF,IND, , BUF(1,1), BUF(1,2), BUF(1,3),
     * BUF(1,4), BUF(1,5), BUF(1,6), BUF(1,7), BUF(1,8))
      WRITE (5, 900)
      READ (5, *) ZDWELL,NCHN
      IF(NCHN.EQ. 1)JJB=22
      IF(NCHN.EQ. 2)JJB=44
      IF(NCHN.EQ. 3)JJB=66
      IF(NCHN.EQ. 4)JJB=88
      IF(NCHN.EQ. 5)JJB=110
      IF(NCHN.EQ. 6)JJB=132
      IF(NCHN.EQ. 7)JJB=154
      IF(NCHN.EQ. 8)JJB=176
      IF(NCHN.EQ. 9)JJB=198
      IF(NCHN.EQ.10)JJB=220
      IF(NCHN.EQ.11)JJB=242
      IF(NCHN.EQ.12)JJB=264
      IF(NCHN.EQ.13)JJB=286
      IF(NCHN.EQ.14)JJB=308
      CALL XRATE(ZDWELL,IRATE,IPRSET,0)
C
C     SET THE CLOCK RATE AND PRESET FOR THE SWEEP
C
      CALL CLOCKA (IRATE, IPRSET,IND)
C
C     THIS IS INPUT,SO RELEASE ALL BUFFERS TO SERVICE
C     ROUTINE
C
      CALL RLSBUF (IBUF,IND, 0,1,2,3,4,5,6,7)
C
C     START THE SWEEP,USE SPECIFIED SIZE BUFFERS, SAMPLE
C     FOREVER, EVENT FLAG 30, SPECIFIED CHANNELS (0).
C
      CALL ADSWP (IBUF, JJB, -1, 0, IPRSET,
     * 30, 0, 0, NCHN)
C
C     HERE WE COULD CHECK THE I/O STATUS BLOCK TO ENSURE
C     THAT THE SWEEP IS ACTUALLY RUNNING
C
      WRITE (5, 910) IOSB(1)
```

```
      IBFCNT=0
C
C     THIS IS THE TOP OF THE DATA PROCESSING LOOP.WE
C     WAIT FOR A BUFFER TO BE COMPLETED,AND THEN DUMP
C     THE BUFFER TO THE SCREEN
C
 10   IBUFNO = IWTBUF(IBUF, 30)+1
C
C     IWTBUF WILL RETURN A POSITIVE NUMBER
C     AS LONG AS THERE IS A BUFFER OF DATA AVAILABLE
C     IF RESULT IS -1,WE PROBABLY HAD DATA OVERRUN, SO STOP
C
      IF (IBUFNO .LE. 0) STOP
      IBFCNT=IBFCNT+1
      WRITE (5,920) IBFCNT
      IF(NCHN.EQ. 1)WRITE(5,931)(BUF(I,IBUFNO),I=1,JJB)
      IF(NCHN.EQ. 2)WRITE(5,932)(BUF(I,IBUFNO),I=1,JJB)
      IF(NCHN.EQ. 3)WRITE(5,933)(BUF(I,IBUFNO),I=1,JJB)
      IF(NCHN.EQ. 4)WRITE(5,934)(BUF(I,IBUFNO),I=1,JJB)
      IF(NCHN.EQ. 5)WRITE(5,935)(BUF(I,IBUFNO),I=1,JJB)
      IF(NCHN.EQ. 6)WRITE(5,936)(BUF(I,IBUFNO),I=1,JJB)
      IF(NCHN.EQ. 7)WRITE(5,937)(BUF(I,IBUFNO),I=1,JJB)
      IF(NCHN.EQ. 8)WRITE(5,938)(BUF(I,IBUFNO),I=1,JJB)
      IF(NCHN.EQ. 9)WRITE(5,939)(BUF(I,IBUFNO),I=1,JJB)
      IF(NCHN.EQ.10)WRITE(5,940)(BUF(I,IBUFNO),I=1,JJB)
      IF(NCHN.EQ.11)WRITE(5,941)(BUF(I,IBUFNO),I=1,JJB)
      IF(NCHN.EQ.12)WRITE(5,942)(BUF(I,IBUFNO),I=1,JJB)
      IF(NCHN.EQ.13)WRITE(5,943)(BUF(I,IBUFNO),I=1,JJB)
      IF(NCHN.EQ.14)WRITE(5,944)(BUF(I,IBUFNO),I=1,JJB)
C
C     RELEASE BUFFER FOR SERVICE ROUTINE TO REFILL
C
      CALL    RLSBUF(IBUF,IND,IBUFNO-1)
      GOTO 10
900   FORMAT (' ENTER SAMPLING TIME, NO OF CHANNELS:', $)
910   FORMAT (' STATUS IS =', I4)
920   FORMAT (' DUMP OF BUFFER NUMBER ',I5,/)
931   FORMAT(1X,1I7)
932   FORMAT(1X,2I7)
933   FORMAT(1X,3I7)
934   FORMAT(1X,4I7)
935   FORMAT(1X,5I7)
936   FORMAT(1X,6I7)
937   FORMAT(1X,7I7)
938   FORMAT(1X,8I7)
939   FORMAT(1X,9I7)
940   FORMAT(1X,10I7)
```

```
941     FORMAT(1X,11I5)
942     FORMAT(1X,12I5)
943     FORMAT(1X,13I5)
944     FORMAT(1X,14I5)
        END
```

E.7 Programme DYNMAG

This programme calculates areas of high dynamic magnification, in accordance with both the CSIR and German methods mentioned in the text of this report.

The input is all interactive.

(i) Enter rotational inertia, mass, and (wheel) spring stiffnes. (RI, AM, SS)

(ii) Enter conveyance length, i.e. the overall length between wheels. (Z)

(iii) Enter the guide inertia and bunton stiffness. (GI, BS)

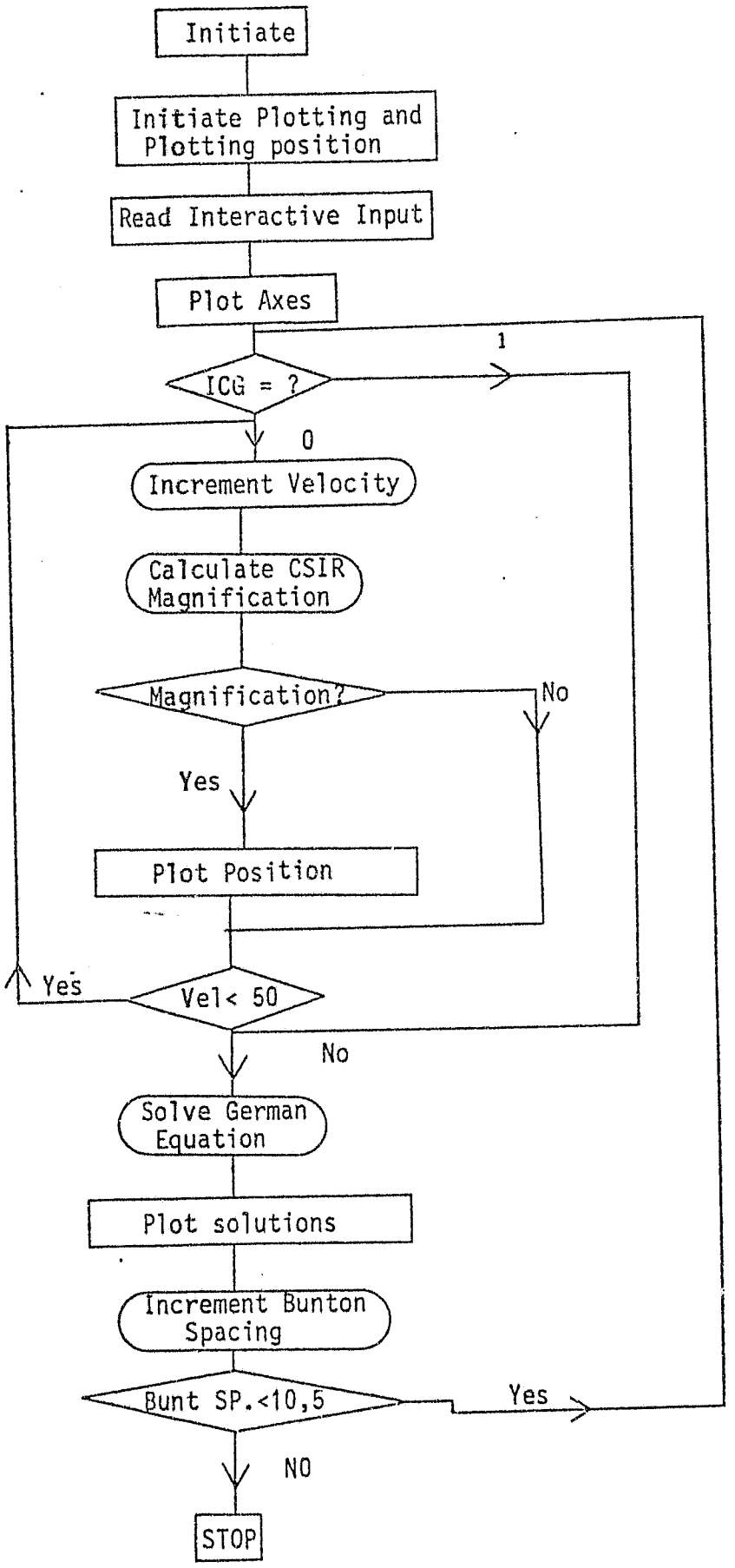
(iv) Enter the distance from the centre of gravity to the bottom of the conveyance. (AL)

(v) Enter damping ratio as percentage. This should usually be entered as 1 or 2. (CS)

(vi) Enter '1' for CSIR and German, or '0' for German only. This simply refers to the method by which the areas of magnification are calculated. (ICG)

The output from this programme is in the form of a graph of hoisting velocity against bunton spacing, on which the areas of dynamic magnification are plotted.

Flowchart for DYNMAG



PROGRAMME DYNMAG : Listing

```
C   THIS PROGRAMME CALCULATES DYNAMIC MAGNIFICATION IN
C   ACCORDANCE WITH CSIR REPORT MEG 706.
C
      DIMENSION RES(4),VEL(4)
      REAL K1,K2,K3,K4,LE
      REAL*8 CONS1,CONS2,CONS3,CONS4,FUNC
      INTEGER IPL(2)
      DATA IPL/'*','o'/
      CALL ASSIGN(4,'PL:',3)
      CALL PLINIT(1)
      CALL PLON
      CALL DWINDO(-10.5,.5,-3.,52.)
      CALL TWINDO(150,1850,150,2350)
      CALL MOVEA(0.,0.)
      TYPE 1
1     FORMAT(' ENTER ROT INERTIA, MASS, AND SPRING STIFF')
      ACCEPT *,RI,AM,SS
      THETA=RI
      AMK=AM
      TYPE 2
2     FORMAT(' ENTER CONV LENGTH')
      ACCEPT *,Z
      H=Z
      A=0.5
      Z=Z/2.
      TYPE 3
3     FORMAT(' ENTER GUIDE INERTIA AND BUNTON STIFFNESS')
      ACCEPT *,GI,BS
      TYPE 7
7     FORMAT(' ENTER DISTANCE FROM C.G.TO BOTTOM')
      ACCEPT *,AL
      TYPE 8
8     FORMAT(' ENTER DAMPING RATIO AS %')
      ACCEPT *,CS
      PX=SQRT(SS/AM)*2.
      ROE=SQRT(RI/AM)
      TYPE 6
6     FORMAT(' ENTER `1` FOR CSIR & GERMAN , `0` FOR GERMAN ONLY')
      ACCEPT *,ICG
      CALL AXIS(0.,0.,90.,'        V E L   ( m / s ) ',13,10.,.2,5)
      CALL AXIS(0.,0.,180.,'  B U N T   S P A C I N G ',13,-2.,.5,5)
      CALL MOVEA(0.,50.)
      CALL DRAWA(-10.,50.)
      CALL DRAWA(-10.,0.)
5     V=0.
      LE=A
```

```
      IF(ICG.EQ.0)GOTO 20
      IF(Z.LT.A)ALPHA=6.283*(2.*Z-A)/A
      IF(Z.GE.A.AND.Z.LT.1.5*A)ALPHA=6.283*(2.*Z-2.*A)/A
      IF(Z.GE.1.5*A.AND.Z.LT.2.0*A)ALPHA=6.283*(2.*Z-3.*A)/A
      IF(Z.GE.2.0*A.AND.Z.LT.2.5*A)ALPHA=6.283*(2.*Z-4.*A)/A
      IF(Z.GE.2.5*A.AND.Z.LT.3.0*A)ALPHA=6.283*(2.*Z-5.*A)/A
      IF(Z.GE.3.0*A.AND.Z.LT.3.5*A)ALPHA=6.283*(2.*Z-6.*A)/A
      IF(Z.GE.3.5*A.AND.Z.LT.4.0*A)ALPHA=6.283*(2.*Z-7.*A)/A
4     V=V+1.0
      AOMEGA=6.283*V/A
      ETA=AOMEGA/PX
      BBB=Z**2./ROE**2.*SQRT(2.*(1.-COS(ALPHA)))/2./(Z**2./ROE**2.-ETA
     @**2.)
      AAA=SQRT(2.*(1.+COS(ALPHA)))/2./(1.-ETA**2.)
      FORCE=SQRT(AAA**2.+BBB**2.-2.*AAA*COS(ALPHA/2.)-2.*BBB*SIN(
     @ALPHA/2.)+1.)
      IF(FORCE.LT.4.)GOTO 19
      CALL FLCHAR(20,30)
      CALL MOVEA(-A,V)
      CALL A1OUT(1,IFL(1))
19    IF(V.LT.50.)GOTO 4
C
C   THIS PROGRAMME CALCULATES INSTABILITY FOLLOWING THE GERMAN REPORT
C   BY REINKE
C
20    CC=162.*208.*GI/(3.*LE)**3.
      BS1=1./(CL/BS+5.)
      BS2=BS1*7./3./(CC/BS+1./3.)
      GK=CC/(2.667-12.555*BS1-0.111*BS2)
      CENS=CC/(3.375-16.531*BS1)
      GK=GK*SS/(GK+SS)
      CENS=CENS*SS/(CENS+SS)
      AL0=GK+CENS
      AL1=0.5*(GK-CENS)
      A0=AL0
      A1=AL1*(1.+COS(6.2832*H/LE))
      AM0=AL0/2.*(H-2.*AL)
      AM1=AL1*(H-AL*(1.+COS(6.2832*H/LE)))
      AN1=-AL1*H*SIN(6.2832*H/LE)
      Q0=AL0/2.*((H-AL)**2.+AL**2.)
      Q1=AL1*((H-AL)**2.+AL**2.*COS(6.2832*H/LE))
      W01=SQRT(A0/AMK)
      W02=SQRT(Q0/THETA)
      RR=CS/100.*W01*AMK
      R1=4.*RR/AMK
      R2=2.*RR*((H-AL)**2.+AL**2.)/THETA
      C0=A0/AMK+A1/2./AMK
```

```
      C1=A0/AMK-A1/2./AMK
      C2=Q0/THETA+Q1/2./THETA
      C3=Q0/THETA-Q1/2./THETA
      K1=AM0/AMK+AM1/2./AMK
      K2=AM0/AMK-AM1/2./AMK
      K3=AM0/THETA+AM1/2./THETA
      K4=AM0/THETA-AM1/2./THETA
      BB=AN1/2./AMK
      AA=AN1/2./THETA
      PHI=0.
      J=1
      CONS1=C0+C1+C2+C3-R1**2.-R2**2.
      CONS2=C1*C0+C2*C3-2.*AA*BB-K1*K3-K2*K4+(R1**2.-C1-C0)*(R2**2.-C2
     @-C3)
      CONS3=C2*C3*(C0+C1)+C0*C1*(C2+C3)-AA*BB*(C0+C1+C2+C3)-R1*R2*(K1*
     @K4+K2*K3)-R1**2.*C2*C3-R2**2.*C0*C1-K1*K3*(C1+C3)-K2*K4*(C0+C2)+2.
     @*R1*R2*AA*BB
      CONS4=-K1*K2*K3*K4+AA*BB*(C1*C2+C0*C3)-C0*C1*C2*C3-AA**2.*BB**2.
     @+AA**2.*K1*K2+BB**2.*K3*K4+K1*K3*C1*C3+K2*K4*C0*C2
100   FUNC=-PHI**8.+PHI**6.*CONS1-PHI**4.*CONS2+PHI**2.*CONS3+CONS4
      IF(PHI.EQ.0..AND.FUNC.LT.0.)I=1
      IF(PHI.EQ.0..AND.FUNC.GE.0.)I=2
      IF(I.EQ.1.AND.FUNC.GE.0.)GOTO 110
      IF(I.EQ.2.AND.FUNC.LT.0.)GOTO 110
      IF(PHI.GE.50.)GOTO 120
      PHI=PHI+0.1
      GOTO 100
110   RES(J)=PHI
      IF(J.EQ.4)GOTO 120
      J=J+1
      I=2/I
      PHI=PHI+0.1
      GOTO 100
120   DO 130 J=1,4
      VEL(J)=RES(J)*LE/3.1416
      IF(VEL(J).EQ.0.0)GOTO 130
      CALL MOVEA(-LE,VEL(J))
      CALL A1OUT(1,IPL(2))
      RES(J)=0.0
130   CONTINUE
      A=A+.5
      IF(A.LT.10.5)GOTO 5
      STOP
      END
```

E.8 Programme TF

This programme calculates a transfer function between any two calculated power spectra. The interactive input is:-

(i) Filename

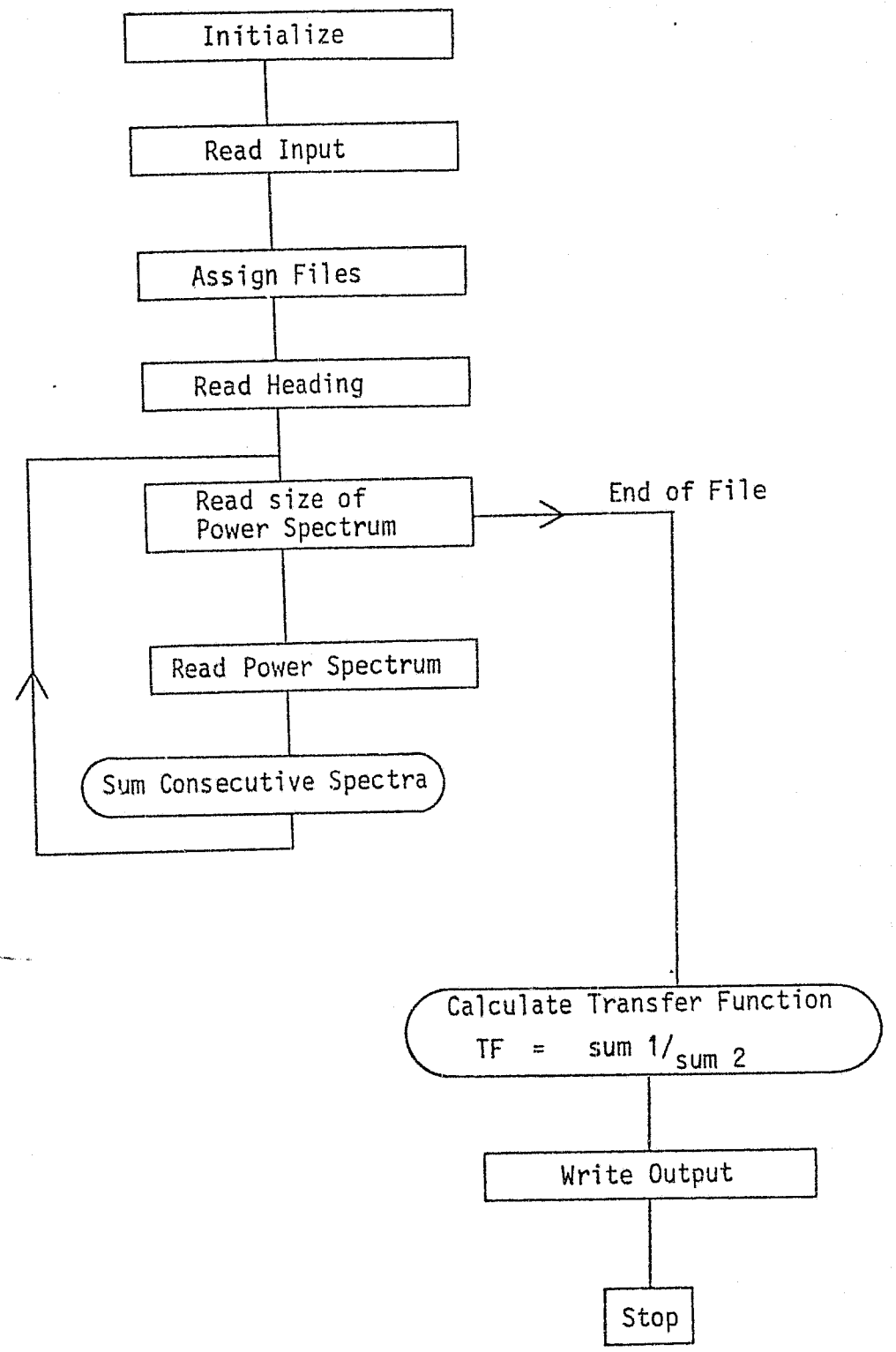
(ii) Transfer function between versions 'N1' and 'N2'. Each power spectrum with the same filename, i.e. from the same run, is a new version of the same filename, versions being in octal.

i.e.	Channel	1	=	version 1
		2	=	2
		3	=	3
		4	=	4
		5	=	5
		6	=	6
		7	=	7
		8	=	10
		9	=	11
		10	=	12
		11	=	13

etc.

The specified power spectra are then read and the first one is divided by the second and the square root of the solution gives the result, which is printed out.

Flowchart of programme TF



LISTING OF PROGRAMME TF

```
C  PROGRAMME TF
C  THIS PROGRAMME CALCULATES THE TRANSFER FUNCTION BETWEEN
C    ANY TWO MEASURED FUNCTIONS .
         LOGICAL*1 A(18),B(18),HEAD(80)
         DIMENSION X(512),XX(512),F(512)
         TYPE 1
1        FORMAT(' FILENAME')
         READ(5,2)(A(I),I=5,10)
2        FORMAT(6A1)
         DATA A(1),A(2),A(3),A(4)/'D','L','1',':'/
         DATA A(11),A(12),A(13),A(14),A(15),A(16)/'5','.','D','A','T',
     @';'/
         TYPE 3
3        FORMAT(' TRANSFER FUNCTION BETWEEN VERSIONS `N1` & `N2` (SEPARAT
     @E LINES)')
         READ(5,4)(A(I),I=17,18)
         READ(5,4)(B(I),I=17,18)
4        FORMAT(2A1)
14       FORMAT(80A1)
         DO 5 I=1,16
5        B(I)=A(I)
         CALL ASSIGN(1,A,18)
         CALL ASSIGN(2,B,18)
C
C  READ INPUT
C
         READ(1,14)(HEAD(I),I=1,80)
         READ(2,14)(HEAD(I),I=1,80)
         L=0
6        READ(1,7,END=8)J
         READ(2,7,END=8)J
         DO 9 I=1,J
         READ(1,10)DUM,Z,F(I)
         IF(F(I).GE.25.0.AND.L.EQ.0)L=I/4
         READ(2,10)DUM,Y,DOM
         XX(I)=Y+XX(I)
9        X(I)=Z+X(I)
7        FORMAT(5X,I4)
10       FORMAT(5X,3F10.6)
         GOTO 6
C
C  CALCULATE TRANSFER FUNCTION
C
8        DO 11 I=1,J
         IF(XX(I).EQ.0.)XX(I)=0.0001
11       X(I)=SQRT(X(I)/XX(I))
```

```
      WRITE(6,15)(HEAD(I),I=1,80),(A(I),I=17,18),(B(I),I=17,18)
15    FORMAT(5X,80A1,/,5X,80('='),//,5X,'TRANSFER FUNCTION BETWEEN',
     @'CHANNELS ',2A1,' AND ',2A1,//,4(7X,'FREQUENCY',2X,'TR. FUNC'))
      DO 12 I=1,L
12    WRITE(6,13)F(I),X(I),F(I+L),X(I+L),F(I+2*L),X(I+2*L),F(I+3*L),
     @X(I+3*L)
13    FORMAT(4(8X,F8.3,2X,F8.5))
      STOP
      END
```

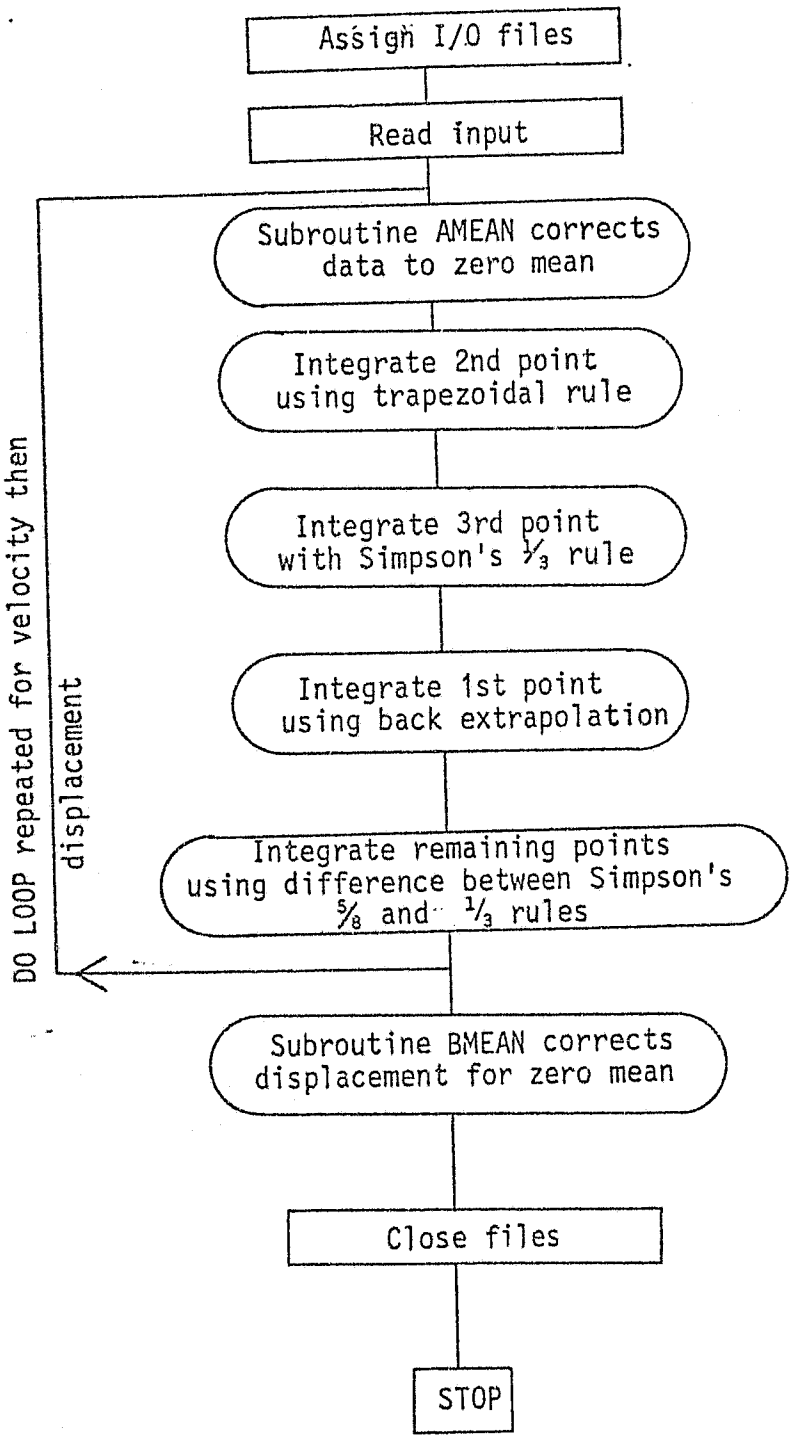
APPENDIX E.9 PROGRAMME INTEG

This programme calculates the velocity and displacement of a conveyance from an acceleration record.

The data is initially corrected to zero mean and zero linear slope, and it is then integrated to give the curve of velocity. This is again corrected to zero mean and zero linear slope and integrated to give the displacement. The output is written into a file DL1: Filename 7.DAT which can then be plotted by VELPL (which is similar to DATAPL so it is not described here).

The input to INTEG is a filename and then the output from either DISCS or CALIB.

PROGRAMME INTEG : FLOWCHART



```
C*************************************************************************
C  PROGRAMME INTEG
C  THIS PROGRAMME PERFORMS A DOUBLE INTEGRATION ON A RECORD
C  TO OBTAIN VELOCITY AND DISPLACEMENT FROM ACCELERATION
C*************************************************************************
        DIMENSION X(4,2000),Y(10)
        LOGICAL*1 IN(15),IM(15),HEAD(80),I3,I7,IP(15)
        TYPE 1
1       FORMAT(' FILENAME TO INTEGRATE')
        READ(5,2)(IN(I),I=5,10)
2       FORMAT(6A1)
        DATA IN(1),IN(2),IN(3),IN(4),IN(11),IN(12),IN(13),IN(14),IN(15)
     @ ,I3,I7 /'D','L','1',':','2','.','D','A','T','3','7'/
        DO 3 I=1,15
        IP(I)=IN(I)
3       IM(I)=IN(I)
        IM(11)=I3
        IP(11)=I7
        TYPE 4
4       FORMAT('  CHANNEL & TOTAL NO OF CHANNELS')
        ACCEPT *,ICHN,JCHN
        TYPE 6
6       FORMAT(' START & END SAMPLE NUMBERS')
        ACCEPT *,IST,IPT
        IPT=IPT-IST
        JCHN=JCHN+1
100     CALL ASSIGN(1,IN,15)
        CALL ASSIGN(2,IM,15)
        CALL ASSIGN(3,IP,15)
        READ(1,5)(HEAD(I),I=1,80)
        READ(2,5)(HEAD(I),I=1,80)
        WRITE(3,5)(HEAD(I),I=1,80)
5       FORMAT(80A1)
        READ(2,7)H,VEL,IBUNT
7       FORMAT(3X,F12.4,F12.4,I6)
        READ(2,8)IS
8       FORMAT(I7)
        IF(IPT.GT.IS)IPT=IS
        DO 11 J=1,IST
11      READ(1,9)DUM
        DO 16 J=1,IPT
        READ(1,9)(Y(I),I=1,JCHN)
        X(1,J)=Y(ICHN)
        X(4,J)=Y(JCHN)
16      CONTINUE
9       FORMAT(<JCHN>F11.3)
```

```
C
C  USE TRAPEZOIDAL RULE FOR SECOND POINT
C
      DO 10 J=2,3
      CALL AMEAN(X,IPT,J-1)
      X(J,2)=H/2.*(X((J-1),1)+X((J-1),2))
C
C  USE SIMPSON'S 1/3 RULE FOR 3RD POINT
C
      X(J,3)=H/3.*(X((J-1),1)+4.*X((J-1),2)+X((J-1),3))
C
C  USE LINEAR BACK EXTRAPOLATION FOR 1ST POINT
C
      X(J,1)=2.*X(J,2)-X(J,3)
      DO 14 L=4,IPT
C
C  USE DIFFERENCE BETWEEN SIMPSON'S 3/8 AND 1/3 RULES FOR EACH
C  SUBSEQUENT POINT.
C
14    X(J,L)=H/24.*(X((J-1),(L-3))-5.*X((J-1),(L-2))+
     @19.*X((J-1),(L-1))+9.*X((J-1),L))+X(J,(L-1))
10    CONTINUE
      IF(IPT.GT.500)CALL BMEAN(X,IPT)
      DO 15 L=1,IPT
15    WRITE(3,13)X(1,L),X(2,L),X(3,L),X(4,L)
      READ(2,2,END=101)(IN(I),I=5,10)
      CALL CLOSE(1)
      CALL CLOSE(2)
      CALL CLOSE(3)
      DO 102 I=5,10
      IM(I)=IN(I)
102   IP(I)=IN(I)
      GOTO 100
101   CALL CLOSE(2)
13    FORMAT(4F11.3)
      STOP
      END
C
C  THIS SUBROUTINE CALCULATES THE MEAN OF THE DATA
C
      SUBROUTINE AMEAN(X,IPT,J)
      REAL*8 SUM4
      DIMENSION X(4,2000)
      KPT=IPT/2
      SUM1=0.
      SUM2=0.
      DO 10 I=1,KPT
```

```
          SUM1=SUM1+X(J,I)
10        SUM2=SUM2+X(J,(IPT-I+1))
          SUM3=(SUM1+SUM2)/(2*KPT)
          SUM4=(SUM1-SUM2)/KPT/(IPT-KPT)
          DO 20 I=1,IPT
20        X(J,I)=X(J,I)-SUM3-(IPT/2-I)*SUM4
          RETURN
          END
C
C   THIS SUBROUTINE CORRECTS DISPLACEMENT FOR ZERO
C
          SUBROUTINE BMEAN(X,IPT)
          DIMENSION X(4,2000)
          KPT=IPT/500
          LPT=IPT-KPT*500
          DO 10 I=1,KPT
          SUM=0.
          DO 20 J=(I-1)*500+1,I*500
20        SUM=SUM+X(3,J)
          SUM=SUM/500
          DO 30 J=(I-1)*500+1,I*500
30        X(3,J)=X(3,J)-SUM
10        CONTINUE
          SUM=0.
          IF(LPT.EQ.0)GOTO 60
          DO 40 I=KPT*500+1,IPT
40        SUM=SUM+X(3,I)
          SUM=SUM/LPT
          DO 50 I=KPT*500+1,IPT
50        X(3,I)=X(3,I)-SUM
60        RETURN
          END
```

E.10 PROGRAMME LAYOUT

The interelation of all the programmes is shown schematically below:

PREDICTIONS

Basic input data

DISDAT

DL1:filename 1.DAT

DISCS

DL1: filename 2.DAT

DL1: filename 3.DAT

MEASUREMENTS

measurements from A/D convertor

SAMPLER

DL1: filename 4.DAT

CALIB

DL1: filename 2.DAT

DL1: filename 3.DAT

INIT

Data display for zero and calibration information

ANALYSIS

DATAPL

Plotted output of basic data.

POWER

Printer output of probability analysis

DL1: filename 8.DAT (permanent record of peak values)

FFT

DL1: filename 5.DAT

FFTPL

Plotter and Printer output of FFT

TF

Printer output of transfer funtions

CMP

DL1: filename 6.DAT

PL

Plotter output of correlations or covariances

INTEG

DL1: filename 7.DAT

VELPL

Plotter output of acceleration, velocity and displacement

APPENDIX F : TYPICAL DISCS RESULTS AND MEASUREMENTS

This appendix shows the results from one run at Deelkraal No. 1 shaft in the 21 tonne skip running empty at 10 m/s, as well as the DISCS model of the same case. It was not felt necessary to include more results, which would in any case have been far too lengthy. The results shown here represent one of eighteen runs completed at Deelkraal, which was typical of the sets of measurements obtained at each mine when tests were conducted.

```
 RUN SAMPLER
DATA FILENAME ?
DK1009
NO OF SAMPLES PER CHANNEL AND NO OF CHANNELS ?
6000 6
SAMPLING RATE ?
100.
    ACTUAL SAMPLING TIME       0.01000 secs        1  -10000
SWEEP STARTED WITH STATUS =   0
    OPERATION COMPLETED SUCCESSFULLY
    OPERATION COMPLETE WITH STATUS   0  AFTER WRITING      36 BUFFERS


 RUN CALIB
NUMBER OF FILES TO CONVERT ?
1
ENTER HEADING (80 CHARS)
DEELKRAAL 1#  21T SKIP  EMPTY  10M/S
DATA FILENAME ?
DK1009
NO. CHANNELS,SAMPLES EACH,BUNTONS & TIME STEP,VEL ?
6 6000 150 0.01 10.
ZERO VALUES AND SCALES FOR EACH CHANNEL ?
2075, -11.6
2330, -9.0
2270, 10.4
2960, 10.4
2040, 10.4
2035, 10.5\5\4
TT1  --  STOP.
```

```
 RUN DATAPL
FILENAME TO PLOT ?
DK1008
TOTAL NO OF CHANNELS & HIGHEST WHEEL LOAD CHANNEL ?
6 2
NO OF CHANNELS TO PLOT (MAX 4) ?
4
VALUE TO PLOT & NUMBER OF PLOT ON PAGE ?
1 1.
2 2
3 3.
4 4
START TIME & TIME SCALE (1/10 OF RANGE) ?
0. 1.
VERT SCALE & MIN VALUE? (SCALE=0. FOR AUTO SCALING)
10. 20.
10. 0.
10. -10.
10. -10.
TT1 --  PAUSE : WHEN PLOTTER STOPS TYPE 'RES' TO RESUME

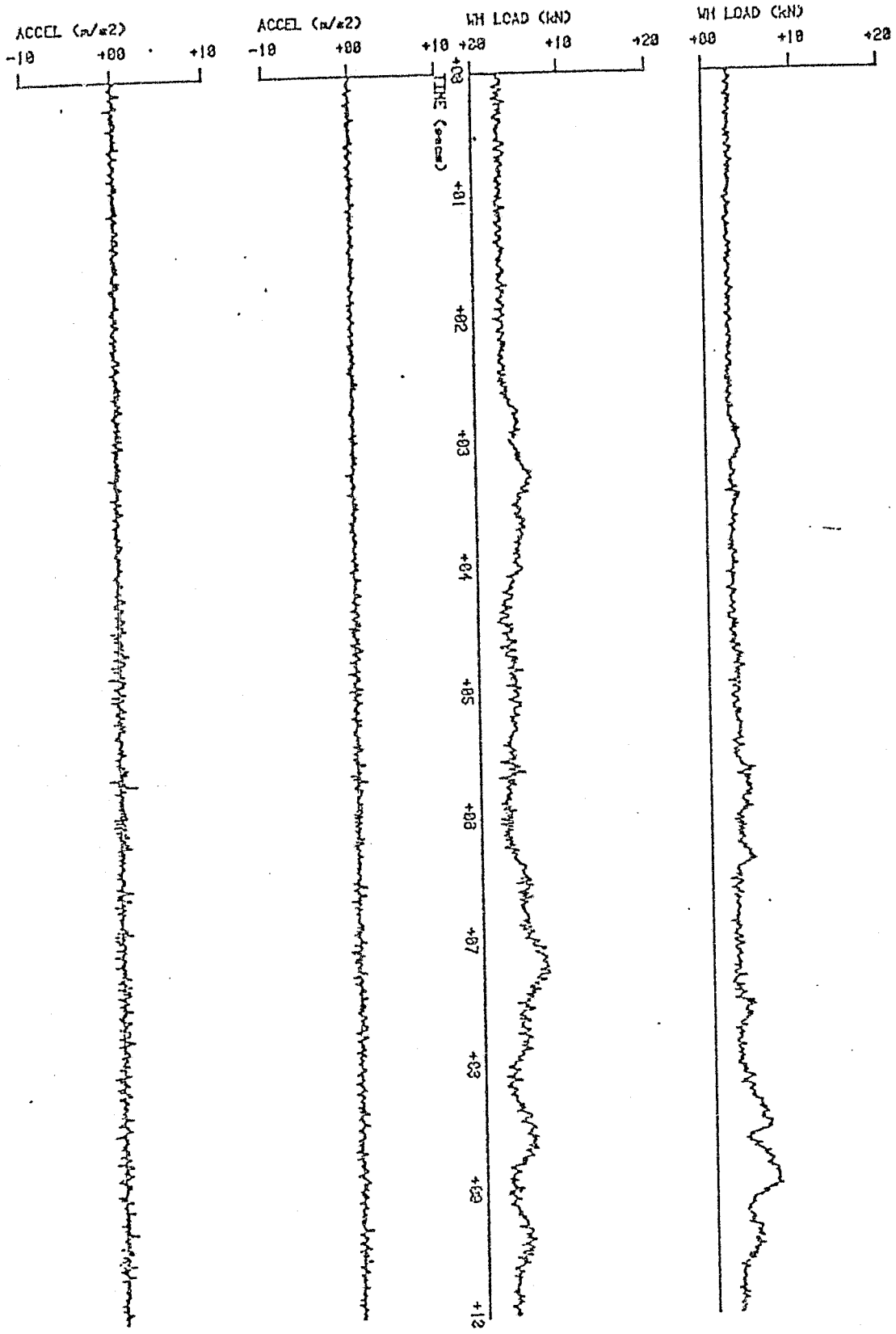
RES
>
TT1 --  PAUSE : WHEN PLOTTER STOPS TYPE 'RES' TO RESUME

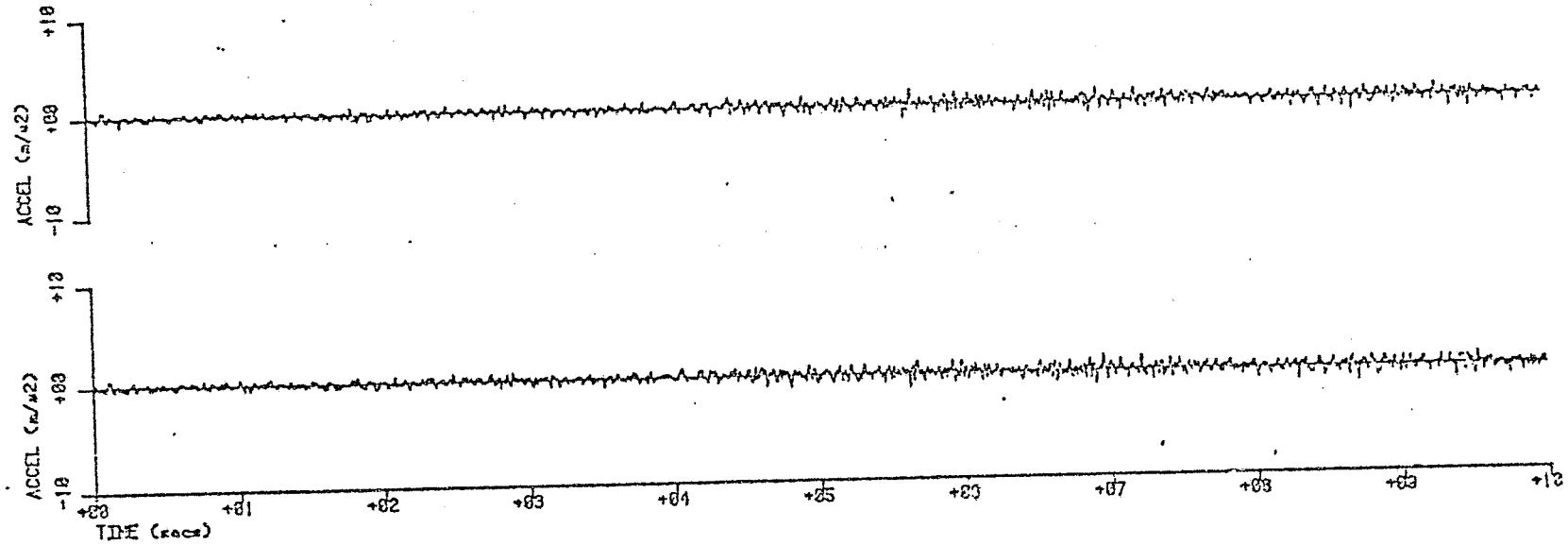
RES
>
TT1 --  PAUSE : WHEN PLOTTER STOPS TYPE 'RES' TO RESUME

RES
>
 IF MORE PLOTS ENTER 1 OTHERWISE 0
0
>RUN DATAPL
FILENAME TO PLOT ?
DK1009
TOTAL NO OF CHANNELS & HIGHEST WHEEL LOAD CHANNEL ?
6 2
NO OF CHANNELS TO PLOT (MAX 4) ?
2
VALUE TO PLOT & NUMBER OF PLOT ON PAGE ?
5. 2
6 3
START TIME & TIME SCALE (1/10 OF RANGE) ?
0. 1.
VERT SCALE & MIN VALUE? (SCALE=0. FOR AUTO SCALING)
10. -10.
10. -10.
TT1 --  PAUSE : WHEN PLOTTER STOPS TYPE 'RES' TO RESUME

RES\SE4\ES
>
 IF MORE PLOTS ENTER 1 OTHERWISE 0
0
>
```

DEELKRAAL 1% DOWN EMPTY 10M/S





DEELKRAAL 1# DOWN EMPTY 10M/S

```
 RUN POWER


  INPUT DATA FILE NAME (6 CHARS)
DK1001


ENTER NO OF RETURN EVENTS  :
5

ENTER RETURN PERIODS ONE AT A TIME  :
500
10000
100000
1000000
100000000

NUMBER OF WHEEL LOADS IN DATA ?
2


ENTER '1' FOR DATA PRINTOUT, '2' TO STORE
DATA.  -----   ELSE NUMBER '0'
2
```

RETURN EVENT ANALYSIS BY THE SMEMAX AND THE POWER TRANSFORMATION METHODS
****

OUPUT HEADING : DEELKRAAL 1# DOWN EMPTY 10M/S

FIRST WHEEL ANALYSIS
****

NO OF BUNTONS OF DATA : 150

SKIP OR CAGE VELOCITY : 10.000

STATISTICAL DATA

		MEAN	STD DEV	SKEWNESS	KURTOSIS
UN TRANSFORMED	:	5203.4199	2132.6108	1.2670	3.8653
SMEMAX TRANSFORMED	:	3543.0081	2086.6421	-0.0002	1.8939

PREDICTIONS

RETURN PERIOD	PROBALITY OF OCCURANCE	EVENT SMEMAX TRANSFORMED
500.0	0.00200000	15170.8398
10000.0	0.00010000	18654.1855
100000.0	0.00001000	20915.5312
1000000.0	0.00000100	22939.4121
100000000.0	0.00000001	26496.5273

SECOND WHEEL ANALYSIS
****

STATISTICAL DATA

		MEAN	STD DEV	SKEWNESS	KURTOSIS
UN TRANSFORMED	:	6151.8335	1740.3304	1.5090	5.7423
SMEMAX TRANSFORMED	:	3086.1118	1614.4451	-0.0178	2.4024

PREDICTIONS

RETURN PERIOD	PROBALITY OF OCCURANCE	EVENT SMEMAX TRANSFORMED
500.0	0.00200000	13864.8613
10000.0	0.00010000	16493.0039
100000.0	0.00001000	18199.1660
1000000.0	0.00000100	19726.1621
100000000.0	0.00000001	22409.9629

```
RUN FFTAUTO

  ENTER INPUT DATA FILE NAME (6 CHRS) ie BULLEY
DK1002
NUMBER OF FFT'S ?
5

ENTER THE DEGREE OF POLYNOMIAL TO BE REMOVED
  '0' FOR CONSTANT,  '1' FOR LINEAR
0

ENTER PROPORTION OF DATA TO BE TAPERED (ie 0.2)
.2


ENTER SERIES LENGTH
512

ENTER DATA POINTS BEFORE ANALYSIS SECTION
1500

ENTER 'NO' FOR DATA CHANNEL TO BE ANALYSED
    AND 'NCHN' FOR NUMBER OF CHANNELS
1 6
```

DEELKRAAL 18 DOWN EMPTY 10M/S

FREQ	POW SPEC	SUM SPEC	FREQ	POW SPEC	SUM SPEC	FREQ	POW SPEC	SUM SPEC	FREQ	POW SPEC	SUM SPEC
0.20	0.1124	0.1124	0.39	0.1134	0.2258	0.59	0.0826	0.3084	0.78	0.2500	0.5583
0.98	0.5518	1.1101	1.17	0.2276	1.3377	1.37	0.0879	1.4255	1.56	0.1050	1.5305
1.76	0.1328	1.6633	1.95	0.1208	1.7841	2.15	0.1043	1.8884	2.34	0.0375	1.9259
2.54	0.0734	1.9992	2.73	0.0396	2.0388	2.93	0.0159	2.0547	3.12	0.0148	2.0695
3.32	0.0132	2.0827	3.52	0.0086	2.0913	3.71	0.0116	2.1029	3.91	0.0049	2.1078
4.10	0.0034	2.1112	4.30	0.0024	2.1136	4.49	0.0008	2.1144	4.69	0.0023	2.1167
4.88	0.0015	2.1182	5.08	0.0019	2.1201	5.27	0.0012	2.1213	5.47	0.0009	2.1222
5.66	0.0010	2.1232	5.86	0.0019	2.1251	6.05	0.0012	2.1263	6.25	0.0019	2.1281
6.45	0.0014	2.1296	6.61	0.0013	2.1308	6.84	0.0013	2.1321	7.03	0.0006	2.1328
7.23	0.0007	2.1335	7.42	0.0011	2.1346	7.62	0.0007	2.1353	7.81	0.0004	2.1357
8.01	0.0008	2.1365	8.20	0.0006	2.1371	8.40	0.0008	2.1379	8.59	0.0003	2.1382
8.79	0.0003	2.1386	8.98	0.0005	2.1390	9.18	0.0006	2.1396	9.37	0.0004	2.1400
9.57	0.0005	2.1404	9.77	0.0003	2.1408	9.96	0.0006	2.1414	10.16	0.0007	2.1421
10.35	0.0016	2.1437	10.55	0.0028	2.1464	10.74	0.0008	2.1472	10.94	0.0011	2.1483
11.13	0.0026	2.1508	11.33	0.0013	2.1522	11.52	0.0025	2.1547	11.72	0.0037	2.1584
11.91	0.0041	2.1626	12.11	0.0024	2.1650	12.30	0.0031	2.1681	12.50	0.0024	2.1705
12.70	0.0029	2.1734	12.89	0.0006	2.1740	13.09	0.0016	2.1756	13.28	0.0011	2.1767
13.48	0.0011	2.1778	13.67	0.0009	2.1787	13.87	0.0005	2.1792	14.06	0.0005	2.1797
14.26	0.0006	2.1803	14.45	0.0004	2.1807	14.65	0.0008	2.1815	14.84	0.0002	2.1817
15.04	0.0002	2.1819	15.23	0.0004	2.1823	15.43	0.0002	2.1825	15.62	0.0006	2.1831
15.82	0.0004	2.1836	16.02	0.0002	2.1837	16.21	0.0007	2.1844	16.41	0.0005	2.1849
16.60	0.0004	2.1853	16.80	0.0004	2.1857	16.99	0.0005	2.1862	17.19	0.0002	2.1864
17.38	0.0005	2.1868	17.58	0.0006	2.1875	17.77	0.0005	2.1880	17.97	0.0003	2.1884
18.16	0.0005	2.1889	18.36	0.0005	2.1894	18.55	0.0005	2.1899	18.75	0.0001	2.1900
18.95	0.0005	2.1905	19.14	0.0005	2.1911	19.34	0.0005	2.1915	19.53	0.0003	2.1918
19.73	0.0004	2.1923	19.92	0.0006	2.1929	20.12	0.0005	2.1934	20.31	0.0002	2.1936
20.51	0.0003	2.1939	20.70	0.0015	2.1954	20.90	0.0003	2.1957	21.09	0.0003	2.1960
21.29	0.0009	2.1969	21.48	0.0003	2.1972	21.68	0.0004	2.1976	21.87	0.0005	2.1980
22.07	0.0003	2.1983	22.27	0.0008	2.1991	22.46	0.0014	2.2004	22.66	0.0005	2.2009
22.85	0.0004	2.2013	23.05	0.0005	2.2018	23.24	0.0010	2.2027	23.44	0.0006	2.2033
23.63	0.0002	2.2036	23.83	0.0003	2.2039	24.02	0.0014	2.2053	24.22	0.0003	2.2056
24.41	0.0003	2.2060	24.61	0.0007	2.2066	24.80	0.0008	2.2074	25.00	0.0005	2.2079
25.20	0.0012	2.2091	25.39	0.0006	2.2097	25.59	0.0003	2.2100	25.78	0.0015	2.2115
25.98	0.0005	2.2120	26.17	0.0004	2.2123	26.37	0.0003	2.2126	26.56	0.0005	2.2131
26.76	0.0009	2.2141	26.95	0.0008	2.2149	27.15	0.0002	2.2151	27.34	0.0002	2.2154
27.54	0.0031	2.2155	27.73	0.0002	2.2157	27.93	0.0006	2.2163	28.12	0.0003	2.2166
28.32	0.0003	2.2169	28.52	0.0008	2.2177	28.71	0.0002	2.2179	28.91	0.0008	2.2187
29.10	0.0006	2.2193	29.30	0.0002	2.2195	29.49	0.0005	2.2200	29.69	0.0003	2.2203
29.88	0.0005	2.2208	30.08	0.0003	2.2211	30.27	0.0004	2.2216	30.47	0.0007	2.2223
30.66	0.0010	2.2233	30.86	0.0009	2.2242	31.05	0.0007	2.2249	31.25	0.0005	2.2254
31.45	0.0016	2.2270	31.64	0.0009	2.2279	31.84	0.0015	2.2294	32.03	0.0006	2.2300
32.23	0.0009	2.2310	32.42	0.0008	2.2318	32.62	0.0010	2.2328	32.81	0.0012	2.2340
33.01	0.0005	2.2345	33.20	0.0004	2.2349	33.40	0.0008	2.2357	33.59	0.0006	2.2363
33.79	0.0003	2.2366	33.98	0.0002	2.2368	34.18	0.0005	2.2373	34.37	0.0003	2.2376
34.57	0.0005	2.2382	34.77	0.0002	2.2384	34.96	0.0007	2.2390	35.16	0.0001	2.2391
35.35	0.0008	2.2399	35.55	0.0005	2.2404	35.74	0.0004	2.2408	35.94	0.0006	2.2414
36.13	0.0018	2.2432	36.33	0.0003	2.2435	36.52	0.0006	2.2442	36.72	0.0005	2.2446
36.91	0.0002	2.2449	37.11	0.0004	2.2452	37.30	0.0001	2.2453	37.50	0.0002	2.2455
37.70	0.0004	2.2459	37.89	0.0002	2.2460	38.09	0.0003	2.2463	38.28	0.0001	2.2465
38.48	0.0000	2.2465	38.67	0.0003	2.2468	38.87	0.0002	2.2470	39.06	0.0002	2.2472
39.26	0.0002	2.2474	39.45	0.0001	2.2476	39.65	0.0001	2.2477	39.84	0.0001	2.2478
40.04	0.0002	2.2480	40.23	0.0001	2.2481	40.43	0.0002	2.2484	40.62	0.0002	2.2486
40.82	0.0002	2.2488	41.02	0.0003	2.2491	41.21	0.0001	2.2492	41.41	0.0001	2.2493
41.60	0.0001	2.2494	41.80	0.0001	2.2495	41.99	0.0003	2.2498	42.19	0.0002	2.2498
42.38	0.0004	2.2502	42.58	0.0003	2.2504	42.77	0.0002	2.2506	42.97	0.0002	2.2508
43.16	0.0004	2.2512	43.36	0.0001	2.2513	43.55	0.0002	2.2515	43.75	0.0002	2.2517
43.95	0.0002	2.2519	44.14	0.0001	2.2520	44.34	0.0001	2.2522	44.53	0.0003	2.2525
44.73	0.0002	2.2527	44.92	0.0002	2.2529	45.12	0.0003	2.2532	45.31	0.0001	2.2533
45.51	0.0001	2.2534	45.70	0.0004	2.2538	45.90	0.0001	2.2540	46.09	0.0002	2.2541
46.29	0.0001	2.2543	46.49	0.0002	2.2545	46.68	0.0002	2.2547	46.87	0.0001	2.2548
47.07	0.0002	2.2551	47.27	0.0001	2.2552	47.46	0.0002	2.2554	47.66	0.0002	2.2556
47.85	0.0002	2.2558	48.05	0.0001	2.2559	48.24	0.0001	2.2560	48.44	0.0001	2.2561
48.63	0.0003	2.2564	48.83	0.0002	2.2566	49.02	0.0004	2.2570	47.22	0.0002	2.2572
49.41	0.0002	2.2573	49.61	0.0001	2.2574	49.80	0.0002	2.2576	50.00	0.0004	2.2580

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