"KNEE MECHANISM PERFORMANCE IN AMPUTEE ACTIVITY"

by

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in BioEngineering

Appendices

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Goniometer Circuit

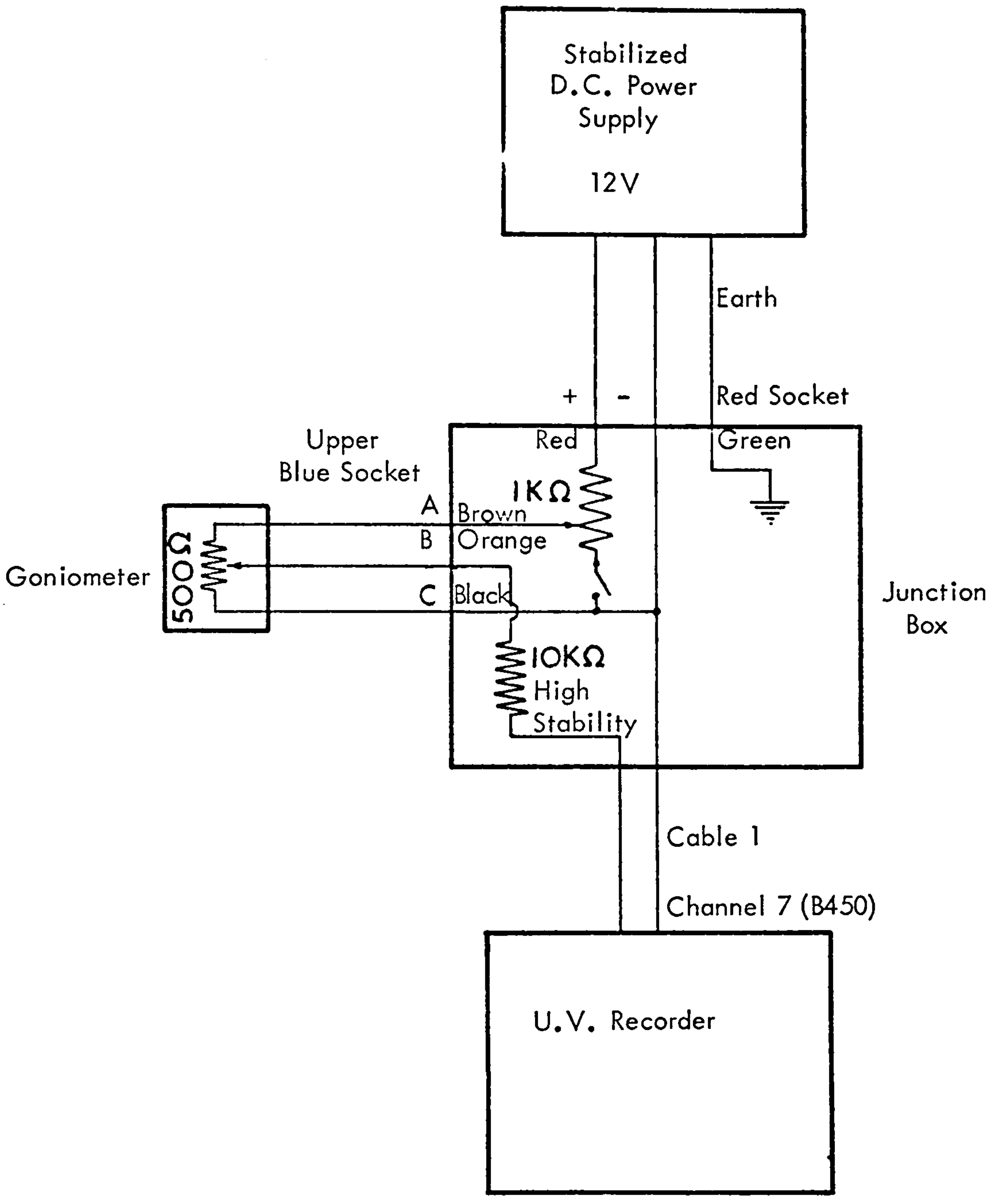


Fig.1.1

Typical Strain Bridge Circuit

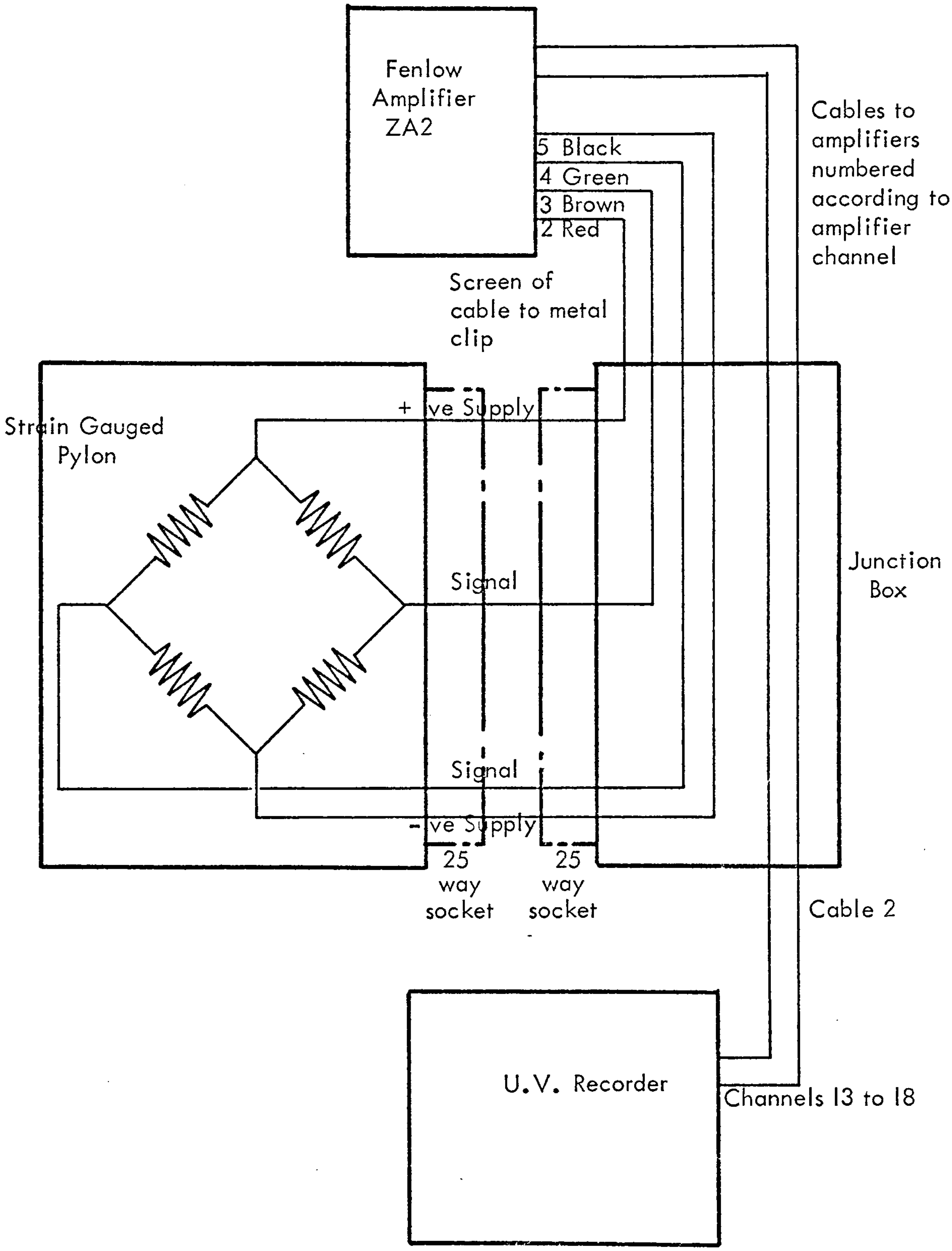


TABLE I.1

Strain Bridge Connections, Colour Codes and Galvanometers

Bridge Circuit	Number and Type of Galvanometer	Recorder Channel and Amplifier	25 - way plug		
			Pin No.	Colour Code	Wire Description
M_{LZ}, lower bending moment in Z plane	6-0694 A1600	13 1	2 3 14 15	Red Orange White/Blue Green/Yellow	Signal O/P +ve Signal O/P -ve
M_{LY}, lower bending moment in Y plane	5-6757 A3300	14 2	4 5 16 17	Yellow Light Green Blue/Yellow Red/Yellow	Signal O/P +ve Signal O/P -ve
M_{UZ}, upper bending moment in Z plane	6-0766 A1600	16 3	12 13 24 25	Dark Green Red/White Red/Blue Red/Black	Signal O/P +ve Signal O/P -ve
M_{UY}, upper bending moment in Y plane	3-7498 A3300	15 4	10 11 22 23	Black Pink Green/Red Red/Brown	Signal O/P +ve Signal O/P -ve
T torque about long axis	6-0710 A1600	17 5	6 7 18 19	Blue Violet Blue/Black Blue/Orange	Signal O/P +ve Signal O/P -ve
f_x axial load along shank	6-8792 A1000	18 6	8 9 20 21	Grey White Green/Orange Green/White	Signal O/P +ve Signal O/P -ve

The red, blue and yellow sockets are situated at the rear of the junction box.

The lower blue socket has an identical wiring system to the upper blue socket, shown in Fig.3.1 and is connected to channel 8 on the U.V. recorder.

The yellow sockets are connected directly to channels 9 and 10 on the U.V. recorder.

APPENDIX II

Determination of Strain Gauge Positions

Introduction

To ensure accurate extrapolation of the bending moment at the hip from the strain gauge readings on the shank, the precise position of the gauges has to be determined. The gauges do not necessarily record the bending moment at their centre, so simply measuring to the centre of the gauge is not sufficient.

Method

The pylon was fastened to a steel stanchion as shown in Fig. II.1, and a 6 in. long tube attached to it.

A weight of 85 lb. was suspended from the tube at 3 in., 4 in., 5 in. and 6 in. from the reference point. The strain at U and L was recorded on the Budd Strain Indicator Model P-350. The zero reading was taken before and after each load application and the mean subtracted from the reading under load. The pylon was unclamped, rotated through each of the four positions, two in each of the Z and Y planes, and the readings repeated. Two sets of readings were taken in each of the pylon positions making a total of four replications for each plane.

The gauge readings r, were plotted against x and a linear regression of r on x was calculated. The intercept on the x-axis was determined together with its standard deviation.

This value was defined as the distance of the gauge from the reference point.

THE LOADING TECHNIQUE

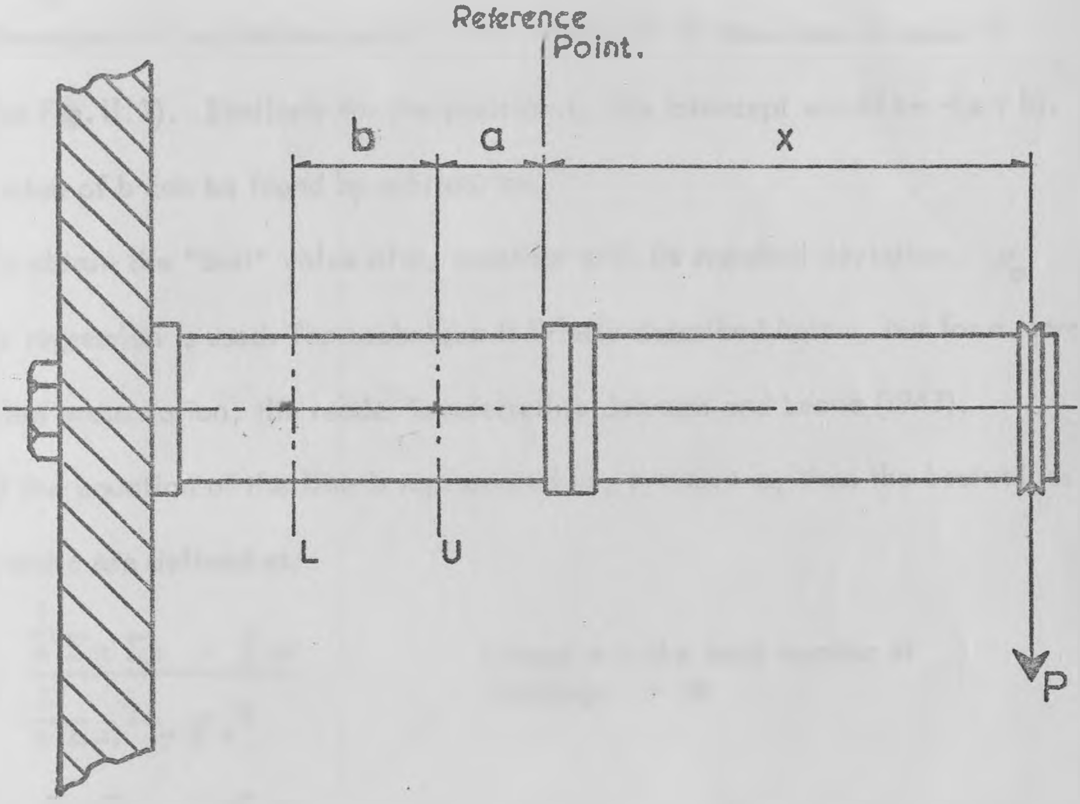


fig. II.1.

Theory

Referring to Fig. II.1, if a load P is applied at distance x from the reference point, the bending moment at U is:-

P (a + x)

$$r = \frac{P(a+x)}{k} \quad \ldots\ldots \text{(II.1)} \quad \text{(k is the calibration coefficient)}$$

Therefore if r is plotted against x, the intercept on the x axis is equal to -a (see Fig. II.2). Similarly for the position L, the intercept would be -(a + b). The value of b can be found by subtraction.

To obtain the "best" value of a, together with its standard deviation, σ_a, linear regression is used. The technique is briefly described below, but for a more detailed presentation, the reader is referred to Johnson and Leone (1943).

If the equation of the line is represented by, r = mx + c, then the best values of m and c are defined as:-

$$\hat{m} = \frac{\frac{1}{n}\Sigma x \, \Sigma r - \Sigma xr}{\frac{1}{n}(\Sigma x)^2 - \Sigma x^2}$$

(where n is the total number of
(readings = 16

$$= \frac{\Sigma x \, \Sigma r - 16\Sigma xr}{(\Sigma x)^2 - 16\Sigma x^2} \quad \ldots\ldots\ldots \text{(II.2)}$$

$$\text{and } \hat{c} = \frac{1}{n}(\Sigma r - m\Sigma x)$$

$$= \frac{1}{16}(\Sigma r - m\Sigma x) \quad \ldots\ldots \text{(II.3)}$$

$$\text{if } r = 0 \text{ then } mx + c = 0$$

$$\text{or } \quad x = -\frac{c}{m}$$

$$\therefore \quad a = \frac{c}{m} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(II.4)}$$

Therefore the best value of a, $\hat{a}$, can be derived from $\frac{\hat{c}}{\hat{m}}$.

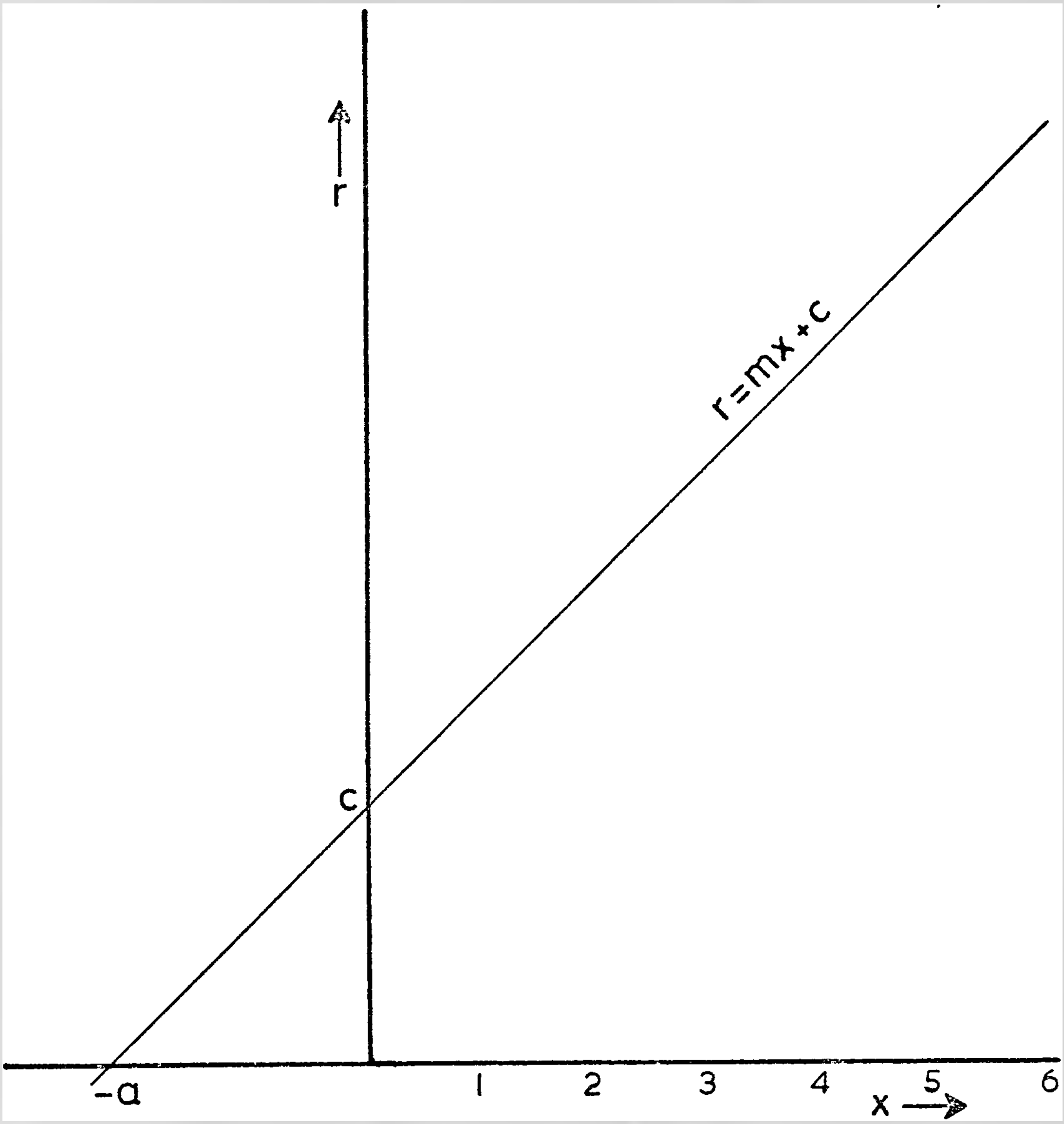


fig. II.2.

To find the standard deviation of a, σ_a, use is made of the formula given in Scarborough (1966).

$$\sigma_A^2 = \left(\frac{\partial A}{\partial B} \cdot \sigma_B\right)^2 + \left(\frac{\partial A}{\partial C} \cdot \sigma_C\right)^2 + \ldots \qquad \ldots\ldots\ldots (II.5)$$

where $A = f(B, C \ldots\ldots\ldots)$

From equation (II.5) and equation (II.4),

$$\sigma_{\hat{a}}^2 = \frac{\sigma_{\hat{c}}^2}{\hat{m}^2} + \frac{a^2}{\hat{m}^2} \sigma_{\hat{m}}^2 \qquad \ldots\ldots \quad (II.6)$$

Now $\sigma_{\hat{c}}^2 = \sigma^2 \left\{ \frac{1}{n} + \frac{\bar{x}^2}{\Sigma(x_i - \bar{x})^2} \right\}$ (Johnson and Leone)

which rearranged and substituting for n gives:

$$\sigma_{\hat{c}}^2 = \frac{\sigma^2 \, \Sigma x^2}{16\Sigma x^2 - (\Sigma x)^2} \qquad \ldots\ldots\ldots \; (II.7)$$

and $\sigma_{\hat{m}}^2 = \sigma^2 \left\{ \frac{1}{\Sigma(x_i - \bar{x})^2} \right\}$ (Johnson and Leone)

$$= \frac{16\,\sigma^2}{16\Sigma x^2 - (\Sigma x)^2} \qquad \ldots\ldots\ldots \; (II.8)$$

Since $\sigma^2 = \dfrac{\Sigma r^2 - \hat{c}\Sigma r - \hat{m}\,\Sigma xr}{n-2}$ .... (II.9)

Therefore equation (II.6) can be solved by substitution from the other equations.

a + b can be found in a similar way and b derived by subtraction.

The standard deviation of b is given by:-

$$\sigma_b^2 = \sigma_{(a+b)}^2 + \sigma_a^2 \qquad \ldots\ldots\ldots\ldots \; (II.10)$$

Results

The modified gauge readings are shown in Table II.1.

TABLE II.1

Modified Gauge Readings

x inches	Z Plane		Y Plane	
	$a_Z + b_Z$	a_Z	$a_Y + b_Y$	a_Y
3	1579	1100	1124	1618
	1588	1101	1139	1627
	1594	1098	1124	1612
	1577	1094	1139	1623
4	1841	1359	1391	1895
	1857	1365	1401	1904
	1859	1355	1397	1896
	1848	1357	1418	1889
5	2122	1631	1662	2168
	2139	1643	1675	2175
	2142	1633	1668	2162
	2130	1631	1688	2164
6	2392	1895	1941	2445
	2413	1907	1957	2456
	2410	1898	1951	2438
	2399	1899	1971	2448

Since the values of x are the same for all positions and the number of readings taken at each position are the same; referring to Table II.1:-

Equation (II.7) becomes:-

$$\sigma^2_{\hat{c}} = 1.075\,\sigma^2 \quad \ldots\ldots (II.11)$$

and equation (II.8):-

$$\sigma^2_{\hat{m}} = 0.05\,\sigma^2 \quad \ldots\ldots (II.12)$$

To calculate $(a_Z + b_Z)$

From (II.2):-

$\hat{m} = 273.9000$

and from (II.3):-

$\hat{c} = 760.5750$

and $(a_Z + b_Z) = \dfrac{\hat{c}}{\hat{m}} = 2.777$ inches

Equation (II.9) gives:-

$\sigma^2 = 77.68214$

$\therefore$ from equation (II.10) and (II.11)

$\sigma^2_{\hat{c}} = 83.5083$

and $\sigma^2_{\hat{m}} = 3.8841$

Therefore from equation (II.6)

$\sigma_{(a_Z + b_Z)} = 0.0389$

$\therefore\ a_Z + b_Z = 2.777 \pm 0.039$ inches

Carrying out a similar procedure for a_Z :-

$\Sigma r^2 = 37334960$ $\Sigma r = 23966$

$\Sigma xr = 113207$

$\hat{m} = 268.0000$

$\hat{c} = 291.8750$

$\sigma^2 = 29.12500$

$\therefore \sigma^2_{\hat{c}} = 31.30937$

and $\sigma^2_{\hat{m}} = 1.45625$

$a_Z = 0.021$

$\therefore a_Z = \frac{\hat{c}}{\hat{m}} = 1.089$

and since $(a_Z + b_Z) = 2.777$, $b_Z = 1.688$ inches

(II.10) gives:-

$$\sigma^2_{b_Z} = \sigma^2_{(a_Z+b_Z)} + \sigma^2_{a_Z}$$

$\therefore \sigma_{b_Z} = 0.044$

$\therefore a_Z = 1.089 \pm 0.021$ inches

and $b_Z = 1.688 \pm 0.044$ inches

The procedure is repeated for a_Y and b_Y.

$a_Y = 1.118 \pm 0.042$ inches

and $b_Y = 1.769 \pm 0.050$ inches

APPENDIX III

Determination of Foot Centre of Pressure and Shank Angle

Introduction

If filming is not resorted to, information regarding the limb configuration and the point of application of the load on the foot is not available. A technique is required whereby a reasonable approximation of these parameters may be obtained. This would allow the weight of the limb to be taken into account in the force analysis particularly with respect to the hip moment in the A/P plane.

The method suggested here is based on a knowledge of the deformation characteristics of the foot and ankle assembly worn.

Theory

Referring to Fig. III.1, the coordinates of the centre of pressure of the foot are g, h in the -x and y directions.

The foot-ankle unit of a prosthesis can be thought of as a curved surface rolling along the ground during the stance phase. If the surface could be represented by a simple function of the form $g = f(h)$, then using equation 4.19 from Chapter 4, g and h could be calculated. Further, since $\frac{dh}{dg}$ represents the shape of the curve at g, h, the angle between the tangent (i.e. the ground) and the x-axis (the shank) could be found by differentiation.

In fact some account must be taken of the load deformation characteristics. The more common foot-ankle units used are linearly elastic in nature. Therefore at any distance h from the x-axis, the value of g may be expressed as:-

DERIVATION OF FOOT EQUATION

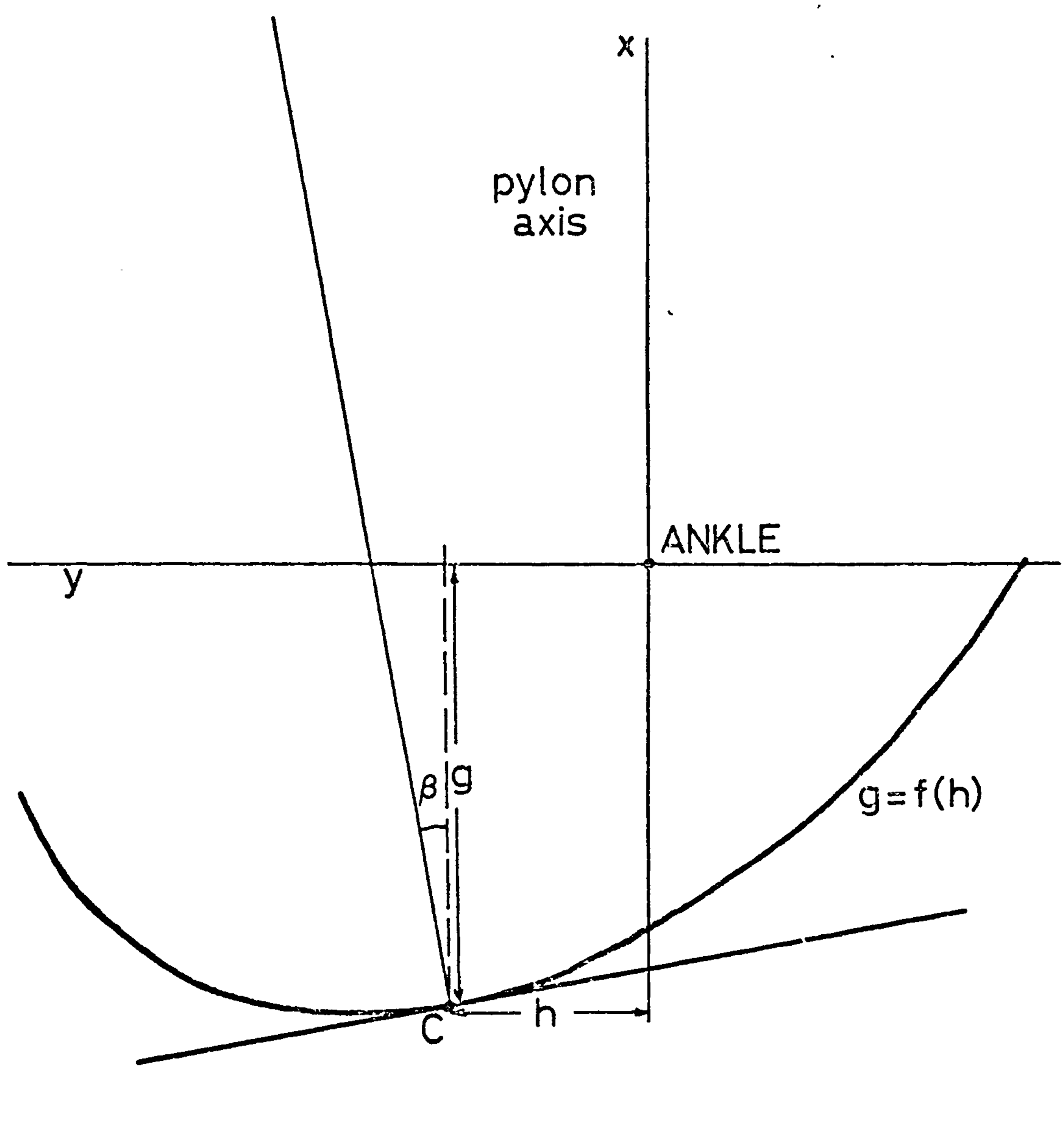


fig. III.1

$$g = -k.R + g_o$$

where R is the resultant load

k is the elastic modulus or stiffness

and g_o is the undeformed value of g at that particular value of h.

In general both g_o and k are functions of h and the expression assumed for the relationship between g and h is:-

$$g = f_o(h) - R.f_1(h) \quad ...... \quad (III.1)$$

where $f_o(h)$ is the undeformed shape

and $f_1(h)$ is the stiffness function.

Therefore the shank angle, β, may be found from:-

$$\tan\beta = \frac{dg}{dh} = f_o'(h) - \frac{dR}{dh}.f_1(h) - R f_1'(h) \quad ...... \quad (III.2)$$

Practical Considerations

The undeformed shape of the foot-ankle assembly, with a shoe on, can be found by simply tracing the projection of it onto graph paper. The position of the ankle joint can be estimated by marking the horizontal and vertical lines on the paper that intersect under it. This shape can then be expressed as discrete data for each value of h. The instep is not included in the undeformed shape. A straight line was drawn tangential to the sole and heel, and this was used as the required shape for the instep area.

To obtain the load deformation characteristics, the foot was filmed while the amputee walked up and down a ramp and on the level. The actual centre of pressure coordinates were calculated. At each value of h, the g coordinate was rationalized with respect to the undeformed shape already found, by simply reading off the values from the graph. The stiffness was calculated and the resulting stiffness versus y coordinate graph plotted. A smooth curve was drawn through the points and transcribed onto discrete data as with the undeformed shape.

To fit these two sets of data with a polynomial of degree n, use was made of Chebychev polynomials (Scheid 1968). The advantage of this method is that the difference between the function approximating to the data and the data itself can be estimated much more easily than with the usual techniques.

The Chebychev polynomial is defined:-

$$T_n = \cos n (\cos^{-1} x)$$

$$\therefore T_o = 1$$

$$T_1 = x$$

$$T_2 = 2x^2 - 1$$

etc.

and has the property, since it is a cosine, that:-

$$T_n \leqslant 1$$

Assume that the maximum error that can be tolerated is Δ, and the Chebychev polynomial of degree 3 is:-

$$a_o T_o + a_1 T_1 + a_2 T_2 + a_3 T_3$$

Then if $a_3 \leqslant \Delta$ no more terms are required.

Once the Chebychev polynomials have been found, it is only necessary to convert them into the required form.

A computer programme to carry out the necessary curve fitting is reproduced in Appendix IV for reference.

Substituting equation (III.1) into equation 4.19 gives:-

$$h = \frac{M_{AZ} + \left[f_0(h) - R f_1(h)\right] f_y}{f_x} \quad \ldots\ldots \text{(II.3)}$$

This polynomial is solved by a modified Newton's method designed to speed up the convergence. The technique is described by Runge and König (1924).

Referring to Fig. III.2, the usual Newton's method is as follows:-

Assume $y = f(x)$

It is required to find the value of x, $\underline{x}$ such that $f(x) = 0$.

An initial trial value of x, x_0, is made and the value of $f(x_0)$ evaluated. $f(x)$ is differentiated to give $f'(x)$ and the value of $f'(x_0)$ also calculated. A better approximation to $\underline{x}$ is given by:-

$$x_1 = x_0 - \frac{f(x_0)}{f'(x_0)}$$

Iteration proceeds until $\left| f(x_i) - 0 \right| \leqslant$ a predetermined amount say 0.01.

To speed up the convergence use is made of the expression:-

$$x_i = x_{i-1} - D \quad \ldots\ldots \text{(III.4)}$$

where $f(x) + f'(x)\,D + f''(x)\,\frac{D^2}{2!} + f'''(x)\,\frac{D^3}{3!} = 0$

This equation is solved by iteration as follows:-

$$D_i = \frac{f(x)}{f'(x)} - \frac{f''(x)}{f'(x)}\,\frac{D^2_{(i-1)}}{2!} - \frac{f'''(x)}{f'(x)}\,\frac{D^3_{(i-1)}}{3!}$$

When $\left| D_i - D_{i-1} \right| \leqslant$ say 0.01, iteration stops and the new value of x_i calculated from equation (III.4).

In the case of equation (III.3), it is required to find h and an initial value of $h_0 = \frac{M_{AZ}}{R}$ is used with the procedure outlined above.

The value of g can be found from equation 4.19, i.e. $g = \frac{hf_x - M_{AZ}}{f_y}$.

NEWTON'S METHOD FOR SOLUTION OF EQUATIONS

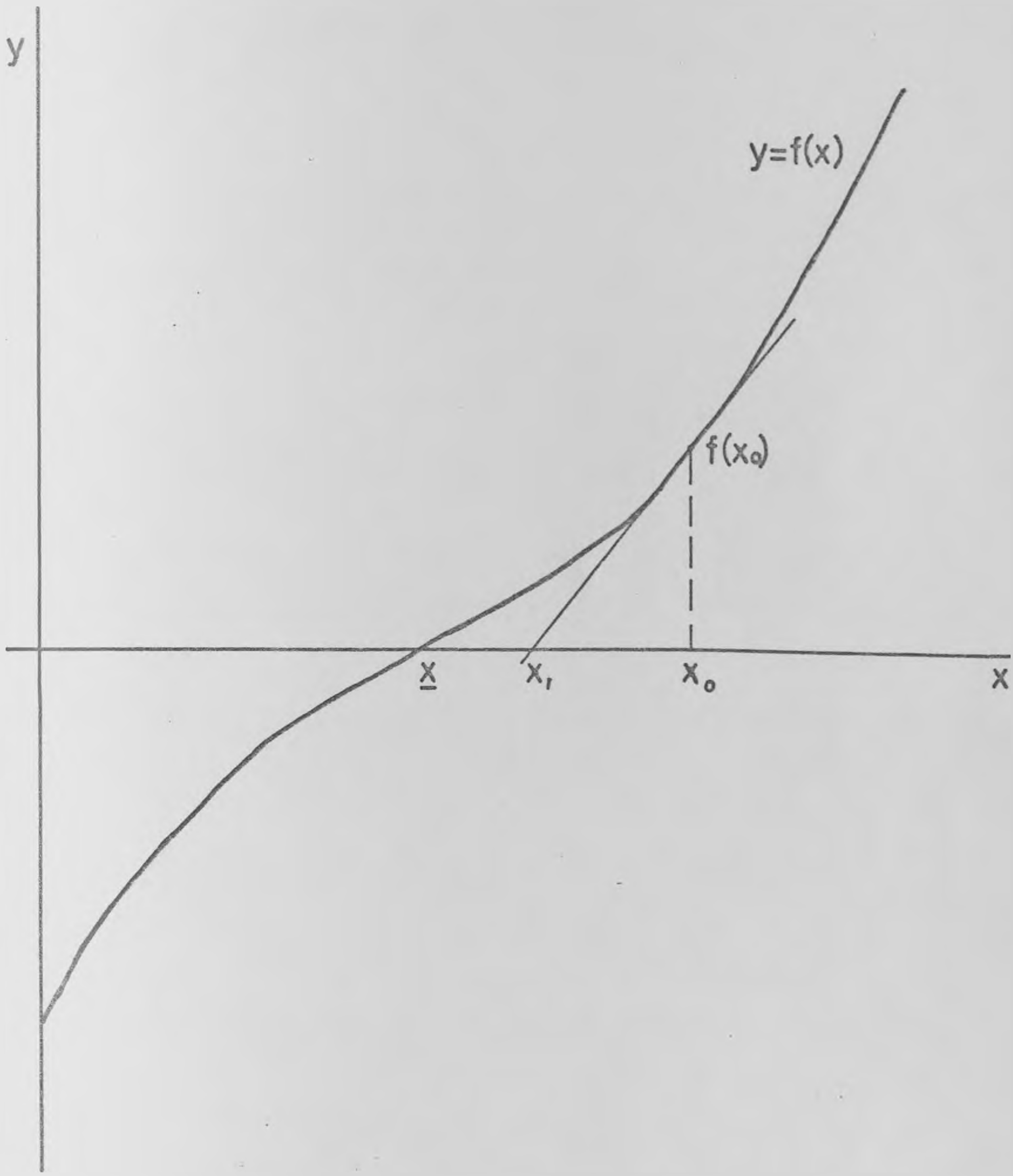


fig. III.2

The calculation of the shank angle proceeds from equation (III.2). Difficulties arise in the evaluation of $\frac{dR}{dh}$ i.e. the rate of change of the resultant load with respect to the y coordinate of the centre of pressure.

As a first approximation, $\frac{dR}{dh}$ was estimated as $\frac{R_i - R_{i-1}}{h_i - h_{i-1}}$ but the combination of the inaccuracies involved in the calculations resulted in virtually meaningless answers. An attempt was made with a modified value of $\frac{dR}{dh}$ based on the "five point parabola" fit.

Briefly this consists of fitting a parabola to five points about the point of interest i.e. to R_{i+2}, R_{i+1}, R_i, R_{i-1}, R_{i-2} and h_{i+2}, h_{i+1}, h_i, h_{i-1}, h_{i-2} when $\frac{dR_i}{dh_i}$ is required.

This modification improved the accuracy of the calculation but further work along these lines is required. The random errors involved in the calculation influence the five point parabola technique and some reduction or smoothing of these inaccuracies is necessary to achieve greater precision in the calculation of the shank angle.

APPENDIX IV

Computer Programmes

```
'PROGRAM'(PBOE16027PBO Lowe pylon studies, foot equation)
'begin'
'procedure'  Cheb(m,v,B,C,x,y,A,XU);  'value'  m,v,B,C,x,y;  'integer'  m,v;
                 'real'  B,C;  'array'  x,y,A,XU;
'begin'  'comment' Forsythe's method as modified by Clenshaw , Comput. J., 2(1959), p170.
                   The procedure produces in array A the coefficients of a Chebychev polynomial of degree
                   v which fits m sets of points (x,y) in the range [C,B];
         'real'  L,M,POS,NEG,eta,phi,KO,K1,c,alpha,beta,delta2,MAX,mu,p,delta,Y;
         'integer'  r,i,j;  'array'  P[-1:v+2,0:1],T[0:v+2];
         'for' r←1 'step' 1 'until' m 'do' x[r]←(2.0*x[r]-C-B)/(B-C);
         'comment' normalise x to lie between -1 and 1;
         beta←K1←0.0;  T[0]←1.0;  P[0,1]←1.0;  P[1,0]←P[1,1]←0.0;
         'for' j←0 'step' 1 'until' v+2 'do' A[j]←0.0;
         'for' i←-1 'step' 1 'until' v 'do'
         'begin' KO←K1; K1←L←M←POS←NEG←MAX←delta2←0.0;
                 'for' r←1 'step' 1 'until' m 'do'
                 'begin' p←P[0,1]/2;  T[1]←x[r];
                         'for' j←1 'step' 1 'until' i+1 'do'
                           T[j+1]←2.0*x[r]*T[j]-T[j-1];
                         'for' j←i+1 'step' -1 'until' 1 'do' p←p+P[j,1]*T[j];
                         K1←K1+p*p;  L←L+x[r]*p*p;  M←M+y[r]*p;
                 'end';
                 'if' i=-1 'then' 'goto' first;
                 'for' r←1 'step' 1 'until' m 'do'
                 'begin' Y←A[0]/2.0;  T[1]←x[r];
                         'for' j←1 'step' 1 'until' i 'do'
                          T[j+1]←2.0*x[r]*T[j]-T[j-1];
                         'for' j←i 'step' -1 'until' 1 'do'
                          Y←Y+A[j]*T[j];
                         delta←Y-y[r];
                         'if' delta>POS 'then' 'begin' POS←delta;  eta←XU[r] 'end'
                         'else' 'if' delta<NEG 'then' 'begin' NEG←delta; phi←XU[r]  'end';
                         Y← 'if' y[r]=0.0 'then' 0.0 'else' 100.0*delta/y[r];
                         'if' abs(Y)>abs(MAX) 'then' 'begin' MAX←Y; mu←XU[r] 'end';
                         delta2←delta2+(delta*delta);
                 'end';
                 beta←K1/KO;
                 newline(1);
                 writetext('('max%pos%dev')');    print(POS,1,3);  print(eta,1,4);
```

```
            newline(1);
            writetext('('max%neg%dev')');  print(NEG,1,3);  print(phi,1,4);newline(1);
            writetext('('percent%dev')');  print(MAX,1,3);  print(mu,1,4); newline(1);
            writetext('('standard%deviation')');  delta2←sqrt(delta2/(m+1));
            print(delta2,1,3);
        first:  alpha←L/K1;  c←M/K1;  P[-1,0]←P[1,1];  newline(2);
            writetext('('coefficients')');
            'for' j←0 'step' 1 'until' i+1 'do'
            'begin' A[j]←A[j]+c*P[j,1];  newline(1);   print(A[j],2,12);
                    Y←P[j+1,1]+P[j-1,0]-2.0*alpha*P[j,1]-beta*P[j,0];
                    P[j,0]←P[j,1];  P[j,1]←Y;
            'end';

            P[i+2,1]←1.0;  P[i+2,0]←P[i+3,1]←0.0;
      'end'
'end'  of Cheb;

'procedure' compute x coeffs(n,a,c,B,C);
           'array' a,c; 'integer' n; 'real' B,C;
'comment' compute coefficients of x given a[0:n], an array containing the
          coefficients of Chebychev polynomials for normalised x, B, the
          maximum value of x, and C, the minimum value of x.
          c[0:n] contains the new coefficients starting with the coefficient
          of x↑n in c[0];
'begin' 'array' b,d[0:n],x[1:3,0:n]; 'integer' i,j,k; 'real' P,Q,R;
        'for' j←0 'step' 1 'until' n 'do'
        'begin' b[j]←c[j]←0.0;
                'for' i←1 'step' 1 'until' 3 'do' x[i,j]←0.0;
        'end';
        b[0]←a[0]/2; b[1]←a[1]; x[1,0]←1.0; x[2,1]←1.0;
        'for' i←2 'step' 1 'until' n 'do'
        'begin' 'for' j←1 'step' 1 'until' i 'do' x[3,j]←2*x[2,j-1];
                x[3,0]←0.0;
                'for' j←0 'step' 1 'until' i 'do'
                'begin' x[3,j]←x[3,j]-x[1,j];
                        x[1,j]←x[2,j]; x[2,j]←x[3,j];
                        b[j]←b[j]+a[i]*x[3,j];
                'end'
        'end';
        P←(B+C)*0.5; Q←(B-C)*0.5; x[1,0]←1.0;
        'for' i←n 'step' -1 'until' 0 'do'
```

```
        'begin' k←n-i; R←b[i]/Q↑i;
                'for' j←1 'step' 1 'until' i 'do'
                x[1,j]←x[1,j-1]*(-P)*(i-j+1)/j;
                'for' j←0 'step' 1 'until' i 'do'
                c[j+k]←c[j+k]+R*x[1,j];
        'end'
'end' procedure;
'integer'j, i,k;
'real' x10,x20,y10,h,Bf,Cf;
'array' xf0,yf0[1:110],Af0,coeff0[0:7];

k←read;     Bf←read;     Cf←read;   h←Bf;
'for' i←1 'step' 1 'until' k 'do'
        'begin'
        xf0[i]←read;
        yf0[i]←h;
        h←h-0.1;
        'end';
Cheb(k,6,Bf,Cf,yf0,xf0,Af0,yf0);
compute x coeffs(7,Af0,coeff0,Bf,Cf);
newline(2);
write text ('('coefficients%of%polynomial%yf0')');
'for' i←0 'step' 1 'until' 7 'do'
print(coeff0[i],0,10);   newline(3);
write text ('('%%xf0d%%%%xf0c%%%%yf0')');   newline(1);
'for' i←1 'step' 1 'until' k 'do'
        'begin'  x10←xf0[i];     y10←yf0[i];
        h←y10;   x20←coeff0[7];
        'for' j←6 'step' -1 'until' 0 'do'
                'begin' x20←x20+coeff0[j]*h;
                h←h*y10;
                'end';   newline(1);
        print(x10,1,5);   print(x20,1,5);   print(y10,1,1);
        'end';
'end';
```

```
'SEND TO'(ED,COMMONOUTPUT,.SUBFILE NAME)
'LIBRARY'(ED,SUBGROUPSRA3.SUBROUTINES)
'LIBRARY'(ED,SUBGROUPS-RS.SUBROUTINES)

'PROGRAM'(PBOG16027PBO Lowe pylon studies 4 single axis without film no error 2 SIMPLE)
'INPUT'0=TRO
'OUTPUT'0=LPO
'SPACE' 6000
'TRACE' 2
'begin'
'procedure'  timenow;  'external';'procedure' opengp;
'external';
'procedure' hgplott(x,y,ic,l);
   'real' x,y;
   'integer' ic,l;
'external';
'procedure' hgpaxist(x,y,bcd,n,s,theta,xmin,dx);
   'real' x,y,s,theta,xmin,dx;
   'integer' n;   'string' bcd;
'external';
'procedure' hgprectt(x,y,h,w,th,iv);
   'real' x,y,h,w,th;
   'integer' iv;
'external';
'procedure' hgpsymblt(x,y,height,bcd,theta,n);
  'real' x,y,height,theta;
  'integer' n;    'string' bcd;
'external';'procedure' closegp;
'external';
'integer' n,i,j,frame,g,k,s,t0,muz0,muy0,mlz0,mly0,theta0,fx0;
'real'l,b,ay,az,by,bz,cy,cz,muz,mlz,maz,mkz,muy,mly,may,mky,fx,fy,fz,rz,ry,r,phi,alpha,theta,p,dz,
      mhy,mhz,t,d,ruz,ruy,rlz,rly,rfx,rt,it,l1,l2,beta,c,cycle;
'integer''array' scale[1:18];
'real''array' a[1:6,1:6];

l←read;   b←read;   it←read;  c←read;
'for' i←1 'step' 1 'until' 6 'do'
'for' j←1 'step' 1 'until' 6 'do'
a[i,j]←read;
'for' i←1 'step' 1 'until' 18 'do'
```

```
scale[i]←read;
az←read+1.089;  ay←read+1.118;  bz←1.688;  by←1.769;  cz←b-(az+bz);  cy←b-(ay+by);
opengp;
pause(10);
newset:  paperthrow;  timenow;  newline(2);
write text ('('SUBJECT%%')');
write text ('(''('c')'KNEE%TYPE'('c')'ACTIVITY'('c')'CYCLE%TIME')');
n←read;  cycle←read;
print (cycle/10.0,1,2);
write text('('%SECONDS'('2c')'INPUT%DATA'('c8s')'MLZ'('11s')'MLY'('11s')'MUZ'('11s')'MUY'('12s')'T
      '('12s')'FX'('11s')'THETA'('c')'')');
'begin' 'integer' 'array' var[0:n,9:22];  'array' plot[1:19,1:n];
      'for' j←9 'step' 2 'until' 21 'do'
      'for' i←0 'step' 1 'until' n 'do'
      'begin'  var[i,j]←read;    var[i,j+1]←read;  'end';
      'for' i←0 'step' 1 'until' n 'do'
       'begin' 'for' j←9 'step' 1 'until' 22 'do'
      print(var[i,j],4,0);  newline(1); 'end';
      newline(2);

mlz0←var[0,10];  mly0←var[0,12];  muz0←var[0,14];  muy0←var[0,16];  t0←var[0,18];  fx0←var[0,20];
theta0←var[0,22];
'for' i←1 'step'  1 'until' n 'do'
'begin'  frame←i-1;  mlz←var[i,10];  mly←var[i,12];  muz←var[i,14];  muy←var[i,16];  t←var[i,18];
fx←var[i,20];  theta←var[i,22];
      ruz←muz-muz0;   ruy←muy-muy0;   rlz←mlz-mlz0;   rly←mly-mly0;
      rfx←fx-fx0;
      'if'  rfx  'ge' 0 'then'  'begin' 'if' i<4 'then'  'begin'  'for' j←1 'step' 1 'until' 19 'do'
      plot[j,i]←0;
          'goto' false;  'end' 'else' 'for' j←1 'step' 1 'until' 19 'do'
          'begin' plot[j,i]←plot[j,i-1]; 'goto' false ; 'end'; 'end';
        theta←(theta-theta0)*c*1.5708;    rt←t-t0;
      muy←ruy/a[2,2];  mly←rly/a[4,4];  fx←rfx/a[5,5];  t←rt/a[6,6];
repeat:muz←(ruz-a[1,2]*muy-a[1,5]*fx-a[1,6]*t)/a[1,1];
      muy←(ruy-a[2,1]*muz-a[2,5]*fx-a[2,6]*t)/a[2,2];
      mlz←(rlz-a[3,4]*mly-a[3,5]*fx-a[3,6]*t)/a[3,3];
      mly←(rly-a[4,3]*mlz-a[4,5]*fx-a[4,6]*t)/a[4,4];
      fx ←(rfx-a[5,1]*muz-a[5,2]*muy-a[5,6]*t)/a[5,5];
plot[9,i]←t  ←(rt -a[6,1]*muz-a[6,2]*muy-a[6,5]*fx)/a[6,6];
```

```
'if'abs(muy-(ruy-a[2,1]*muz-a[2,5]*fx-a[2,6]*t)/a[2,2])'ge'0.05'then''goto' repeat;
'if'abs(mlz-(rlz-a[3,4]*mly-a[3,5]*fx-a[3,6]*t)/a[3,3])'ge'0.05'then''goto' repeat;
'if'abs(mly-(rly-a[4,3]*mlz-a[4,5]*fx-a[4,6]*t)/a[4,4])'ge'0.05'then''goto' repeat;
'if'abs(fx-(rfx-a[5,1]*muz-a[5,2]*muy-a[5,6]*t)/a[5,5])'ge'0.1'then''goto' repeat;
'if'abs(t-(rt- a[6,1]*muz-a[6,2]*muy-a[6,5]*fx)/a[6,6])'ge'0.1'then''goto' repeat;

      plot[19,i]←frame/cycle/0.8;
      fy←(muz-mlz)/bz;      fz←(muy-mly)/by;      rz←sqrt(fx*fx+fy*fy);      ry←sqrt(fx*fx+fz*fz);
      plot[2,i]←r←sqrt(fx*fx+fy*fy+fz*fz);      phi←arctan(fy/fx);
      plot[15,i]←maz←mlz-cz*fy;      plot[16,i]←may←mly-cy*fz;      plot[4,i]←mkz←muz+az*fy;
      plot[17,i]←mky←muy+ay*fz;
      plot[14,i]←dz←mkz/rz;

l1←b+3.2+l*cos(theta);
      l2←-(3.2+b)*sin(phi)/cos(phi)+dz/cos(phi)+l*sin(theta);
      beta←arctan(l2/l1);
      alpha←beta+phi;
      plot[1,i]←p←rz*cos(alpha);
      plot[3,i]←mhz←(rz*l1*sin(alpha))/cos(beta);
      plot[5,i]←d←(b+3.2)*sin(beta)+(b+3.2)*sin(phi)/cos(phi)*cos(beta)-dz/cos(phi)*cos(beta);
      plot[18,i]←mhy←fz*l2/sin(beta)-it*(fx*cos(beta)+fy*sin(beta));

      phi←phi*57.296;      alpha←alpha*57.296;      plot[6,i]←theta←theta*57.296;
      false:  'end';
mhy←mhz←0;
'for' i←1 'step' 1 'until' n 'do'
      'begin' mhy←mhy+abs(plot[18,i]);
      mhz←mhz+abs(plot[3,i]);  'end';
write text ('(''('2c')'AVERAGE%A-P%HIP%MOMENT'('2c')'')');
print(mhz*0.01,4,1);
write text ('(''('3c')'AVERAGE%M-L%HIP%MOMENT'('2c')'')');
print(mhy*0.01,4,1);
hgplott(0.0,28.0,0,4);
hgpaxist(1.0,1.0,'('PERC%WALK%CYCL')',-14,8.0,0.0,0.0,8.0);
hgpaxist(1.0,1.0,'('PCOM%FORC')',9,5.0,90.0,0.0,scale[1]);
'for' i←1 'step' 1 'until' n 'do'  'for'j←3,2 'do'
hgprectt(plot[19,i]+0.98,plot[1,i]/scale[1]+0.98,0.04,0.04,0.0,j);

hgpaxist(1.0,6.0,'('%')',-1,8.0,0.0,0.0,8.0);
```

```
hgpaxist(1.0,6.0,'('RESL%FORC')',9,5.0,90.0,0.0,scale[2]);
'for' i←1 'step' 1 'until' n 'do'  'for' j←3,2 'do'
hgprectt(plot[19,i]+0.98,plot[2,i]/scale[2]+5.98,0.04,0.04,0.0,j);

hgpaxist(1.0,13.0,'('%')',-1,8.0,0.0,0.0,8.0);
hgpaxist(1.0,11.0,'('MHIP%ANPO')',9,5.0,90.0,-2*scale[3],scale[3]);
'for' i←1 'step' 1 'until' n 'do'  'for' j←3,2 'do'
hgprectt(plot[19,i]+0.98,plot[3,i]/scale[3]+12.98,0.04,0.04,0.0,j);

hgpaxist(1.0,17.0,'('%')',-1,8.0,0.0,0.0,8.0);
hgpaxist(1.0,16.0,'('MKNE%ANPO')',9,5.0,90.0,-scale[4],scale[4]);
'for' i←1 'step' 1 'until' n 'do'  'for' j←3,2 'do'
hgprectt(plot[19,i]+0.98,plot[4,i]/scale[4]+16.98,0.04,0.04,0.0,j);


'for' i←1 'step' 1 'until' n 'do'
hgpsymblt(plot[19,i]+0.98,(plot[5,i]*plot[1,i]*(1+b+3.5)/(b+3.5)/scale[3])+12.965,0.07,'('x')',0.0,1);

hgpaxist(1.0,23.0,'('%')',-1,8.0,0.0,0.0,8.0);
hgpaxist(1.0,21.0,'('KNEE%COFP%HIPD')',14,3.0,90.0,-2*scale[5],scale[5]);
'for' i←1 'step' 1 'until' n 'do'  'for' j←3,2 'do'
hgprectt(plot[19,i]+0.98,plot[5,i]/scale[5]+22.98,0.04,0.04,0.0,j);

hgpaxist(1.0,24.0,'('%')',-1,8.0,0.0,0.0,8.0);
hgpaxist(1.0,24.0,'('KNEE%ANGL')',9,3.0,90.0,0.0,scale[6]);
'for' i←1 'step' 1 'until' n 'do'  'for' j←3,2 'do'
hgprectt(plot[19,i]+0.98,plot[6,i]/scale[6]+23.98,0.04,0.04,0.0,j);

hgpaxist(10.0,10.5,'('%')',-1,8.0,0.0,0.0,8.0);
hgpaxist(10.0,9.0,'('TORQ')',4,3.0,90.0,-1.5*scale[9],scale[9]);
'for' i←1 'step' 1 'until' n 'do'  'for' j←3,2 'do'
hgprectt(plot[19,i]+9.98,plot[9,i]/scale[9]+10.48,0.04,0.04,0.0,j);

hgpaxist(19.0,5.0,'('PERC%WALK%CYCL')',-14,8.0,0.0,0.0,8.0);
hgpaxist(19.0,1.0,'('STAB%DIST%DZIN')',14,5.0,90.0,-4*scale[14],scale[14]);
'for' i←1 'step' 1 'until' n 'do'  'for' j←3,2 'do'
hgprectt(plot[19,i]+18.98,plot[14,i]/scale[14]+4.98,0.04,0.04,0.0,j);

hgpaxist(19.0,10.0,'('%')',-1,8.0,0.0,0.0,8.0);
```

```
hgpaxist(19.0,6.0,'('MANK%ANPO')',9,5.0,90.0,-4*scale[15],scale[15]);
'for' i←1 'step' 1 'until' n 'do'  'for' j←3,2 'do'
hgprectt(plot[19,i]+18.98,plot[15,i]/scale[15]+9.98,0.04,0.04,0.0,j);

hgpaxist(19.0,13.0,'('%')',-1,8.0,0.0,0.0,8.0);
hgpaxist(19.0,11.0,'('MANK%MELA')',9,5.0,90.0,-2*scale[16],scale[16]);
'for' i←1 'step' 1 'until' n 'do'  'for'j←3,2 'do'
hgprectt(plot[19,i]+18.98,plot[16,i]/scale[16]+12.98,0.04,0.04,0.0,j);

hgpaxist(19.0,18.0,'('%')',-1,8.0,0.0,0.0,8.0);
hgpaxist(19.0,16.0,'('MKNE%MELA')',9,5.0,90.0,-2*scale[17],scale[17]);
'for' i←1 'step' 1 'until' n 'do'  'for' j←3,2 'do'
hgprectt(plot[19,i]+18.98,plot[17,i]/scale[17]+17.98,0.04,0.04,0.0,j);

hgpaxist(19.0,23.0,'('%')',-1,8.0,0.0,0.0,8.0);
hgpaxist(19.0,21.0,'('MHIP%MELA')',9,5.0,90.0,-2*scale[18],scale[18]);
'for' i←1 'step' 1 'until' n 'do'  'for' j←3,2 'do'
hgprectt(plot[19,i]+18.98,plot[18,i]/scale[18]+22.98,0.04,0.04,0.0,j);

hgplott(32.0,28.0,3,0);
s←read;
'if' s=1 'then' 'goto' newset
'end';
closegp;
'end';
```

```
'SEND TO'(ED,COMMONOUTPUT,.SUBFILE NAME)
'LIBRARY'(ED,SUBGROUPS-RS.SUBROUTINES)
'PROGRAM'(PBOF16027PBO Lowe pylon studies 4 single axis without film no error 2)
'INPUT'O=TRO
'OUTPUT'O=LPO
'SPACE' 6000
'TRACE' 2
'begin'
'comment' by use of foot deformation equation x=f0(y)+rz.f1(y) and pylon records,various parameters
are calculated for a single axis knee -
          l   thigh length
          b   shank length
          it  distance medially of the ischial tuberosity from the axis of the pylon
          ay, az, by, bz, cy, cz,  are the distances of the bending moment gauges in the y and z planes,
                          a referring to the knee-upper gauge distance
                          b referring to the intergauge distance
                          c referring to the lower gauge-ankle distance
          n   number of observations
          0   refers to zero reading on d-mac
          u   refers to upper gauges
          y and z refer to planes or axes
          m   refers to bending moment reading
          muy0 therefore, is the bending moment at u about the y axis zero reading
          fx  axial thrust
          theta  knee angle
          t   torque
          coeff0[i]  coefficient in f0(y) of y↑7-i
          coeff[i]   coefficient in f1(y) f y↑7-i
          c   is the reciprocal of the goniometer output at 90 degrees minus that at 0 degrees
          a[i,j] are the calibration values of the pylon
          s   sign variable either 1 or 0 ,FOR more data or end of data respectively
               The output parameters are defined by the write text statement below;

'procedure'  timenow;  'external';'procedure' opengp;
'external';
'procedure' hgplott(x,y,ic,l);
   'real' x,y;
   'integer' ic,l;

'external';
```

```
 'procedure' hgpaxist(x,y,bcd,n,s,theta,xmin,dx);
   'real' x,y,s,theta,xmin,dx;
   'integer' n;   'string' bcd;
'external';
'procedure' hgprectt(x,y,h,w,th,iv);
   'real' x,y,h,w,th;
   'integer' iv;
'external';
'procedure' hgpsymblt(x,y,height,bcd,theta,n);
   'real' x,y,height,theta;  'integer' n;  'string' bcd;
'external';
'procedure' closegp;
'external';
'integer' n,i,j,frame,g,k,s,w,t0,muz0,muy0,mlz0,mly0,theta0,fx0;
'real' x0,y0,x1,x2,l,b,ay,az,by,bz,cy,cz,xa,ya,psi,muz,mlz,
       x3,maz,mkz,muy,mly,may,mky,fx,fy,fz,rz,ry,r,phi,x,y,alpha,theta,omega,p,dz,mhy,mhz,xp,t,d,v,f,ruz,ruy
       rlz,rly,rfx,rt,it,l1,l2,beta,c,cycle,dl,dl0,
       tan,rz0,rd,h;
'integer''array' scale[1:18];
'real''array' a[1:6,1:6],cf,coeff,coeff0[0:7];
xp←rz0←y0←0;
'for' i←0 'step' 1 'until' 7 'do'
'begin'   coeff0[i]←read;  coeff[i]←read;   'end';

l←read;   b←read;   it←read;  c←read;
'for' i←1 'step' 1 'until' 6 'do'
'for' j←1 'step' 1 'until' 6 'do'
a[i,j]←read;
'for' i←1 'step' 1 'until' 18 'do'
scale[i]←read;
az←read+1.089;  ay←read+1.118;  bz←1.688;  by←1.769;  cz←b-(az+bz);  cy←b-(ay+by);
opengp;

newset:   paperthrow;  timenow;  newline(2);
write text ('('SUBJECT%%')');
write text ('(''('c')'KNEE%TYPE'('c')'ACTIVITY'('c')'CYCLE%TIME')');
n←read;  cycle←read;
print (cycle,10.0,1,2);
write text('('%SECONDS'('2c')'INPUT%DATA'('c8s')'MLZ'('11s')'MLY'('11s')'MUZ'('11s')'MUY'('12s')'T
      '('12s')'FX'('11s')'THETA'('c')'')');
```

```
'begin' 'integer' 'array' var[0:n,9:22];  'array' plot[1:19,1:n],zx,zy,zp[1:n];
 'for' j←9 'step' 2 'until' 21 'do'
 'for' i←0 'step' 1 'until' n 'do'
 'begin'  var[i,j]←read;    var[i,j+1]←read;  'end';
 'for' i←0 'step' 1 'until' n 'do'
  'begin' 'for' j←9 'step' 1 'until' 22 'do'
 print(var[i,j],4,0);  newline(1); 'end';
 newline(2);

write text ('('''('p4s')'ANKLE%%%%SHANK'('10s')'FORCES'('14s')'RESULTANTS'('10s')'ANKLE%MOMENTS%%%%
      KNEE%MOMENTS%%%%%%HIP%MOMENTS'('1c3s')'COORDS%%%%ANGLE%%%AXIAL%%%%AP%%%%%ML%%%%%ML%%%%%%AP
      %%%%TOTAL%%%ML%%%%%%AP%%%%%%%ML%%%%%%%AP%%%%%%%%ML%%%%%%AP'('1c2s')'XA%%%%%YA%%%%PSI%%%%%
      FX%%%%%FY%%%%FZ%%%%%RY%%%%%%RZ%%%%%%%%R%%%%%%MAY5%%%%%MAZ%%%%%%MKY%%%%%%%MKZ%%%%%%%MHY%%%%%%%MHZ
      '('3c')'SHANK%%%LOA%%%%KNEE%%GROUND%%HIPCOP%LOA%TO%%%%%%COP%%%%%%%%%COP'('4s')'TORQUE%%KNEE%%%VERT
      %%%SHEAR'('1c1s')'LOA%%%HIPCOP%%ANGLE%%LOA'('4s')'FORCE%%%KNEE%%%%%COORDS%%%%%%PROG%%%%%%%%%
      HIPCOP%%COMP%%%%COMP'('1c1s')'PHI%%%%ALPHA%%THETA%%OMEGA%%%%P%%%%%%DZ%%%%%%X%%%%%%%Y%%%%%%%XP%%%%%%
      T%%%%%%D%%%%%%%%V%%%%%%%F'('3c')'')');

omega←f←v←psi←xa←xp←ya←0.0;

mlz0←var[0,10];  mly0←var[0,12];  muz0←var[0,14];  muy0←var[0,16];  t0←var[0,18];  fx0←var[0,20];
theta0←var[0,22];
'for' i←1 'step'  1 'until' n 'do'
'begin'  frame←i-1;  mlz←var[i,10];  mly←var[i,12];  muz←var[i,14];  muy←var[i,16];  t←var[i,18];
fx←var[i,20];  theta←var[i,22];
      ruz←muz-muz0;   ruy←muy-muy0;   rlz←mlz-mlz0;   rly←mly-mly0;
      rfx←fx-fx0;
      'if'  rfx  'ge' 0 'then'  'begin'  'if' i<4 'then'  'begin''for' j←1 'step' 1 'until' 19 'do' plot[j,i]
      ←0;
            'goto' false;  'end'  'else' 'for' j←1 'step' 1 'until' 19 'do' 'begin' plot[j,i]←plot[j,i-1];
            'goto' false; 'end';  'end';
          theta←(theta-theta0)*c*1.5708;    rt←t-t0;
      muy←ruy/a[2,2];  mly←rly/a[4,4];  fx←rfx/a[5,5];  t←rt/a[6,6];
repeat:muz←(ruz-a[1,2]*muy-a[1,5]*fx-a[1,6]*t)/a[1,1];
      muy←(ruy-a[2,1]*muz-a[2,5]*fx-a[2,6]*t)/a[2,2];
      mlz←(rlz-a[3,4]*mly-a[3,5]*fx-a[3,6]*t)/a[3,3];
      mly←(rly-a[4,3]*mlz-a[4,5]*fx-a[4,6]*t)/a[4,4];
      fx ←(rfx-a[5,1]*muz-a[5,2]*muy-a[5,6]*t)/a[5,5];
plot[9,i]←t  ←(rt -a[6,1]*muz-a[6,2]*muy-a[6,5]*fx)/a[6,6];
```

```
'if'abs(muz-(ruz-a[1,2]*muy-a[1,5]*fx-a[1,6]*t)/a[1,1])'ge'0.05'then''goto' repeat;
'if'abs(muy-(ruy-a[2,1]*muz-a[2,5]*fx-a[2,6]*t)/a[2,2])'ge'0.05'then''goto' repeat;
'if'abs(mlz-(rlz-a[3,4]*mly-a[3,5]*fx-a[3,6]*t)/a[3,3])'ge'0.05'then''goto' repeat;
'if'abs(mly-(rly-a[4,3]*mlz-a[4,5]*fx-a[4,6]*t)/a[4,4])'ge'0.05'then''goto' repeat;
'if'abs(fx-(rfx-a[5,1]*muz-a[5,2]*muy-a[5,6]*t)/a[5,5])'ge'0.1'then''goto' repeat;
'if'abs(t-(rt- a[6,1]*muz-a[6,2]*muy-a[6,5]*fx)/a[6,6])'ge'0.1'then''goto' repeat;

      plot[19,i]←frame/cycle/0.8;
      fy←(muz-mlz)/bz;      fz←(muy-mly)/by;      rz←sqrt(fx*fx+fy*fy);       ry←sqrt(fx*fx+fz*fz);
      plot[2,i]←r←sqrt(fx*fx+fy*fy+fz*fz);              phi←arctan(fy/fx);
      plot[15,i]←maz←mlz-cz*fy;        plot[16,i]←may←mly-cy*fz;      plot[4,i]←mkz←muz+az*fy;
      plot[17,i]←mky←muy+ay*fz;
      plot[14,i]←dz←mkz/rz;

cf[7]←coeff0[7]+rz*coeff[7]-b+dz/sin(phi);
      cf[6]←coeff0[6]+rz*coeff[6]+cos(phi)/sin(phi);
      'for' j←5 'step' -1 'until' 0 'do'
           cf[j]←coeff0[j]+rz*coeff[j]:
      y←-maz/rz;
      newy:   x0←cf[7];   x1←cf[6];   x2←2*cf[5];   x3←6.0*cf[4];   h←y;
        'for' j←6 'step' -1 'until' 0 'do'
            'begin'  x0←x0+cf[j]*h;  h←h*y;  'end':
      h←y; 'for' j←6 'step' -1 'until' 1 'do'
            'begin'  x1←x1+(8-j)*cf[j-1]*h;  h←h*y;   'end';
      h←y; 'for' j←6 'step' -1 'until' 2 'do'
            'begin'  x2←x2+(8-j)*(9-j)*cf[j-2]*h;  h←h*y;  'end';
      h←y; 'for' j←6 'step' -1 'until' 3 'do'
            'begin'  x3←x 3+(8-j)*(9-j)*(10-j)*cf[j-3]*h;  h←h*y;  'end';
      dl←-x0/x1;
      newdl: dl0←-x0/x1-x2/x1/2*dl*dl-x3/x1/6*dl↑3;
      'if' abs(dl-dl0)>0.01 'then'  'begin'  dl←dl0; 'goto' newdl;  'end';
      'if' abs(dl0)>0.01 'then'  'begin'  y←y+dl0; 'goto' newy;  'end';
      x←b-dz/sin(phi)-y*cos(phi)/sin(phi);

zy[i]←y;zp[i]←phi;zx[i]←x;
l1←b-x+l*cos(theta);
      l2←-y+l*sin(theta);
```

```
       beta←arctan(12/11);
       alpha←beta+phi;
       plot[1,i]←p←rz*cos(alpha);
       plot[3,i]←mhz←(rz*l1*sin(alpha))/cos(beta);
       plot[5,i]←d←(b-x)*sin(beta)+y*cos(beta);
       plot[18,i]←mhy←fz*12/sin(beta)-it*(fx*cos(beta)+fy*sin(beta));
plot[13,i]←fx;    plot[11,i]←fy;   plot[12,i]←fz;   plot[8,i]←rz;   plot[7,i]←ry;
plot[10,i]←alpha←alpha*57.296;     plot[6,i]←theta←theta*57.296;
       newline(4);
       false:  'end';
'for' i←1 'step' 1 'until' n 'do'
       'begin'
       'if' i=n-1 'then' rd←(11*plot[1,n]-3*plot[1,n-1]-7*plot[1,n-2]-plot[1,n-3])/
                          (11*zy[n]-3*zy[n-1]-7*zy[n-2]-zy[n-3]);
       'if' i=n'then'  rd←(21*plot[1,n]=13*plot[1,n-1]-17*plot[1,n-2]+9*plot[1,n-3])/
             (21*zy[n]-13*zy[n-1]-17*zy[n-2]+9*zy[n-3]);
       'if' i<n-1'then' 'begin'  'if' i=1 'then' rd←(21*plot[1,1]-13*plot[1,2←-17*plot[1,3]+9*plot[1,4])/
             (21*zy[1]-13*zy[2]-17*zy[3]+9*zy[4]);
       'if' i=2 'then' rd← (11*plot[1,1]-3*plot[1,2]-7*plot[1,3]-plot[1,4])/
             (11*zy[1]-3*zy[2]-7*zy[3]-zy[4]);
       'if' i>2 'then' rd←(2*plot[1,i-2]+plot[1,i-1]-plot[1,i+1]-2*plot[1,i+2])/
             (2*zy[i-2]+zy[i-1]-zy[i+1]-2*zy[i+2])+ 'end';
       tan←-(coeff0[6]+plot[1,i]*coeff[6]+rd*(coeff[7]+zy[i]*coeff[6]));
       h←zy[i];
       'for' j←5 'step' -1 'until' 0 'do'
            'begin' tan←tan-((7-j)*coeff0[j]+(7-j)*plot[1,i]*coeff[j]+zy[i]*coeff[j]*rd)*h;
             h←h*zy[i];
             'end';
       psi←arctan(tan);
       ya←-zx[i]*cos(psi)-zy[i]*sin(psi);
       'if'i=1 'then' plot[11,i]←xp←0.0 'else'
       xp←xp-(zy[i]-zy[i-1])/cos(psi);
       xa←xp+zy[i]*cos(psi)-zx[i]*sin(psi);
       omega←psi-zp[i];  psi←psi*57.296;
print(xa,2,1);  print(ya,2,1);  print(psi,2,1);
print(plot[13,i],3,1);  print(plot[11,i],2,1);  print(plot[12,i],2,1);
print(plot[7,i],3,1);  print(plot[8,i],3,1);  print(plot[2,i],3,1);
print(plot[16,i],4,1);  print(plot[15,i],4,1);
```

```
print(plot[17,i],4,1);  print(plot[4,i],4,1);
print(plot[18,i],4,1);  print(plot[3,i],4,1);
newline(1);
print(zp[i]*57.296,2,1);  print(plot[10,i],2,1);
print(plot[6,i],2,1);  print(omega,2,1);
print(plot[1,i],3,1);  print(plot[14,i],1,2);
print(zx[i],1,2);  print(zy[i],1,2);  print(xp,2,2);
print(plot[9,i],3,1);  print(plot[5,i],1,2);
      plot[8,i]←f←plot[1,i]*sin(omega);
      plot[7,i]←v←plot[1,i]*cos(omega);  omega←omega*57.296;
      plot[10,i]←psi;  plot[13,i]←ya;  plot[12,i]←xa;  plot[11,i]←xp;
      print(v,3,1);  print(f,2,1);  space(10);  print(frame,3,0);
      newline(4);
      'end';
mhy←mhz←0;
'for' i←1 'step' 1 'until' n 'do'
      'begin' mhy←mhy+abs(plot[18,i]);
      mhz←mhz+abs(plot[3,i]);  'end';
write text ('(''('2c')'HIP%MUSCULAR%EFFORT%A-P%PLANE'('2c')'')');
print(mhz*0.01,4,1);
write text ('(''('3c')'HIP%MUSCULAR%EFFORT%M-I%PLANE'('2c')'')');
print(mhy*0.01,4,1);
hgplott(0.0,28.0,0,4);
hgpaxist(1.0,1.0,'('PERC%WALK%CYCL')',-14,8.0,0.0,0.0,8.0);
hgpaxist(1.0,1.0,'('PCOM%FORC')',9,5.0,90.0,0.0,scale[1]);
'for' i←1 'step' 1 'until' n 'do'  'for'j←3,2 'do'
hgprectt(plot[19,i]+0.98,plot[1,i]/scale[1]+0.98,0.04,0.04,0.0,j);

hgpaxist(1.0,6.0,'('%')',-1,8.0,0.0,0.0,8.0);
hgpaxist(1.0,6.0,'('RESL%FORC')',9,5.0,90.0,0.0,scale[2]);
'for' i←1 'step' 1 'until' n 'do'  'for' j←3,2 'do'
hgprectt(plot[19,i]+0.98,plot[2,i]/scale[2]+5.98,0.04,0.04,0.0,j);

hgpaxist(1.0,13.0,'('%')',-1,8.0,0.0,0.0,8.0);
hgpaxist(1.0,11.0,'('MHIP%ANPO')',9,5.0,90.0,-2*scale[3],scale[3]);
'for' i←1 'step' 1 'until' n 'do'  'for' j←3,2 'do'
 hgprectt(plot[19,i]+0.98,plot[3,i]/scale[3]+12.98,0.04,0.04,0.0,j);

 'for' i←1 'step' 1 'until' n 'do'
```

```
hgpsymblt(plot[19,i]+0.98,(plot[5,i]*plot[1,i]*(l+b+3.5)/(b+3.5)/scale[3])+ 2.965,0.07,'('x')',0.0,1);

hgpaxist(1.0,17.0,'('%')',-1,8.0,0.0,0.0,8.0);
hgpaxist(1.0,16.0,'('MKNE%ANPO')',9,5.0,90.0,-scale[4],scale[4]);
'for' i←1 'step' 1 'until' n 'do'  'for' j←3,2 'do'
hgprectt(plot[ 9,i]+0.98,plot[4,i]/scale[4]+16.98,0.04,0.04,0.0,j);

hgpaxist(1.0,23.0,'('%')',-1,8.0,0.0,0.0,8.0);
hgpaxist(!.0,21.0,'('KNEE%COFP%HIPD')',14,3.0,90.0,-2*scale[5],scale[5]);
'for' i←1 'step' 1 'until' n 'do'  'for' j←3,2 'do'
hgprectt(plot[19,i]+0.98,plot[5,i]/scale[5]+22.98,0.04,0.04,0.0,j);

hgpaxist( .0,24.0,'('%')',-1,8.0,0.0,0.0,8.0);
hgpaxist(1.0,24.0,'('KNEE% NGL')',9,3.0,90.0,0.0,scale[6]);
'for' i←1 'step' 1 'until' n 'do'  'for' j←3,2 'do'
hgprectt(plot[19,i]+0.98,plot[6,i]/scale[6]+ 3.98,0.04,0.04,0.0,j);

hgpaxist(10.0,22.0,'('ANKL%COOD%HORZ')',-14,8.0,0.0,entier(plot[12,1]),1.0);
hgpaxist(10.0,22.0,'('ANKL%COOD%VERT')',14,5.0,90.0,scale[ 3],1.0);
'for' i←1 'step' 1 'until' n 'do'  'for' j←3,2 'do'
hgprectt(plot[ 2,i]-entier(plot[ 2,1])+9.98,plot[13,i]-scale[13]+21.98,0.04,0.04,0.0,j);

hgpaxiSt(10.0,17.0,'('%')',-1,8.0,0.0,0.0,8.0);
hgpaxist( 0.0,17.0,'('COFP%PROG')',9,5.0,90.0,entier(plot[11,1]),3.0);
'for' i←1 'step' 1 'until' n 'do'  'for' j←3,2 'do'
hgprectt(plot[ 9,i]+9.98,plot[ 1,i]/3.0-entier(plot[11,1])/3.0+ 6.98,0.04,0.04,0.0,j);

hgpaxist(10.0,14.5,'('%')',-1,8.0,0.0,0.0,8.0);
hgpaxist(10.0,12.0,'('SHNK% NGL')',9,5.0,90.0,-2.5*scale[10],scale[10]);
'for' i←1 'step' 1 'until' n 'do'  'for' j←3,2 'do'
hgprectt(plot[19,i]+9.98,plot[10,i]/scale[ 0]+14.48,0.04,0.04,0.0,j);

hgpaxist(10.0,10.5,'('%')',-1,8.0,0.0,0.0,8.0);
hgpaxist( 0.0,9.0,'('TORQ')',4,3.0,90.0,-1.5*scale[9],scale[9]);
'for' i←1 'step' 1 'until' n 'do'  'for' j←3,2 'do'
hgprectt(plot[ 9,i]+9.98,plot[9,i]/scale[9]+10.48,0.04,0.04,0.0,j);

hgpaxist(10.0,7.5,'('%')',-1,8.0,0.0,0.0,8.0);
hgpaxist( 0.0,6.0,'('HORZ% NPO%FORC')',14,3.0,90.0,-1.5*scale[8],scale[8]);
```

```
'for' i←1 'step' 1 'until' n 'do'  'for' j←3,2 'do'
hgprectt(plot[19,i]+9.98,plot[8,i]/scale[8]+7.48,0.04,0.04,0.0,j)+;

hgpaxist(10.0,1.0,'('PERC%WALK%CYCL')',-14,8.0,0.0,0.0,8.0);
hgpaxist(10.0,1.0,'('VERT%FORC')',9,5.0,90.0,0.0,scale[7]);
'for' i←1 'step' 1 'until' n 'do'  'for' j←3,2 'do'
hgprectt(plot[19,i]+9.98,plot[7,i]/scale[7]+0.98,0.04,0.04,0.0,j);

hgpaxist(19.0,5.0,'('PERC%WALK%CYCL')',-14,8.0,0.0,0.0,8.0);
hgpaxist(19.0,1.0,'('STAB%DIST%DZIN')',14,5.0,90.0,-4*scale[14],scale[14]);
'for' i←1 'step' 1 'until' n 'do'  'for' j←3,2 'do'
hgprectt(plot[19,i]+18.98,plot[14,i]/scale[14]+4.98,0.04,0.04,0.0,j);

hgpaxist(19.0,10.0,'('%')',-1,8.0,0.0,0.0,8.0);
hgpaxist(19.0,6.0,'('MANK%ANPO')',9,5.0,90.0,-4*scale[15],scale[15]);
'for' i←1 'step' 1 'until' n 'do'  'for' j←3,2 'do'
hgprectt(plot[19,i]+18.98,plot[15,i]/scale[15]+9.98,0.04,0.04,0.0,j);

hgpaxist(19.0,13.0,'('%')',-1,8.0,0.0,0.0,8.0);
hgpaxist(19.0,11.0,'('MANK%MELA')',9,5.0,90.0,-2*scale[16],scale[16]);
'for' i←1 'step' 1 'until' n 'do'  'for'j←3,2 'do'
hgprectt(plot[19,i]+ 8.98,plot[16,i]/scale[16]+12.98,0.04,0.04,0.0,j);

hgpaxist(19.0,18.0,'('%')',-1,8.0,0.0,0.0,8.0);
hgpaxist(19.0,16.0,'('MKNE%MELA')',9,5.0,90.0,-2*scale[17],scale[17]);
'for' i←1 'step' 1 'until' n 'do'  'for' j←3,2 'do'
hgprectt(plot[19,i]+ 8.98,plot[17,i]/scale[17]+ 7.98,0.04,0.04,0.0,j);

hgpaxist(19.0,23.0,'('%')',-1,8.0,0.0,0.0,8.0);
hgpaxist(19.0,21.0,'('MHIP%MELA')',9,5.0,90.0,-2*scale[18],scale[18]);
'for' i←1 'step' 1 'until' n 'do'  'for' j←3,2 'do'
hgprectt(plot[19,i]+ 8.98,plot[18,i]/scale[18]+22.98,0.04,0.04,0.0,j);

hgplott( 2.0,28.0,3,0);
s←read;
'if' s= 1 'then' 'Goto' newset
'end';
closegp;
'end';
```

```
'PROGRAM'(PB0316027PBO SCHEFFES METHOD OF MULTIPLE COMPARISONS)
'INPUT'O=CRO
'OUTPUT'O=LPO
'BEGIN'
'COMMENT' THE PROGRAM ALLOWS AN ANALYSIS OF VARIANCE TO BE MADE BETWEEN
ANY M VARIABLES WITH A MAXIMUM OF NMAX REPLICATES OF EACH VARIABLE,
TAKEN IN PAIRS. THE F VALUES FOR THE 0.1%
,1%, AND5% LEVELS OF SIGNIFICANCE ARE READ IN AS FC1, FC2, AND FC3
RESPECTIVELY.
THE REPLICATES AND EFFECT VALUES ARE READ IN AS N[I] AND A[I,J] RESP.
FOR FULL DETAILS OF THE TECHNIQUE SEE "SCHEFFE,H(1953) A METHOD FOR
JUDGING ALL CONTRASTS IN THE ANALYSIS OF VARIANCE. BIOMETRIKA,40,87-104;
'INTEGER' N,M,I,J,S,NTOTAL,NMAX,K;
'REAL' TS,TWS,SW,MSW,L,D,FC1,FC2,FC3;
NEWSET: WRITE TEXT ('(''('P')'COMPARISONS%FOR%THE%SIX%KNEE%
MECHANISMS%OF')'); COPYTEXT('(';')'); NEWLINE(6);
M←READ; NMAX←READ; FC1←READ; FC2←READ; FC3←READ;
'BEGIN'
'ARRAY' S,MT,T[1:M], A[1:M,1:NMAX];
'INTEGER''ARRAY' N[1:M];
NTOTAL←0;
'FOR' I←1 'STEP' 1 'UNTIL' M 'DO'
'BEGIN'
N[I]←READ; NTOTAL←NTOTAL+N[I]; T[I]←0;
'END';
'FOR' I←1 'STEP' 1 'UNTIL' M 'DO'
'BEGIN'
T[I]←0; COPYTEXT('(';')'); SPACE(4);
'FOR' J←1 'STEP' 1 'UNTIL' N[I] 'DO'
'BEGIN'
A[I,J]←READ; PRINT(A[I,J],4,0);
T[I]←T[I]+A[I,J]; TS←TS+A[I,J]*A[I,J];
'END';
TWS←TWS+T[I]*T[I]/N[I]; MT[I]←T[I]/N[I]; NEWLINE(2);
'END';
SW←TS-TWS; MSW←SW/(NTOTAL-M);
'FOR' I←1 'STEP' 1 'UNTIL' M 'DO'
S[I]←(M-1)*MSW/N[I];
WRITE TEXT ('(''('2C')'COMPARISON%ACTUAL%0.1%LEVEL%%1%LEVEL%%5%LEVEL
'('2C')'')');
'FOR' I←1 'STEP' 1 'UNTIL' M-1 'DO'
```

```
'FOR' J←M 'STEP' -1 'UNTIL' I+1 'DO'
'BEGIN' L←MT[I]-MT[J];
PRINT(I,2,0); WRITE TEXT('('%V%')'); PRINT(J,2,0); PRINT(L,4,2);
D←SQRT((S[I]+S[J])*FC1);  PRINT(D,4,2);
D←SQRT((S[I]+S[J])*FC2);  PRINT(D,4,2);
D←SQRT((S[I]+S[J])*FC3);  PRINT(D,4,2); NEWLINE(2);
'END';
'END';
S←READ; 'IF' S=1 'THEN' 'GOTO' NEWSET;
'END';
```

APPENDIX V

Detailed Analysis of Experimental Accuracy

V.1 Calibration Coefficients

For calibrating the pylon in bending and torque, dead weights are applied to a lever arm of known length, k. The error in the weights is of the order of $\pm$ 0.5% and the reading error of the resulting output $\pm$ 0.1 mm. Since a large number of readings are taken, the effective error of the slope of the curve is very small. By far the largest contribution is due to the error in k, Δk.

Therefore the error in a calibration factor a_{ij}, Δa_{ij} is given by:-

$$\frac{\Delta a_{ij}}{a_{ij}} = \frac{\Delta k}{k} \qquad \ldots\ldots \quad (V.1)$$

The length of the lever arm used was about 6 in. and $\Delta k = \pm 0.01$ in.

For the A/P bending moment gauges, $a_{11} = a_{33} = 1.5$

For the M/L " " " $a_{22} = a_{44} = 3$

For the torque gauges, $a_{66} = 5$

For the axial load gauges, $a_{55} = 10$

$\therefore$ From equation (V.1),

$$\Delta a_{11} = \Delta a_{33} = \pm 0.003 \qquad \ldots\ldots \quad (V.2)$$

$$\Delta a_{22} = \Delta a_{44} = \pm 0.005 \qquad \ldots\ldots \quad (V.3)$$

$$\Delta a_{66} = \pm 0.01 \qquad \ldots\ldots \quad (V.4)$$

The error in the calibration factor for the axial load Δa_{55}, is negligible as it was calibrated by dead weights only.

With the goniometer, the main source of error is due to the resulution of the potentiometer, i.e. ± 0.005 radiam or $\pm 0.3^{\circ}$.

V.2 The Accuracy of the Rationalised Gauge Readings

For the analysis, it is assumed, that the errors are normally distributed, and that only the principle calibration coefficient affects the magnitude of the error. In general for any function $z = f(x, y, w \text{ etc......})$

$$\frac{\Delta Z}{Z} = \sqrt{\left(\frac{\partial x}{\partial Z}\right)^2 \Delta x^2 + \left(\frac{\partial y}{\partial Z}\right)^2 \Delta y^2 + \left(\frac{\partial w}{\partial Z}\right)^2 \Delta w^2 + \text{etc....}} \quad (V.5)$$

For the derivation of this equation, the reader is referred to Scarborough (1966).

Rationalisation of a reading, Z, may be defined as:-

$$Z = \frac{var - var_o}{a_{ij}}$$

where var is the value obtained from the gauges under load var_o is the zero reading of the gauges.

It is much easier to measure var_o than var since the trace is always at right angles to the time interval traces. Further, the error in var_o is a systemic error, as defined in Chapter 3 for any particular stride. To differentiate between these two the following terminology will be adopted:-

$$var = e = \pm 2 \text{ unit}$$

$$var_o = e' = \pm 1 \text{ unit}$$

The exception to this rule is the rationalisation of θ where the main error is not the reading error but the resolution of the potentiometer.

Using equation (V.5),

$$Z = \frac{1}{a_{ij}} \sqrt{e^2 + e'^2 + Z^2 . \ \Delta a_{ij}^2} \quad \text{......} \ (V.6)$$

Let $M_Y = M_{UY}$ or M_{LY} and $M_Z = M_{UZ}$ or M_{LZ}

$$\Delta M_Z = \pm \frac{1}{1.5}\sqrt{e^2 + e'^2 + (0.002M_Z)^2} \text{ lbf. in. } \quad \ldots. \text{ (V.7)}$$

$$\Delta M_Y = \pm \frac{1}{3}\sqrt{e^2 + e'^2 + (0.005M_Y)^2} \text{ lbf. in. } \quad \ldots. \text{ (V.8)}$$

$$\Delta T = \pm \frac{1}{5}\sqrt{e^2 + e'^2 + (0.01\, T)^2} \text{ lbf. in. } \quad \ldots. \text{ (V.9)}$$

$$\Delta f_x = \pm \frac{1}{10}\sqrt{e^2 + e'^2} \text{ lbf. in. } \quad \ldots. \text{ (V.10)}$$

$$\Delta \theta = \pm 0.005\sqrt{1 + 1 + (0.9\theta)^2} \text{ radiam } \quad \ldots. \text{ (V.11)}$$

V.3 The Accuracy of the Output Force Actions

In any expression of the form:-

$$Z = \sqrt{x^2 + y^2}$$

assume that $x \leqslant \frac{y}{2}$, then the maximum value of $Z = \sqrt{(\frac{y}{2})^2 + y^2}$

i.e. $Z = 1.12y$

Therefore only a maximum of 10% inaccuracy is caused by assuming that $Z = y$

Values of parameters used in the analysis are listed below.

Maximum $h = 8$ in. $\quad g = 3.2$ in. $\quad \Delta g = 1.2$ in.

$l = 16$ in. $\quad \Delta l = \pm 0.1$ in.

$b = 15$ in. $\quad \Delta b = \pm 0.1$ in.

$a_Y = a_Z = 12$ in. $\quad \Delta a_Z = \pm 0.05$ in.

$b_Z = 1.69$ in. $\quad \Delta b_Z = \pm 0.04$ in.

$c_Z = 1.9$ in. $\quad \Delta c_Z = \pm 0.05$ in.

$b_Y = 1.77$ in. $\quad \Delta b_Y = \pm 0.05$ in.

Maximum angle of knee flexion in stance phase is about 35°.

i.e. $\theta = 0.61$ radiams, $\sin\theta = 0.57$, $\cos\theta = 0.82$

therefore $\theta = \sin\theta$ (within tolerable limits).

The typical maximum value of the A/P shear force is 30 lbf.

" " " " " " M/L " " is 20 lbf.

Maximum value of:- $(M_{UZ} - M_{LZ}) = 30 \times 1.7 = 51$ lbf. in.

Maximum value of:- $(M_{UY} - M_{LY}) = 20 \times 1.8 = 36$ lbf. in.

When $\theta = 0$, typical maximum values are:-

$T = 90$ lbf. in.

$M_{UZ} = 1000$ lbf. in.

$M_{LZ} = 1000$ lbf. in.

$f_x = 250$ lbf.

$M_{UY} = 500$ lbf. in.

$M_{LY} = 400$ lbf. in.

The contribution to the error of a force action, F, due to a variable Z will be denoted by $\Delta F(Z)$. $R\,\Delta F(Z)$ being random, $S\,\Delta F(Z)$ being systemic

V.3.1 T, the torque about the long axis

Equation (V.9) gives:- a random error of $\pm$ 0.4 lbf. in.

a systemic error per stride of ± 0.2 lbf. in. if $T < 50$ lbf. in.

and ± 0.3 lbf. in. if $50 < T < 90$ lbf. in.

V.3.2 The A/P knee moment, M_{KZ}

Equation 4.8 gives $M_{KZ} = M_{UZ} + \frac{a_Z}{b_Z} (M_{UZ} - M_{LZ})$

$$\therefore \Delta M_{KZ}(M_{UZ}) = \frac{\partial M_{KZ}}{\partial M_{UZ}} \cdot \Delta M_{UZ}$$

$\therefore$ Using equation (V.7):

$$\Delta M_{KZ}(M_{UZ}) = \pm\frac{1}{1.5}\left(1 + \frac{a_Z}{b_Z}\right)\sqrt{e^2 + e'^2 + (0.002\, M_{UZ})^2} \text{ lbf. in.}$$

$$= \pm 5.4\sqrt{e^2 + e'^2 + (0.002\, M_{UZ})^2} \text{ lbf. in.}$$

Similarly using equation (V.7),

$$\Delta M_{KZ}(M_{LZ}) = \pm 4.7\sqrt{e^2 + e'^2 + (0.002\, M_{LZ})^2} \text{ lbf. in.}$$

Further:-

$$\Delta M_{KZ}(a_Z) = \pm 0.03\,(M_{UZ} - M_{LZ}) \text{ lbf. in.}$$

$$\Delta M_{KZ}(b_Z) = \pm 0.17\,(M_{UZ} - M_{LZ}) \text{ lbf. in.}$$

When applying equation (V.5), $\Delta M_{KZ}(b_Z) > 2 \times \Delta M_{KZ}(a_Z)$

and is, therefore, dominant.

$$S\,\Delta M_{KZ}(M_{UZ}) = \pm 5.4\sqrt{1 + (0.002\, M_{UZ})^2} \text{ lbf. in.}$$

$$= \pm 5.4 \text{ lbf. in. if } M_{UZ} < 250 \text{ lbf. in.}$$

and a maximum of $\pm$ 12 lbf. in., if M_{UZ} = 1000 lbf. in.

$$S\,\Delta M_{KZ}(M_{LZ}) = \pm 4.7\sqrt{1 + (0.002\, M_{LZ})^2} \text{ lbf. in.}$$

$$= \pm 4.7 \text{ lbf. in. if } M_{LZ} < 250 \text{ lbf. in.}$$

and a maximum of $\pm$ 11 lbf. in., if M_{LZ} = 1000 lbf. in.

$$S\,\Delta M_{KZ}(b_Z) = \pm 0.17\,(M_{UZ} - M_{LZ}) \text{ lbf. in.}$$

= a maximum of $\pm$ 8.5 lbf. in., if $(M_{UZ} - M_{LZ})$ = 50 lbf. in.

Therefore combining these various contributions according to equation (V.5), the systemic error is given by ± 7.1 lbf. in. $< S\Delta M_{KZ} < \pm 18.3$ lbf. in. and the random error by $R\Delta M_{KZ} = \pm 14$ lbf. in.

V.3.3 The A/P ankle moment, M_{AZ}

Equation 4.9 gives:-

$$M_{AZ} = M_{LZ} - \frac{c_Z}{b_Z}(M_{UZ} - M_{LZ})$$

$$S\,\Delta M_{AZ}(M_{UZ}) = \pm 0.75\sqrt{1 + (0.002\,M_{UZ})^2} \text{ lbf. in.}$$

$$= \pm 0.7 \text{ lbf. in., if } M_{UZ} < 250 \text{ lbf. in.}$$

and a maximum of ± 1.7 lbf. in. if $M_{UZ} = 1000$ lbf. in.

$$S\,\Delta M_{AZ}(M_{LZ}) = \pm 1.4\sqrt{1 + (0.002\,M_{LZ})^2} \text{ lbf. in.}$$

$$= \pm 1.4 \text{ lbf. in. if } M_{LZ} < 250 \text{ lbf. in.}$$

and a maximum of ± 3.1 lbf. in. if $M_{LZ} = 1000$ lbf. in.

$$S\,\Delta M_{AZ}(c_Z \text{ and } b_Z) = \pm 0.038\,(M_{UZ} - M_{LZ}) \text{ lbf. in.}$$

$$= \text{a maximum of } \pm 1.3 \text{ lbf. in. if } M_{UZ} - M_{LZ} = 50 \text{ lbf. in.}$$

Therefore, the systemic error is given by $\pm 1.6 \text{ lbf. in.} < S\Delta M_{AZ} < \pm 3.2$ lbf. in.

and the random error by $R\Delta M_{AZ} = \sqrt{(1.4)^2 + (0.75)^2} = \pm 3.2$ lbf. in.

V.3.4 The A/P hip moment, M_{HZ}

Equation 4.10 gives:-

$$M_{HZ} = M_{UZ} + f_x \cdot l \cdot \sin\theta + \frac{(a_Z + l.\cos\theta)}{b_Z}(M_{UZ} - M_{LZ})$$

$$S\Delta M_{HZ}(M_{UZ}) = \pm 11.5\sqrt{1 + (0.002\,M_{UZ})^2} \text{ lbf. in. (if } \theta = 0)$$

$$= \pm 11.5 \text{ lbf. in. if } M_{UZ} < 250 \text{ lbf. in.}$$

and a maximum of ± 25.5 lbf. in. if $M_{UZ} = 1000$ lbf. in.

$$S\,\Delta M_{HZ}(M_{LZ}) = \pm 11\sqrt{1 + (0.002\,M_{LZ})^2} \text{ lbf. in. (if } \theta = 0)$$

$$= \pm 11 \text{ lbf. in. if } M_{LZ} < 250 \text{ lbf. in.}$$

and a maximum of ± 25 lbf. in. if $M_{LZ} = 1000$ lbf. in.

$S\,\Delta M_{HZ}(a_Z) = \pm 0.03\,(M_{UZ} - M_{LZ})$ lbf. in., i.e. a maximum of ± 1.5 lbf. in.

$$S\,\Delta M_{HZ}(l) = \pm (0.1\,f_x.\sin\theta + 0.06\,(M_{UZ} - M_{LZ})\cos\theta) \text{ lbf. in.}$$

Assuming that an approximate relationship between f_x and θ is:-

$f_x = 250 - 430\,\theta$ (giving a maximum of 250 for f_x when $\theta = 0$ and a maximum of 0.57 for θ when $f_x = 0$) it can be shown that the maximum value of $0.1\, f_x.\sin\theta + 0.06\,(M_{UZ} - M_{LZ})\cos\theta$ is:- ± 6.5 lbf. in.

$S\,\Delta\, M_{HZ}(b_Z) = \pm 0.39\,(M_{UZ} - M_{LZ})$ lbf. in. (maximum at $\theta = 0$), i.e. a maximum of $\pm$ 19.5 lbf. in.

$$S\,\Delta\, M_{HZ}(\theta) = \pm\, 0.08\, f_x.\cos\theta - 0.05\,(M_{UZ} - M_{LZ})\sin\theta)\sqrt{1 + 0.81\,\theta^2} \text{ lbf. in.}$$

since $0.9\,\theta \leqslant 0.5$, $\sqrt{1 + 0.81\,\theta^2} = 1$ (within 10%)

$\therefore$ $S\,\Delta\, M_{HZ}(\theta) = \pm\,(20\cos\theta - 2.5\sin\theta)$ lbf. in. i.e. a maximum of $\pm$ 20 lbf. in.

$S\,\Delta\, M_{HZ}(f_x) = \pm\, 1.6\sin\theta$ lbf. in. i.e. a maximum of $\pm$ 1.6 lbf. in.

Total systemic error is given by $\pm$ 16 lbf. in. $< S\,\Delta\, M_{HZ} < \pm$ 50.5 lbf. in.

The random error $R\,\Delta\, M_{HZ}$

$$= \sqrt{(11.4e)^2 + (11e)^2 + 20^2} \text{ lbf. in.}$$

$$= \pm\, 37.6 \text{ lbf. in.}$$

V.3.5 The M/L hip moment $M_{HY'}$

Equation 4.20 gives:-

$$M_{HY'} = f_z\sqrt{(h + l\sin\theta)^2 + (b - g + l\cos\theta)^2} \text{ lbf. in.}$$

When $\theta = 0$, maximum value of $M_{HY'} = f_z\sqrt{8^2 + 34^2}$ lbf. in. $= 34\, f_z$ lbf.in.

When $\theta = 0.61$ radiams, $M_{HY'} = f_z\sqrt{17^2 + 31^2}$ lbf. in. $= 35\, f_z$ lbf. in.

Therefore $M_{HY'}$ may be assumed equal to $34\, f_z$ lbf. in. for the purposes of the analysis, with respect to f_z.

$S\,\Delta\, M_{HY'}(b_Y) = \pm\, 0.54\,(M_{UY} - M_{LY})$ lbf. in., i.e. a maximum of $\pm$ 19.4 lbf. in.

$$S\,\Delta M_{HY'}(M_{UY}) = S\,\Delta M_{HY'}(M_{LY}) = \pm 6.4\sqrt{1 + (0.005\,M_Y)^2}\ \text{lbf. in.}$$

i.e. constant at $\pm$ 6.4 lbf. in. if $M_Y < 100$ lbf. in.

and a maximum of $\pm$ 17.2 lbf. in., if M_Y = 500 lbf. in.

$$S\,\Delta M_{HY'}(l) = \pm \frac{f_z}{34} \times 0.1 \left[(h + l \sin\theta)\sin\theta + (b - g + l\cos\theta)\cos\theta\right]\ \text{lbf. in.}$$

Even when $\theta = 0.61$ radiam, $(h + l\sin\theta)\sin\theta \ll (b - g + l\cos\theta)\cos\theta$ and

$S\,\Delta M_{HY'}(l) = \pm \dfrac{0.1\,f_z}{34}\ (b - g + l\cos\theta)\cos\theta$ lbf. in. and is maximum at $\theta = 0$.

$$\text{i.e. maximum value of } S\,\Delta M_{HY'}(l) = \pm \frac{0.1 \times 20 \times 34}{34}\ \text{lbf. in.}$$

$$= \pm\ 2\ \text{lbf. in.}$$

$$S\,\Delta M_{HY'}(\theta) = \pm \frac{f_z}{34} \times 0.005\ h\cos\theta - (b - g)\sin\theta\ \ \text{lbf. in.}$$

$$= \pm \frac{0.005\,f_z}{34}\ (8\cos\theta - 18\sin\theta)\ \text{lbf. in.}$$

when $\theta = 0$ the maximum value of $S\,\Delta M_{HY'}(\theta) = \pm 0.02$ lbf. in.

when $\theta = 0.61$ the maximum value of $S\,\Delta M_{HY'}(\theta) = \pm 0.01$ lbf. in.

$S\,\Delta M_{HY'}(g) = \pm\ 1.2\,f_z$ lbf. in.

i.e. maximum of $\pm$ 24 lbf. in.

$S\,\Delta M_{HY'}(b) = \pm 0.1\,f_z$ lbf. in.

i.e. maximum of $\pm$ 2 lbf. in.

The total systemic error is given by ± 9 lbf. in. $< S\,\Delta M_{HY'} < \pm 39$ lbf. in.

and the random error is $\pm\sqrt{2} \times 6.4\,e$ lbf. in.

$$= \pm\ 18\ \text{lbf. in.}$$

V.3.6 <u>The resultant force, R</u>

From equation 4. $\quad R = \sqrt{f_x^2 + f_y^2 + f_z^2}$.

With very few exceptions, e.g. at heel strike, $f_x \gg f_y$ and f_z and for the purposes of this discussion, $\Delta R = \Delta f_x$.

$\therefore$ The systemic error in R is given by $S \Delta R = \pm 0.1$ lbf.

and the random error by $R \Delta R = \pm 0.2$ lbf.

V.3.7 <u>The hip moment required to stabilize the knee, M_{HRZ}</u> As explained in Chapter 4, g was assumed constant in the calculation of M_{HRZ}. The effect of this inaccuracy is discussed below.

M_{HRZ} may be approximated as $\frac{P.d.(l + b - g)}{b - g}$

$$\therefore \quad \frac{\Delta M_{HRZ}(g)}{M_{HRZ}} = \frac{l.\ \Delta x}{(b-x)(l+b-g)}$$

$$= 0.05 \quad g .$$

Now from filming Δg was found to vary between 2" and 3.5", therefore the maximum value of Δg is 1.2".

$$\therefore \quad \frac{\Delta M_{HRZ}(g)}{M_{HRZ}} = 6\%$$

The only other significant source of error in M_{HRZ} is due to P. Since P is approximately equal to R, the error is:- a systemic error of ± 0.1 lbf., and a random error of ± 0.2 lbf.

$$S \Delta M_{HRZ}(P) = \pm d \frac{(l+b-g)}{b-g} \times 0.1 \quad \text{lbf.in.}$$

$$= \pm 4 \times 0.1 \text{ lbf.in.} = \pm 0.4 \text{ lbf.in.}$$

APPENDIX VI

Variations of Force Actions in all Activities

Introduction

The graphs of A/P hip moment are presented in order of knee mechanism as follows:-

S.A.	Single-Axis, Non-stabilized knee with pneumatic swing phase control (Fig. VI. 1 to Fig. VI. 16)
B.S.K.	Blatchford Stabilized knee with pneumatic swing phase control (Fig. VI. 17 to Fig. VI. 31)
O.B.	Otto Bock Safety knee (Fig. VI. 32 to Fig. VI. 46)
G.R.	Otto Bock Greissinger knee (Fig. VI. 47 to Fig. VI. 60)
U.C.B.	University of California Polycentric knee with pneumatic swing phase control (Fig. VI. 61 to Fig. VI. 75)
L.A.	Lammers knee (Fig. VI. 76 to Fig. VI. 90)

In the case of the activities; standing, sitting down and lifting and lowering a weight, the resultant load on the prosthesis is reproduced adjacent to the A/P hip moment to assist in comparing the effectiveness of the devices.

The remaining force actions are illustrated for the single axis, non-stabilized knee only, to indicate the typical variations between activities.

A/P knee moment	(Fig. VI. 91 to Fig. VI. 100)
A/P ankle moment	(Fig. VI. 101 to Fig. VI. 110)
M/L hip moment	(Fig. VI. 111 to Fig. VI. 120)
Torque	(Fig. VI. 121 to Fig. VI. 130)
Resultant load	(Fig. VI. 131 to Fig. VI. 140)

For all the activities involving cyclic variations with time, the graphs begin at heel strike and end at toe off. These points are defined as the first and last time interval traces at which the axial load gauges register a positive value of load. The cycle time for any stride is the time between the preceding toe off and toe off of the stride considered.

The beginning and end of all the other activities are defined thus:-

Stepping over an object:	Heel strike and toe off.
Standing up:	Initiation and completion of knee extension.
Sitting down:	Initiation and completion of knee flexion.
Lifting and lowering weight:	Approximate time when weight is first lifted from the floor and finally released.

An explanation of the use of the M_{HRZ} results is presented below.

If a single-axis, non-stabilized knee is incorporated in an artificial leg and a force applied between the centre of pressure on the foot and the hip joint, then the knee will collapse in flexion or hyperextension unless this force passes through the knee centre. This can be prevented by the application of a hip moment by the amputee which causes the line of action of the resultant load to pass through the knee joint. It is this moment that is referred to in the results as M_{HRZ}. Hyperextension of the knee is prevented by a check strap or stop, so collapse can only occur in flexion. Therefore, if the value M_{HRZ} is positive, i.e. an extensor moment is required to maintain stability of the knee, the knee will collapse if no hip extensor moment is exerted. Further, when knee flexion is initiated prior to toe off, the hip moment required to cause this is exactly M_{HRZ} and the two curves reproduced on the A/P hip moment graphs should intersect at this point.

If some stabilizing action is present at the knee, its effect can easily be seen by comparing the hip moment produced with that required for stability. This subject is covered in more detail in Chapter 5.

A/P HIP MOMENT IN LEVEL WALKING WITH S.A.

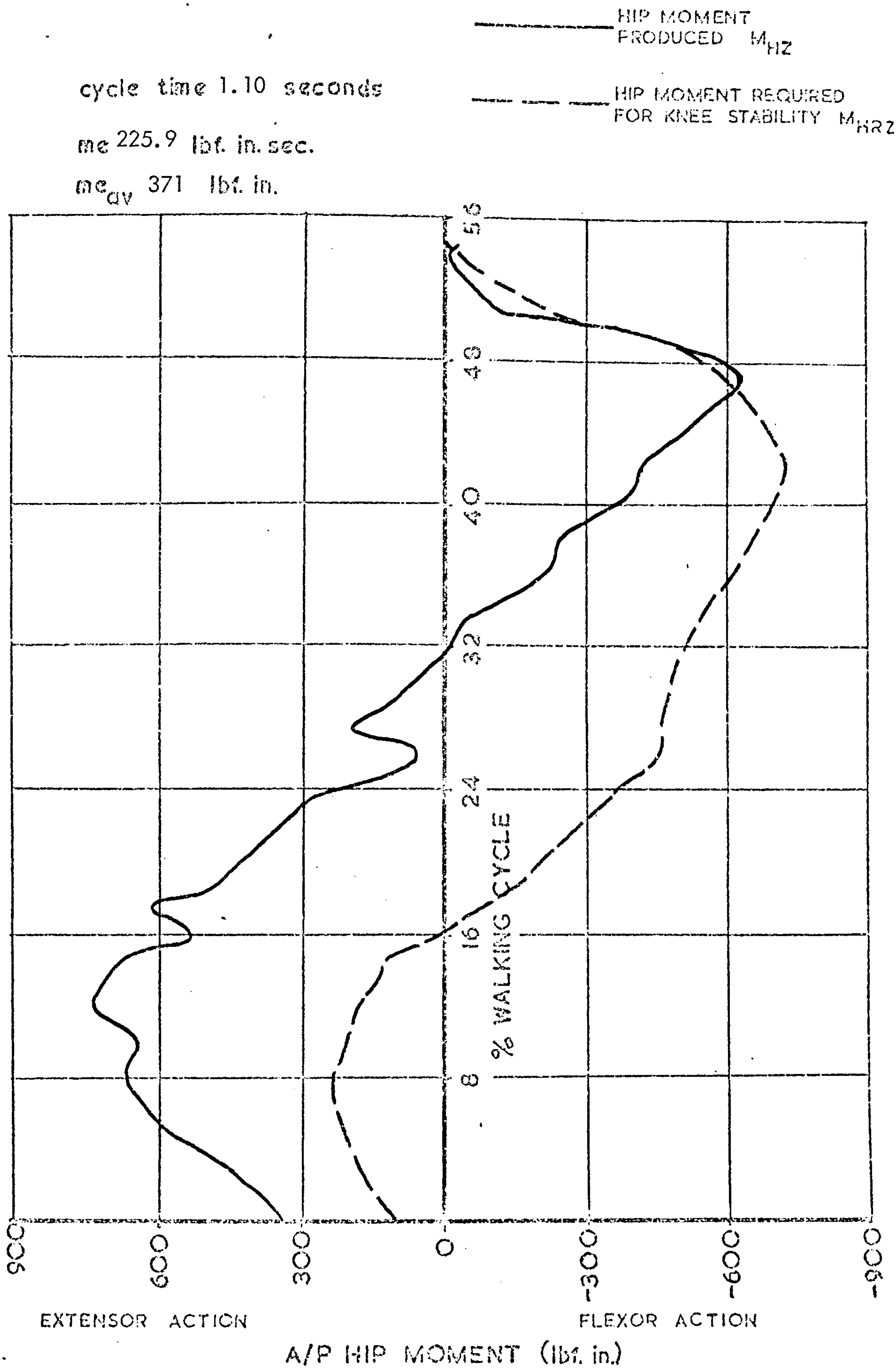


fig. VI. 1

A/P HIP MOMENT IN WALKING UP RAMP WITH S.A.

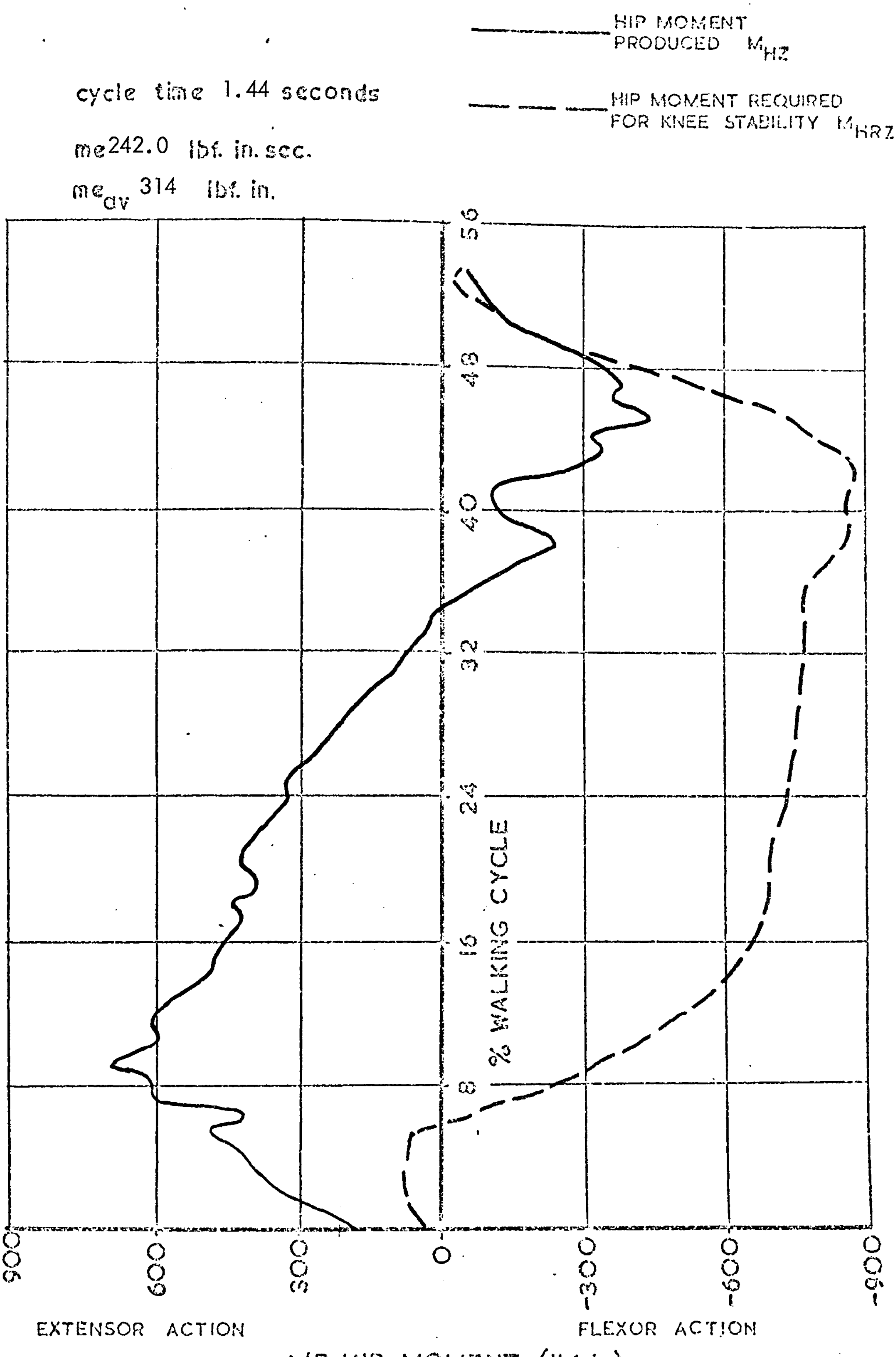


fig. VI. 2

A/P HIP MOMENT IN WALKING DOWN RAMP WITH S.A.

——————— HIP MOMENT PRODUCED M_{HZ}

— — — — HIP MOMENT REQUIRED FOR KNEE STABILITY M_{HRZ}

cycle time 1.14 seconds

me 197.2 lbf. in. sec.

me_{av} 318 lbf. in.

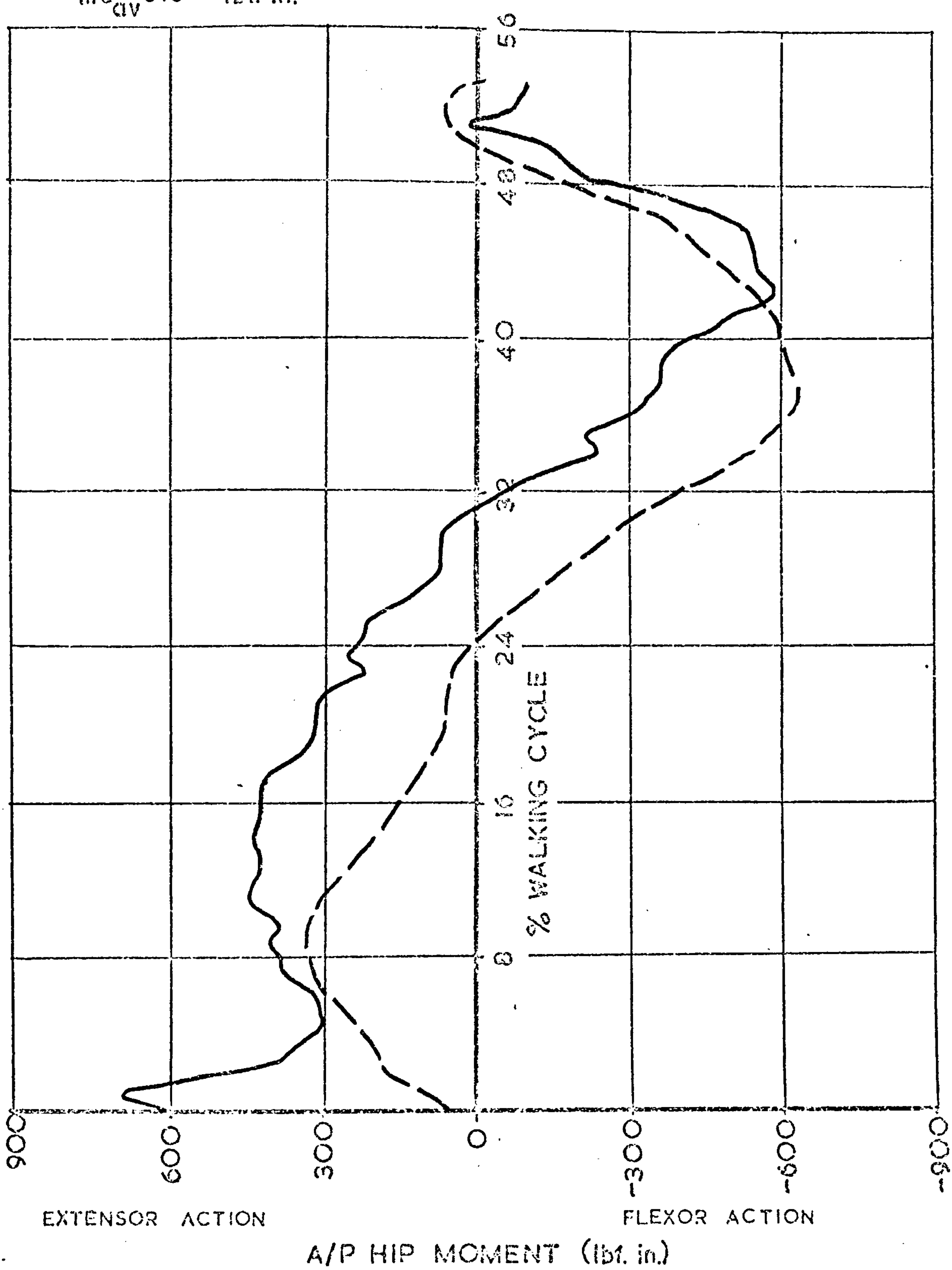


fig.VI.3

A/P HIP MOMENT IN WALKING UP STAIRS WITH S.A.

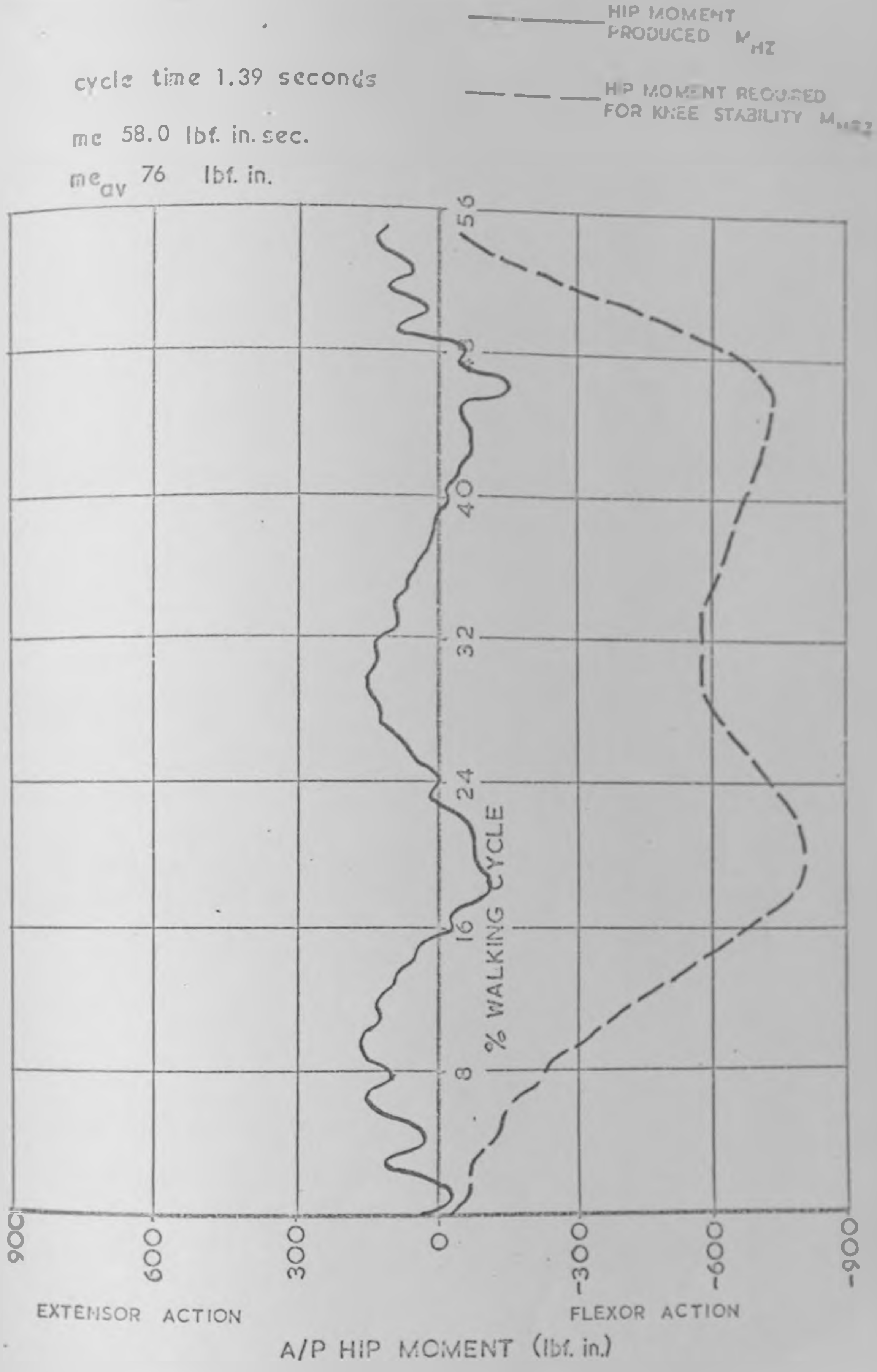


fig. VI.4

A/P HIP MOMENT IN WALKING DOWN STAIRS WITH S.A.

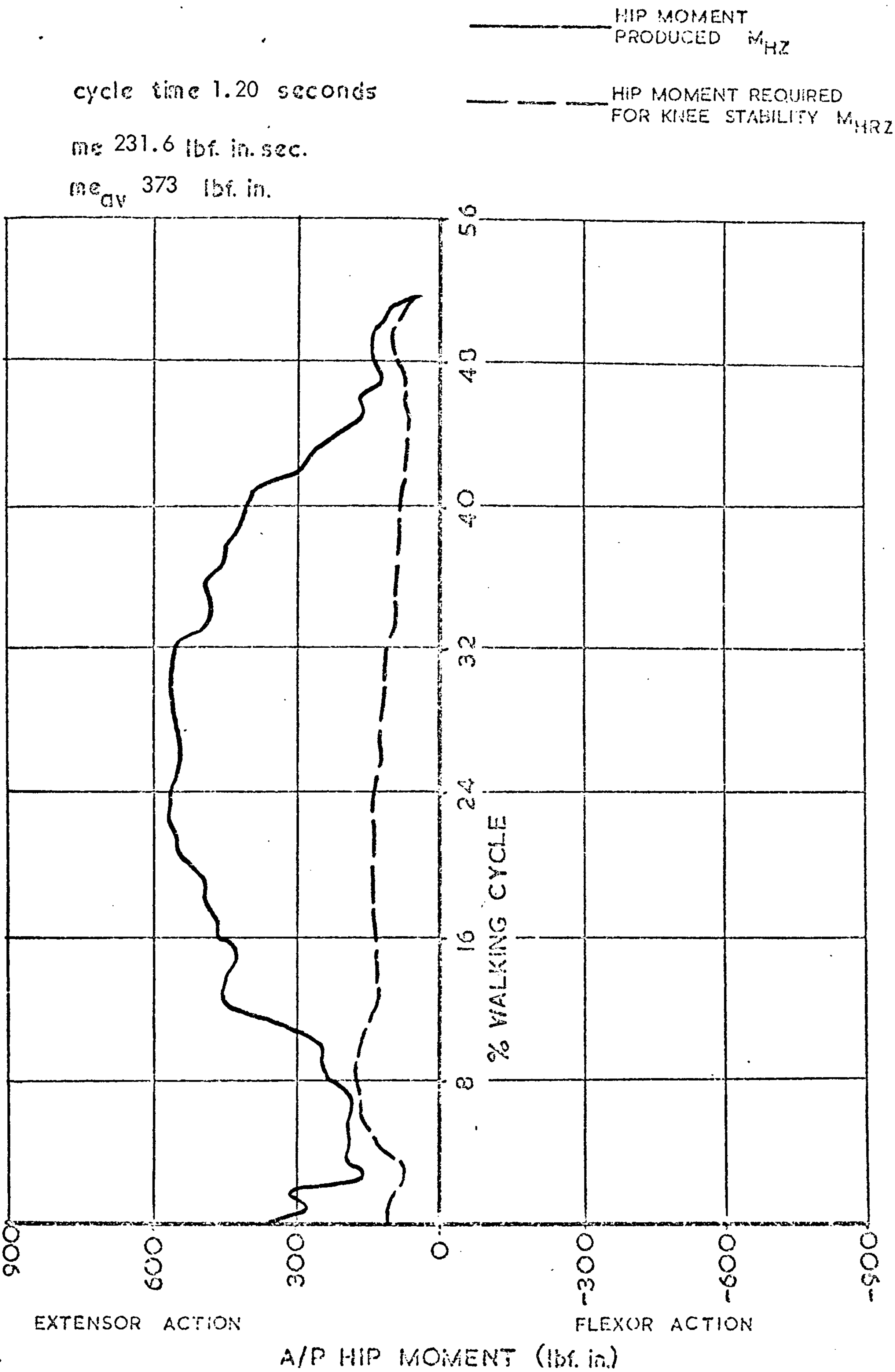


fig. VI. 5

A/P HIP MOMENT IN STEPPING OVER AN OBJECT (from a standing position) WITH S.A.

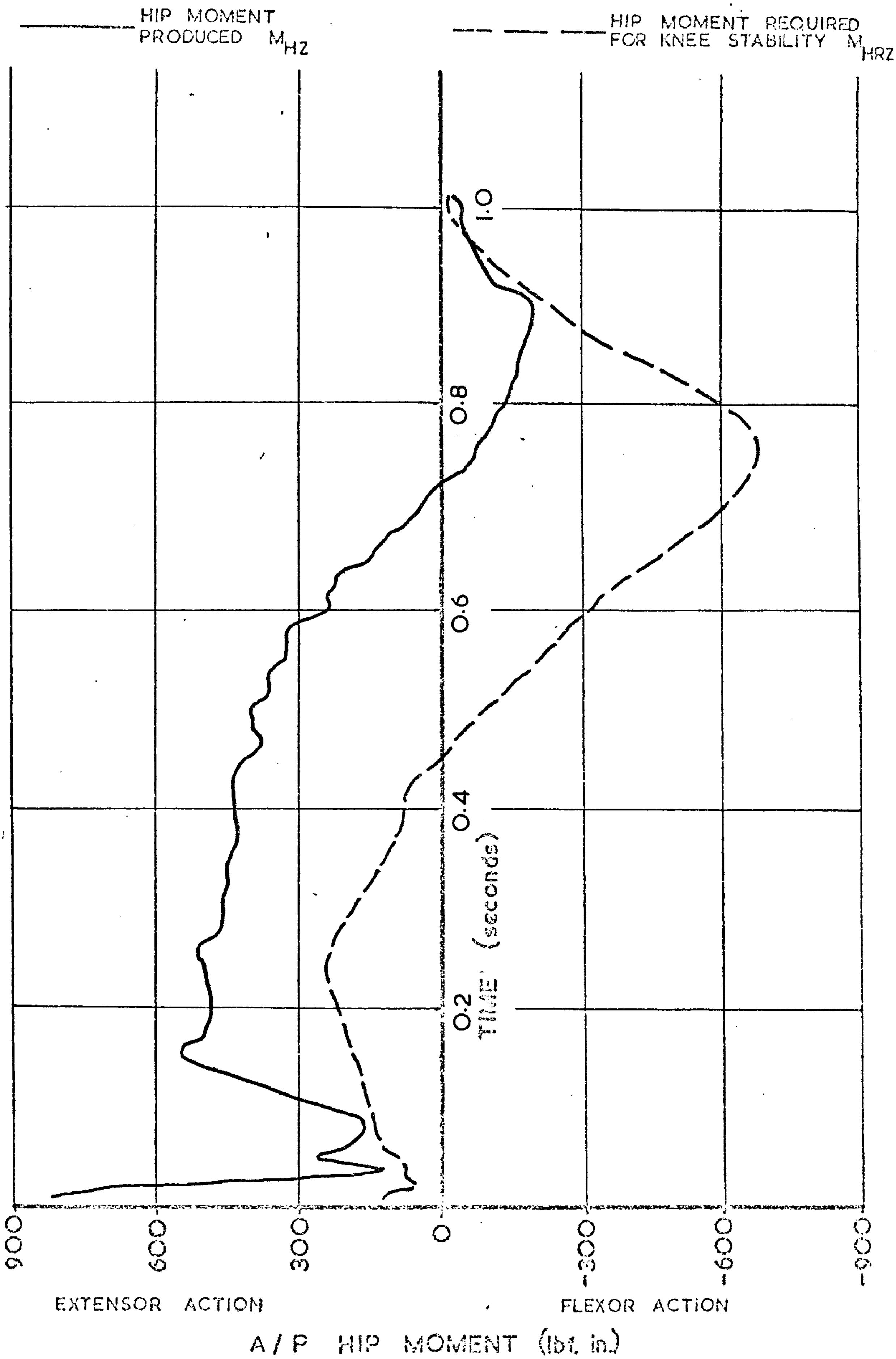


fig.VI.6

A/P HIP MOMENT IN STEPPING OVER AN OBJECT (after walking up to it) WITH S.A.

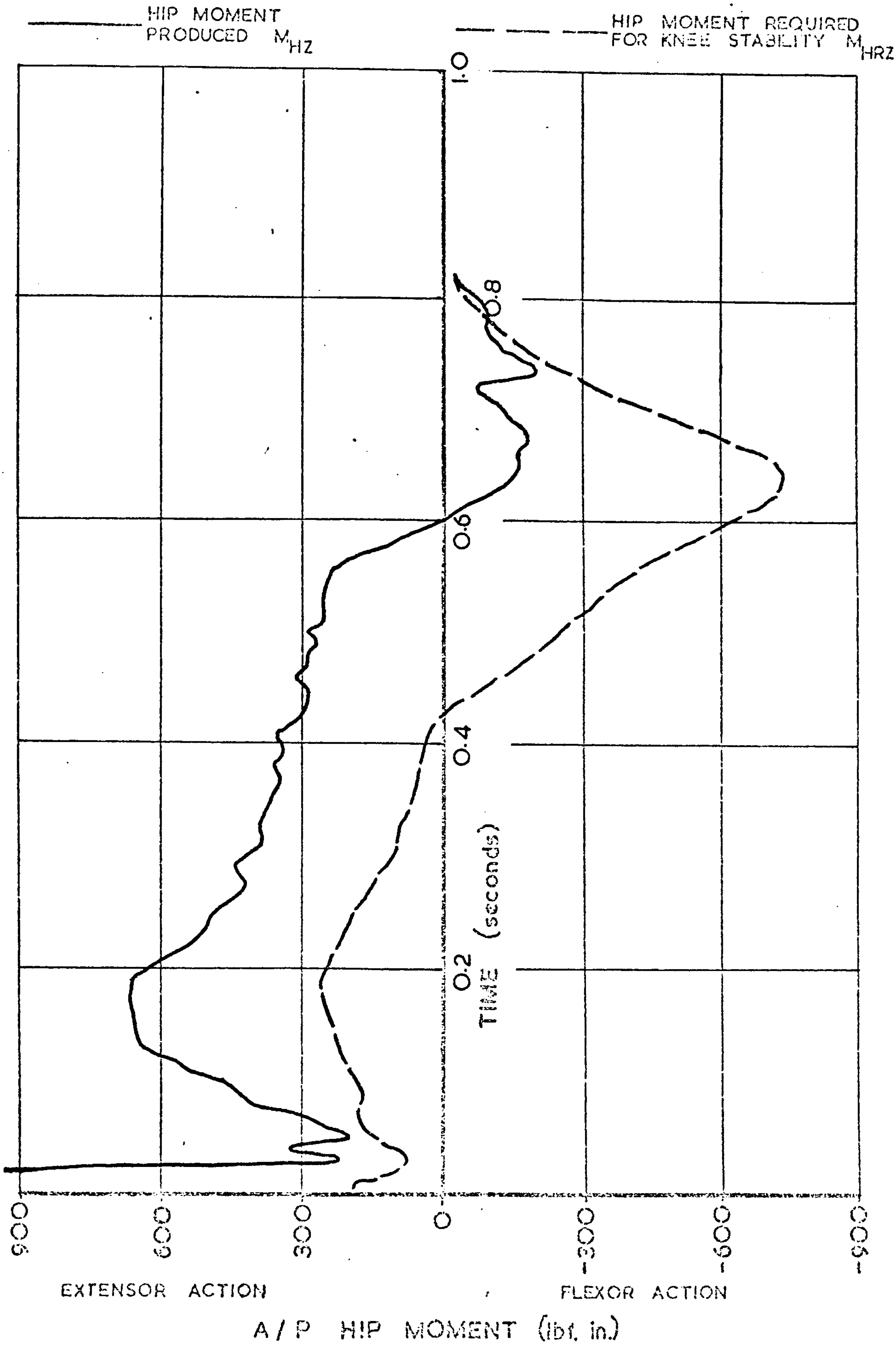


fig. VI.7

A/P HIP MOMENT IN RUNNING WITH S.A.

———— HIP MOMENT PRODUCED M_{HZ}

— — — HIP MOMENT REQUIRED FOR KNEE STABILITY M_{HRZ}

cycle time 1.09 seconds

me 132.3 lbf. in. sec.

me_{av} 294 lbf. in.

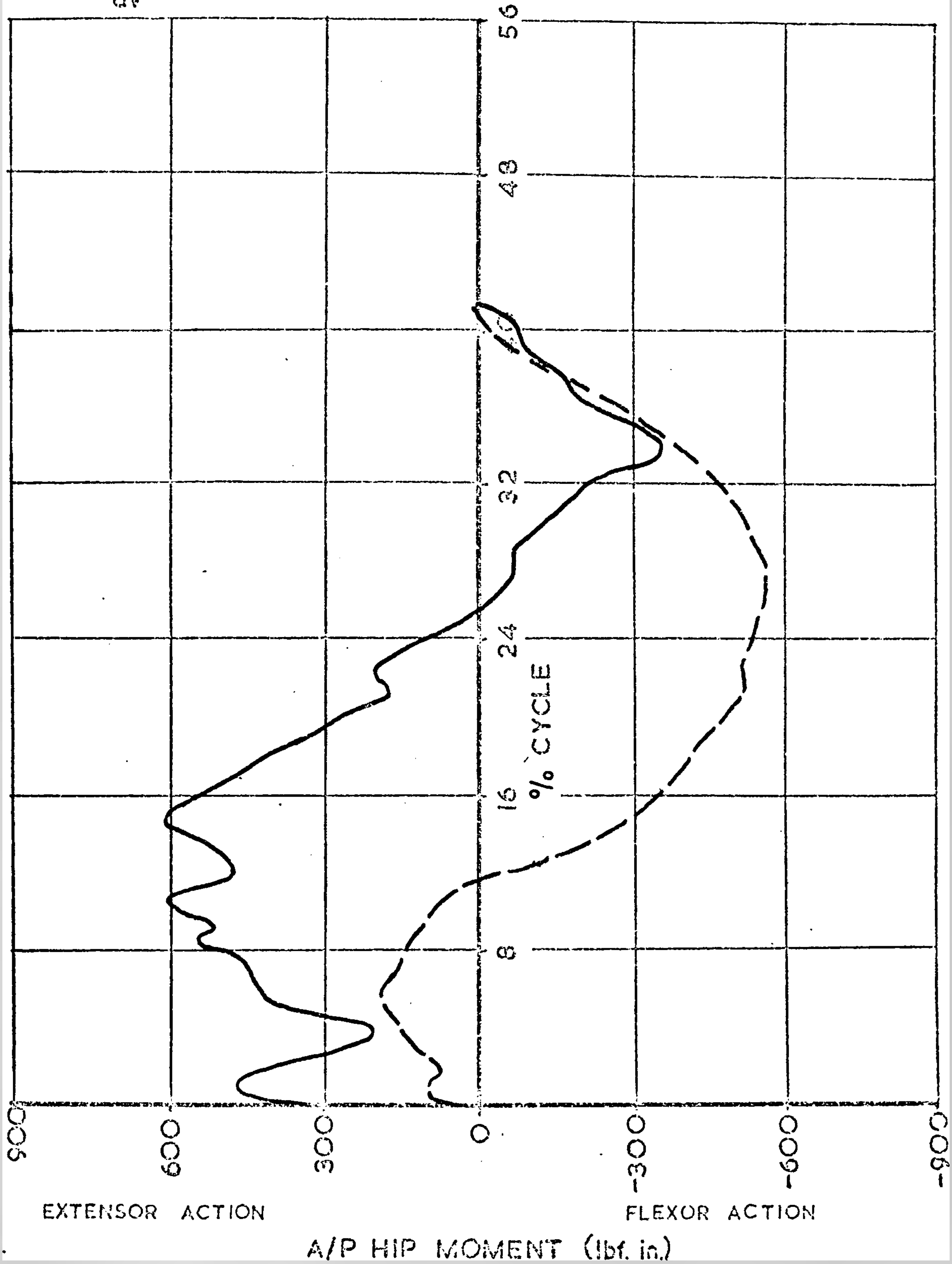


fig. VI. 8

A/P HIP MOMENT IN WALKING SIDEWAYS (Prosthesis Leading) WITH S.A.

——— HIP MOMENT PRODUCED M_{HZ}

— — — HIP MOMENT REQUIRED FOR KNEE STABILITY M_{HRZ}

cycle time 1.00 seconds

me 119.5 lbf. in. sec.

me_{av} 234 lbf. in.

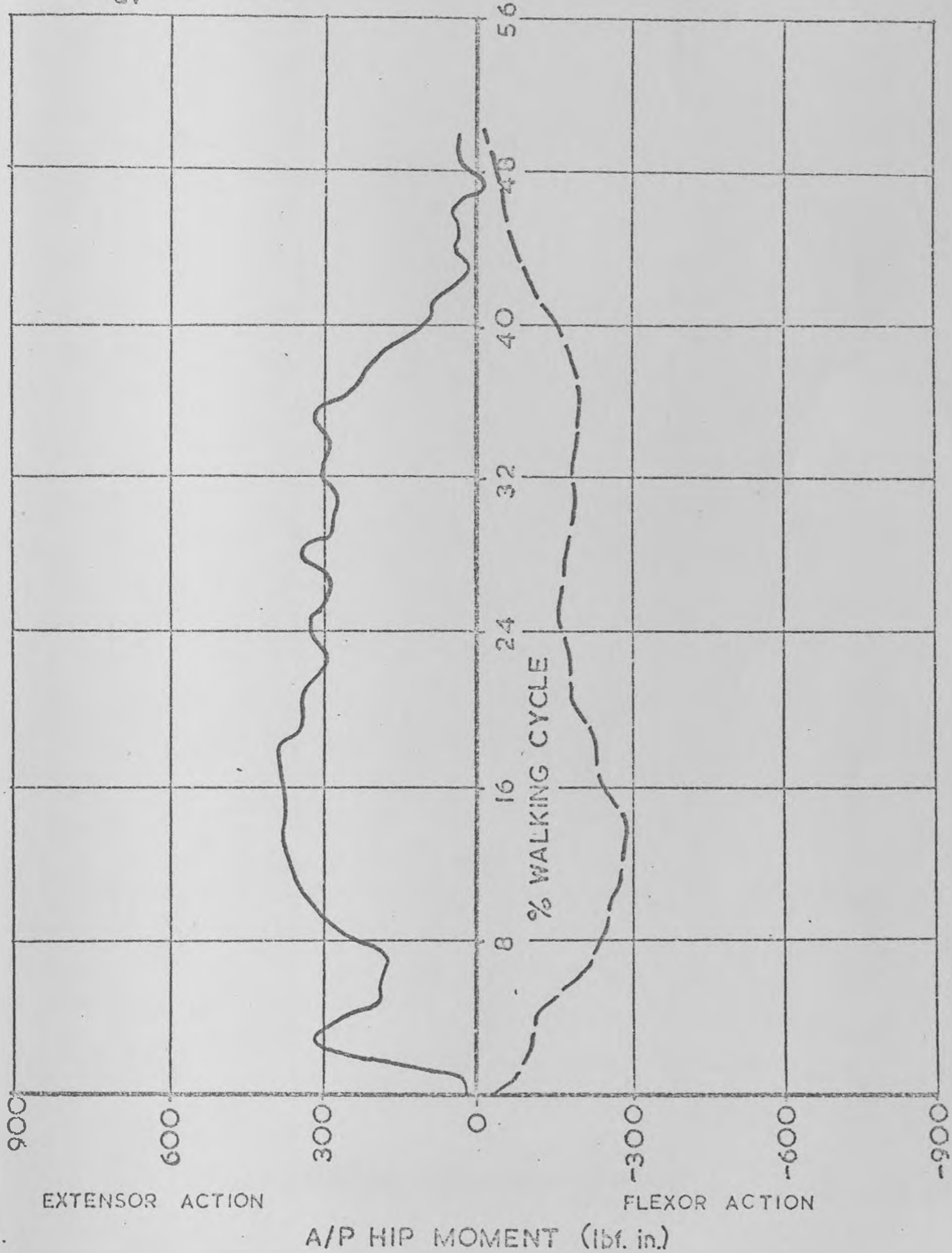


fig. VI.9

A/P HIP MOMENT IN WALKING SIDEWAYS (Normal Leg Leading) WITH S.A.

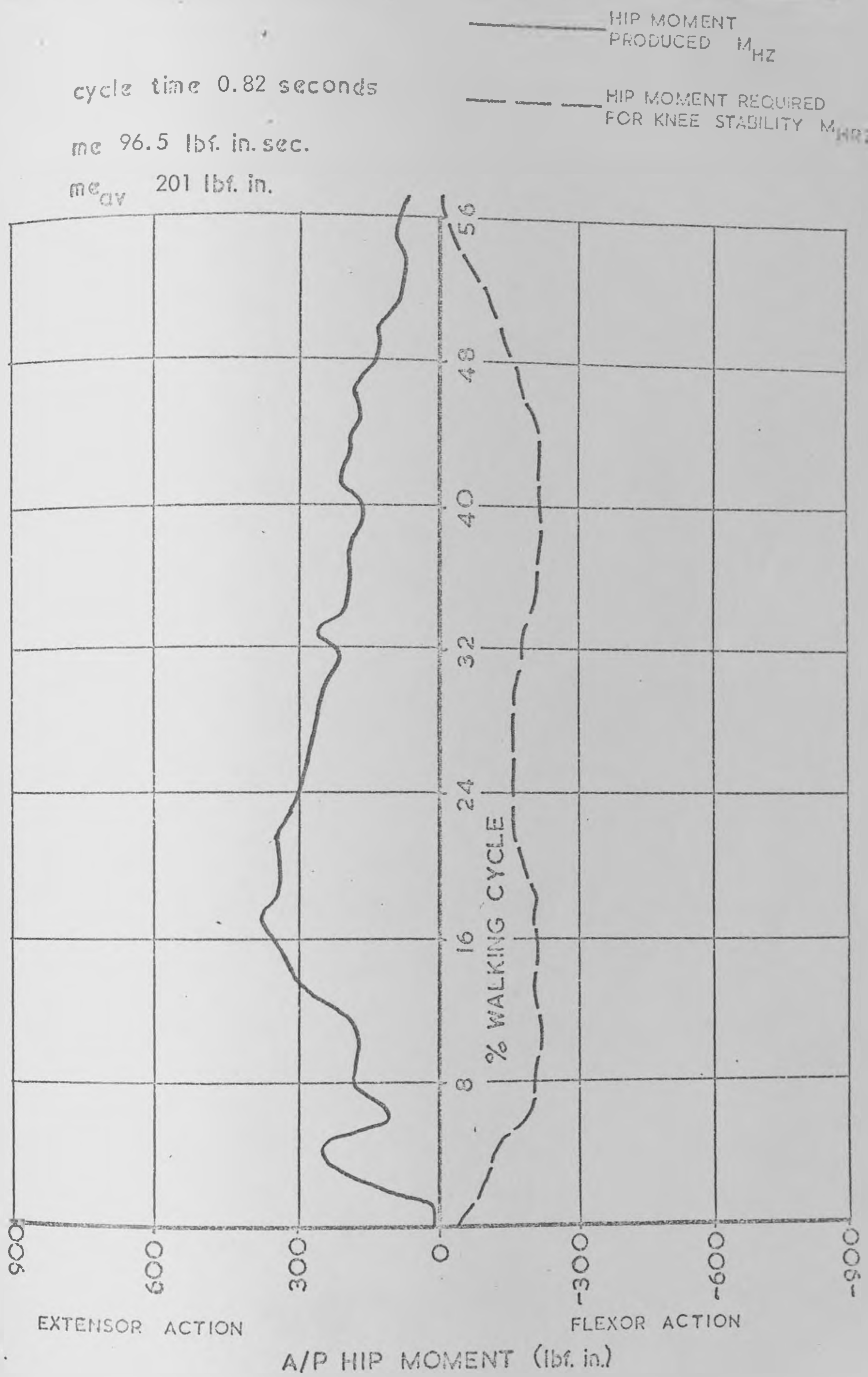
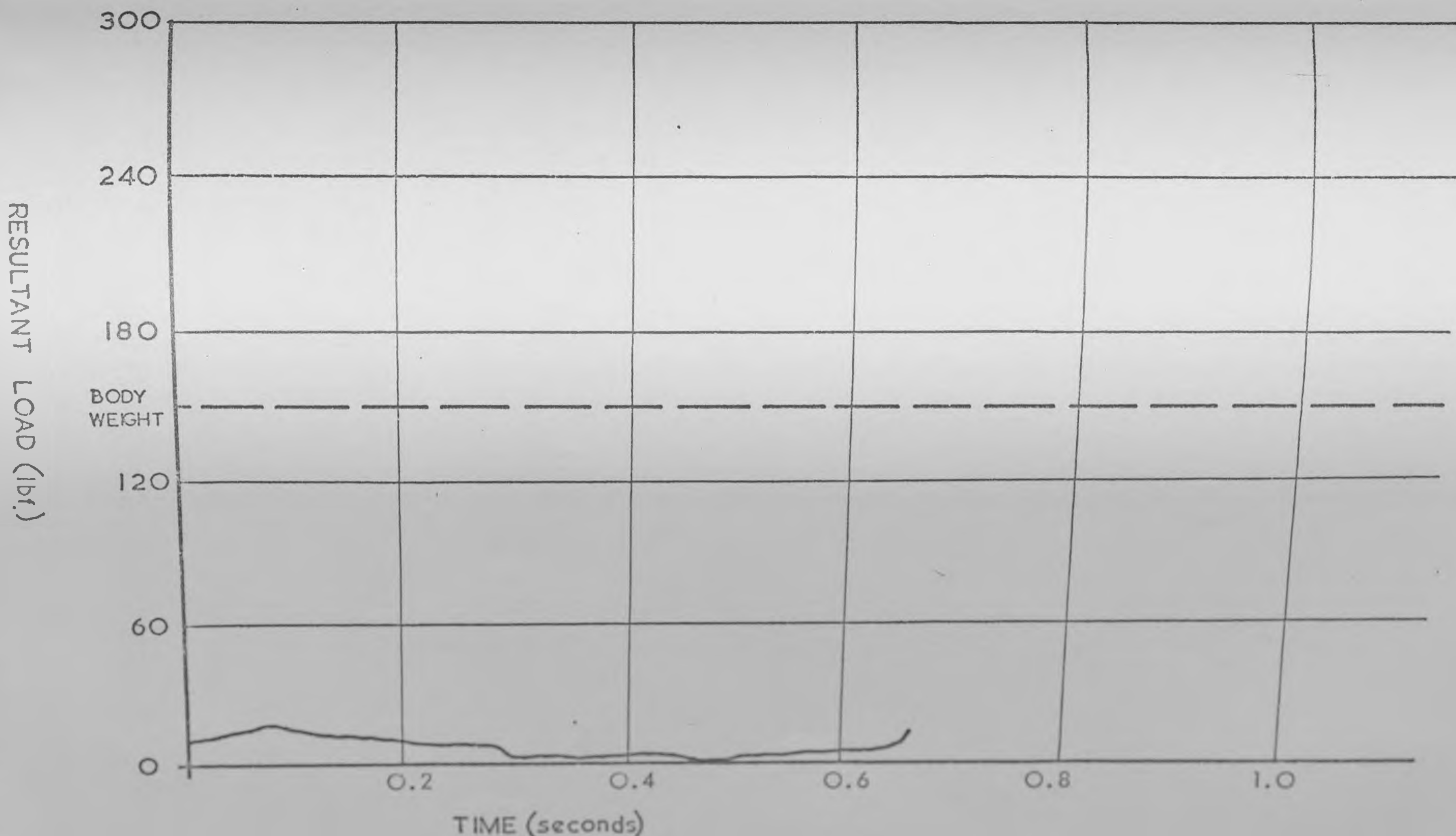


fig. VI.10



RESULTANT LOAD IN STANDING UP WITH S.A.

fig.VI.11

A/P HIP MOMENT IN STANDING UP WITH S.A.

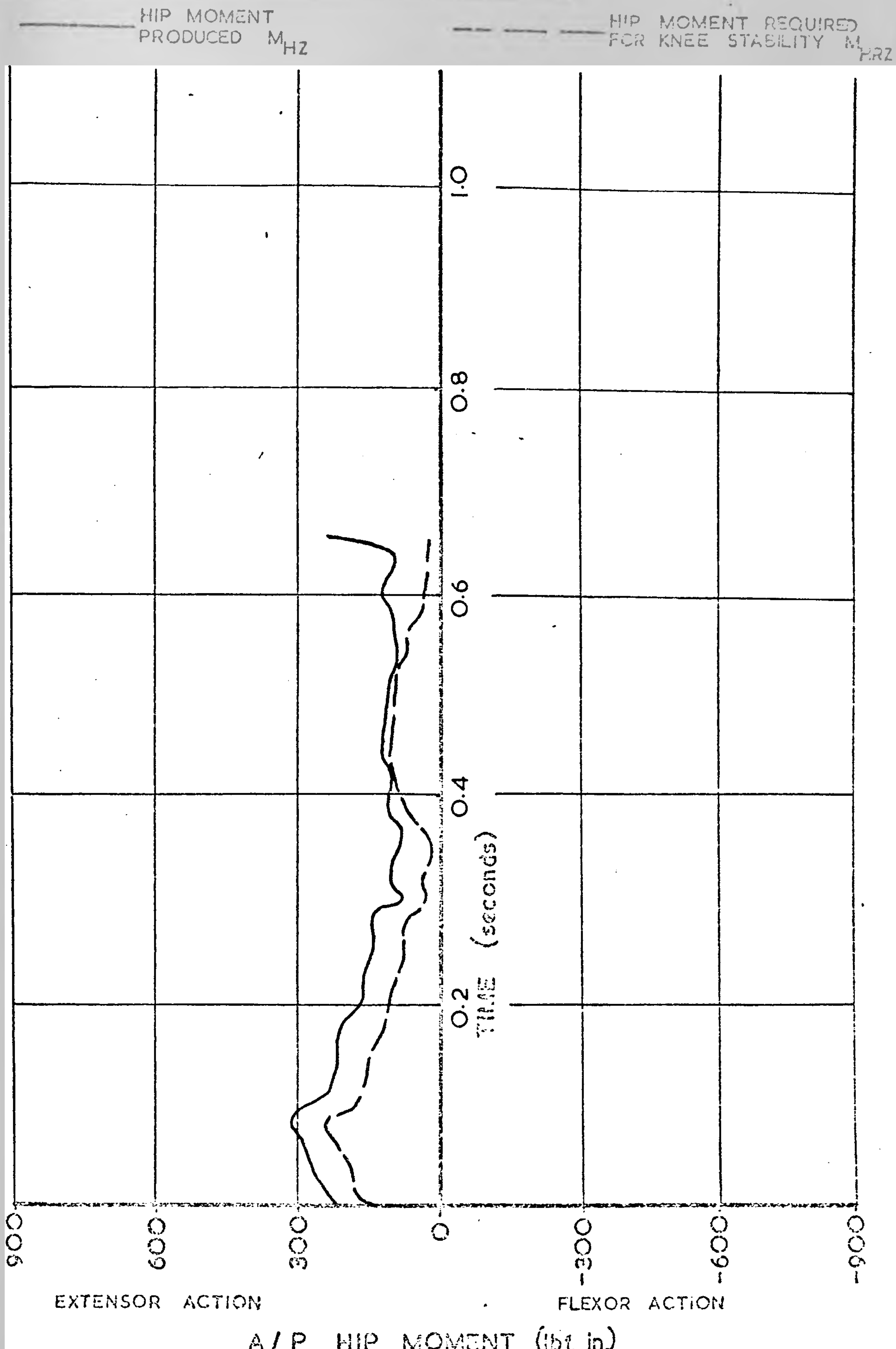


fig. VI. 12

RESULTANT LOAD IN SITTING DOWN WITH S.A.

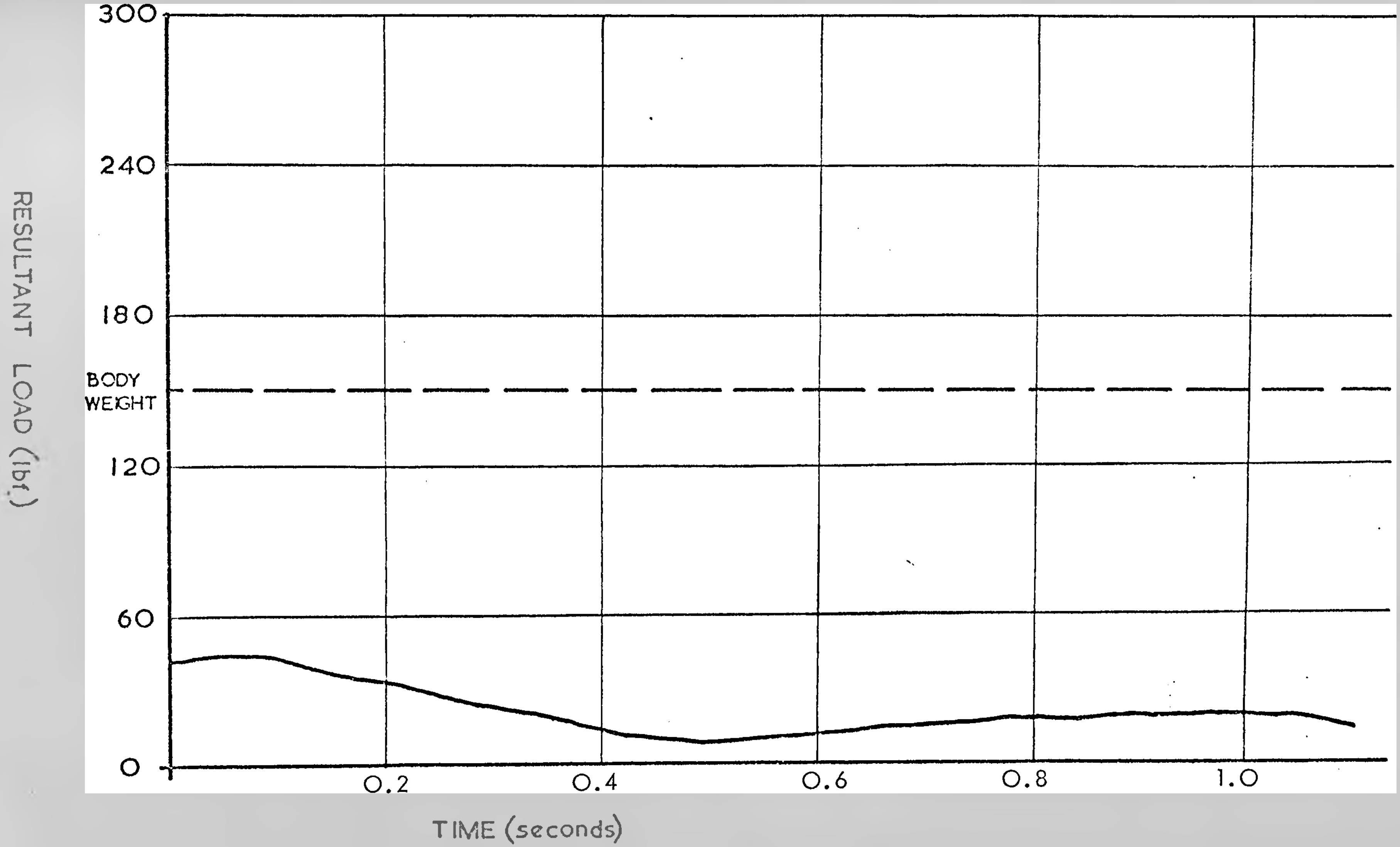


fig. VI.13

A/P HIP MOMENT IN SITTING DOWN WITH S. A.

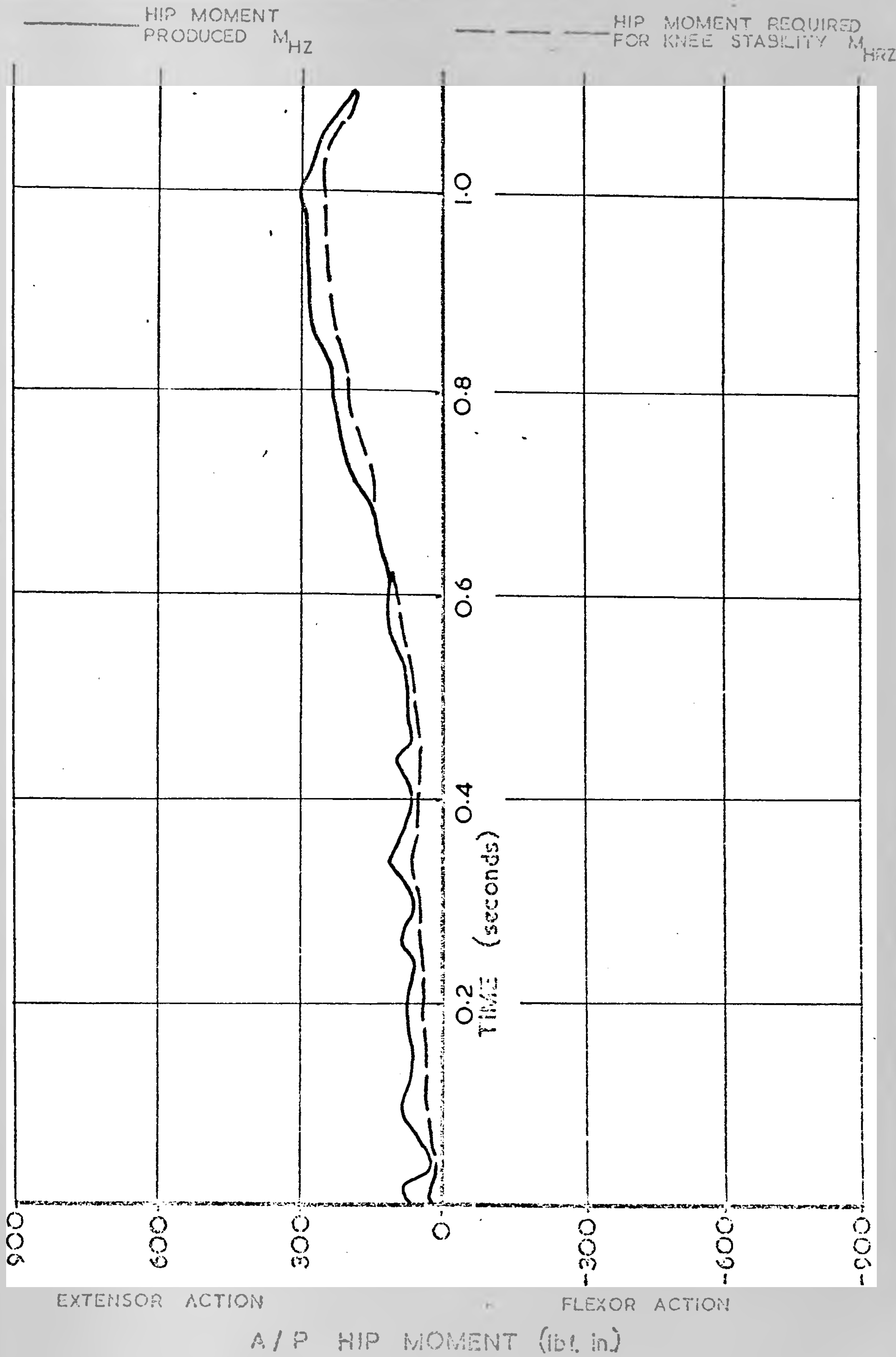


fig. VI.14

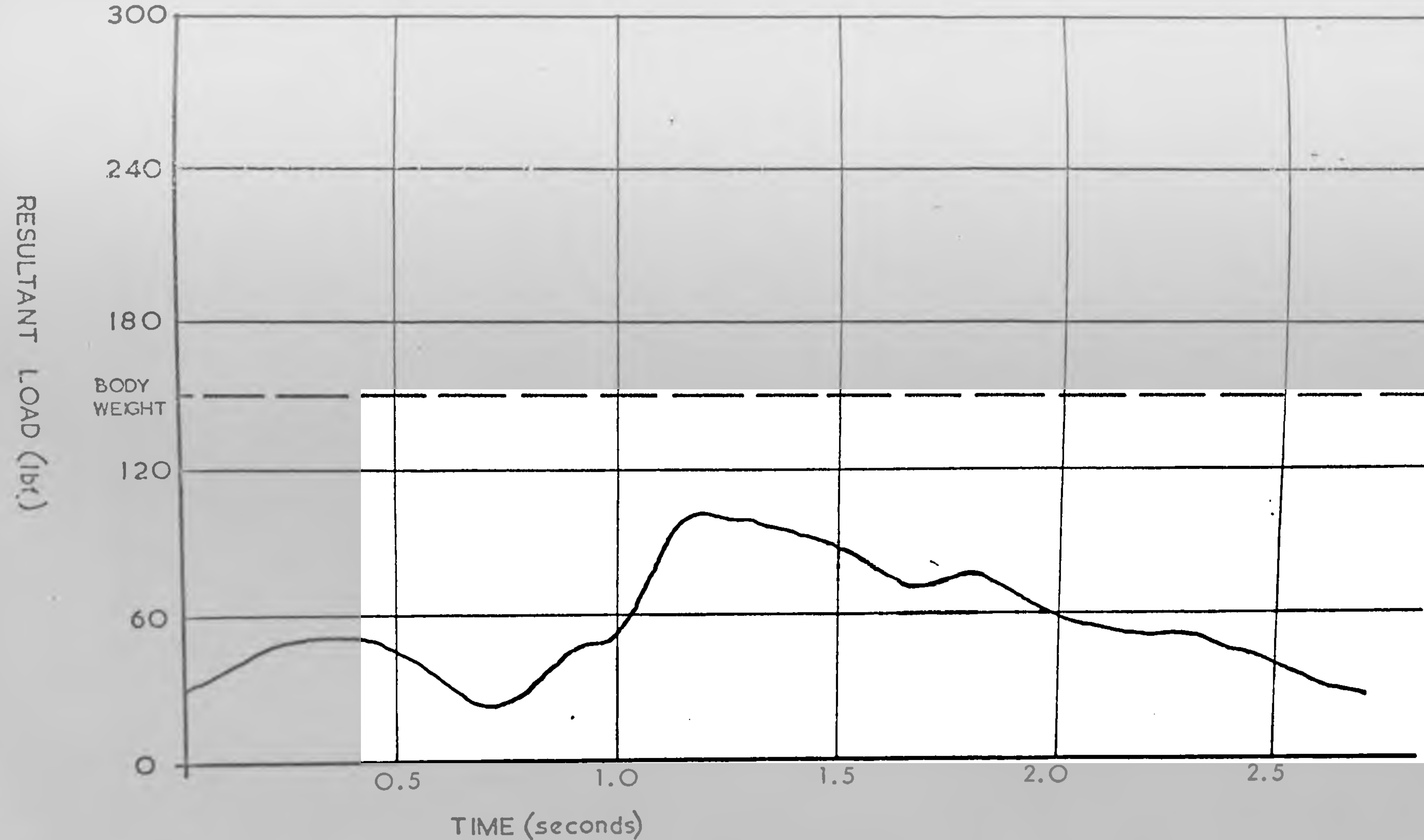


fig.VI.15

RESULTANT LOAD IN LIFTING AND LOWERING A WEIGHT WITH S.A.

A/P HIP MOMENT IN LIFTING AND LOWERING A WEIGHT WITH S.A.

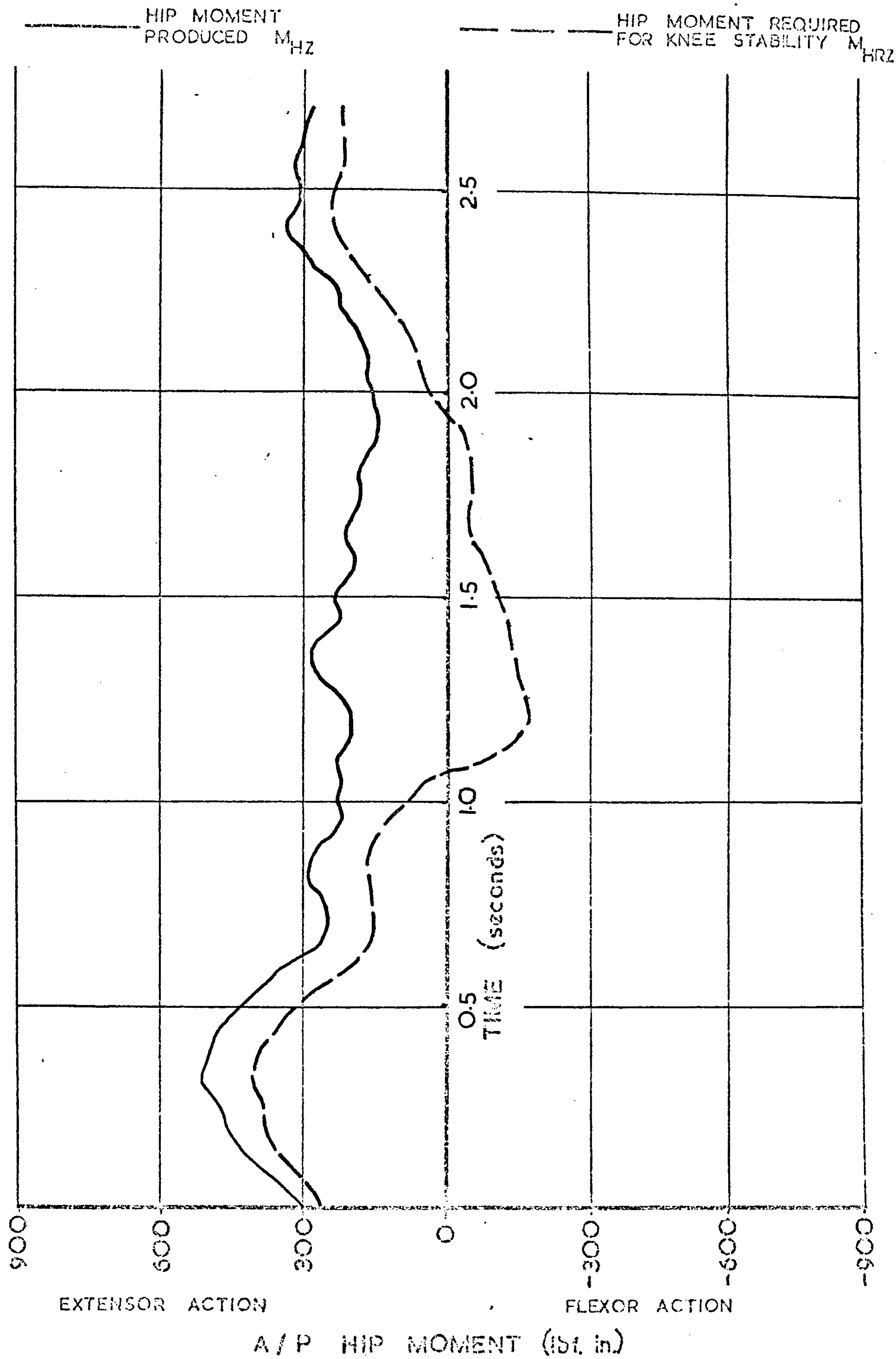


fig.VI.16

A/P HIP MOMENT IN LEVEL WALKING WITH B.S.K.

——————— HIP MOMENT PRODUCED M_{HZ}

— — — HIP MOMENT REQUIRED FOR KNEE STABILITY M_{HRZ}

cycle time 1.20 seconds

me 200 lbf. in. sec.

me_{av} 286 lbf. in.

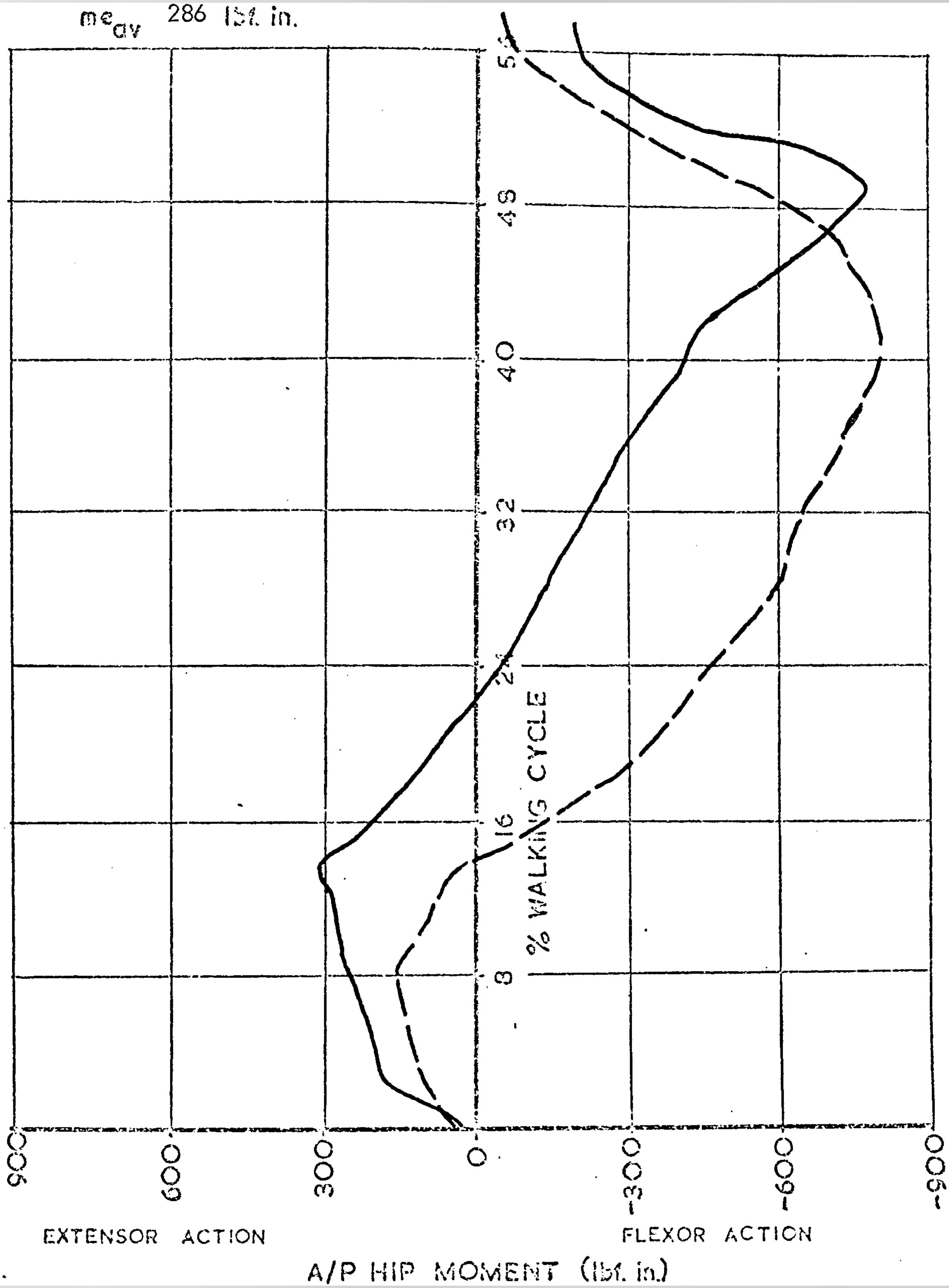


fig. VI.17

A/P HIP MOMENT IN WALKING UP RAMP WITH B.S.K.

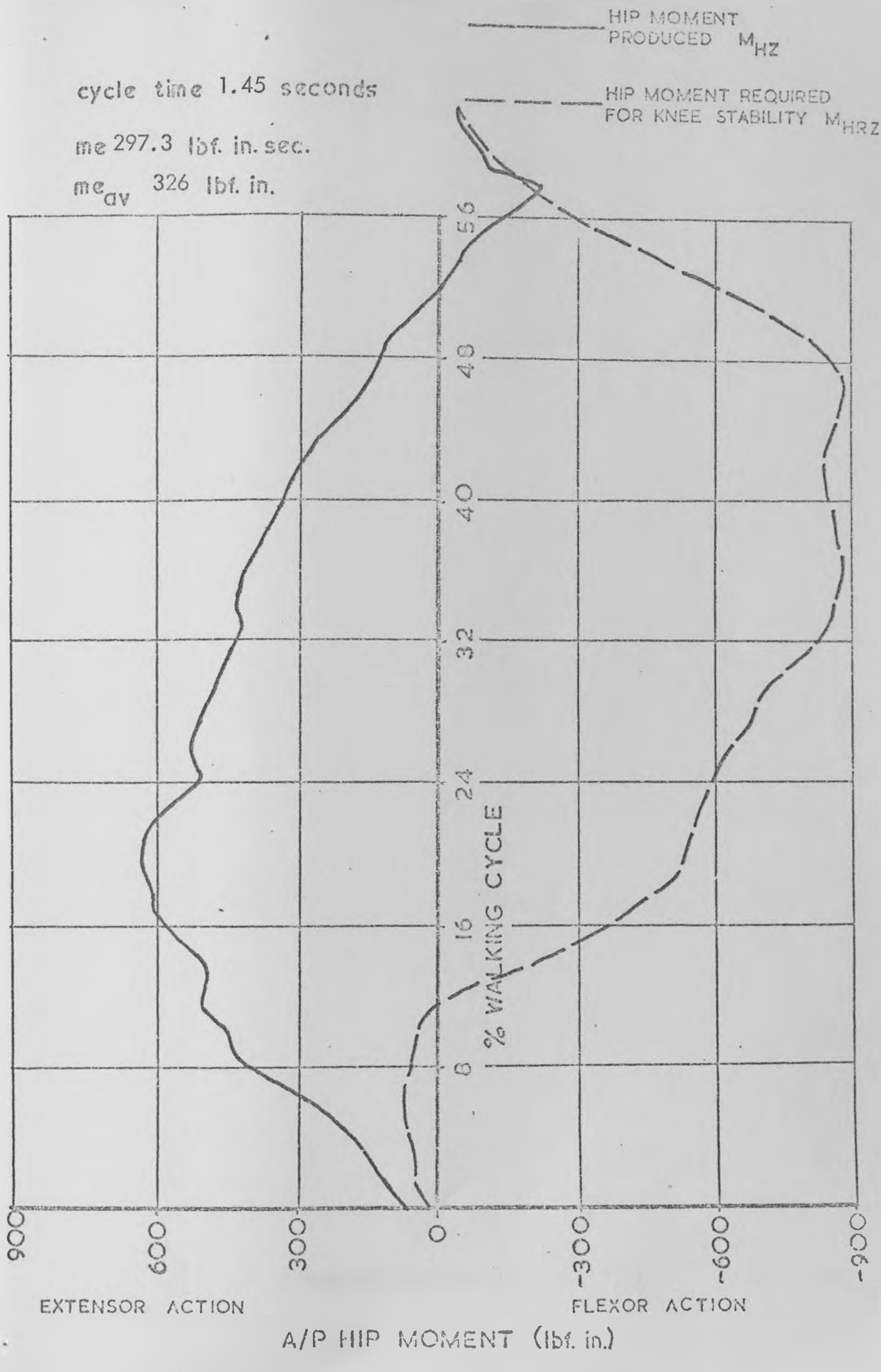


fig. VI.18

A/P HIP MOMENT IN WALKING DOWN RAMP WITH B.S.K.

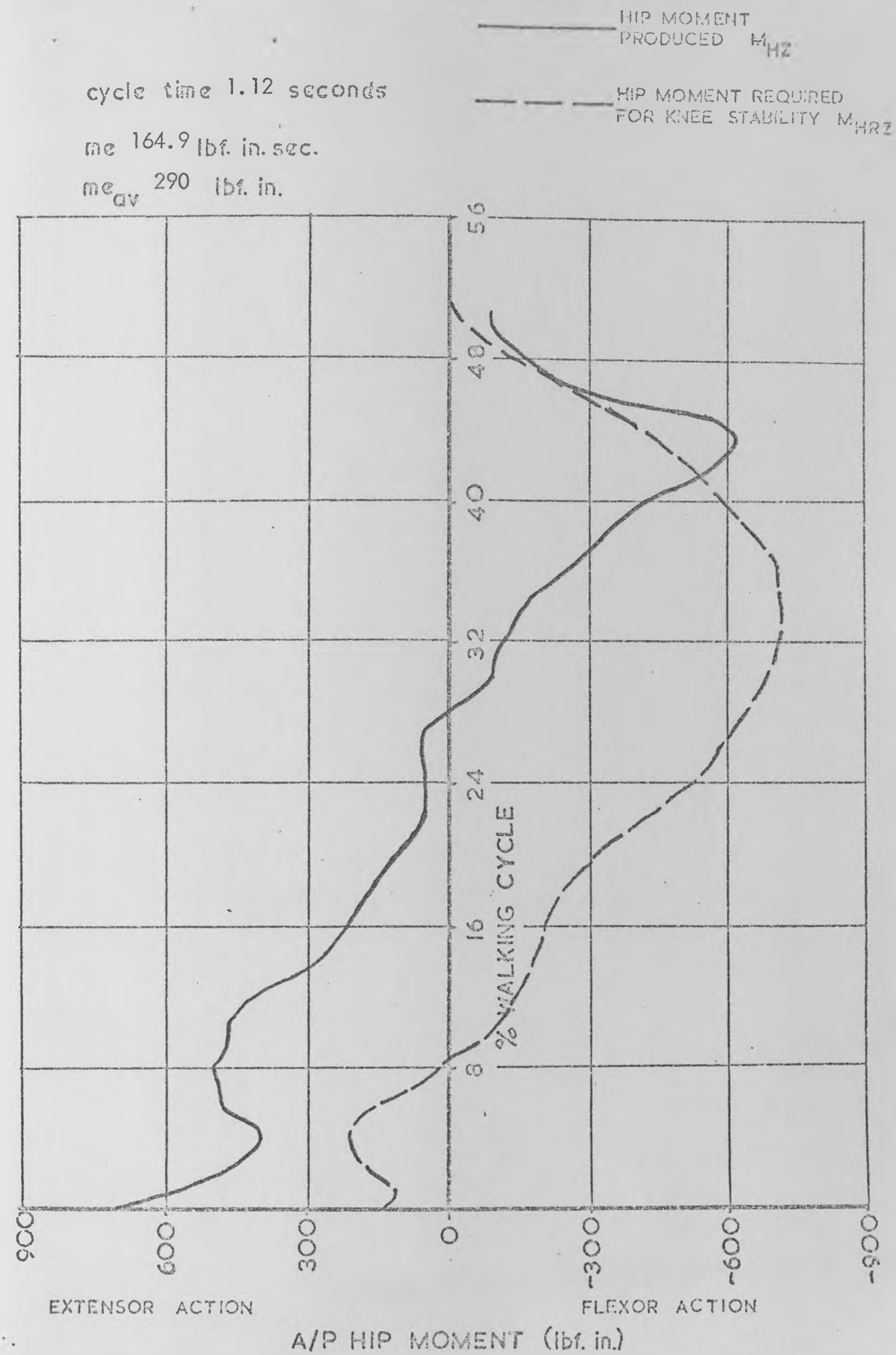


fig. VI.19

A/P HIP MOMENT IN WALKING UP STAIRS WITH B. S. K.

cycle time 1.55 seconds

me 348.8 lbf. in. sec.

me_{av} 460 lbf. in.

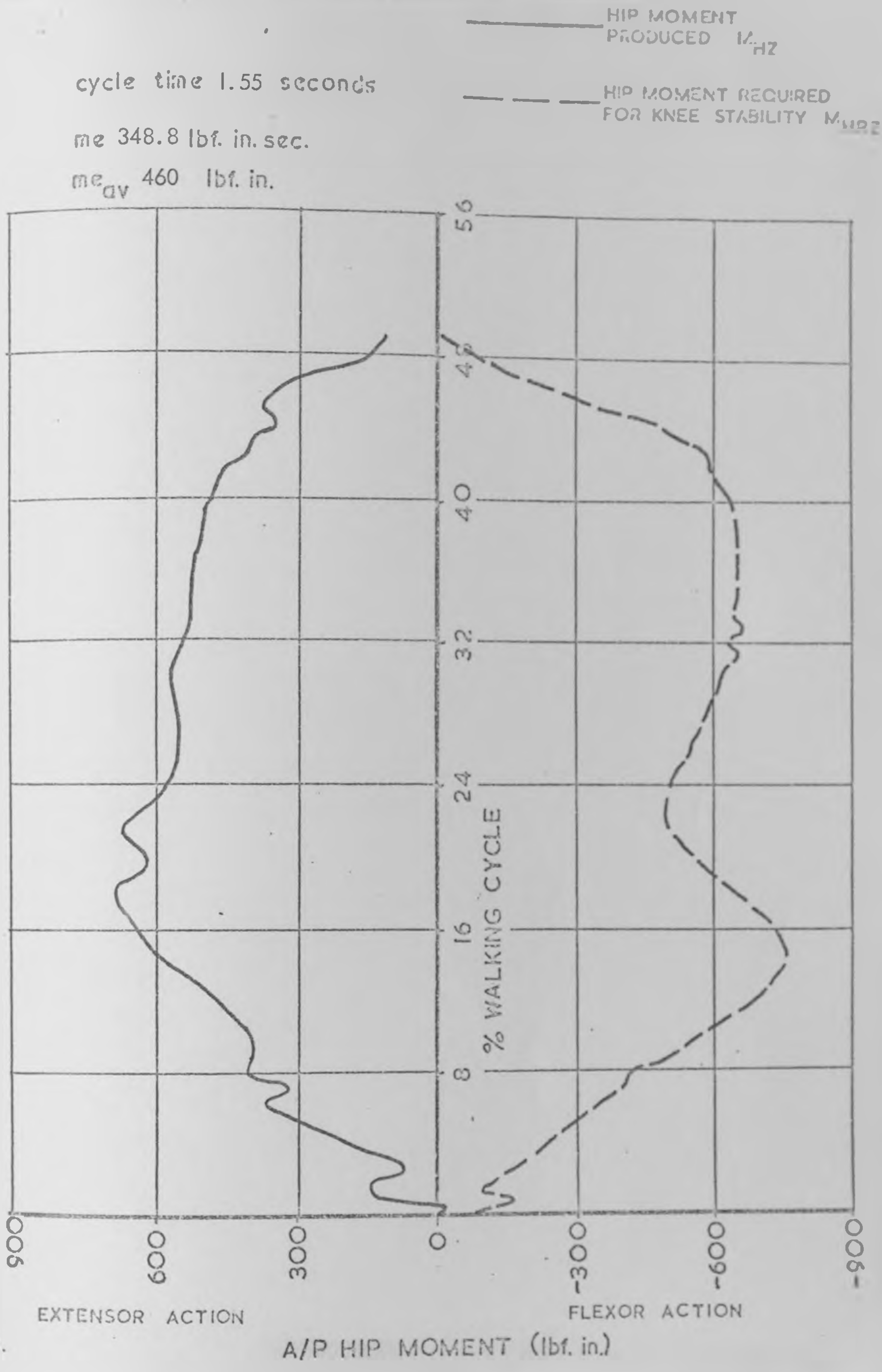


fig.VI.20

A/P HIP MOMENT IN WALKING DOWN STAIRS WITH B.S.K.

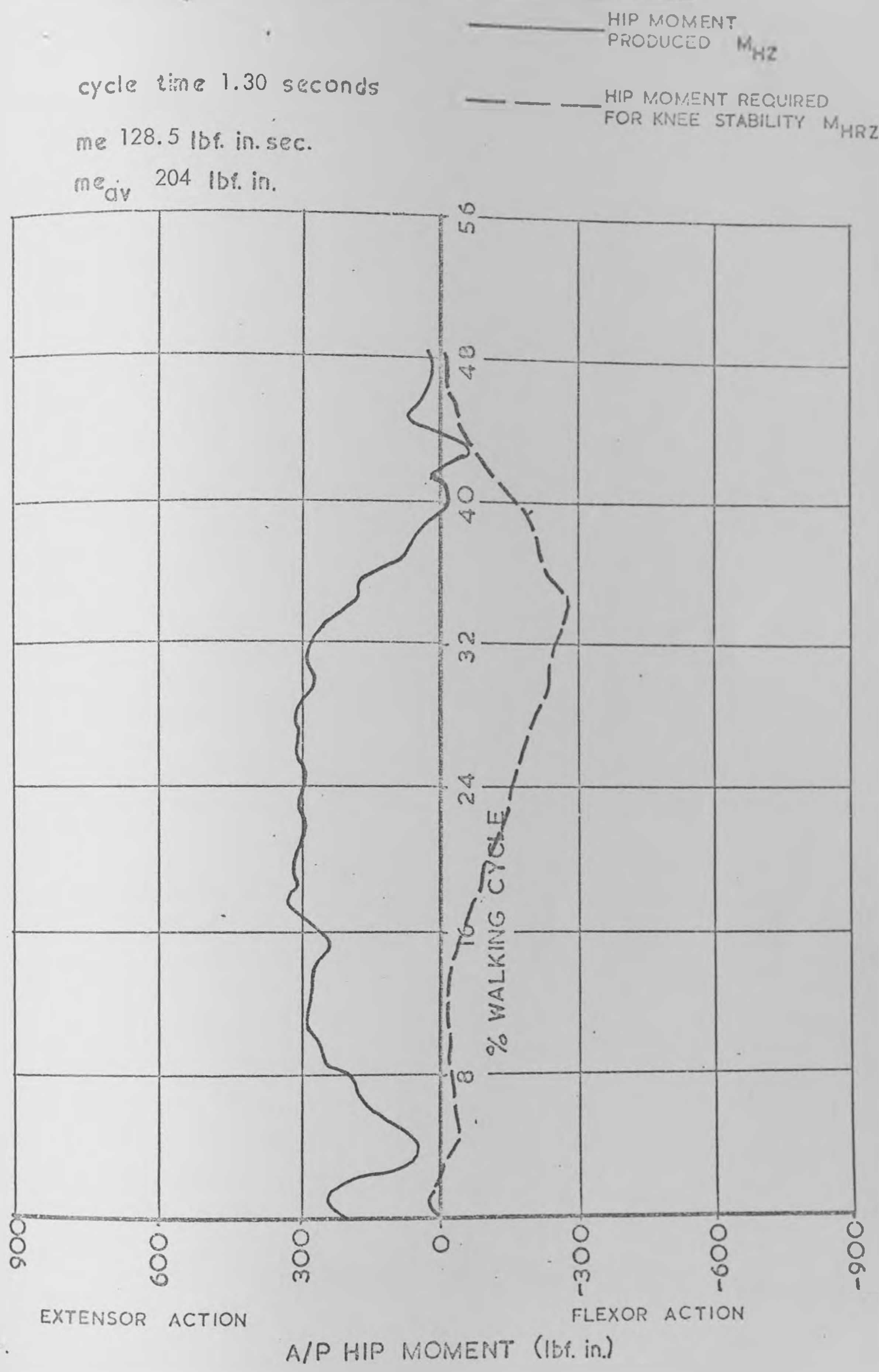


fig. VI.21

A/P HIP MOMENT IN STEPPING OVER AN OBJECT (from a standing position) WITH B.S.K.

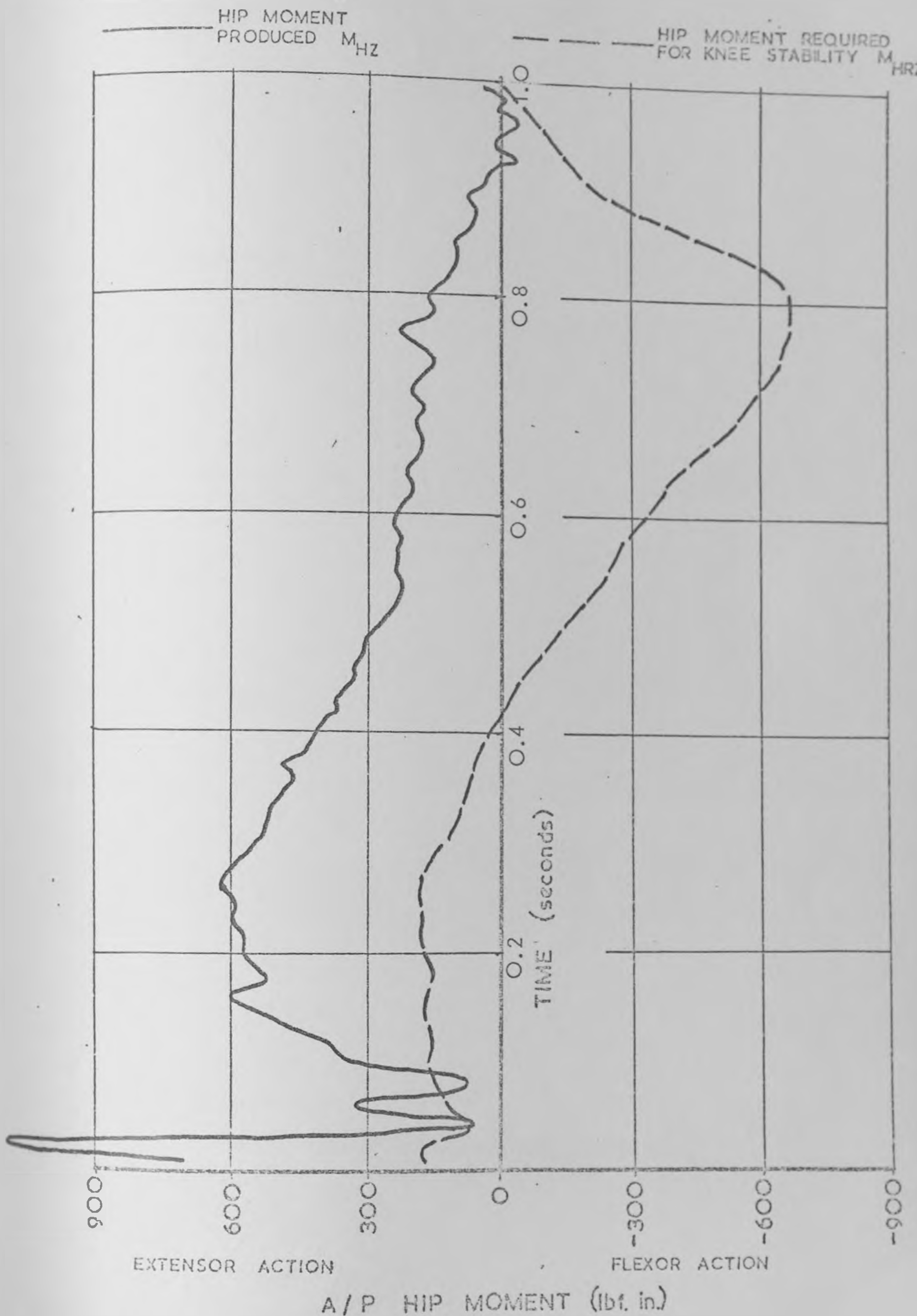


fig.VI.22

A/P HIP MOMENT IN STEPPING OVER AN OBJECT (after walking up to it) WITH B.S.K.

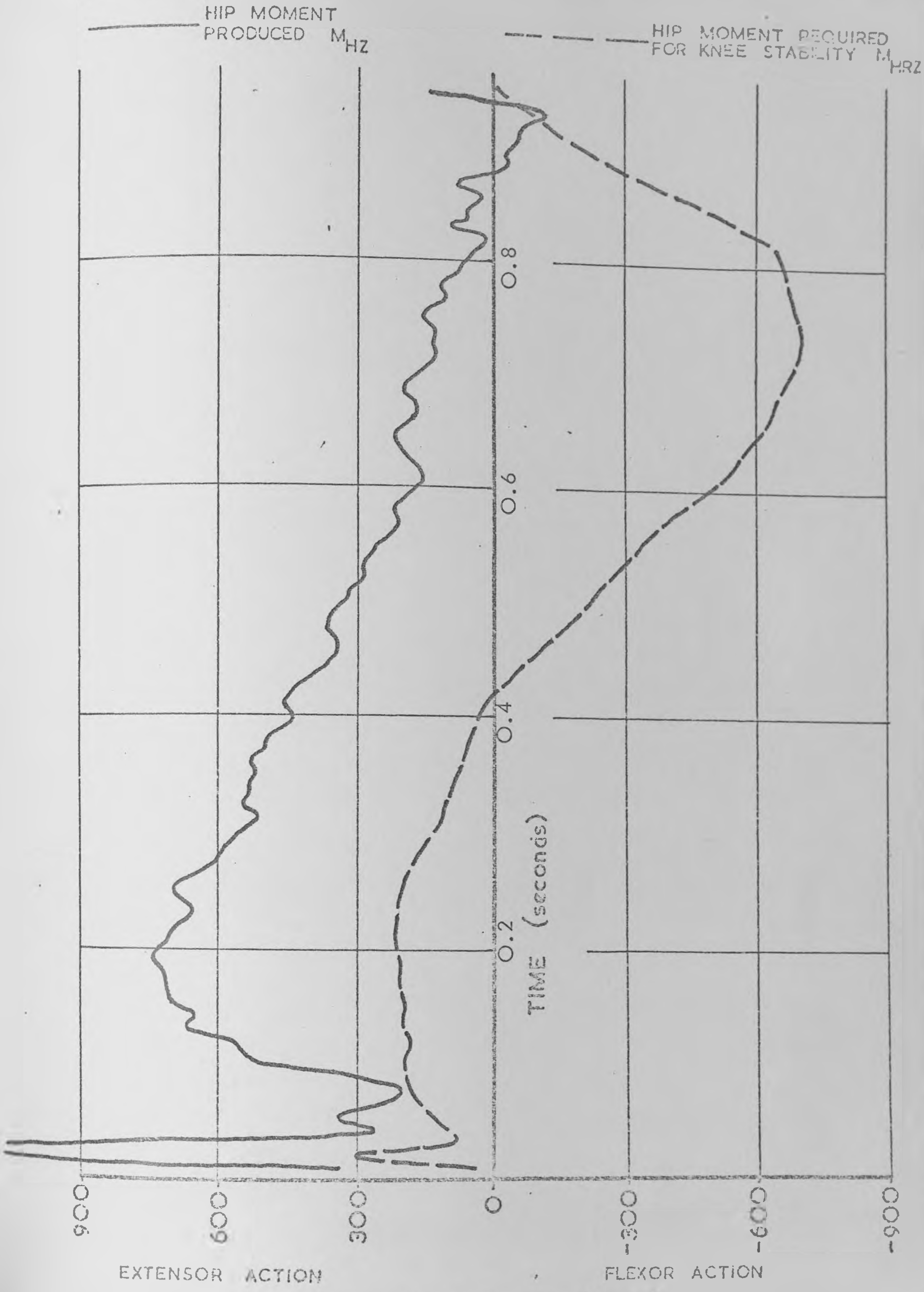


Fig. VI.23

A/P HIP MOMENT IN WALKING SIDEWAYS(Prosthesis Leading) WITH B.S.K.

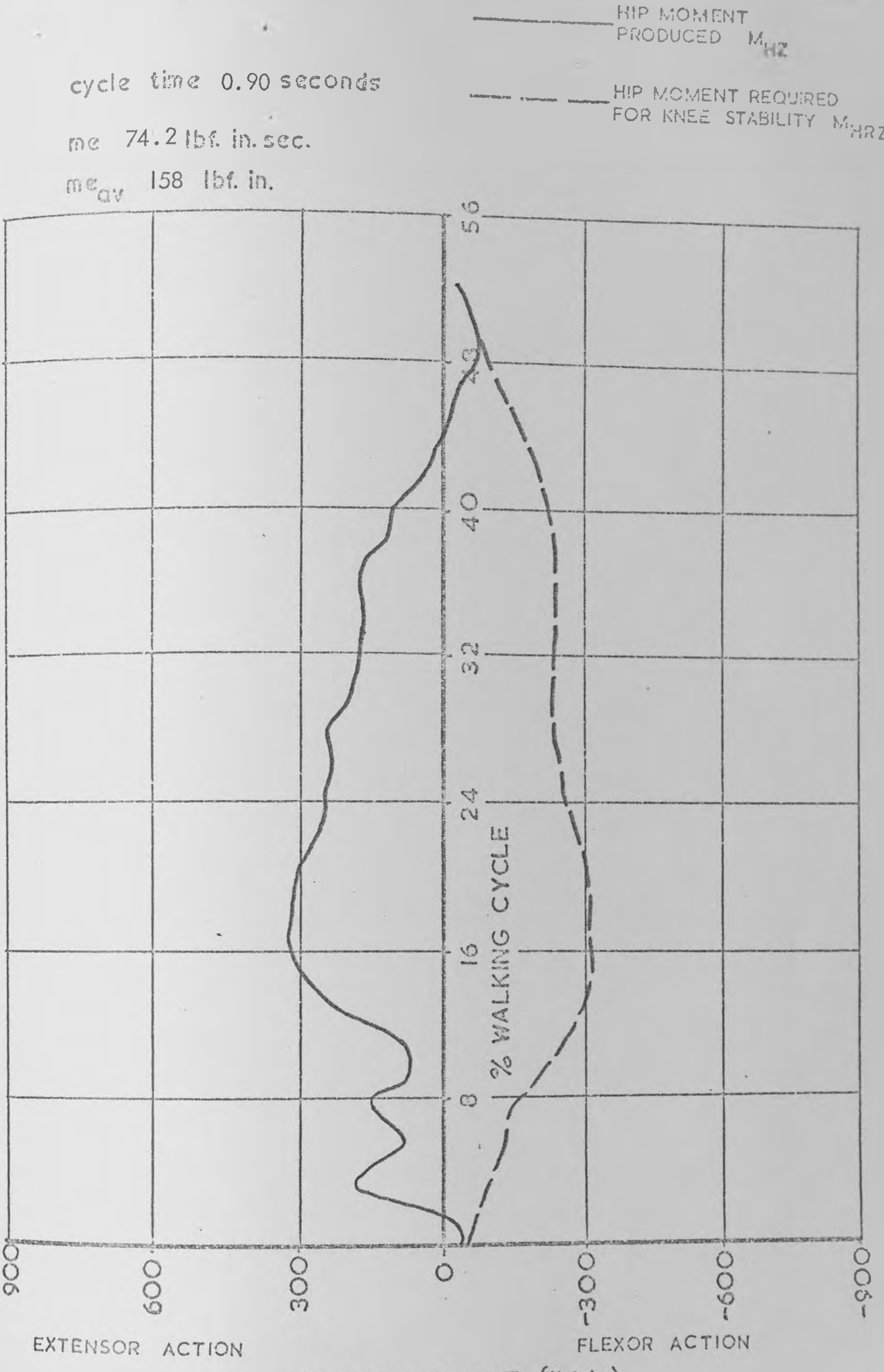


fig. VI.24

A/P HIP MOMENT IN WALKING SIDEWAYS (Normal Leg Leading) WITH B.S.K.

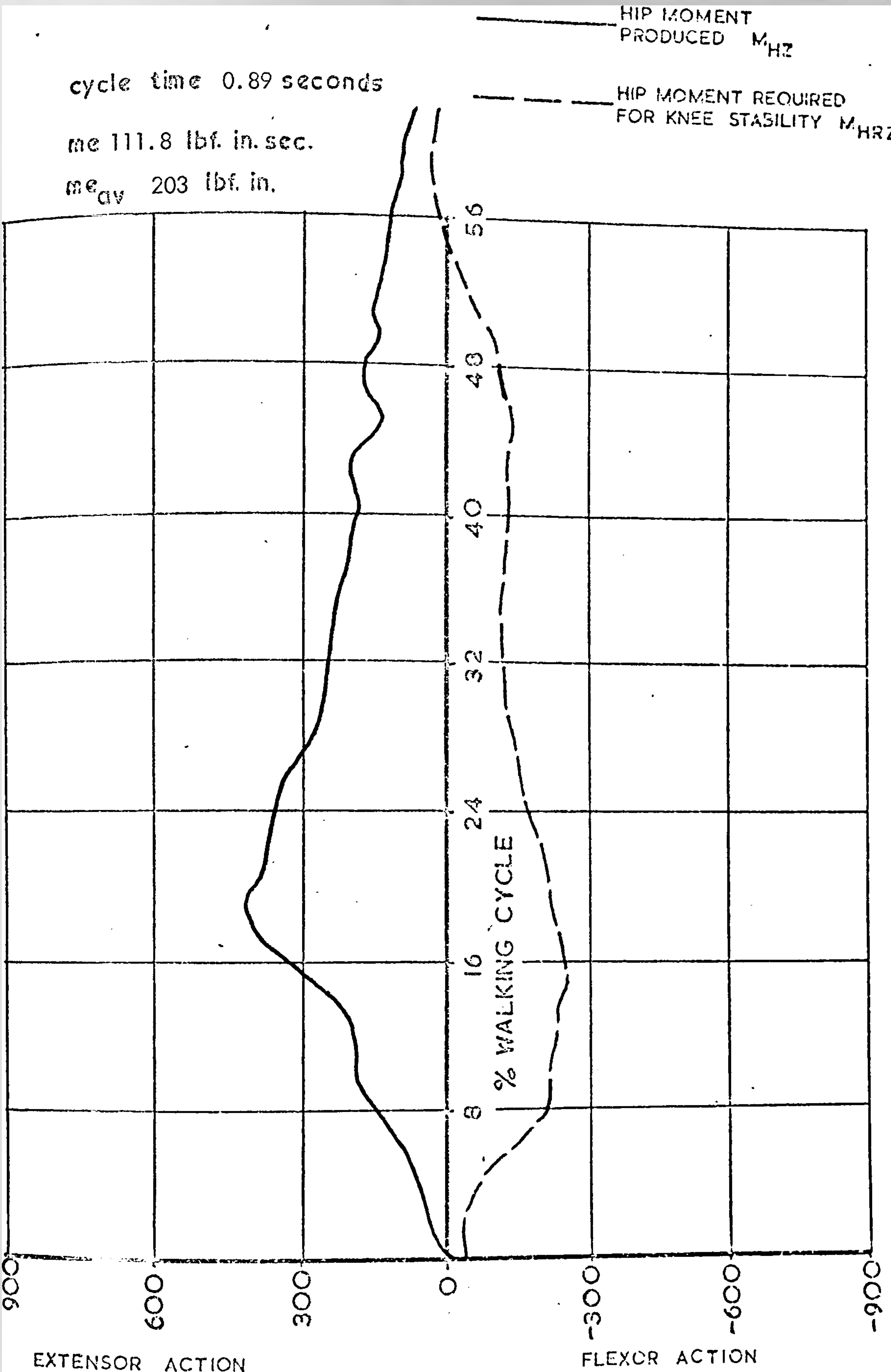
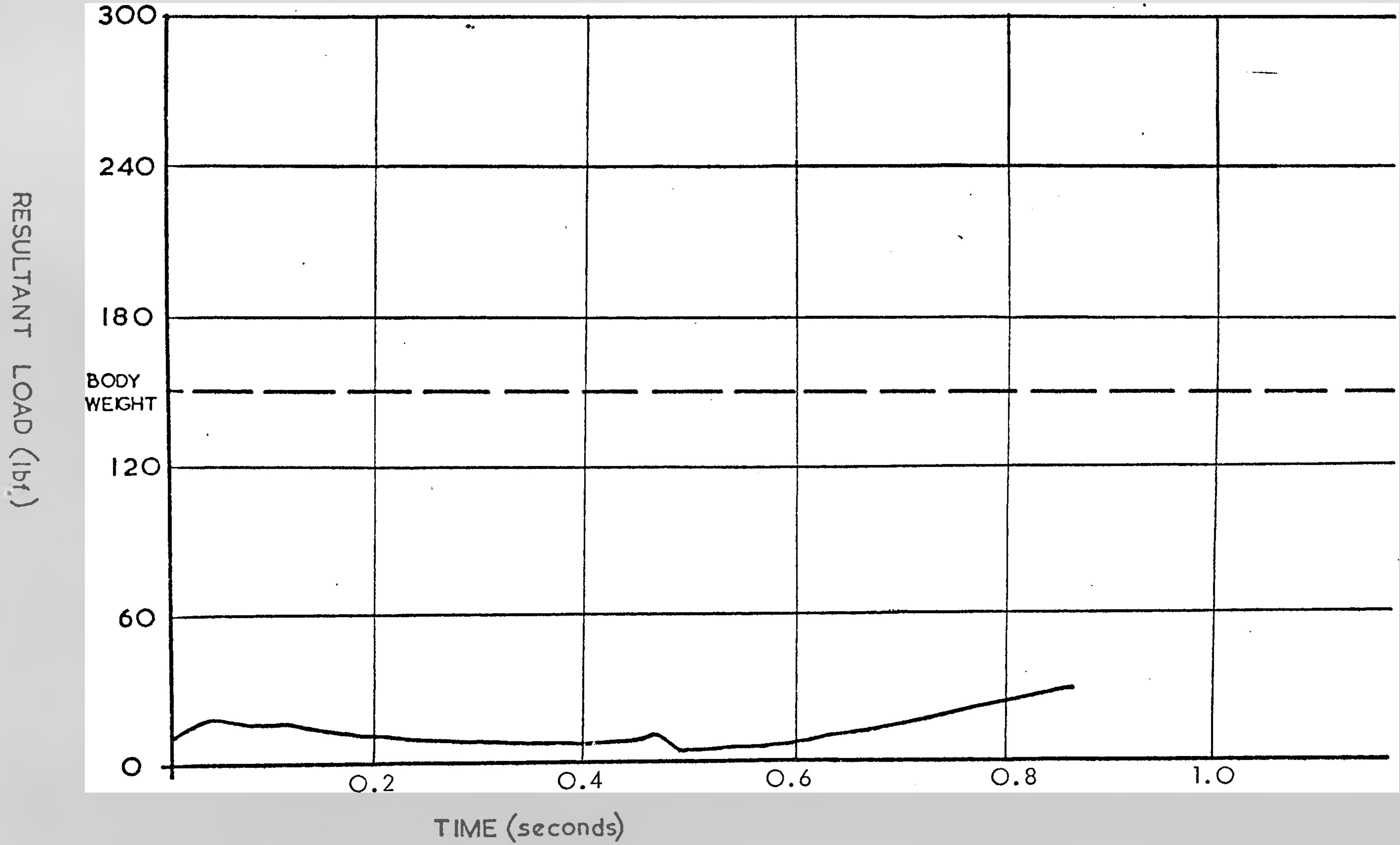


fig. VI.25



RESULTANT LOAD IN STANDING UP WITH B.S.K.

fig. VI.26

A/P HIP MOMENT IN STANDING UP WITH B.S.K.

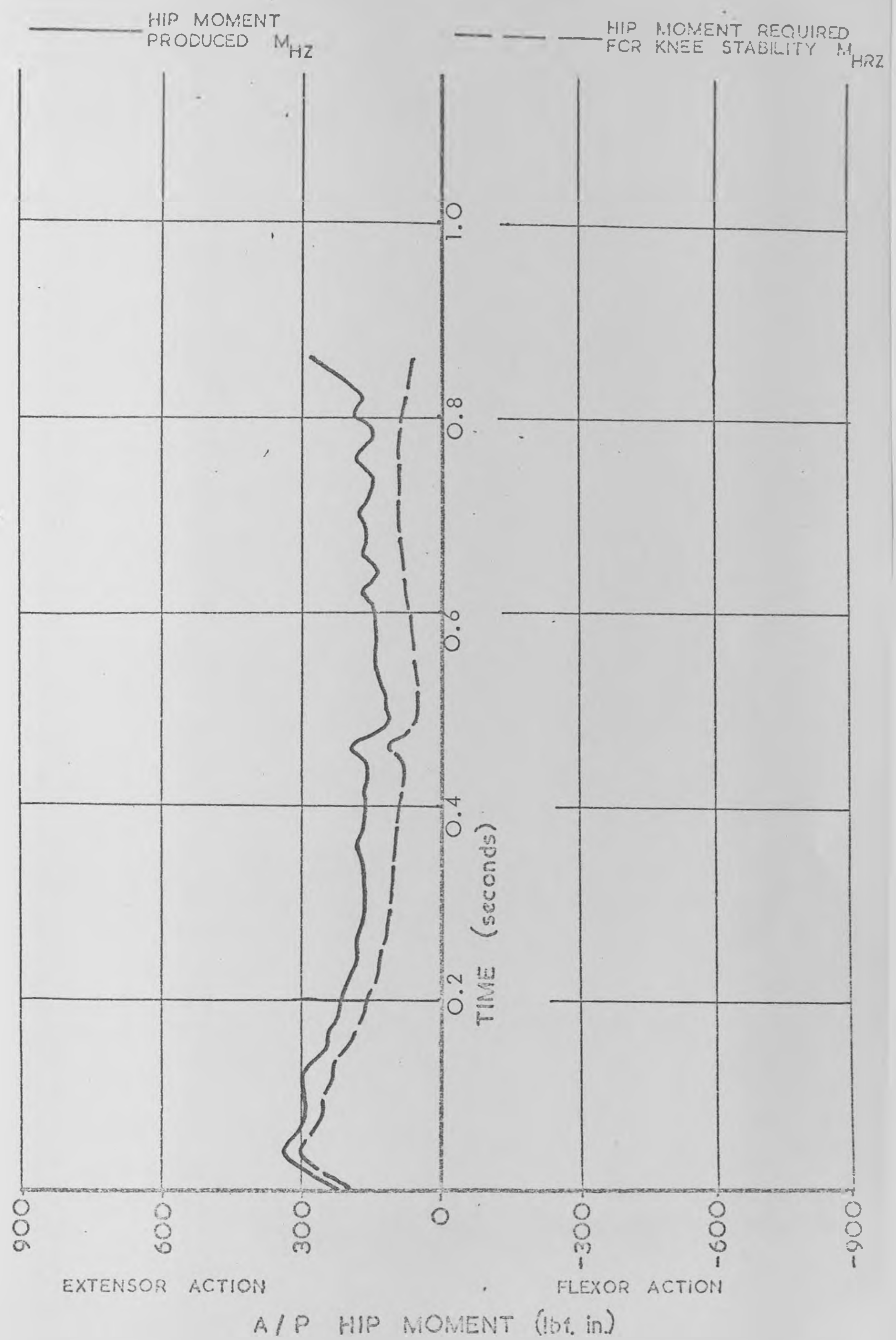
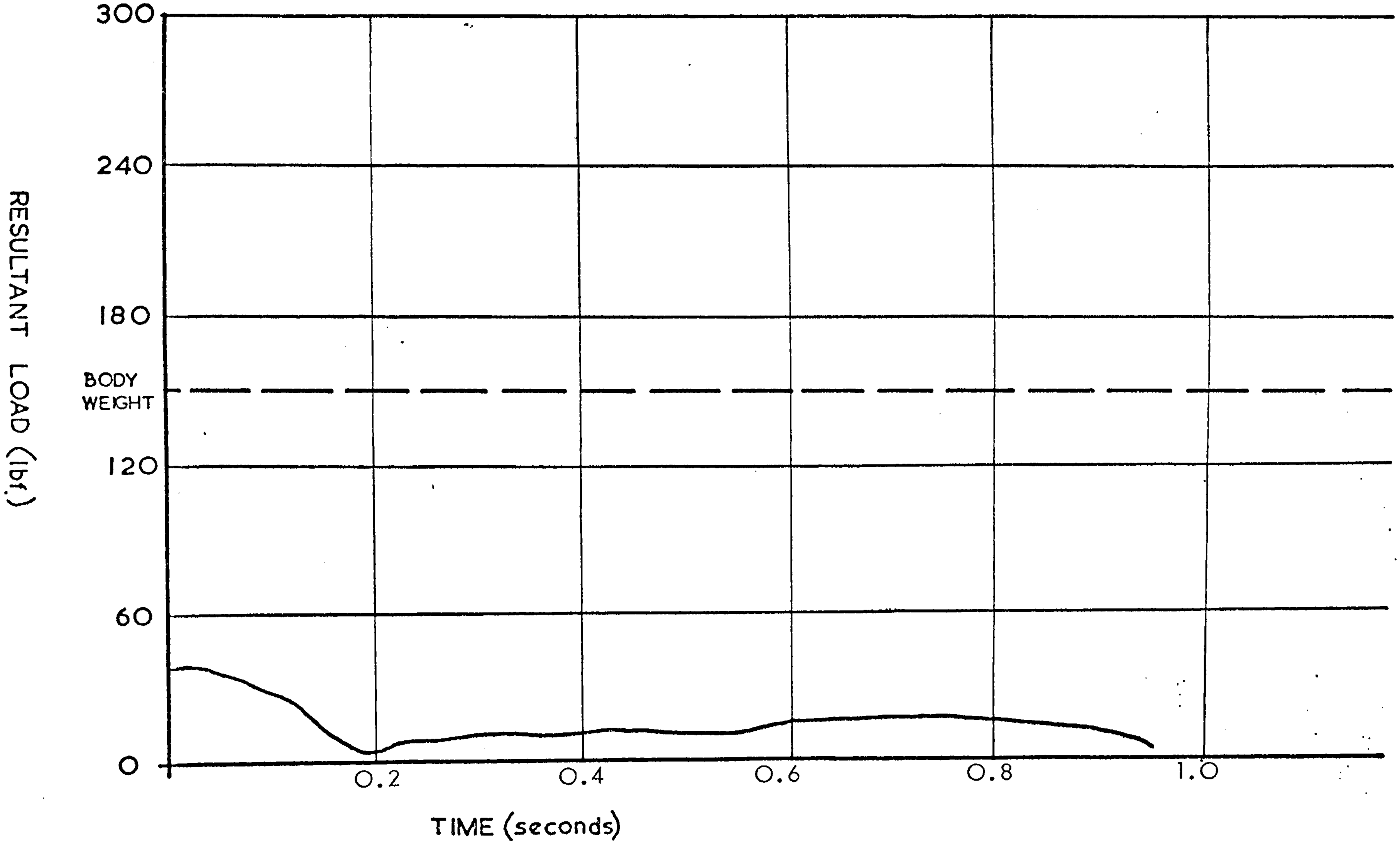


fig. VI. 27



RESULTANT LOAD IN SITTING DOWN WITH B.S.K.

fig.VI.28

A/P HIP MOMENT IN SITTING DOWN WITH B.S.K.

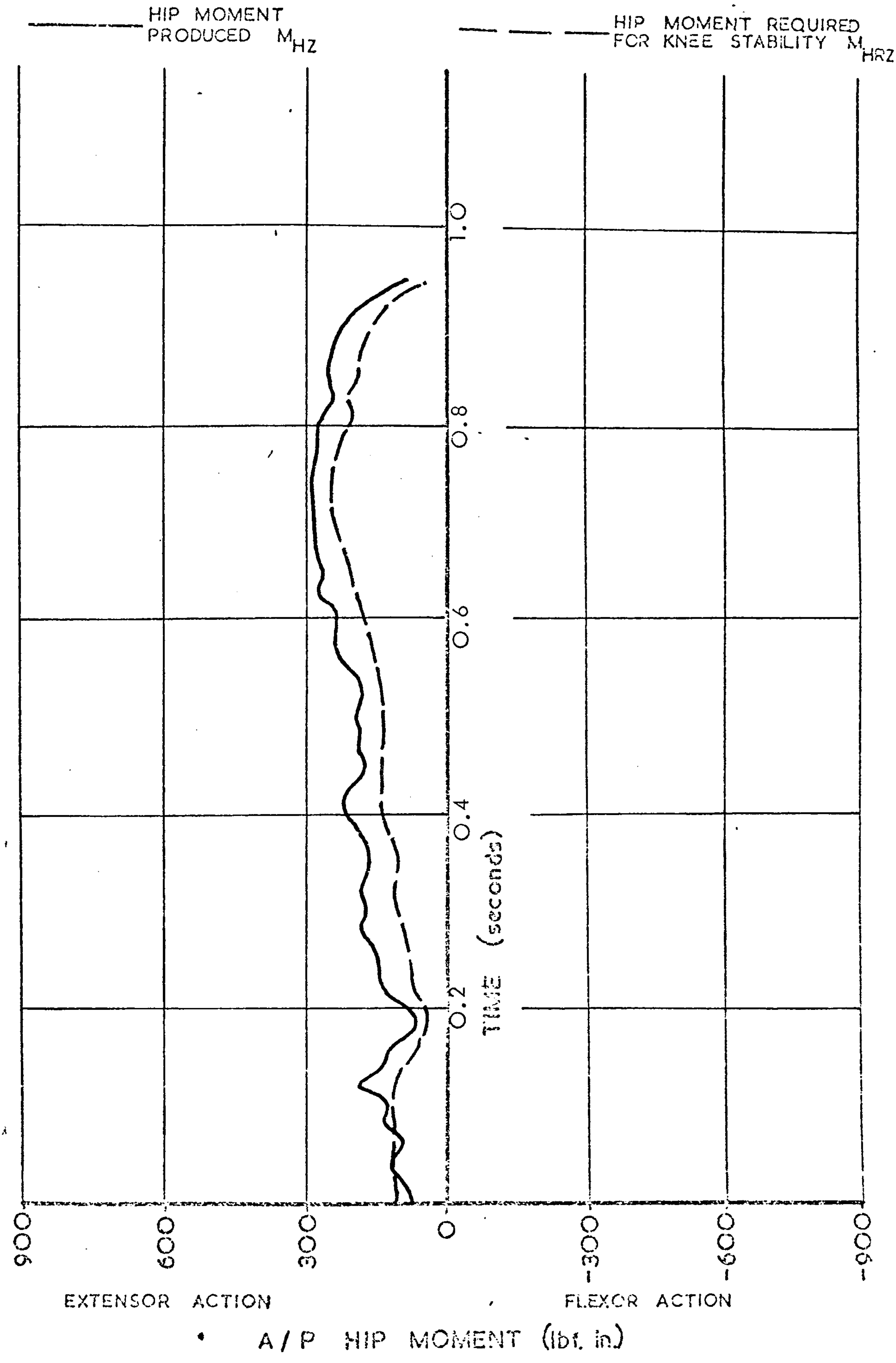
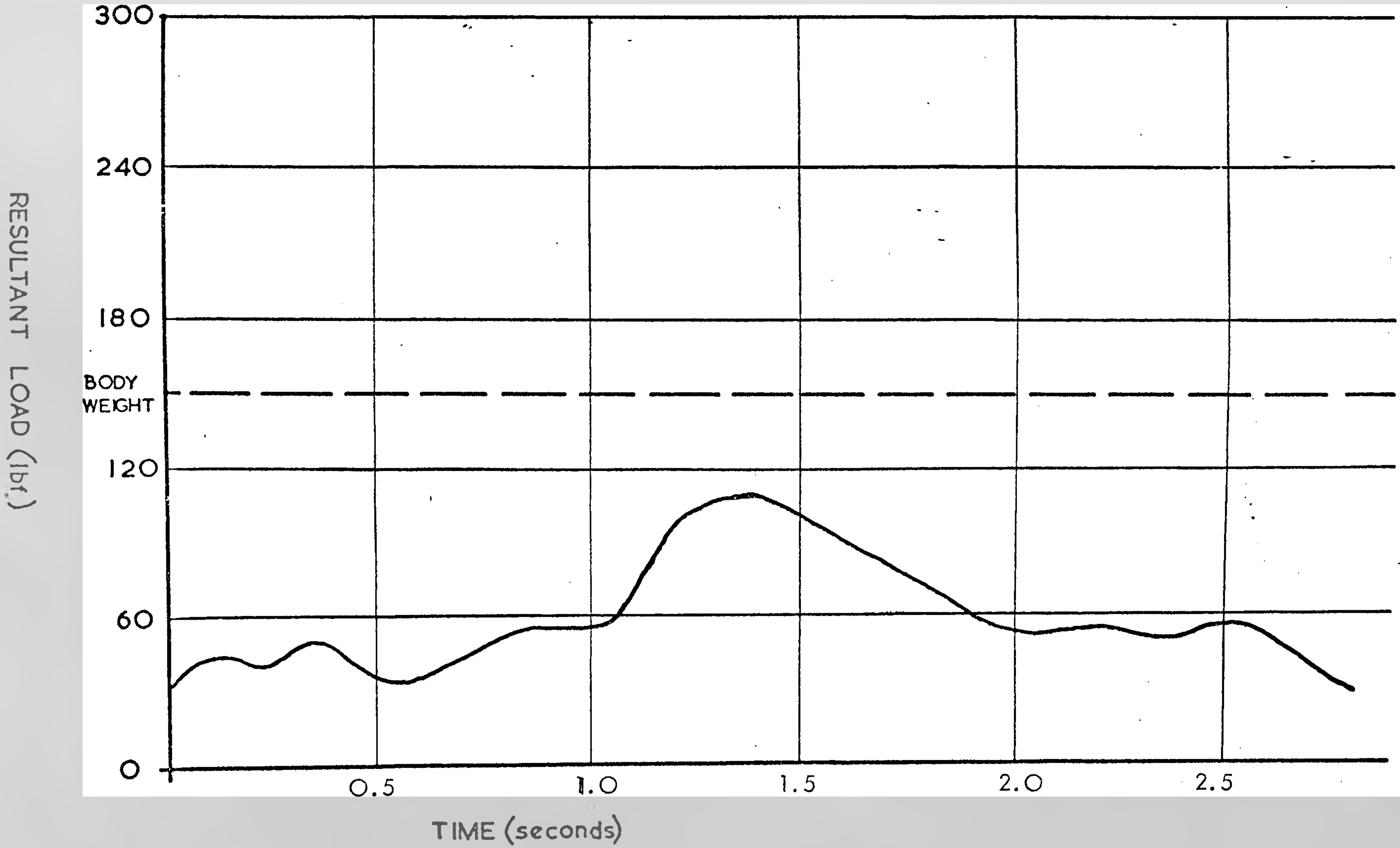


fig.VI.29



RESULTANT LOAD IN LIFTING AND LOWERING A WEIGHT WITH B.S.K.

fig. VI.30

A/P HIP MOMENT IN LIFTING AND LOWERING A WEIGHT WITH B.S.K.

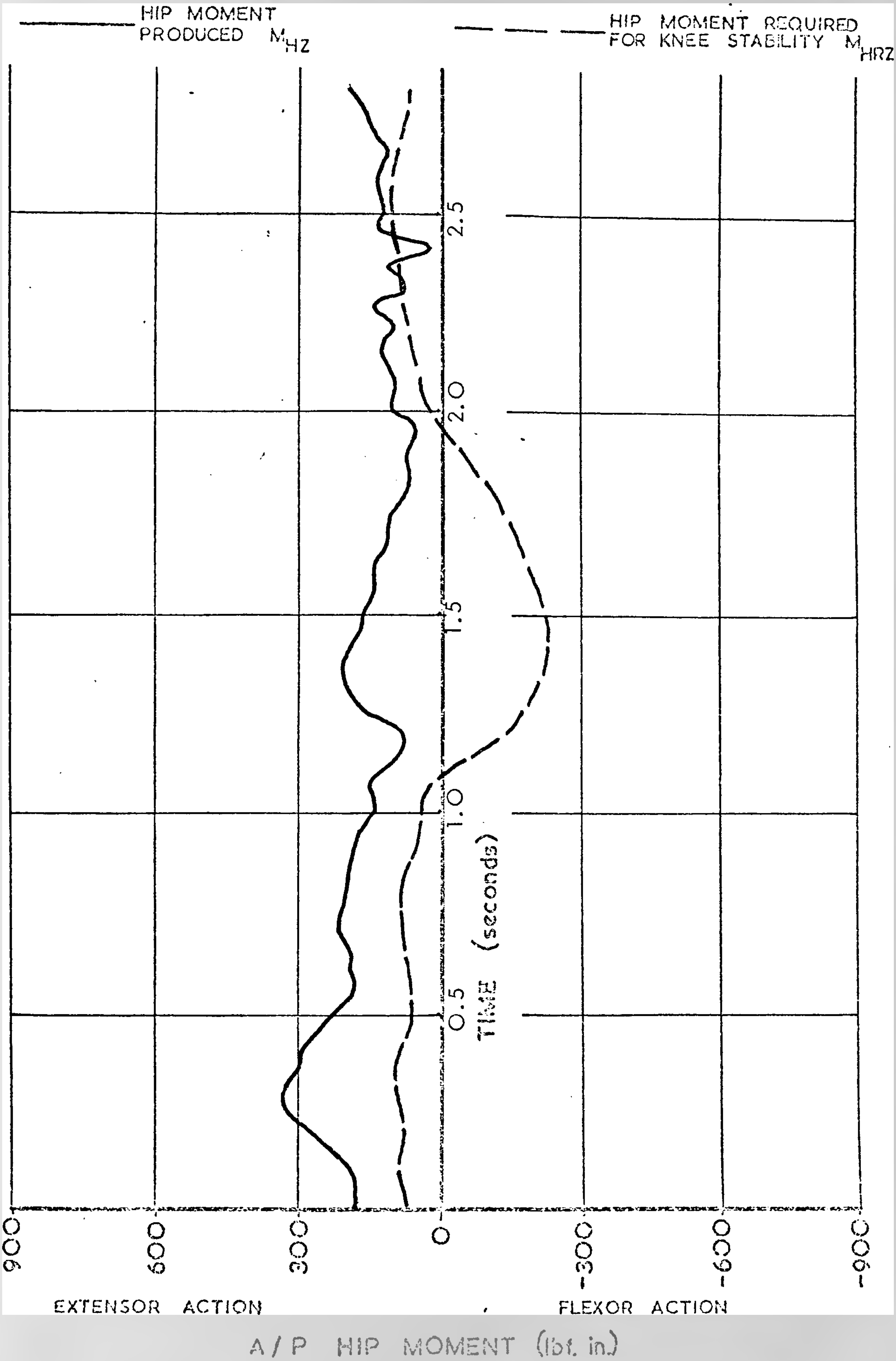


fig. VI.31

A/P HIP MOMENT IN LEVEL WALKING WITH O.B.

cycle time 1.18 seconds

me 254.5 lbf. in. sec.

me_{av} 392 lbf. in.

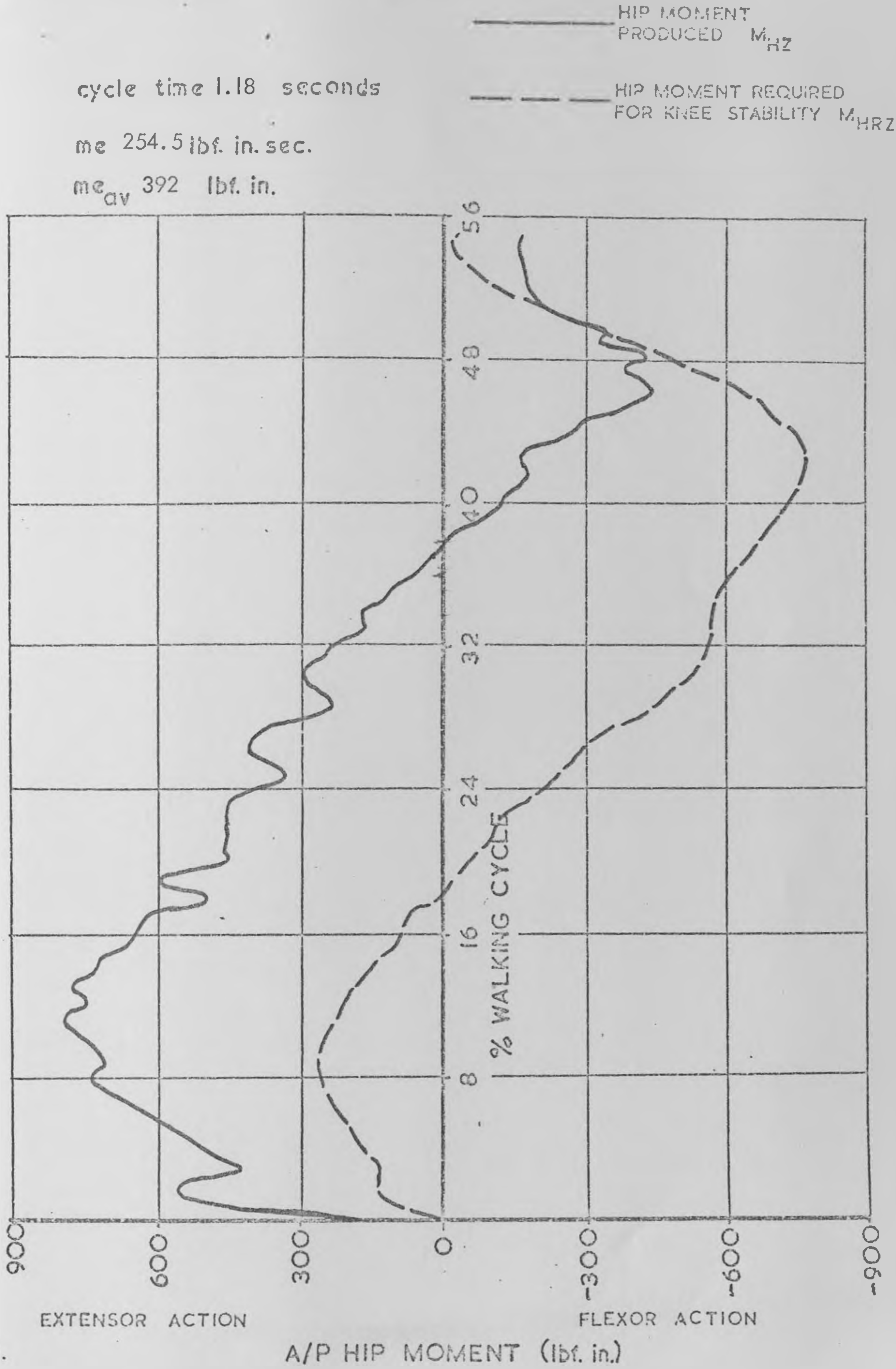


fig. VI.32

A/P HIP MOMENT IN WALKING UP RAMP WITH O.B.

cycle time 1.31 seconds

me 263.8 lbf. in. sec.

me_{av} 394 lbf. in.

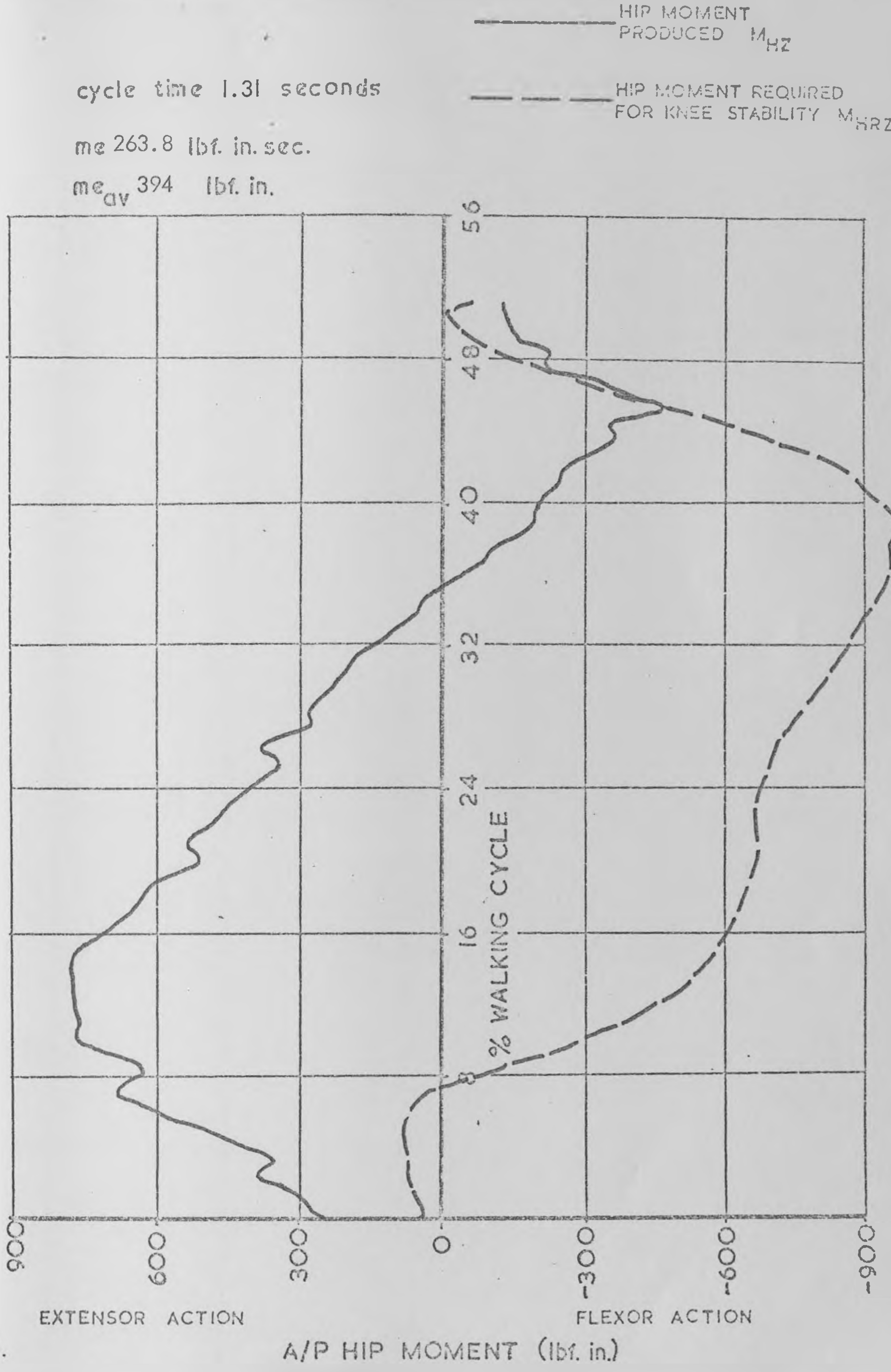


fig.VI.33

A/P HIP MOMENT IN WALKING DOWN RAMP WITH O.B.

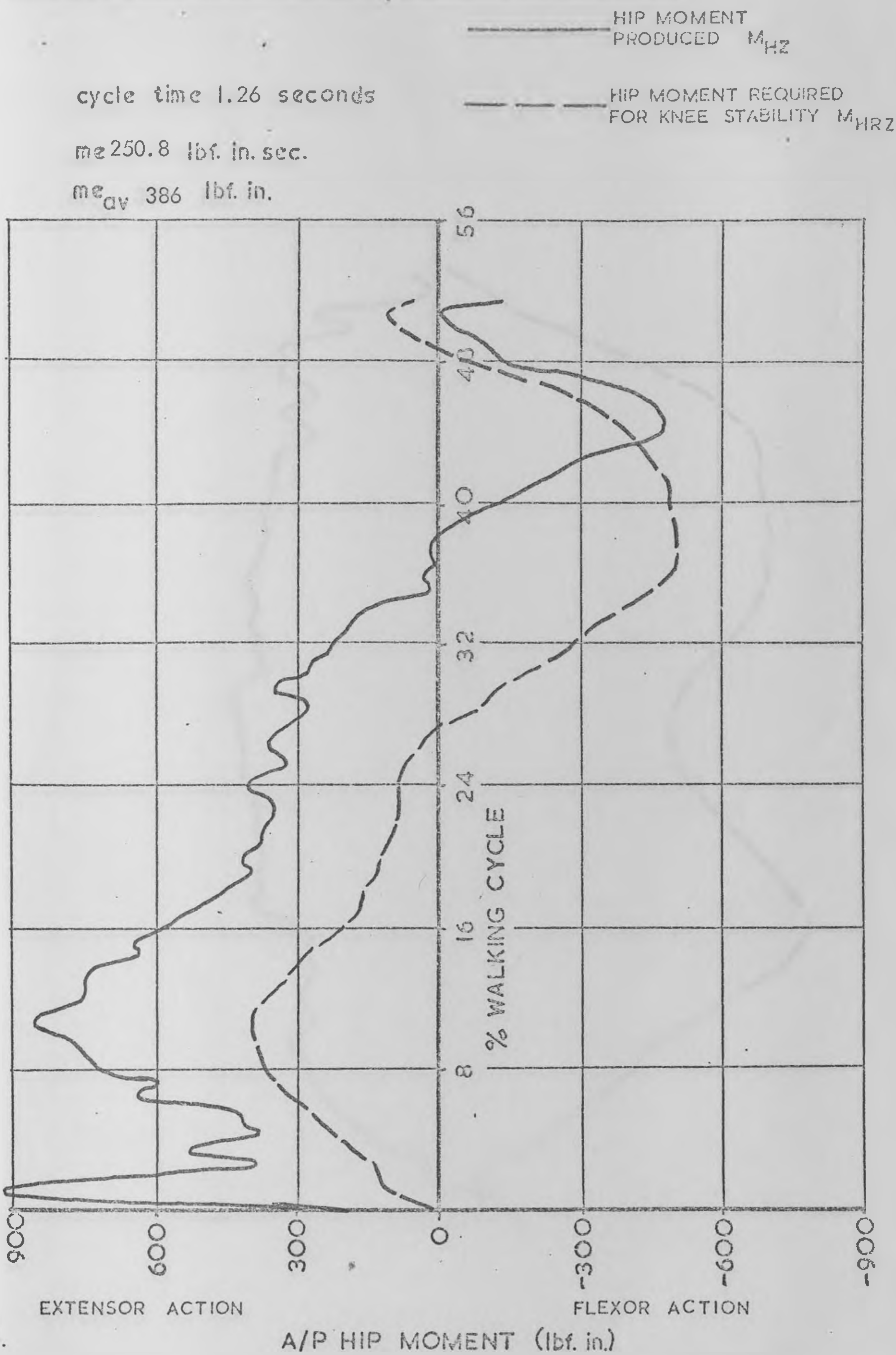


fig. VI.34

A/P HIP MOMENT IN WALKING UP STAIRS WITH O.B.

——————— HIP MOMENT PRODUCED M_{HZ}

— — — HIP MOMENT REQUIRED FOR KNEE STABILITY M_{HRZ}

cycle time 1.37 seconds

me 221.9 lbf. in. sec.

mc_{av} 300 lbf. in.

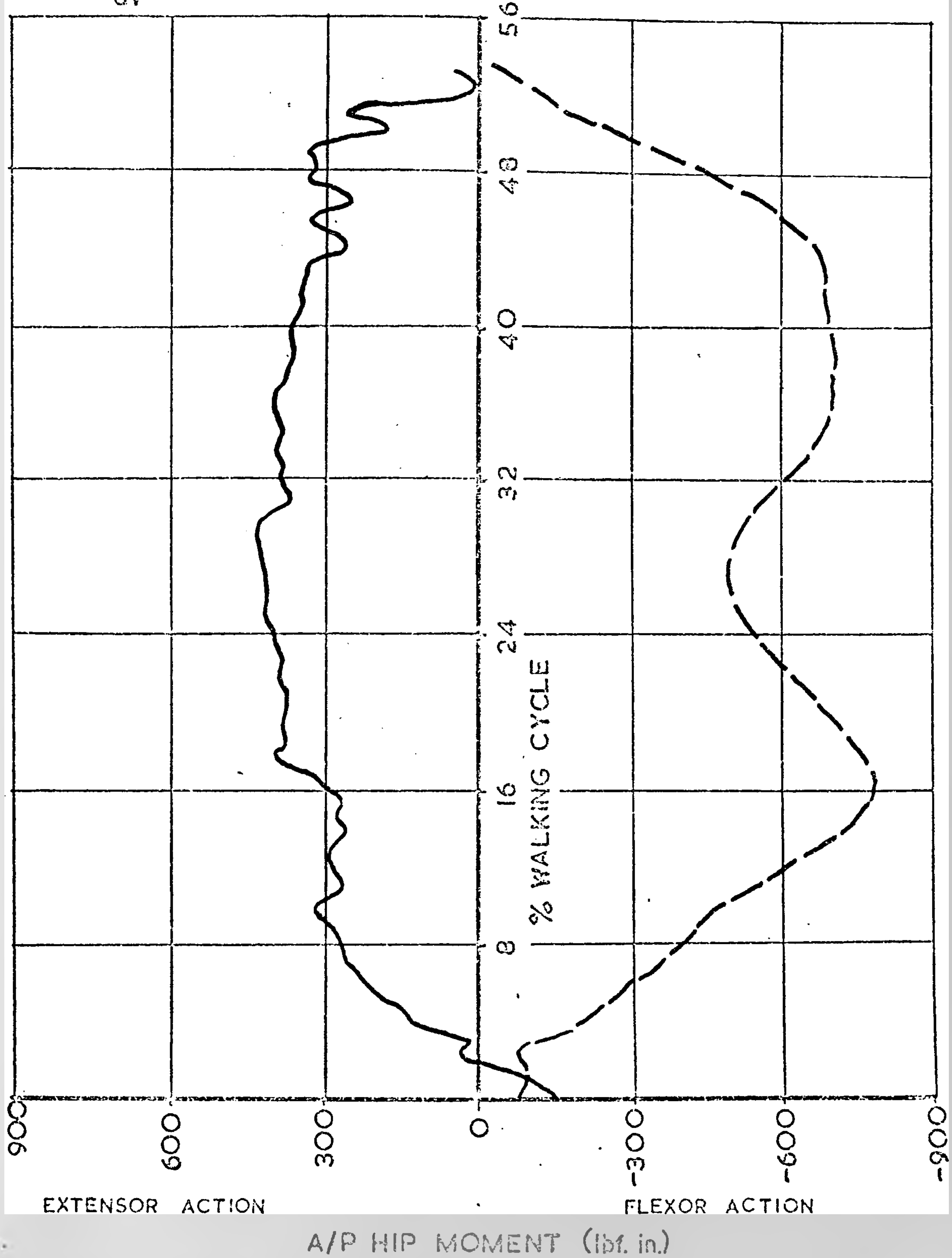


fig. VI.35

A/P HIP MOMENT IN WALKING DOWN STAIRS WITH O.B.

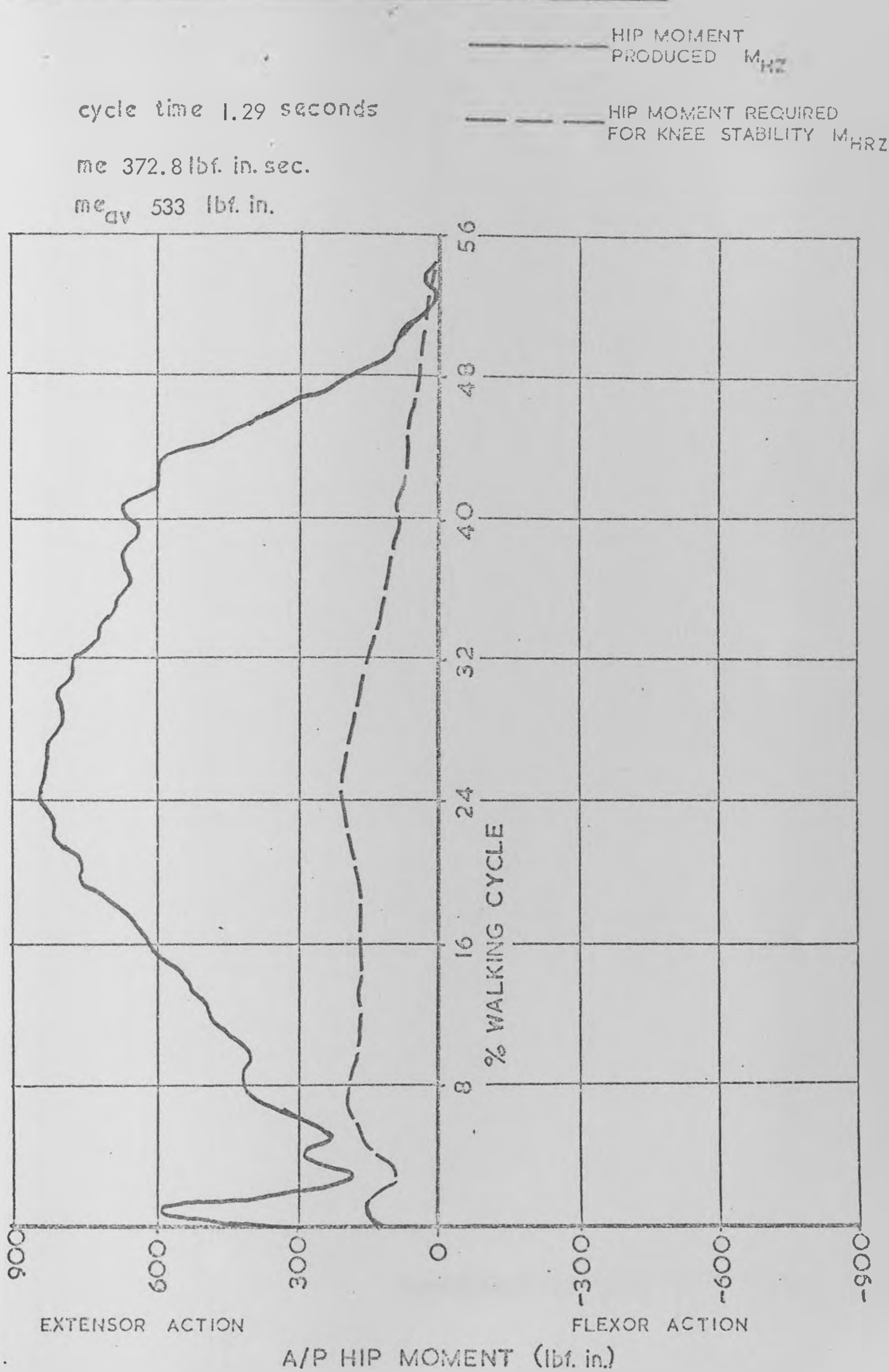


fig.VI.36

A/P HIP MOMENT IN STEPPING OVER AN OBJECT (from a standing position) WITH C.B.

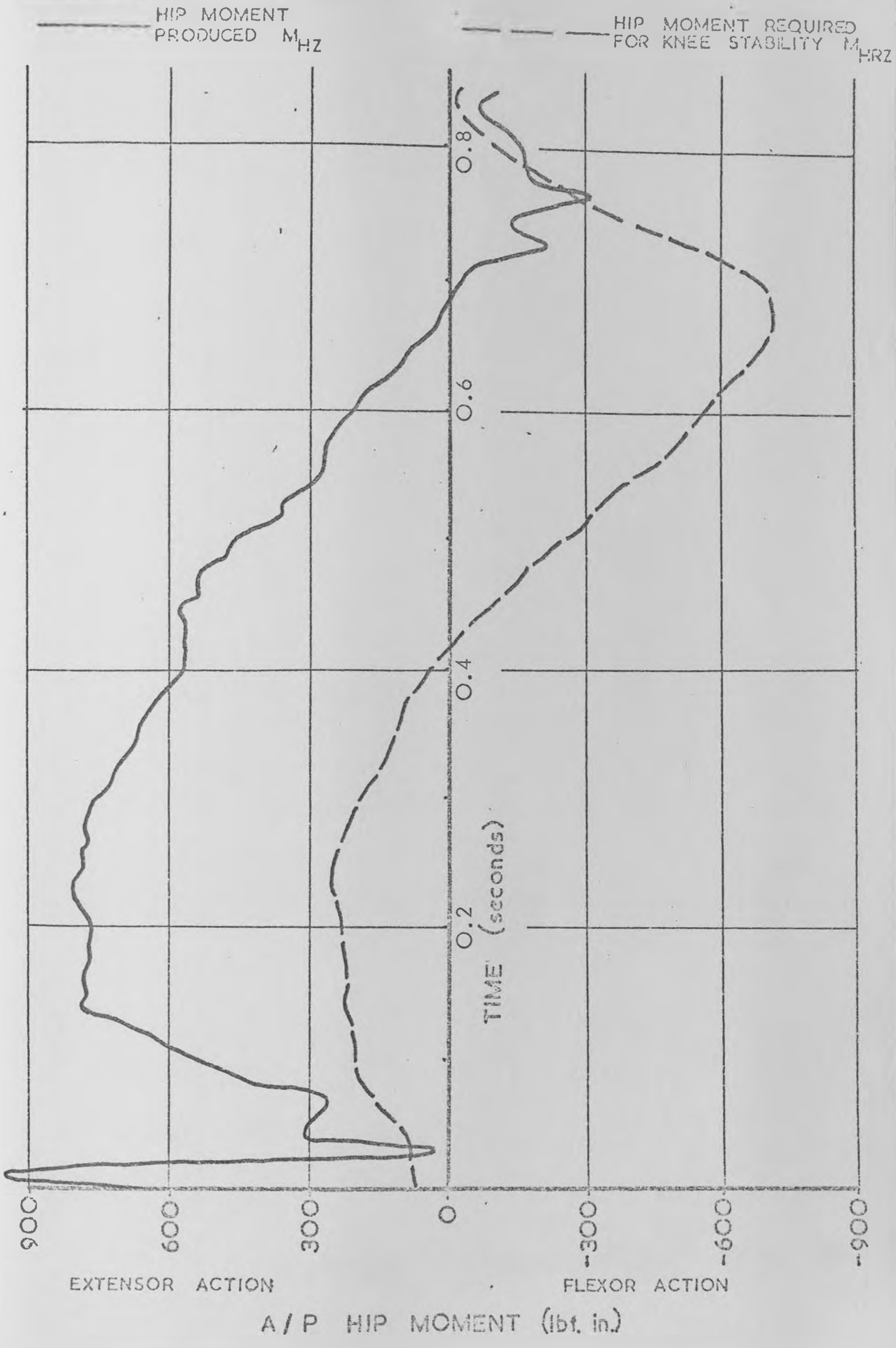


fig.VI.37

A/P HIP MOMENT IN STEPPING OVER AN OBJECT (after walking up to it) WITH O. B.

——— HIP MOMENT PRODUCED M_{HZ} — — — HIP MOMENT REQUIRED FOR KNEE STABILITY M_{HRZ}

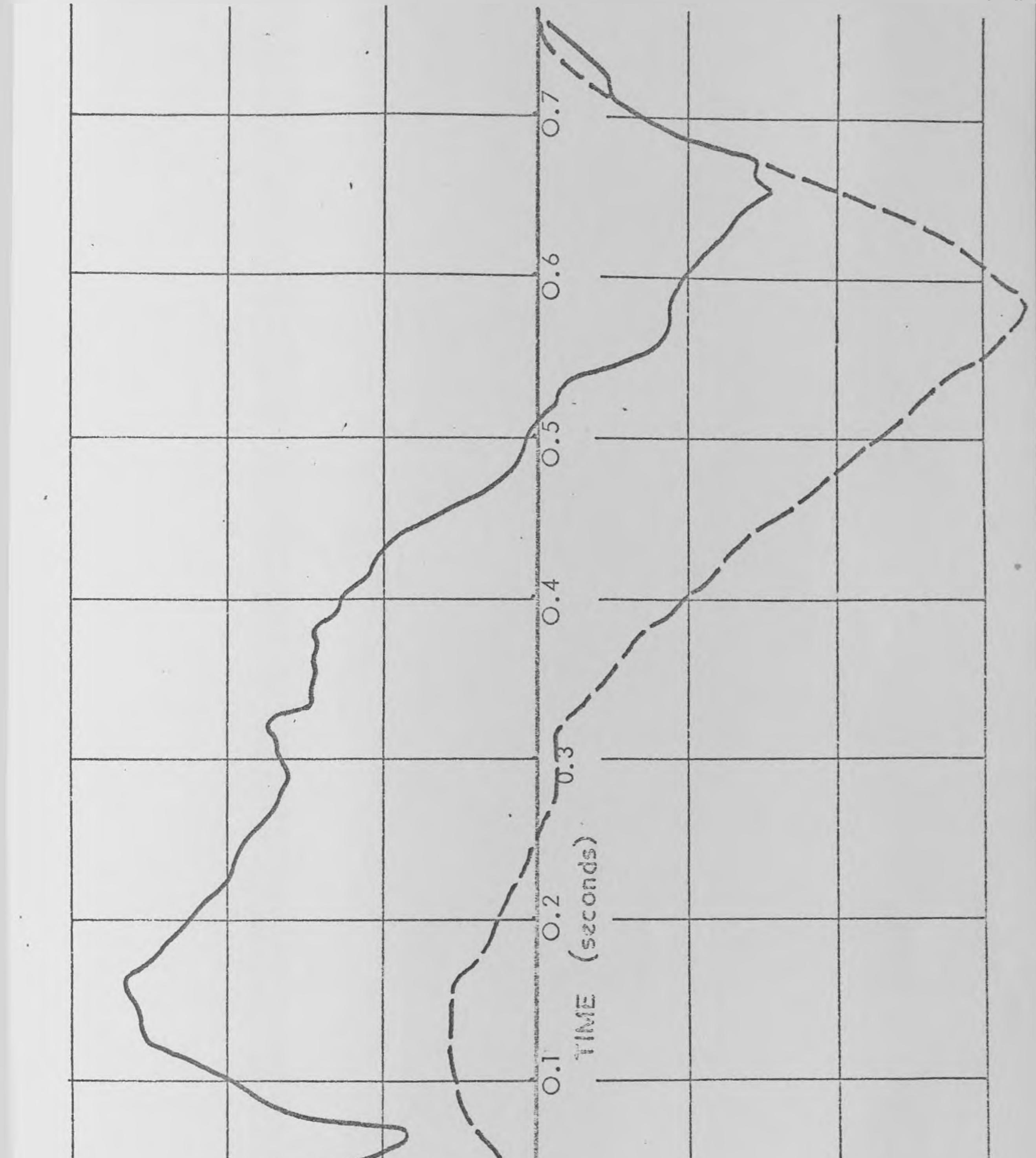


fig.VI.38

A/P HIP MOMENT IN WALKING SIDEWAYS (Prosthesis Leading) WITH O.B.

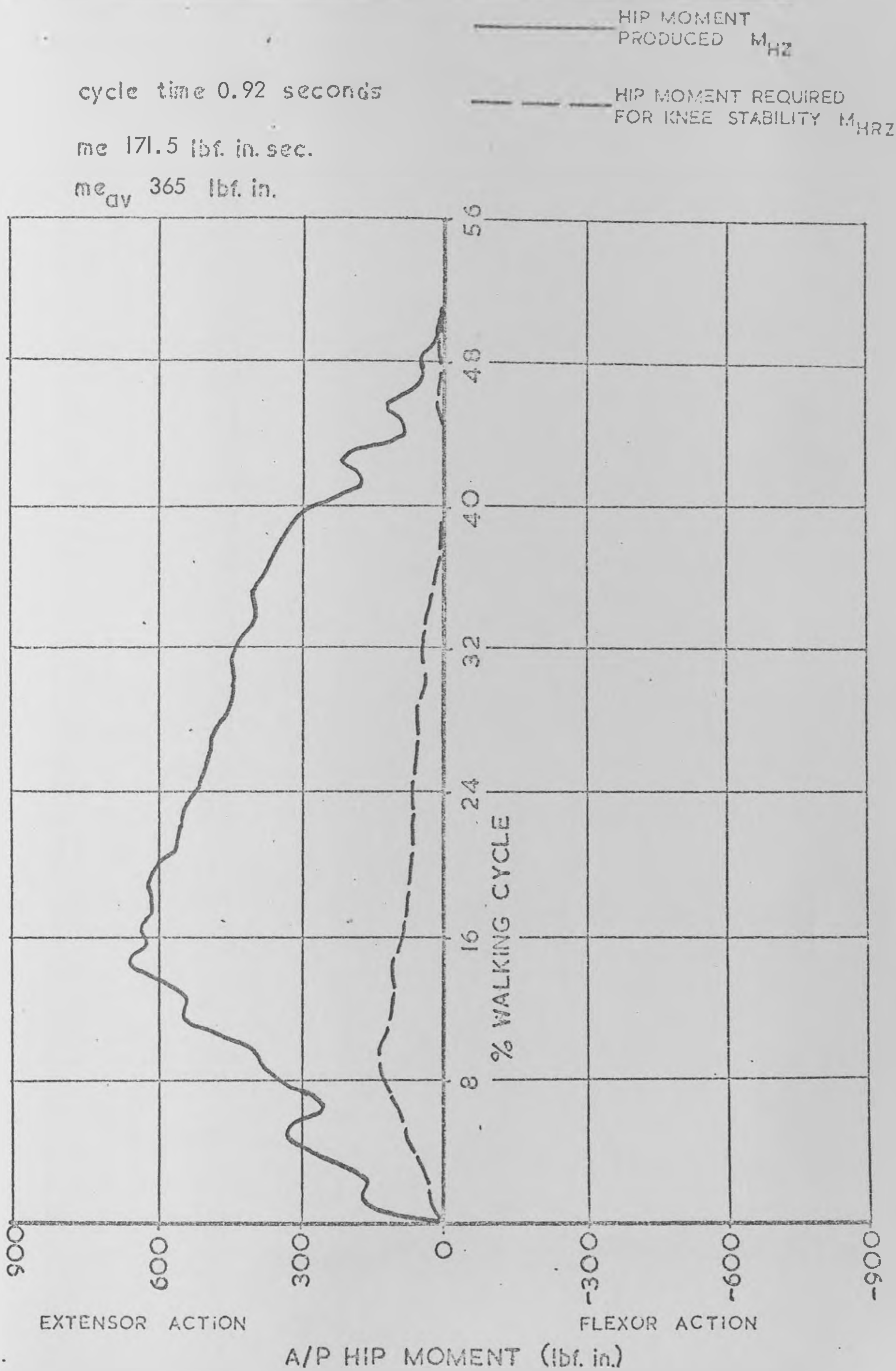
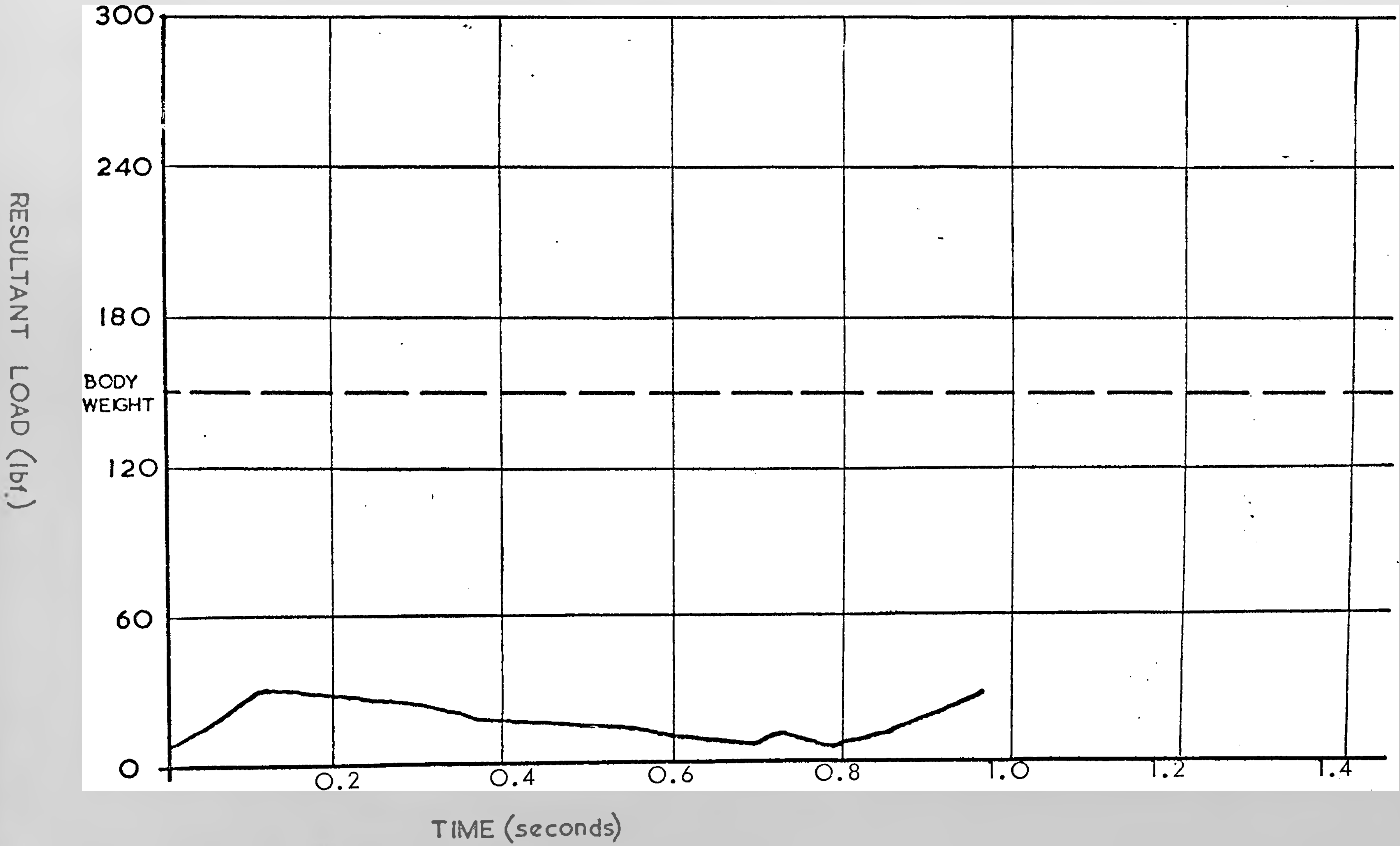


fig. VI.39

A/P HIP MOMENT IN WALKING SIDEWAYS (Normal Leg Leading) WITH O.B.

fig.VI.40



RESULTANT LOAD IN STANDING UP WITH O.B.

fig. VI.41

A/P HIP MOMENT IN STANDING UP WITH O.B.

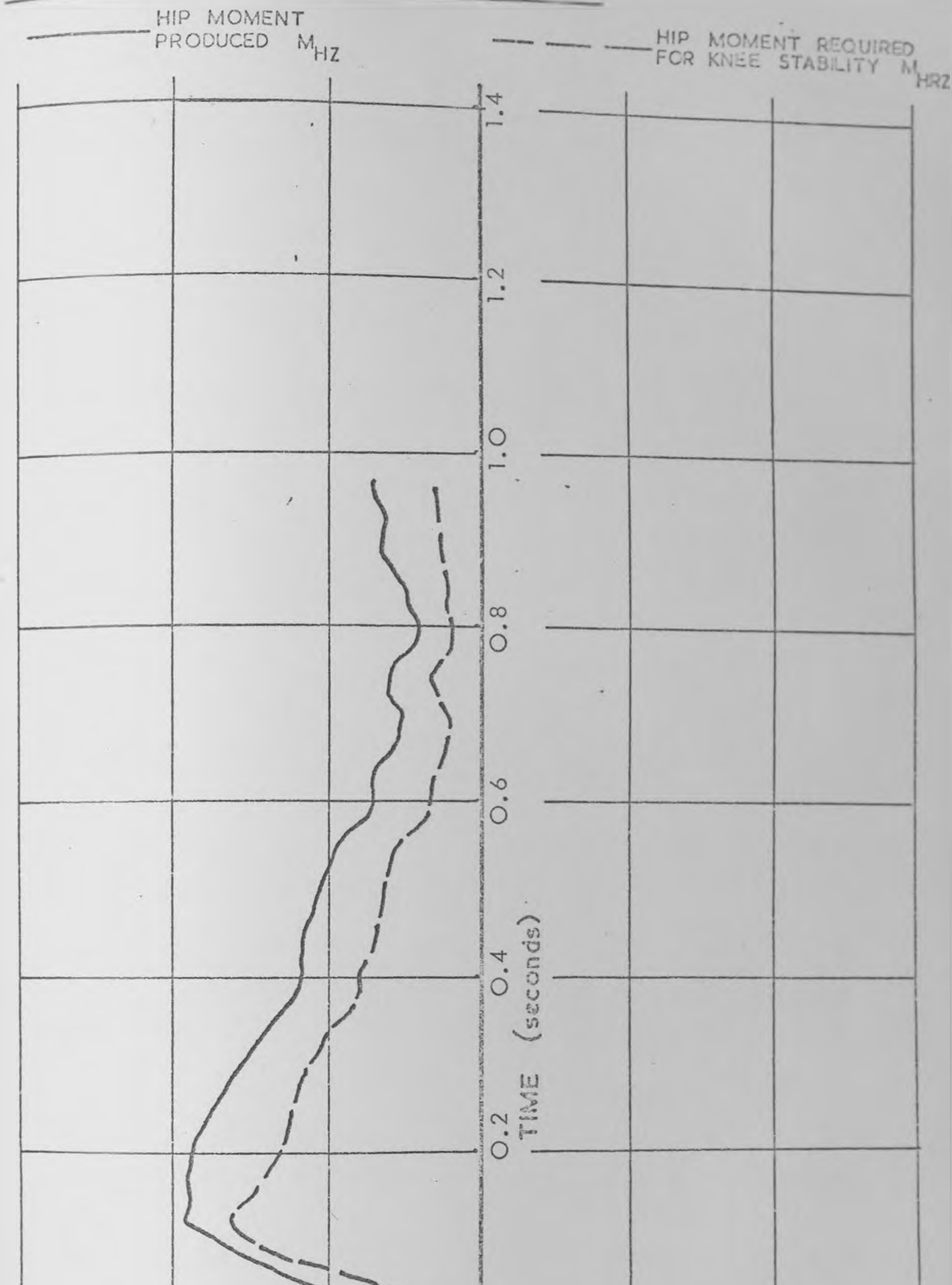
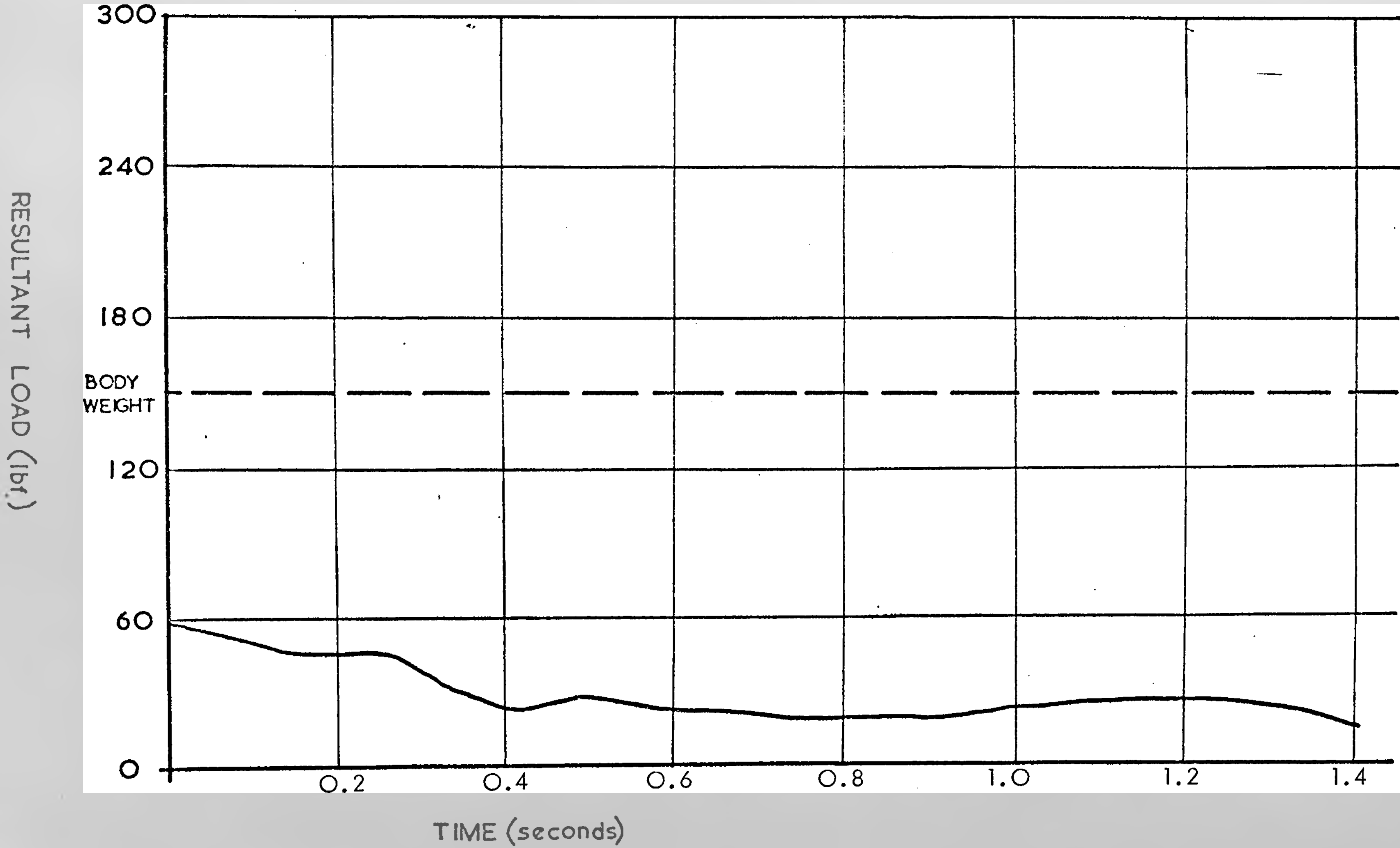


fig. VI.42



RESULTANT LOAD IN SITTING DOWN WITH O.B.

fig. VI.43

A/P HIP MOMENT IN SITTING DOWN WITH O.B.

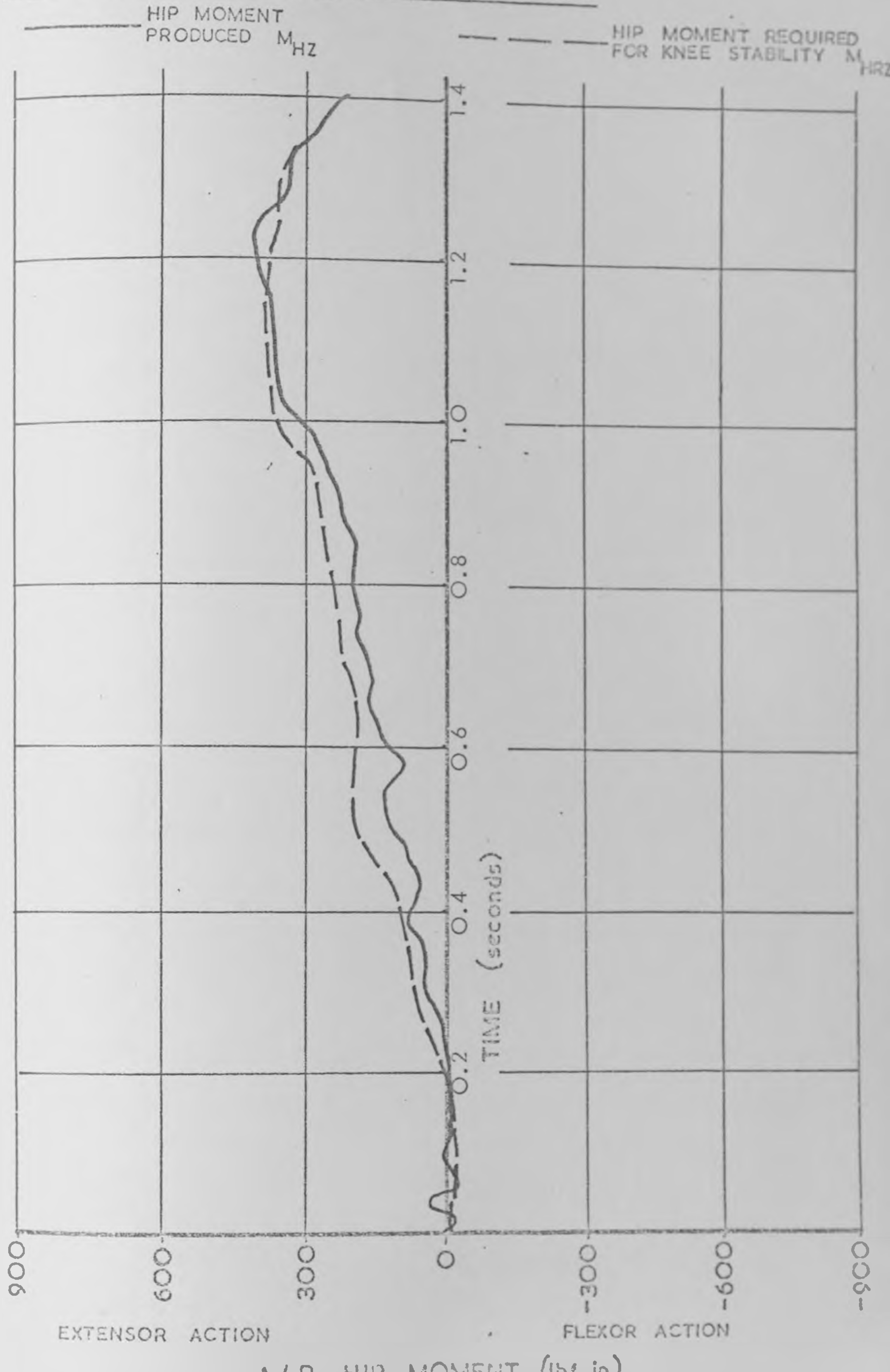


fig. VI.44

RESULTANT LOAD IN LIFTING AND LOWERING A WEIGHT WITH O.B.

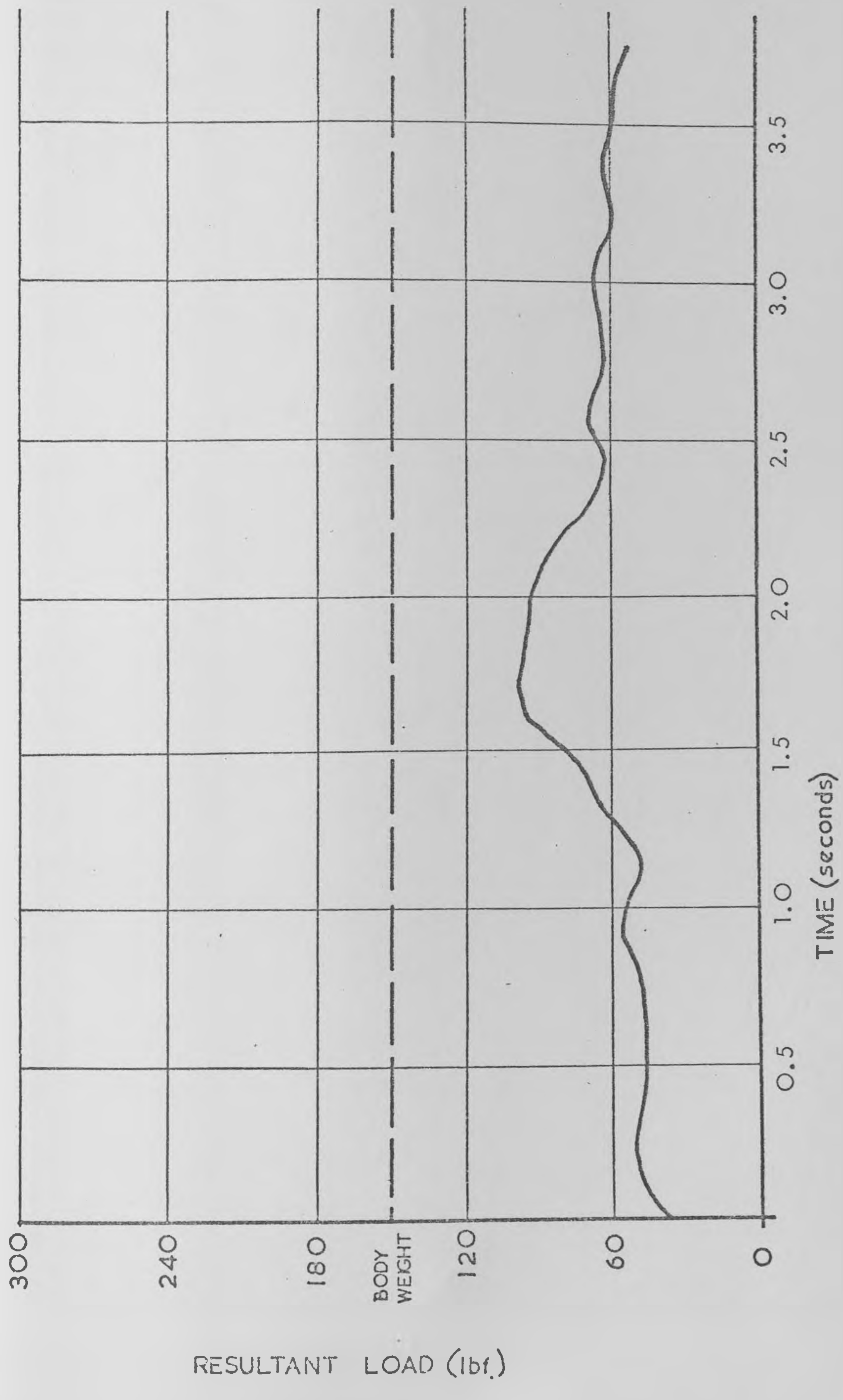


fig. VI.45

A/P HIP MOMENT IN LIFTING AND LOWERING A WEIGHT WITH O.B.

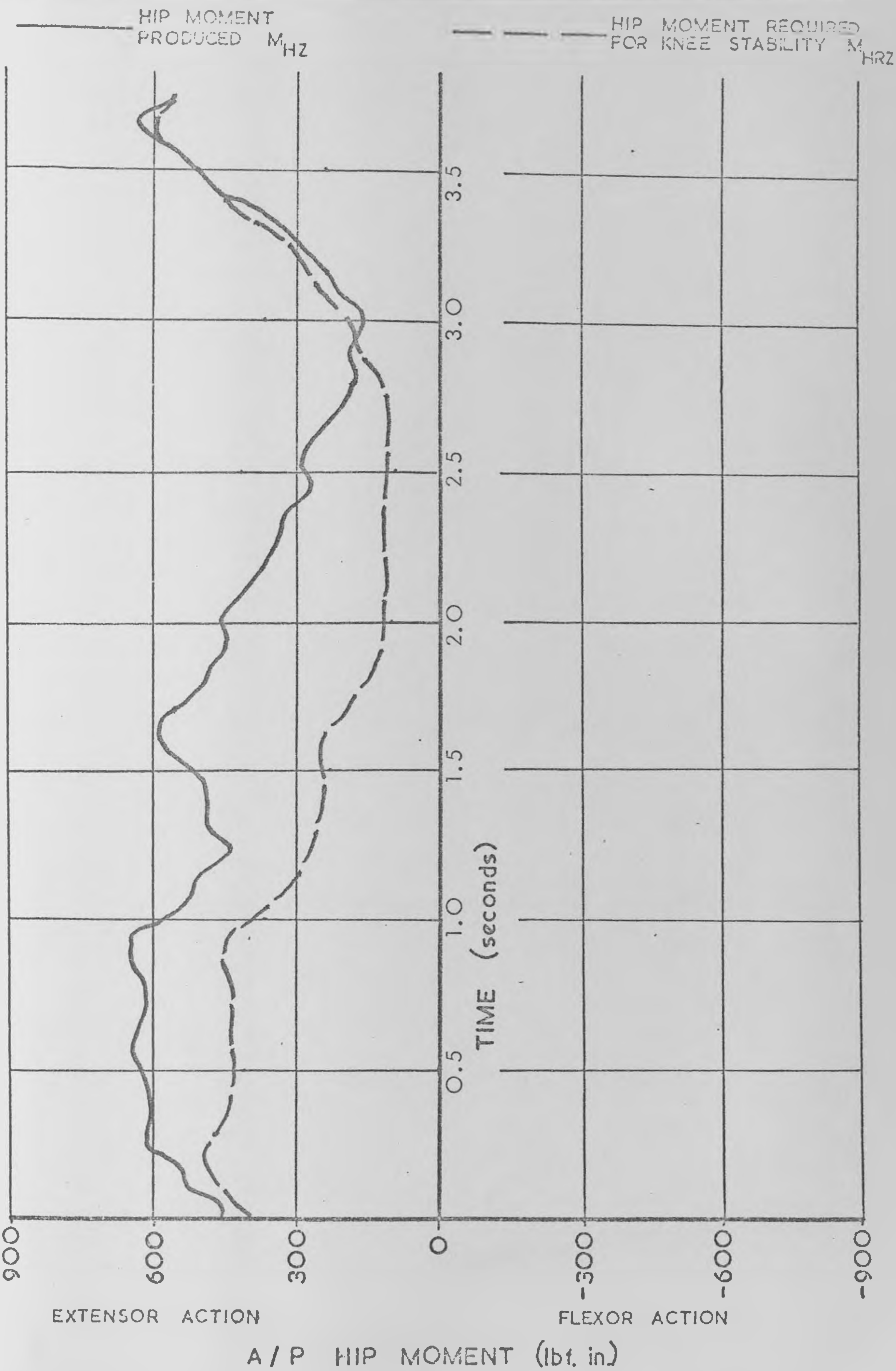


fig. VI.46

A/P HIP MOMENT IN LEVEL WALKING WITH G.R.

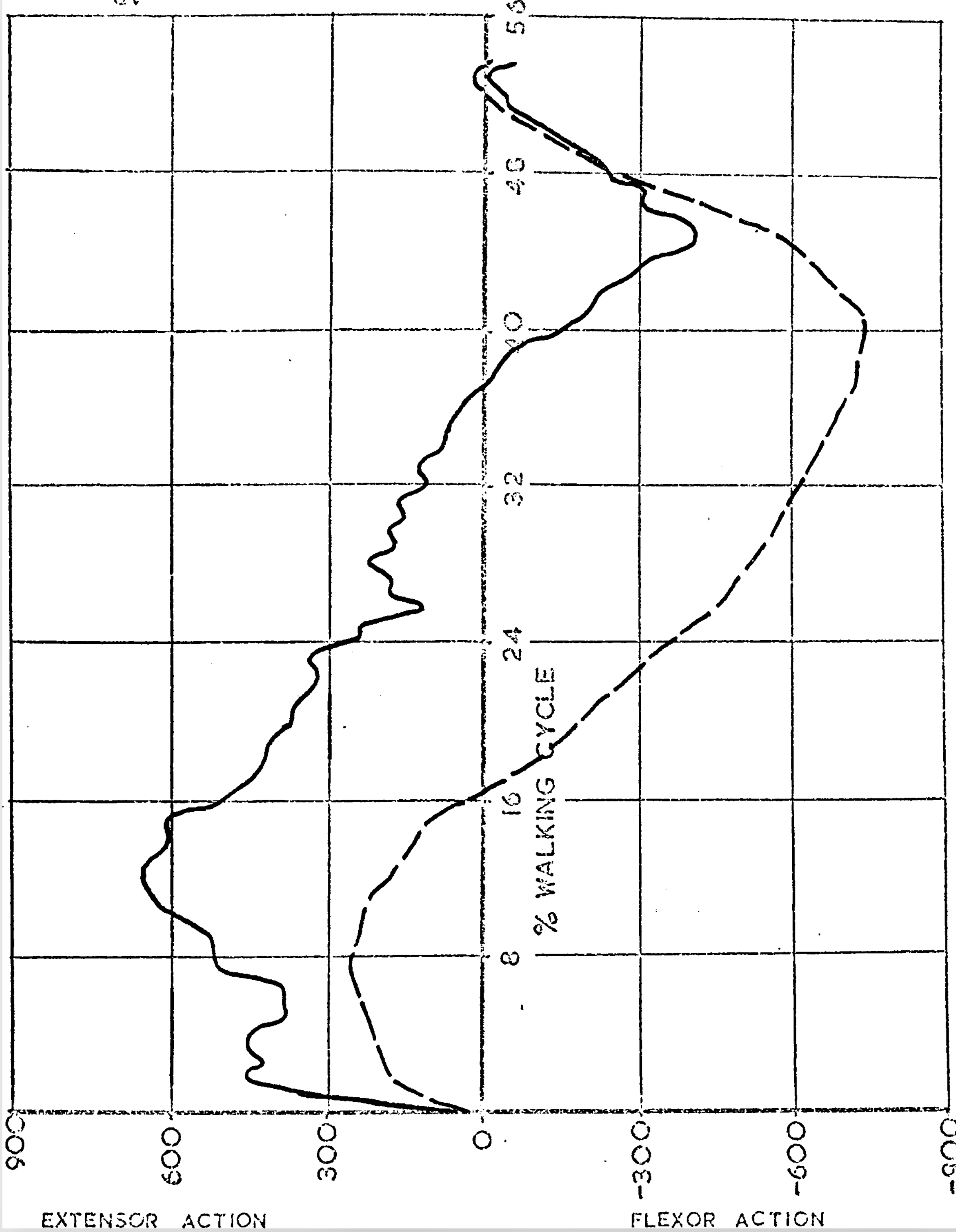
——————— HIP MOMENT PRODUCED M_{HZ}

— — — HIP MOMENT REQUIRED FOR KNEE STABILITY M_{HRZ}

cycle time 1.21 seconds

me 192.7 lbf. in. sec.

me_{av} 292 lbf. in.



A/P HIP MOMENT (lbf. in.)

fig. VI. 47

A/P HIP MOMENT IN WALKING UP RAMP WITH G.R.

fig. VI.48

A/P HIP MOMENT IN WALKING DOWN RAMP WITH G.R.

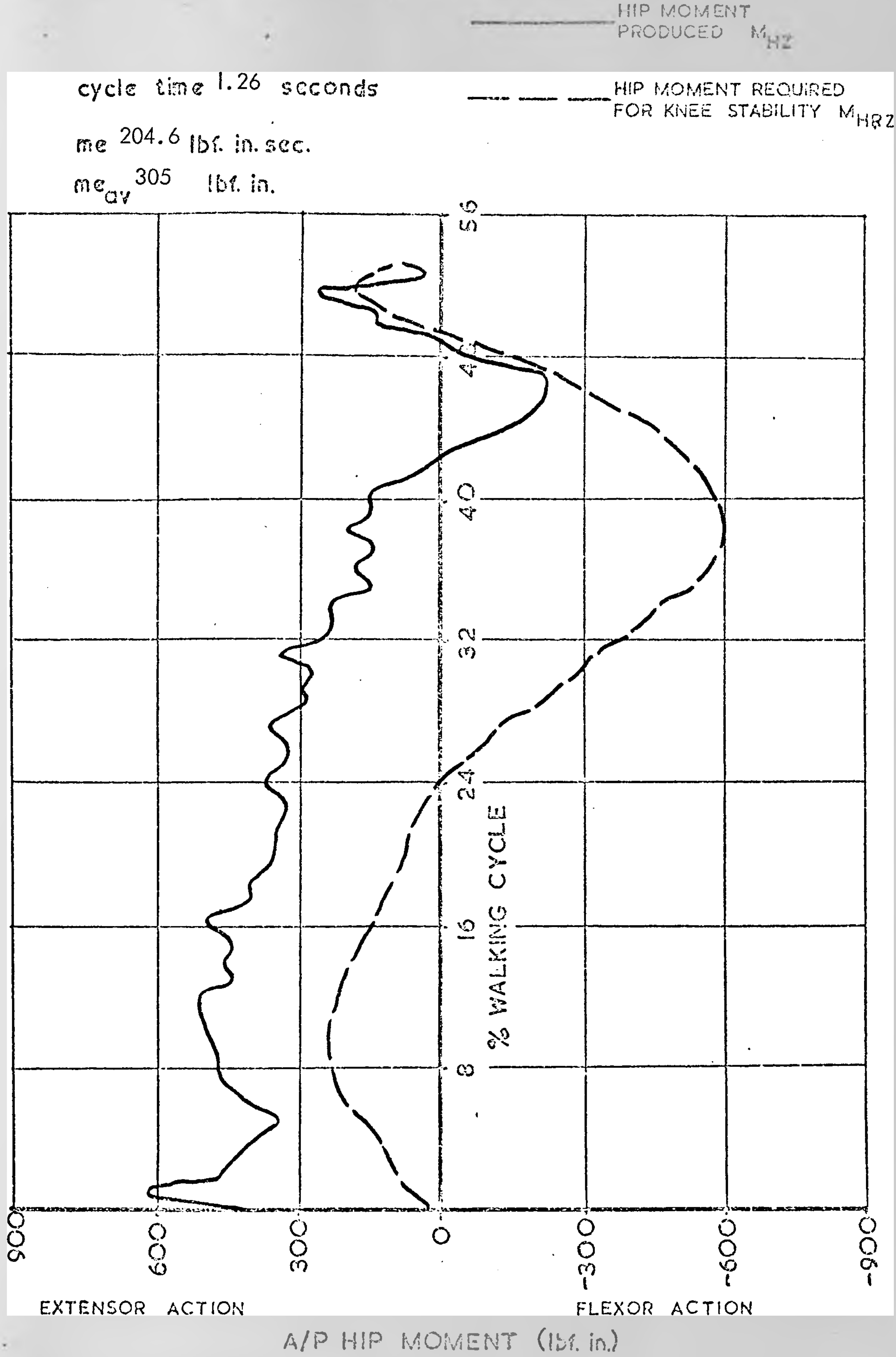


fig.VI.49

A/P HIP MOMENT IN WALKING UP STAIRS WITH G.R.

cycle time 1.44 seconds

me 305.7 lbf. in. sec.

me_{av} 476 lbf. in.

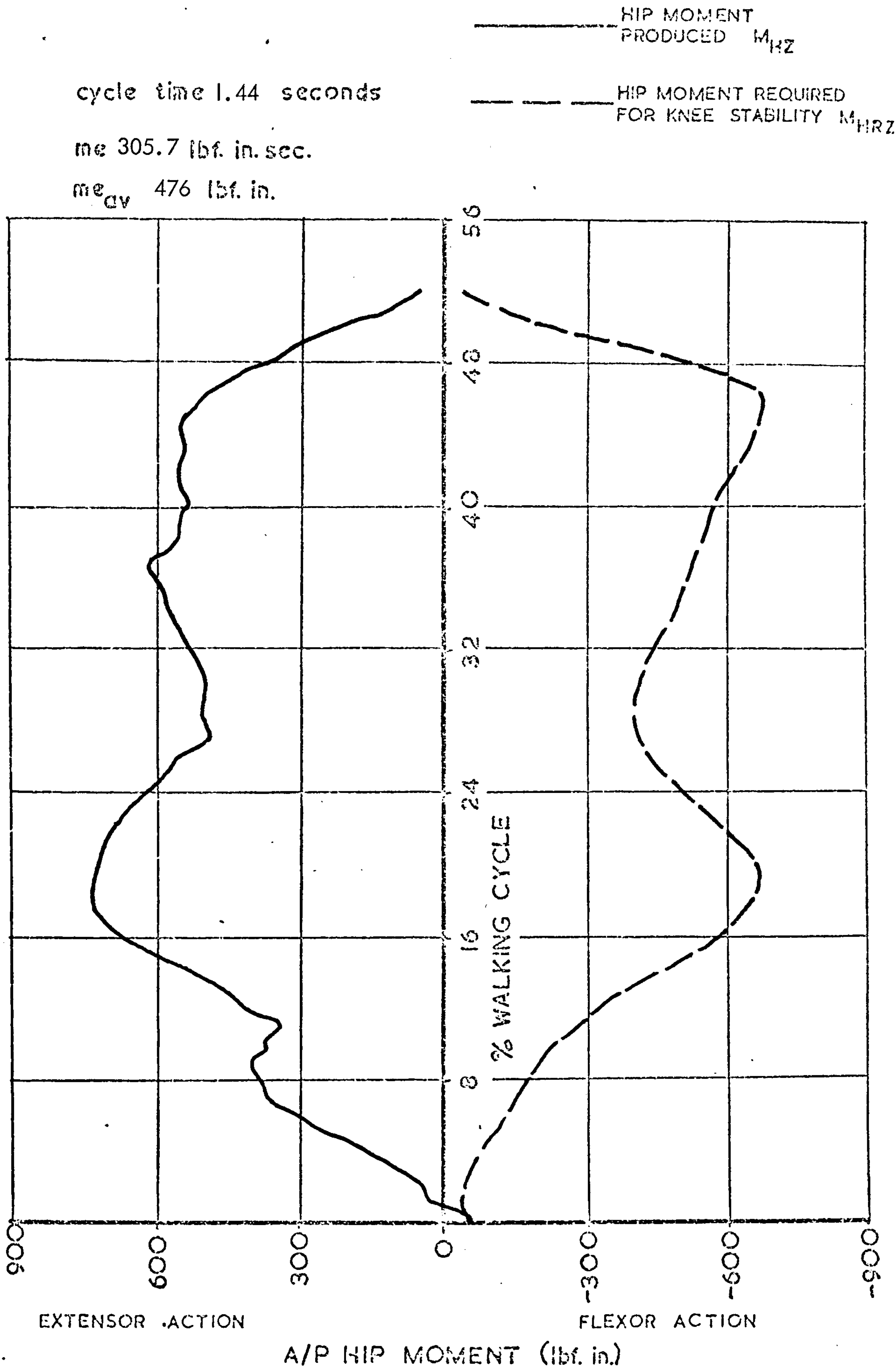


fig. VI. 50

A/P HIP MOMENT IN WALKING DOWN STAIRS WITH G.R.

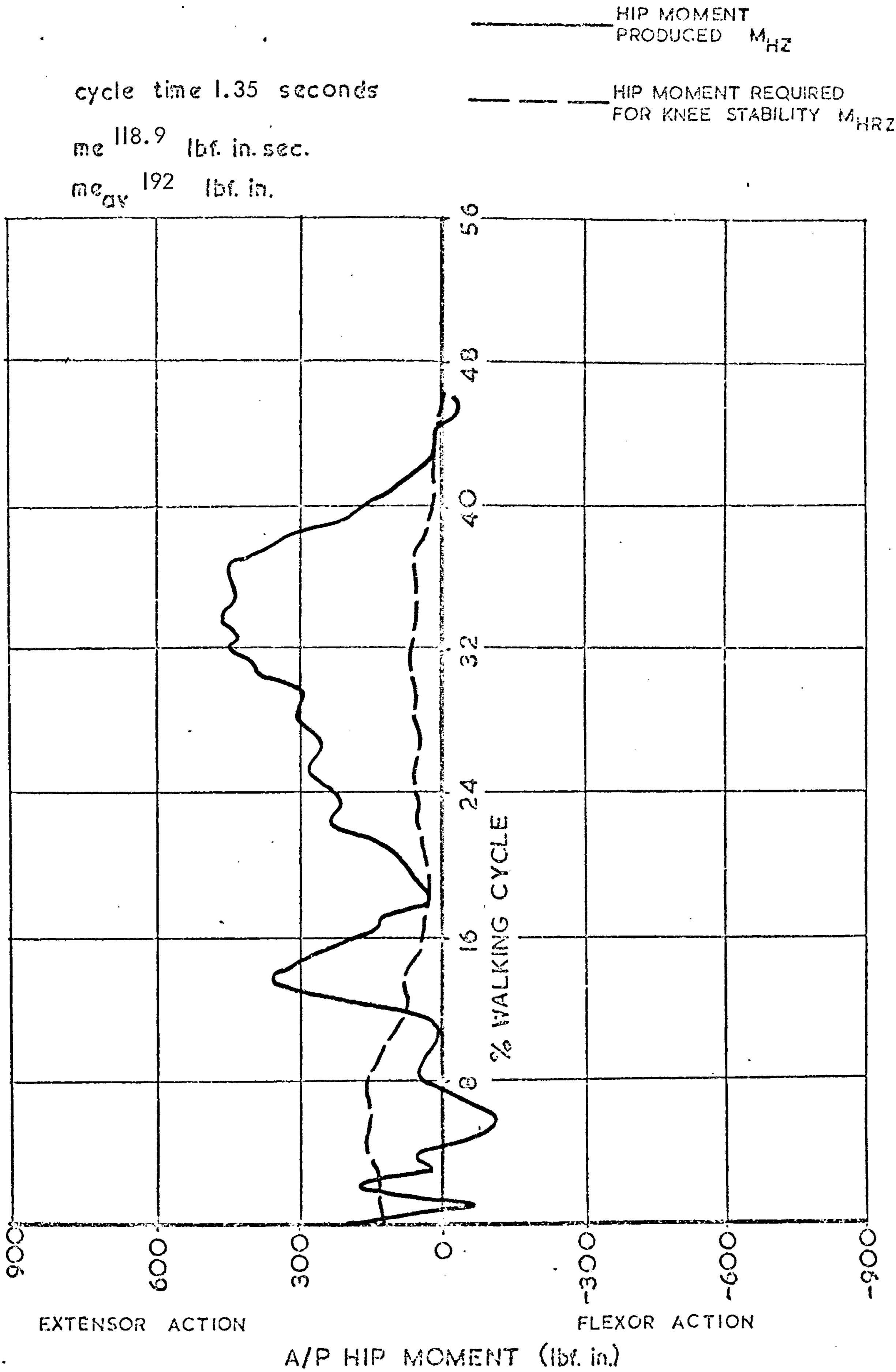


fig. VI.51

A/P HIP MOMENT IN STEPPING OVER AN OBJECT (after walking up to it) WITH G.R.

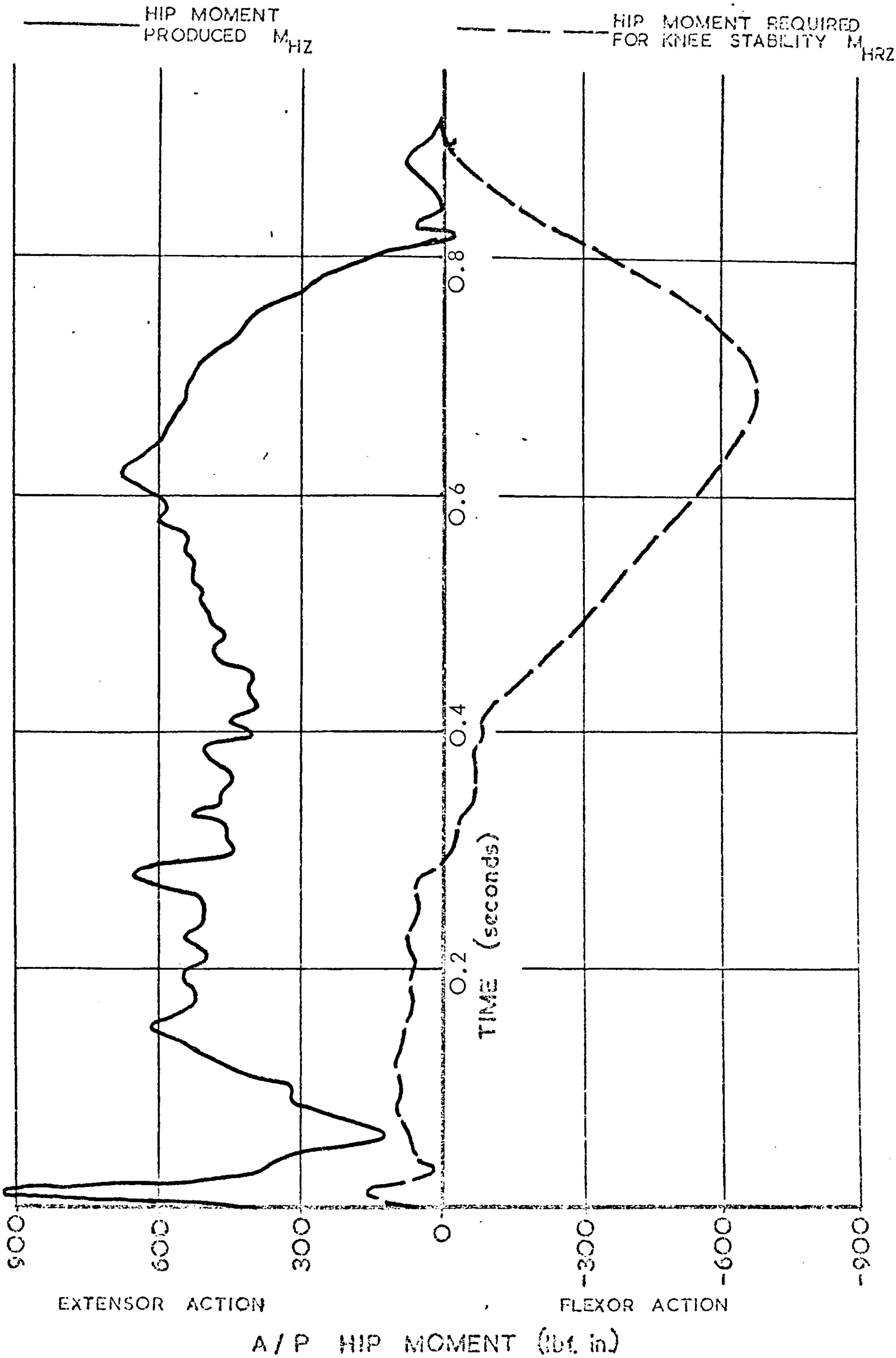


fig. VI. 52

A/P HIP MOMENT IN WALKING SIDEWAYS (Prosthesis Leading) WITH G.R.

——— HIP MOMENT PRODUCED M_{HZ}

— — — HIP MOMENT REQUIRED FOR KNEE STABILITY M_{HRZ}

cycle time 0.97 seconds

me 59.0 lbf. in. sec.

me_{av} 123 lbf. in.

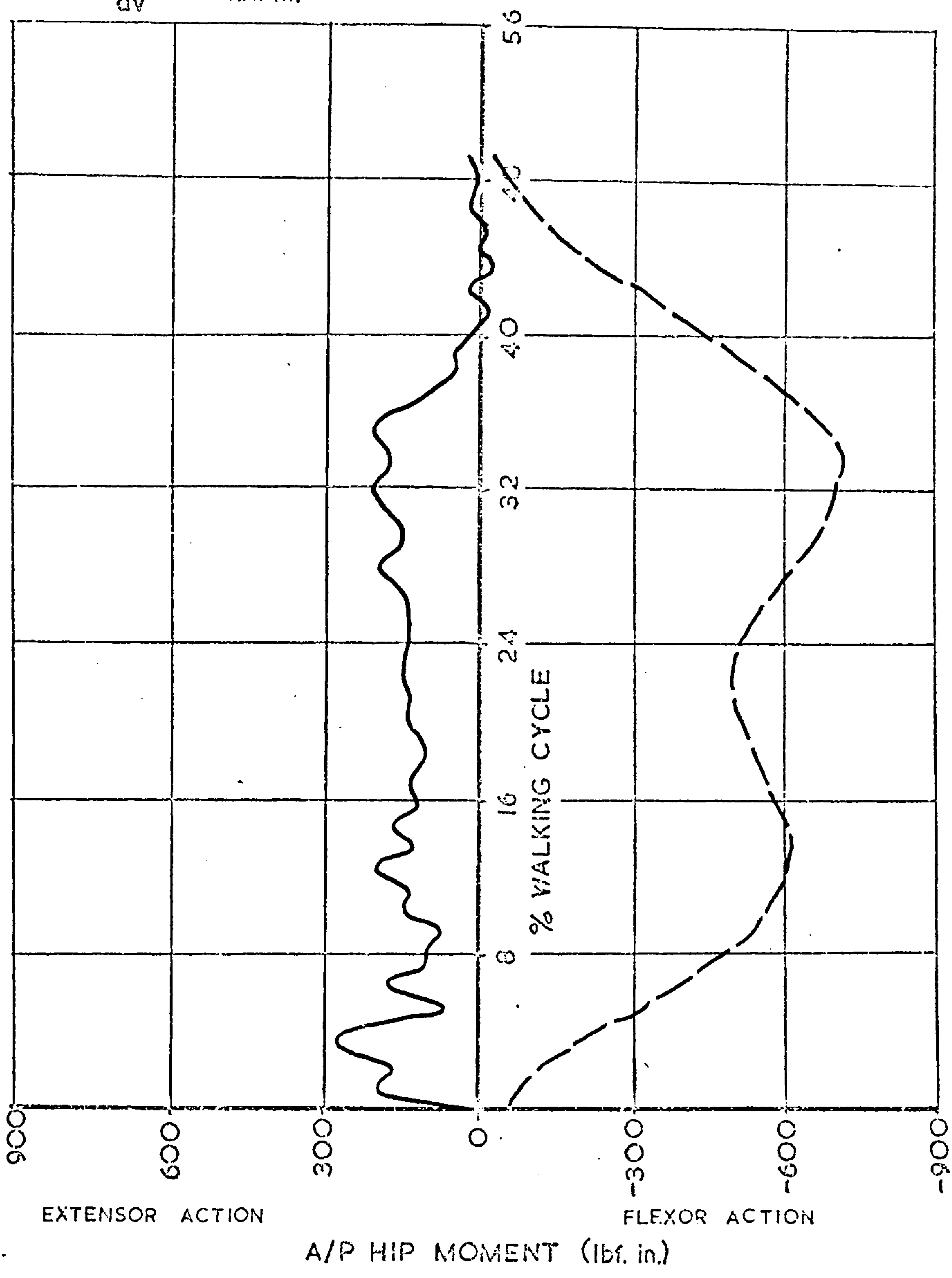


fig. VI.53

A/P HIP MOMENT IN WALKING SIDEWAYS (Normal Leg Leading) WITH G.R.

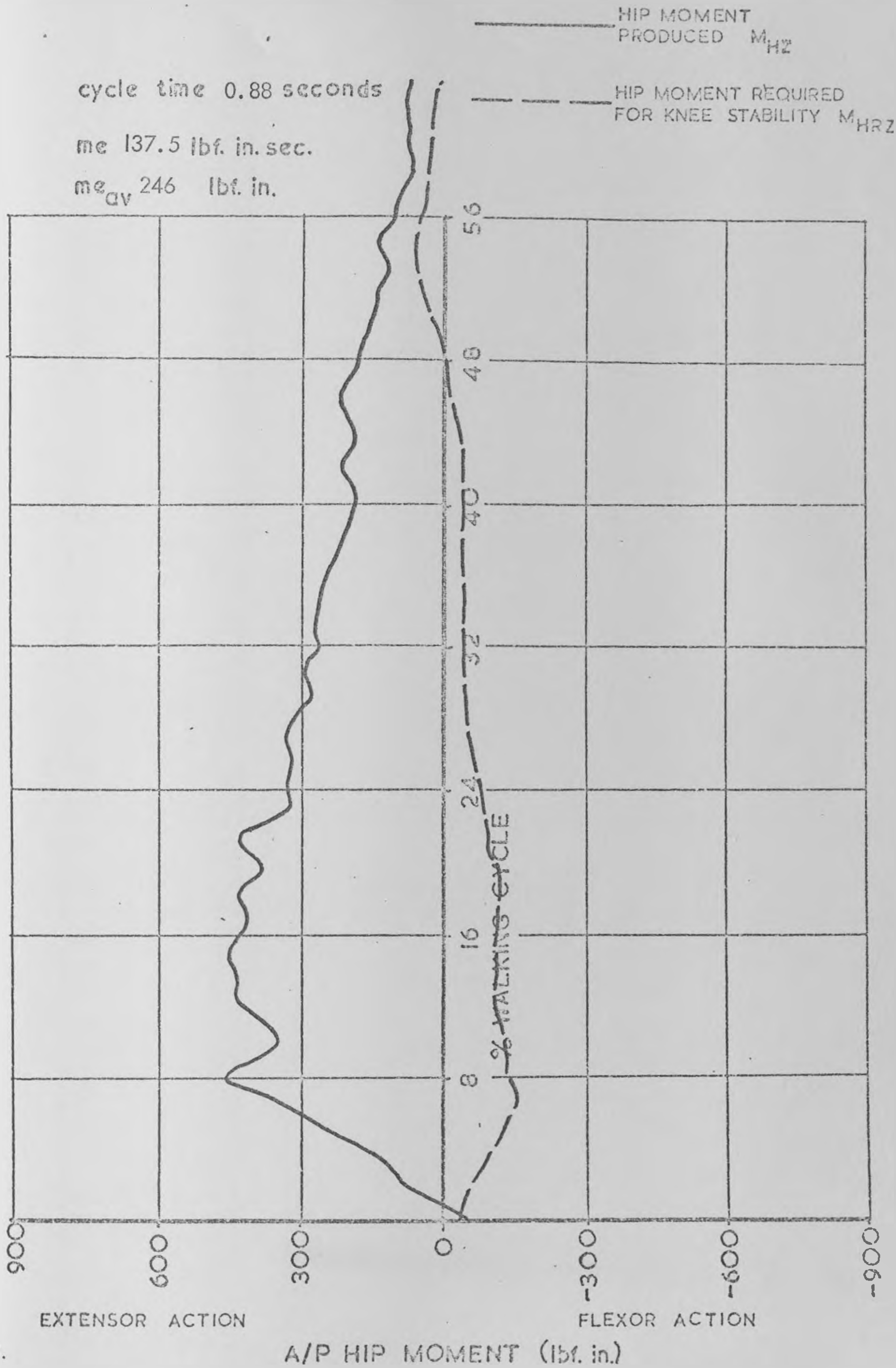


fig. VI. 54

RESULTANT LOAD IN STANDING UP WITH G.R.

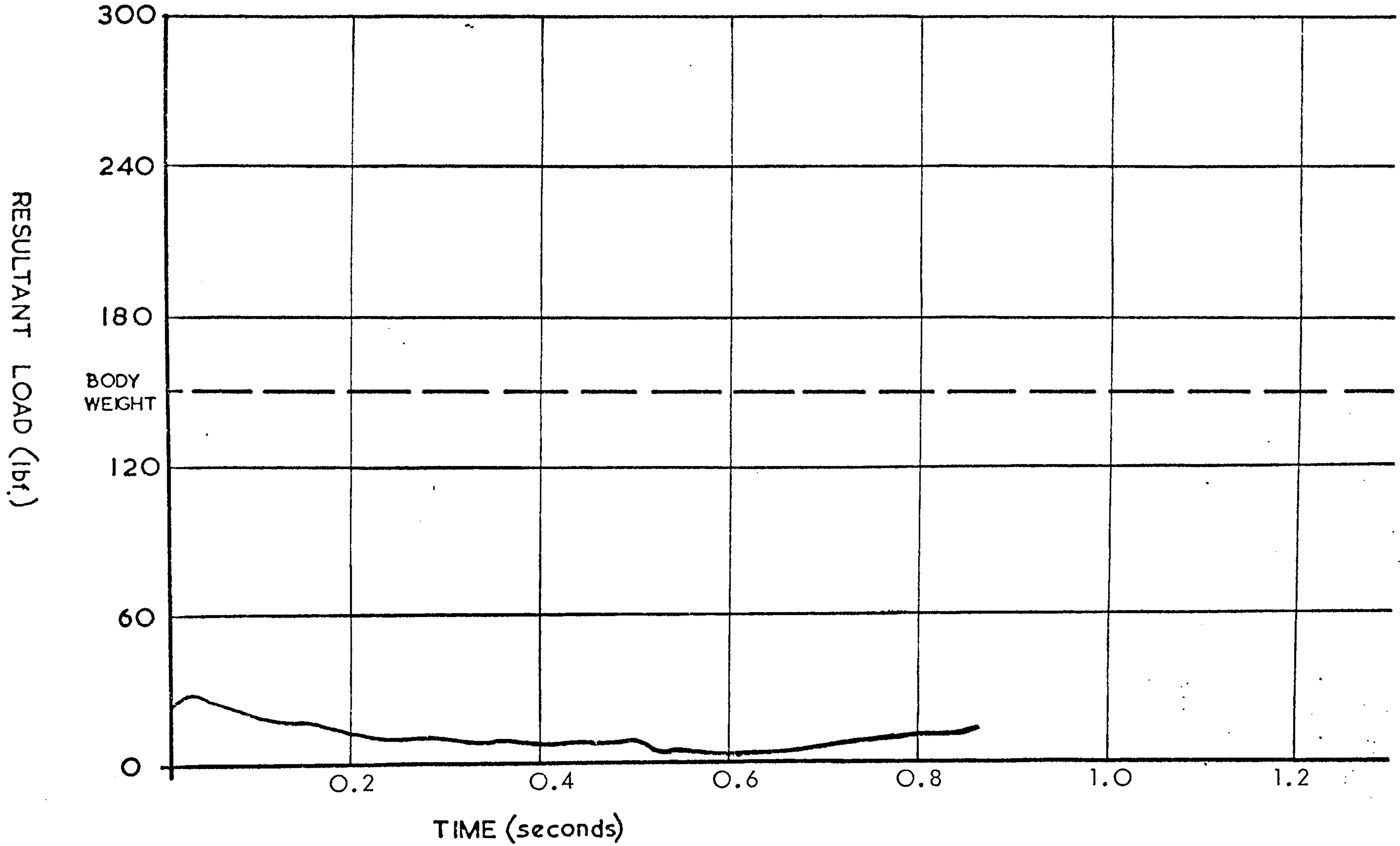


fig. VI.55

A/P HIP MOMENT IN STANDING UP WITH G.R.

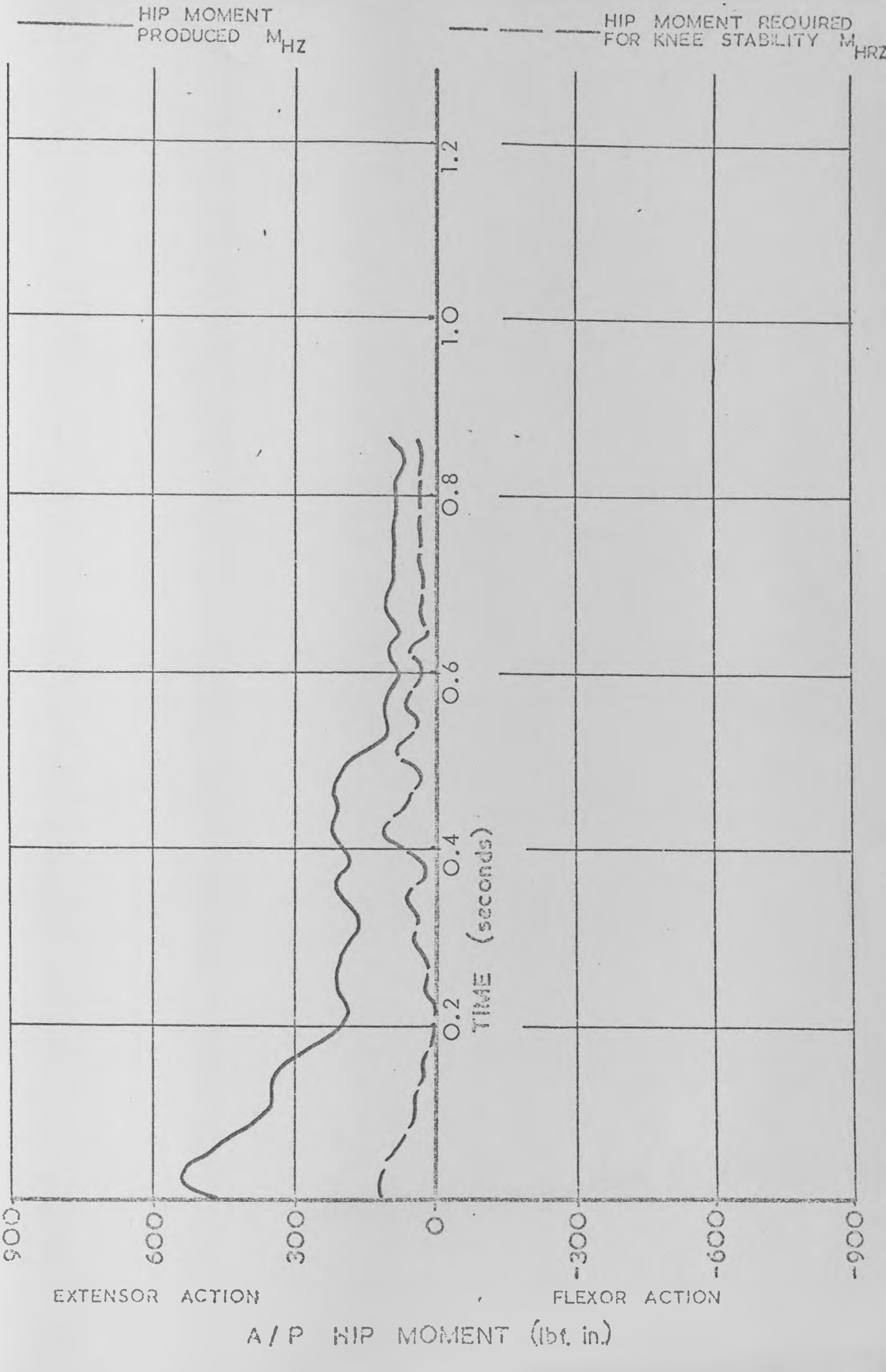


Fig.VI.56

RESULTANT LOAD IN SITTING DOWN WITH G.R.

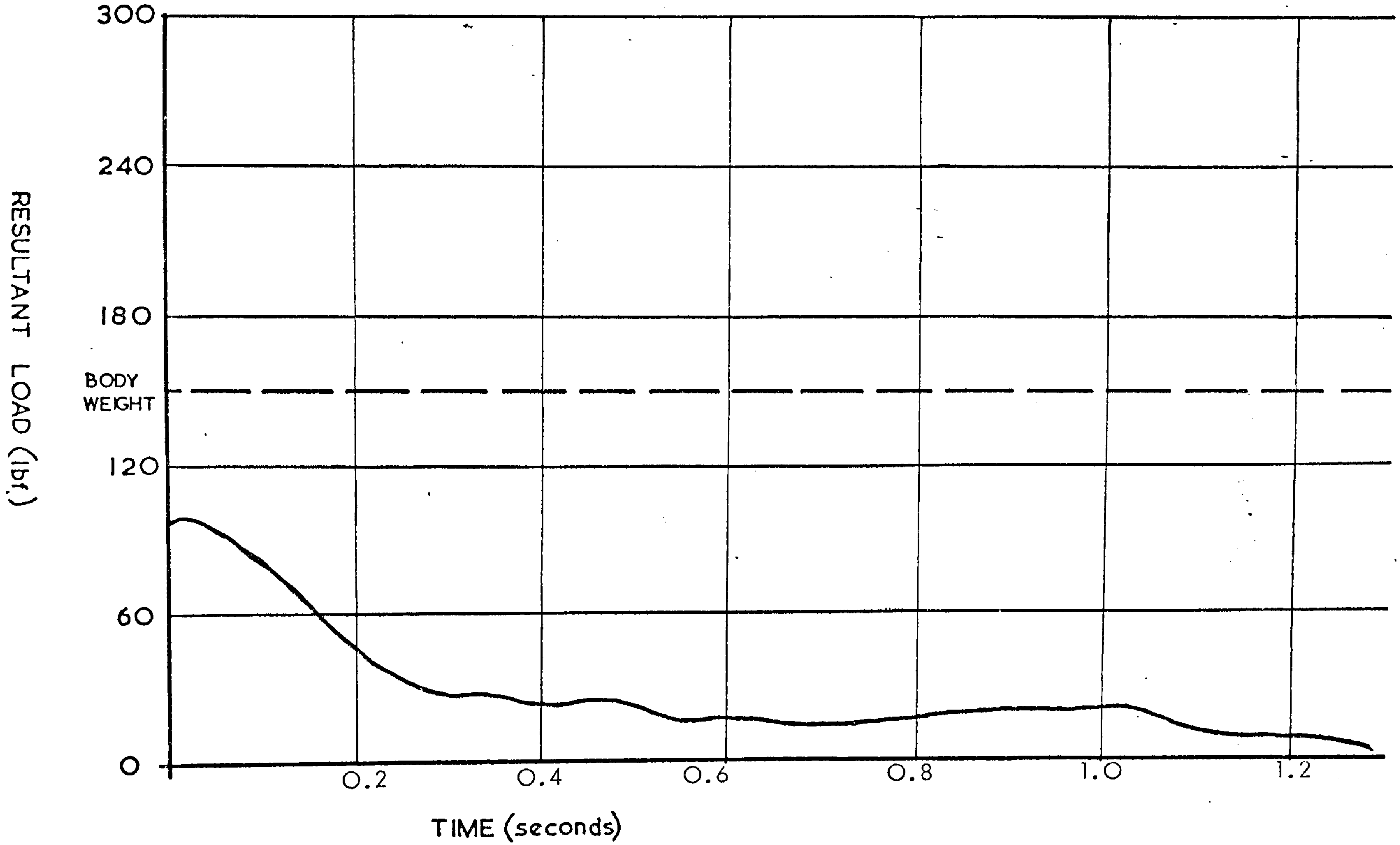


fig. VI.57

A/P HIP MOMENT IN SITTING DOWN WITH G.R.

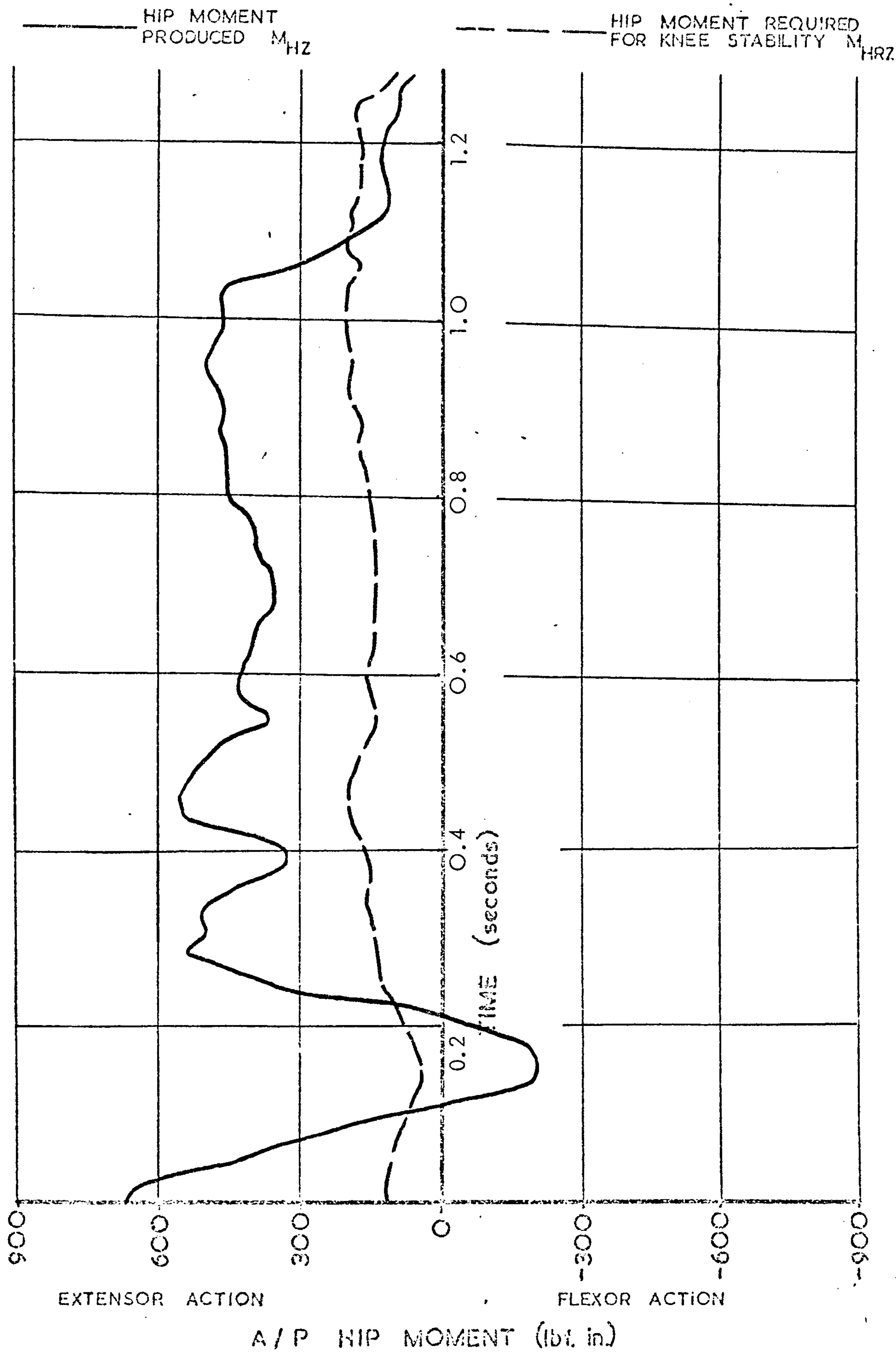


fig. VI. 58

RESULTANT LOAD IN LIFTING AND LOWERING A WEIGHT WITH G.R.

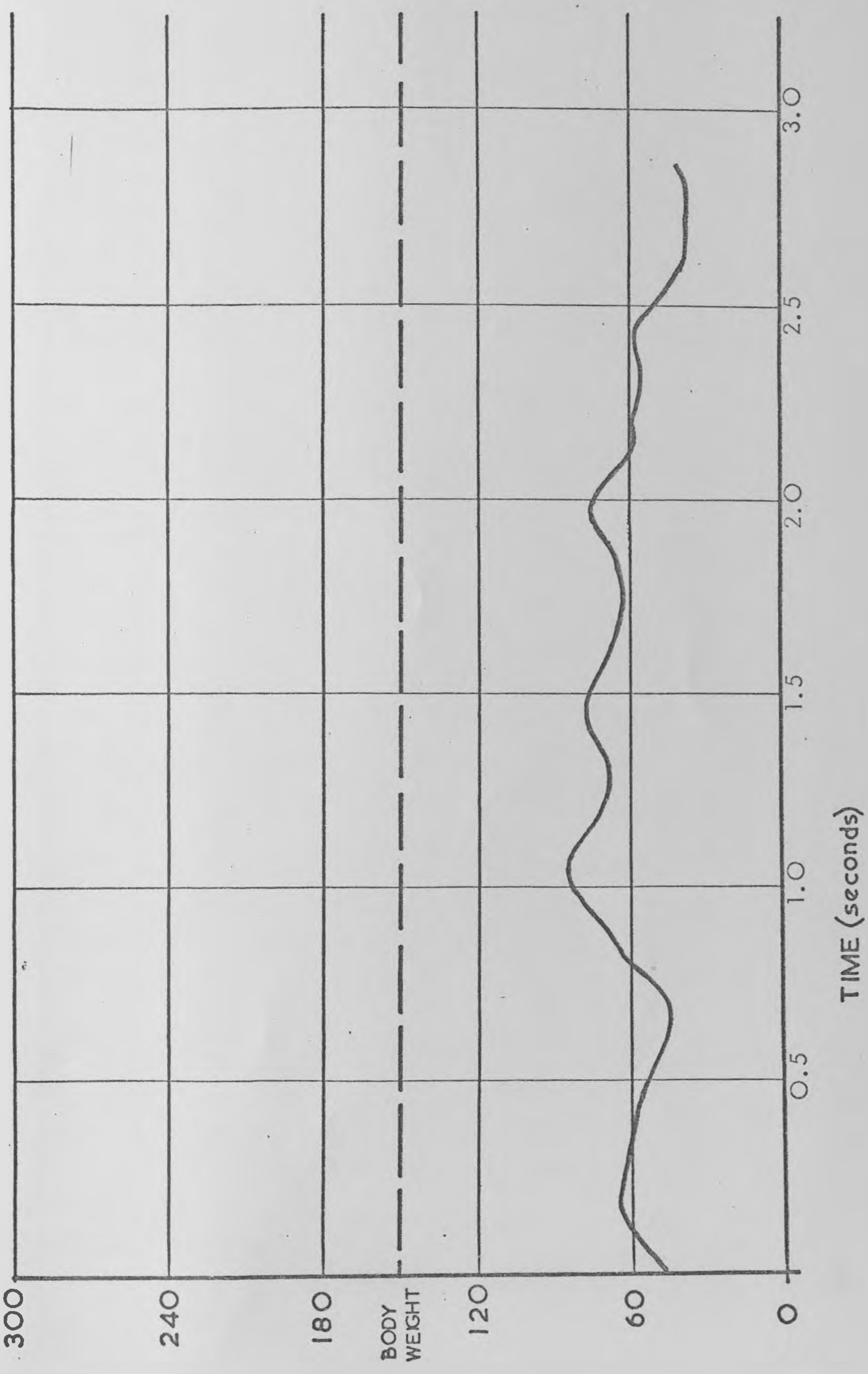


fig. VI.59

A/P HIP MOMENT IN LIFTING AND LOWERING A WEIGHT WITH G.R.

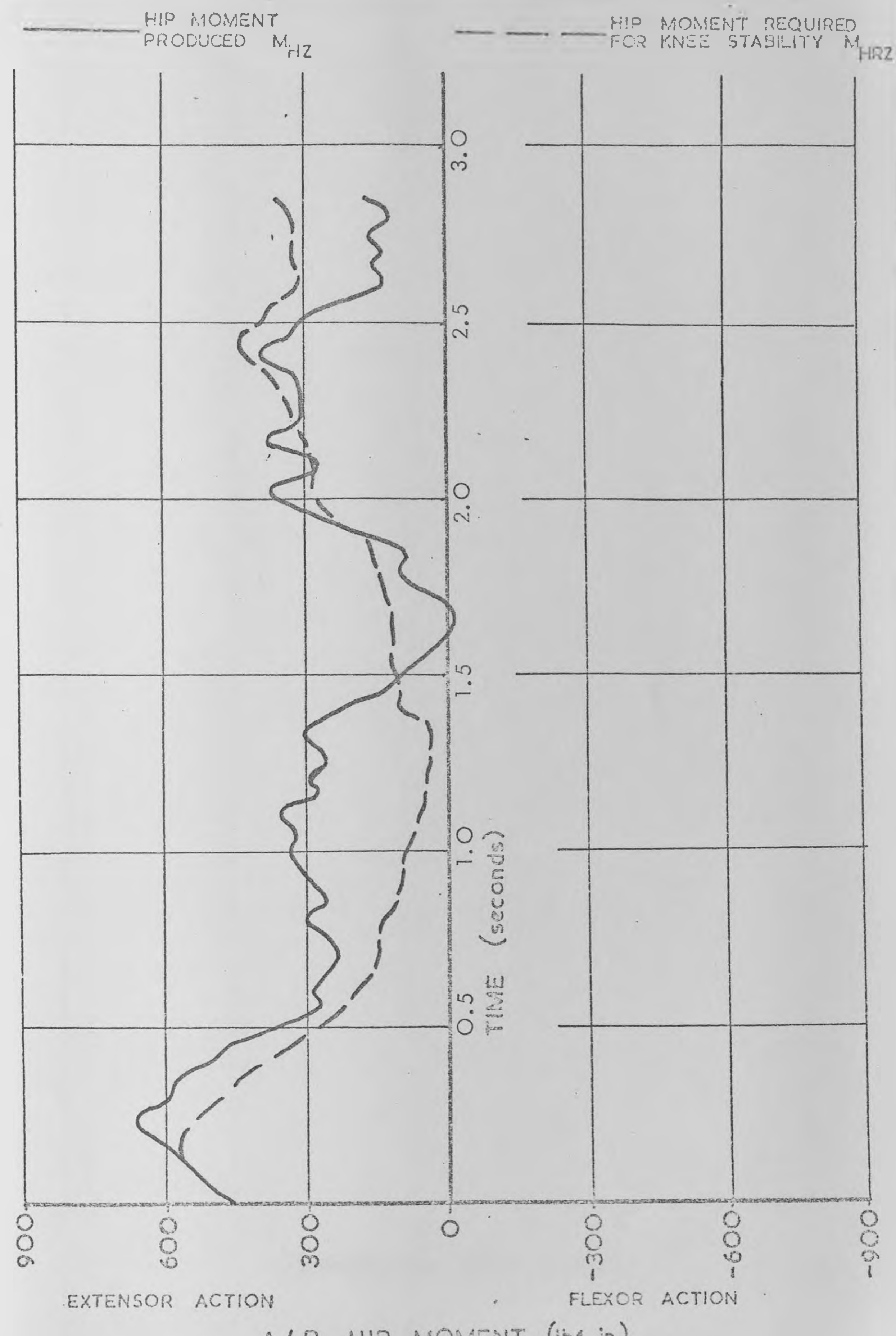


fig. VI. 60

A/P HIP MOMENT IN LEVEL WALKING WITH U.C.B.

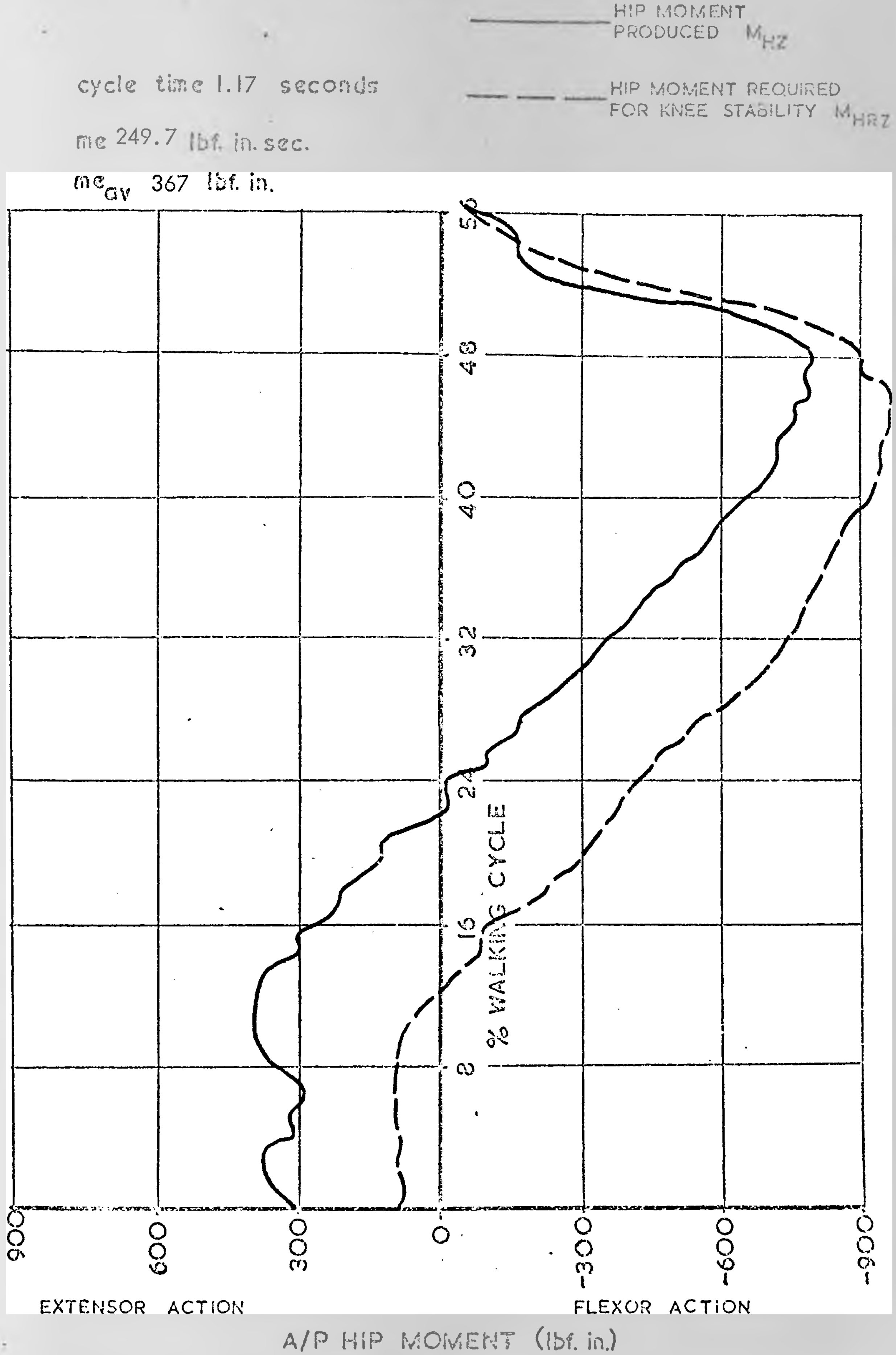


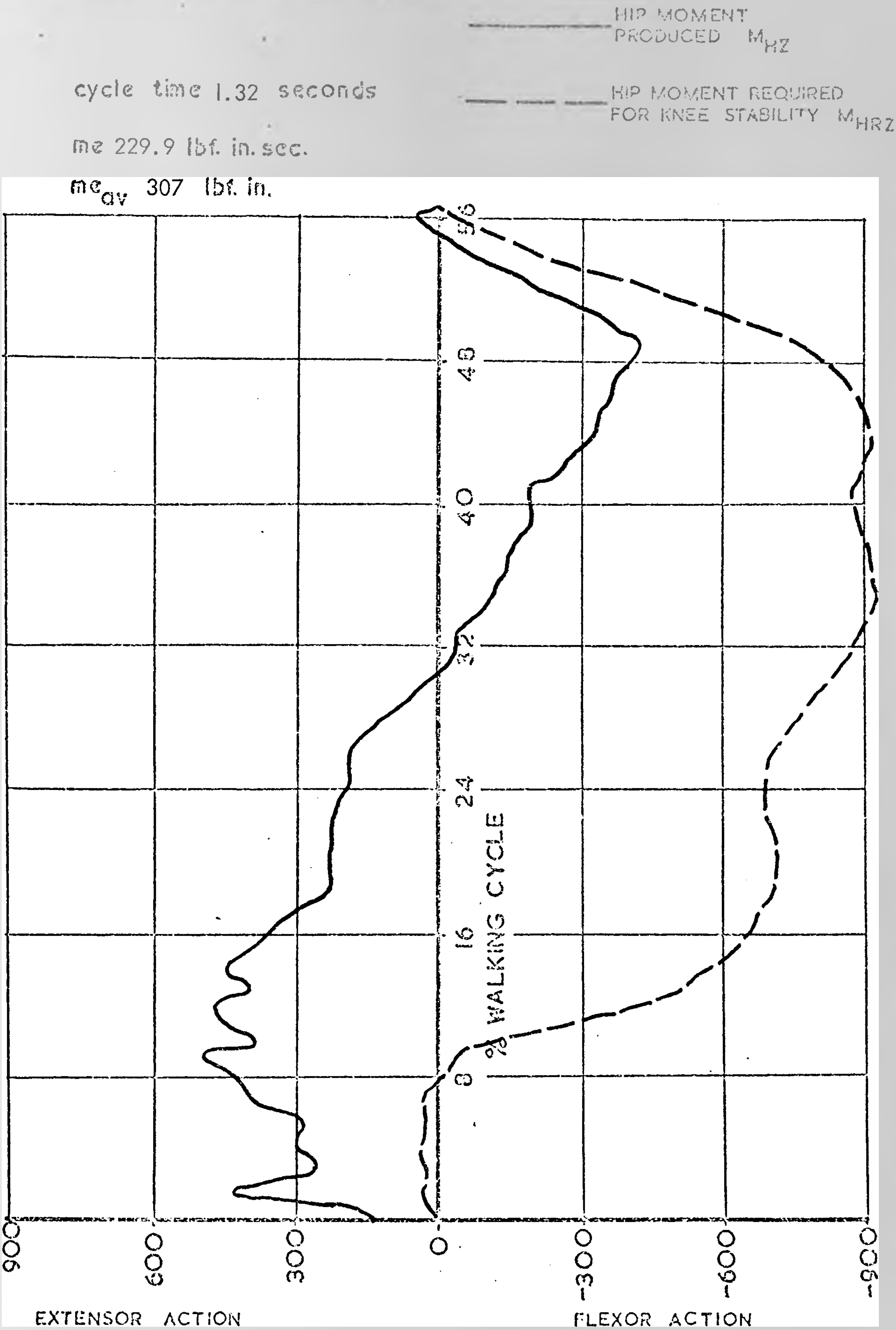
fig. VI.61

A/P HIP MOMENT IN WALKING UP RAMP WITH U.C.B.

cycle time 1.32 seconds

me 229.9 lbf. in. sec.

me_{av} 307 lbf. in.



A/P HIP MOMENT (lbf. in.)

fig.Vi.62

A/P HIP MOMENT IN WALKING DOWN RAMP WITH U.C.B.

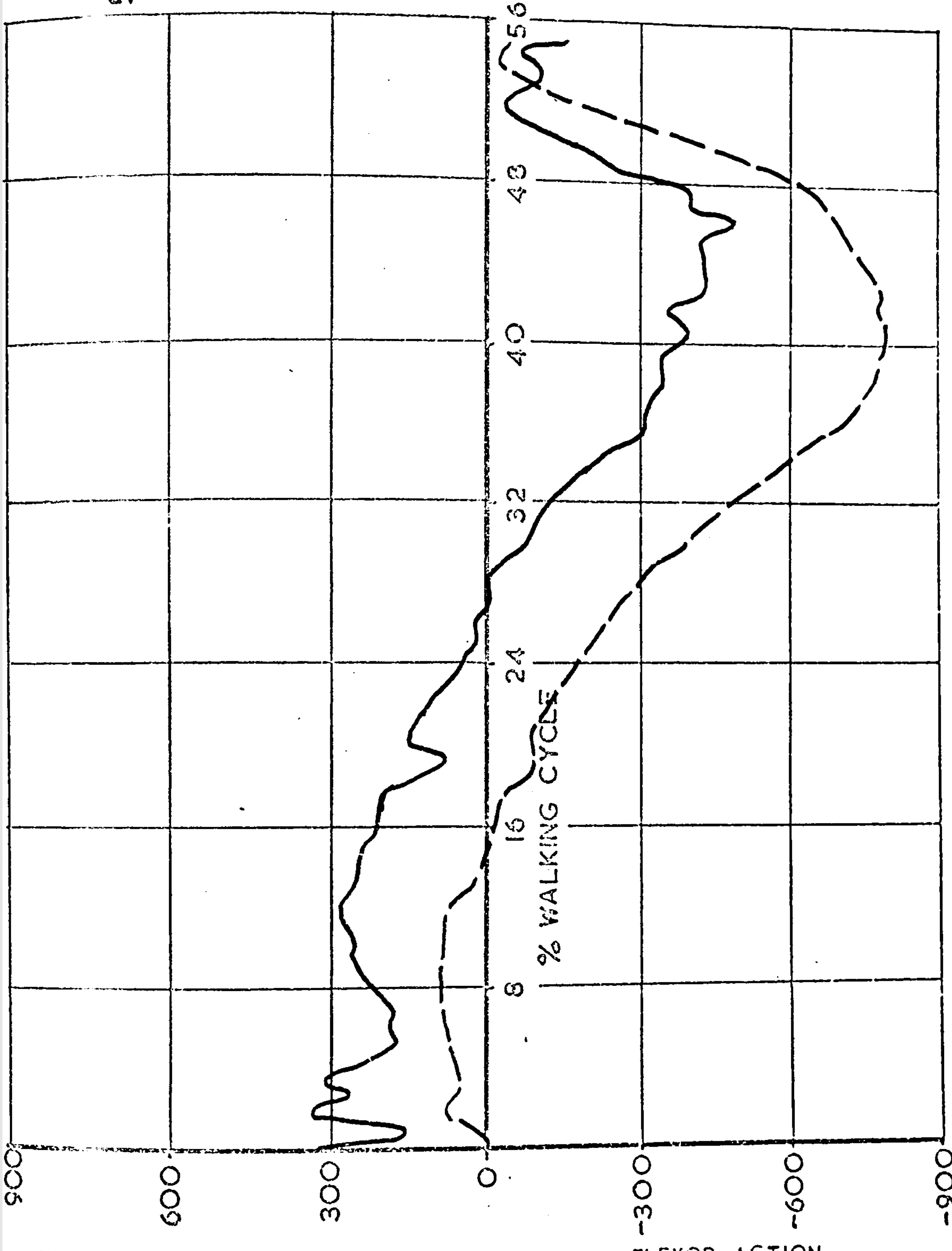
HIP MOMENT PRODUCED M_{HZ}

HIP MOMENT REQUIRED FOR KNEE STABILITY M_{HRZ}

cycle time 1.15 seconds

me 137.4 lbf. in. sec.

me_{av} 215 lbf. in.



A/P HIP MOMENT (lbf. in.)

fig.VI.63

A/P HIP MOMENT IN WALKING UP STAIRS WITH U.C.B.

cycle time 1.29 seconds

me 62.9 lbf. in. sec.

me_{av} 93 lbf. in.

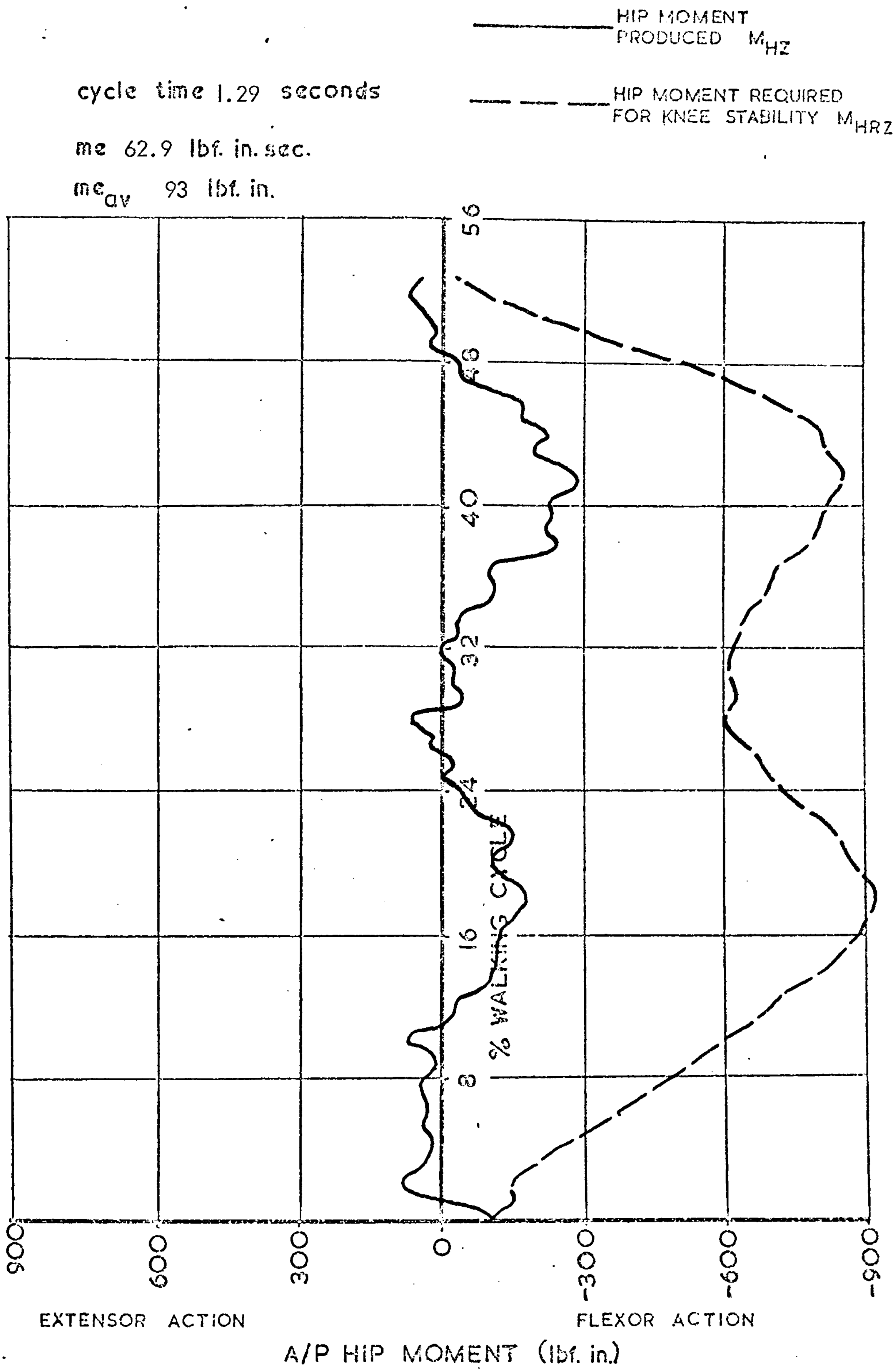


fig. VI. 64

A/P HIP MOMENT IN WALKING DOWN STAIRS WITH U.C.B.

cycle time 1.18 seconds

me 139.9 lbf. in. sec.

me_{av} 246 lbf. in.

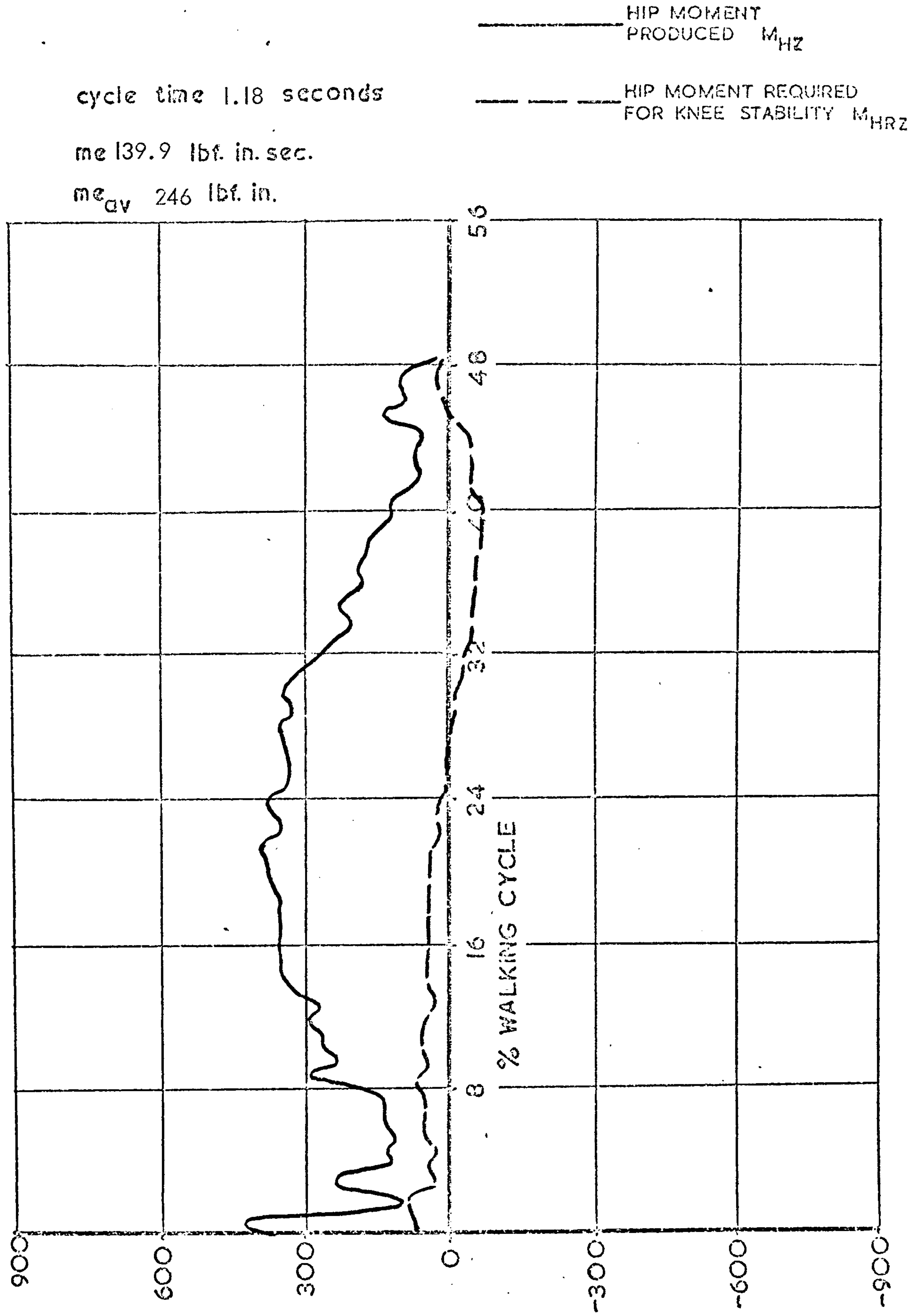


fig. VI.65

A/P HIP MOMENT IN STEPPING OVER AN OBJECT (from a standing position) WITH U.C.B.

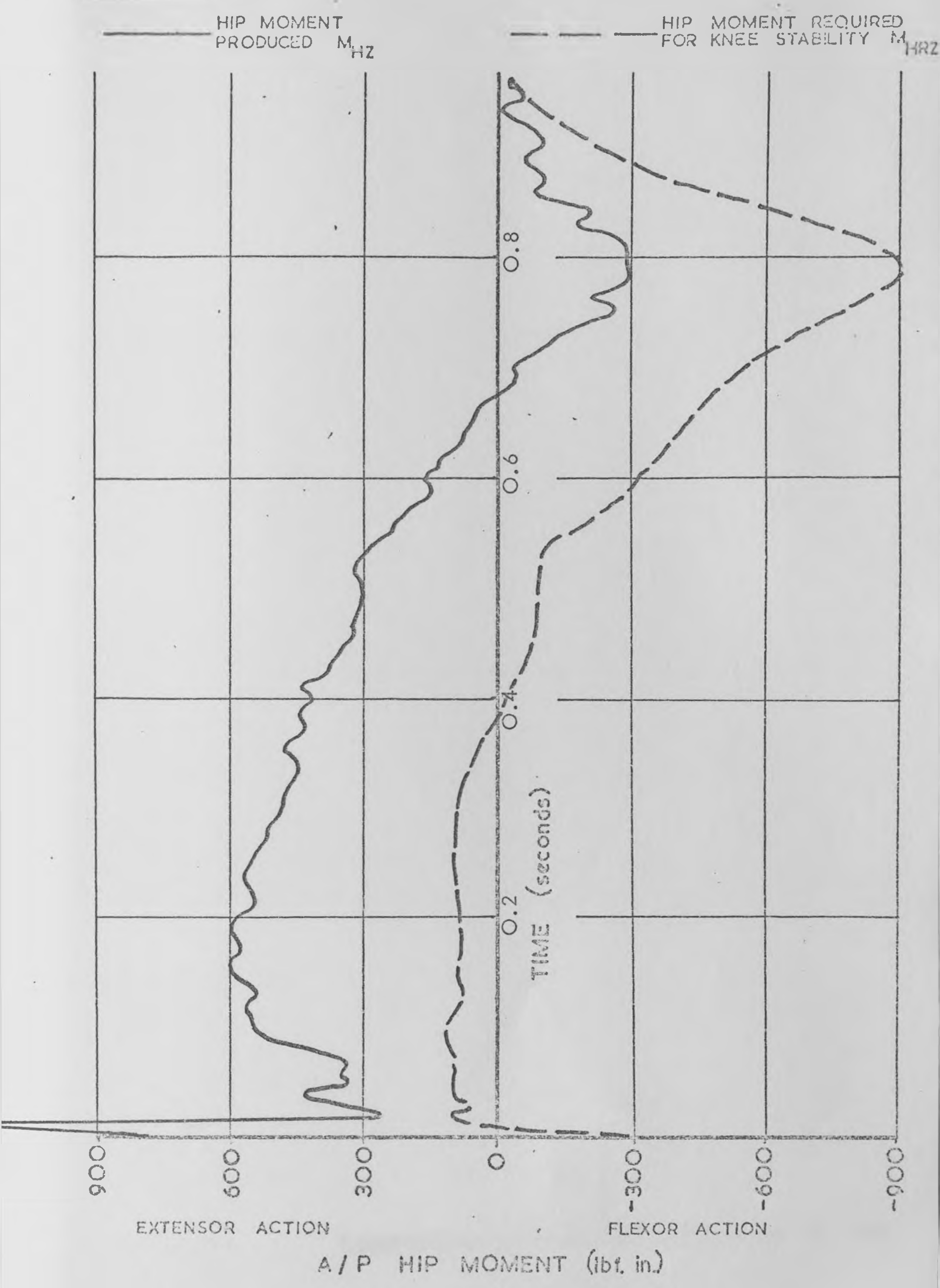
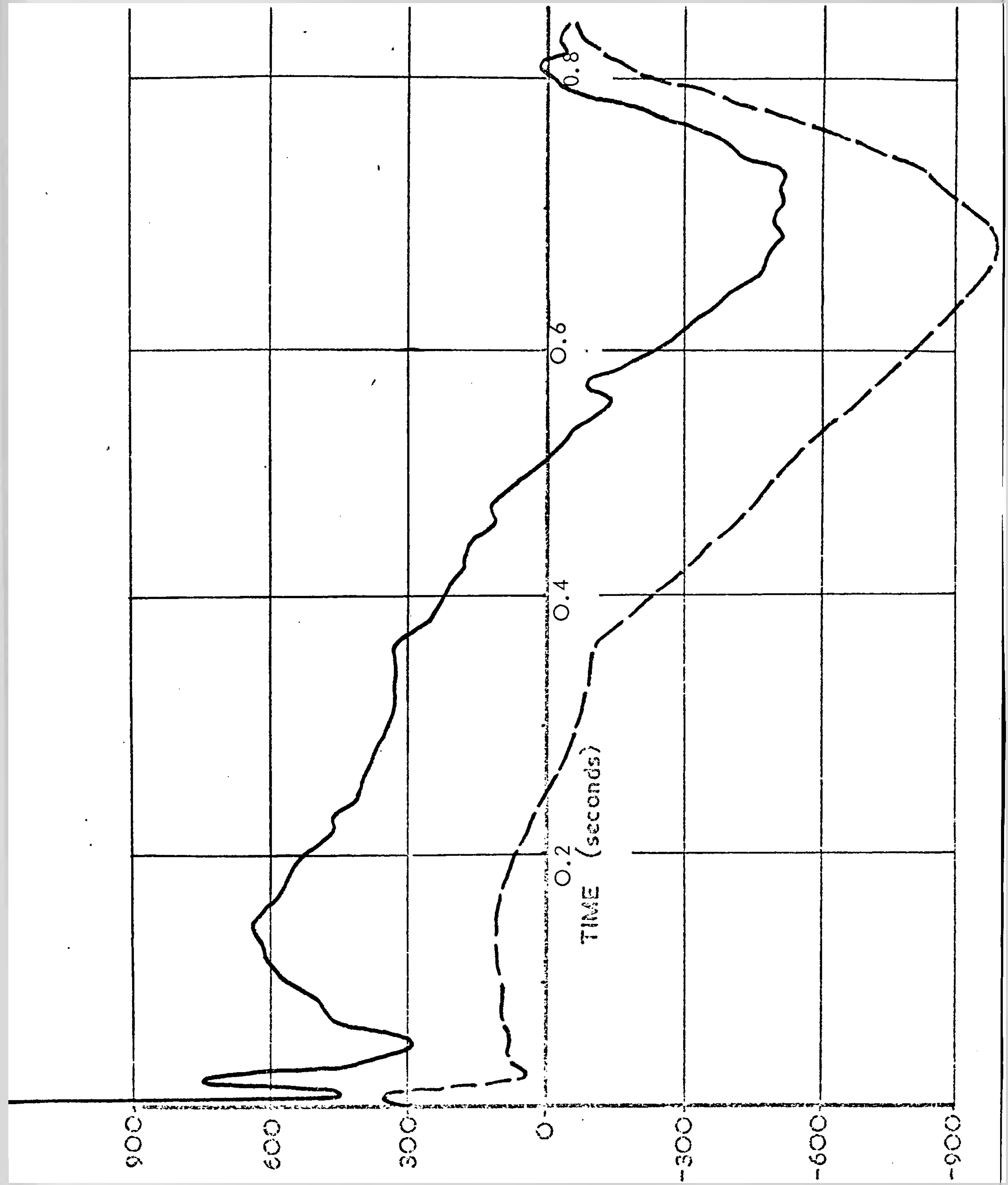


fig. Vi. 66

A/P HIP MOMENT IN STEPPING OVER AN OBJECT (after walking up to it) WITH U.C.B.

——— HIP MOMENT PRODUCED M_{HZ}

— — — HIP MOMENT REQUIRED FOR KNEE STABILITY M_{HRZ}



EXTENSOR ACTION   FLEXOR ACTION

A / P HIP MOMENT (lbf. in.)

fig.VI.67

A/P HIP MOMENT IN WALKING SIDEWAYS (Prosthesis Leading) WITH U.C.B.

cycle time 0.94 seconds

me 67.1 lbf. in. sec.

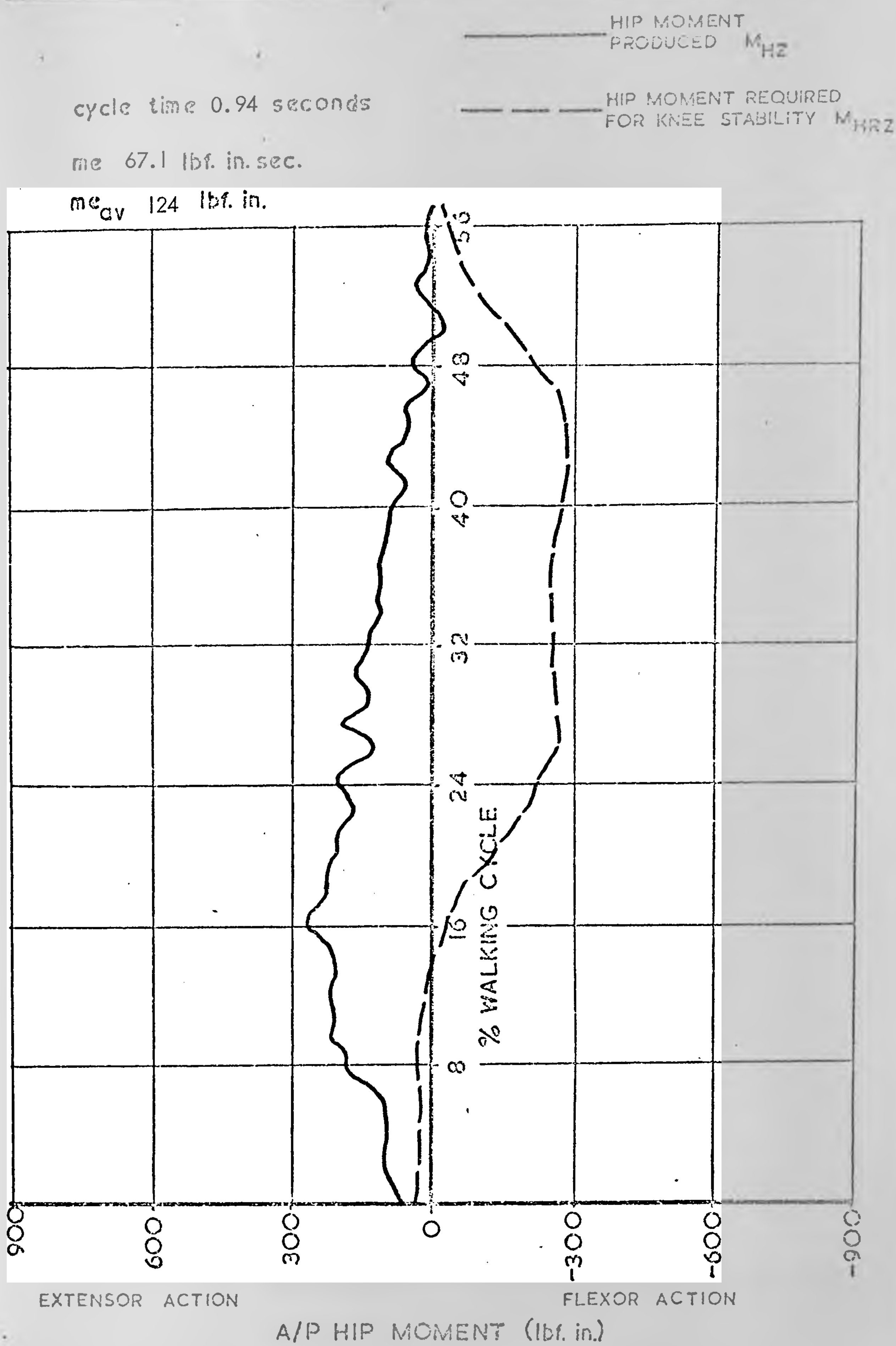


fig. VI. 68

A/P HIP MOMENT IN WALKING SIDEWAYS (Normal Leg Leading) WITH U.C.B.

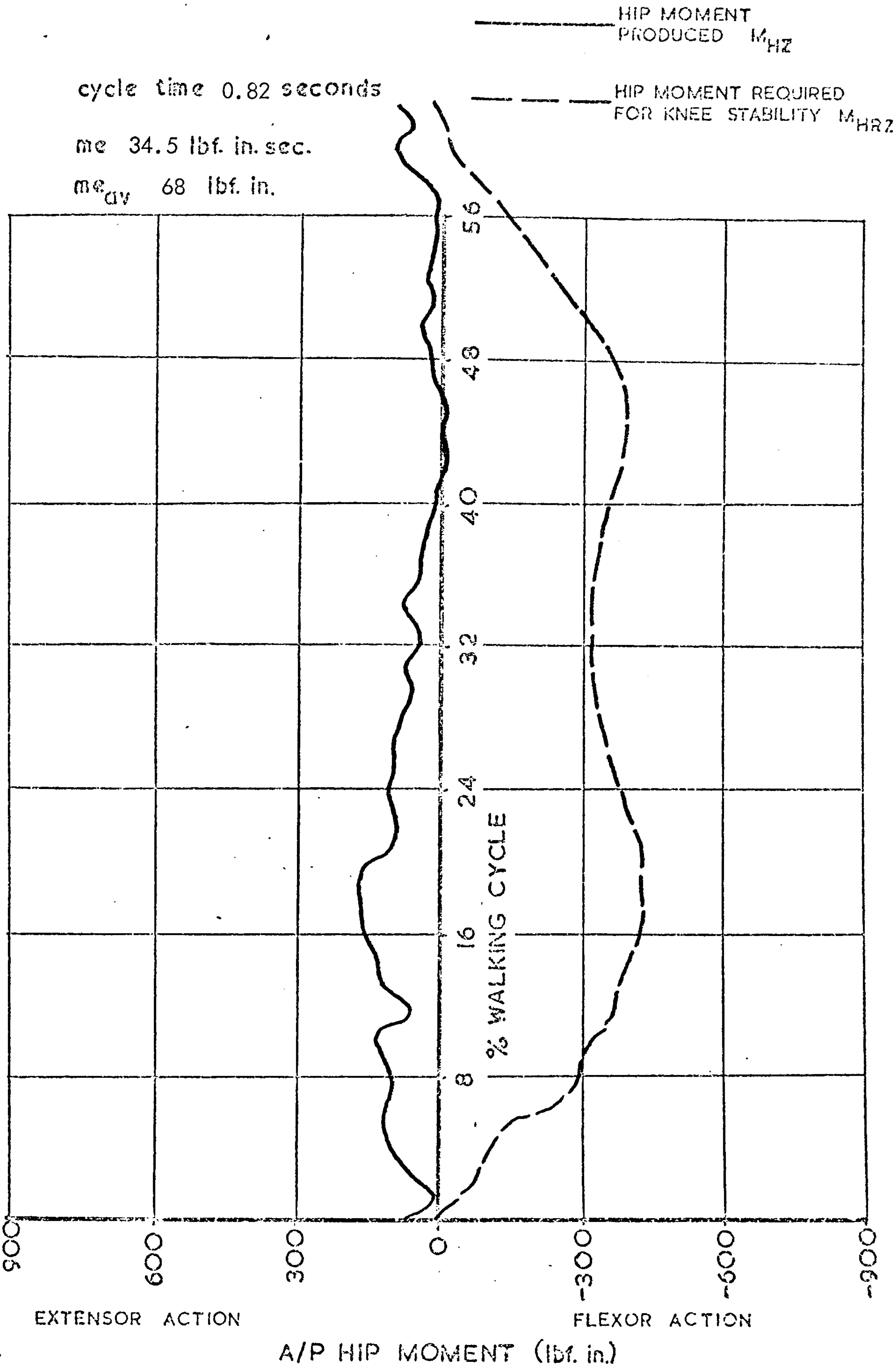


fig. VI. 69

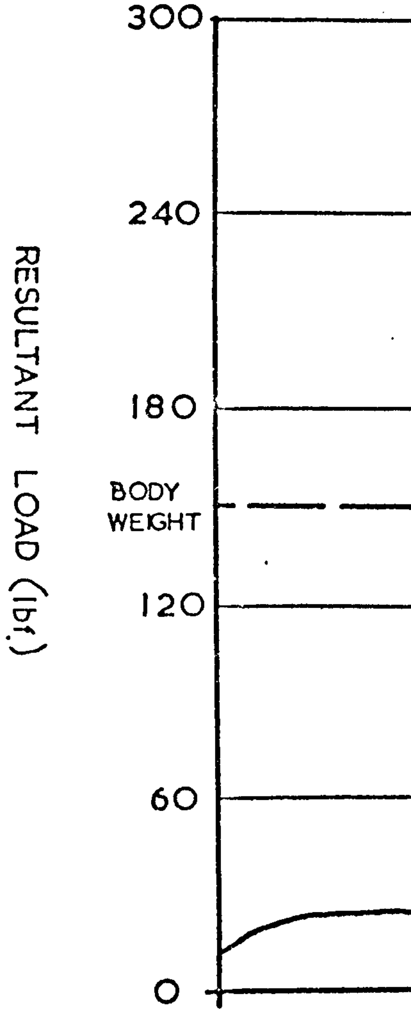
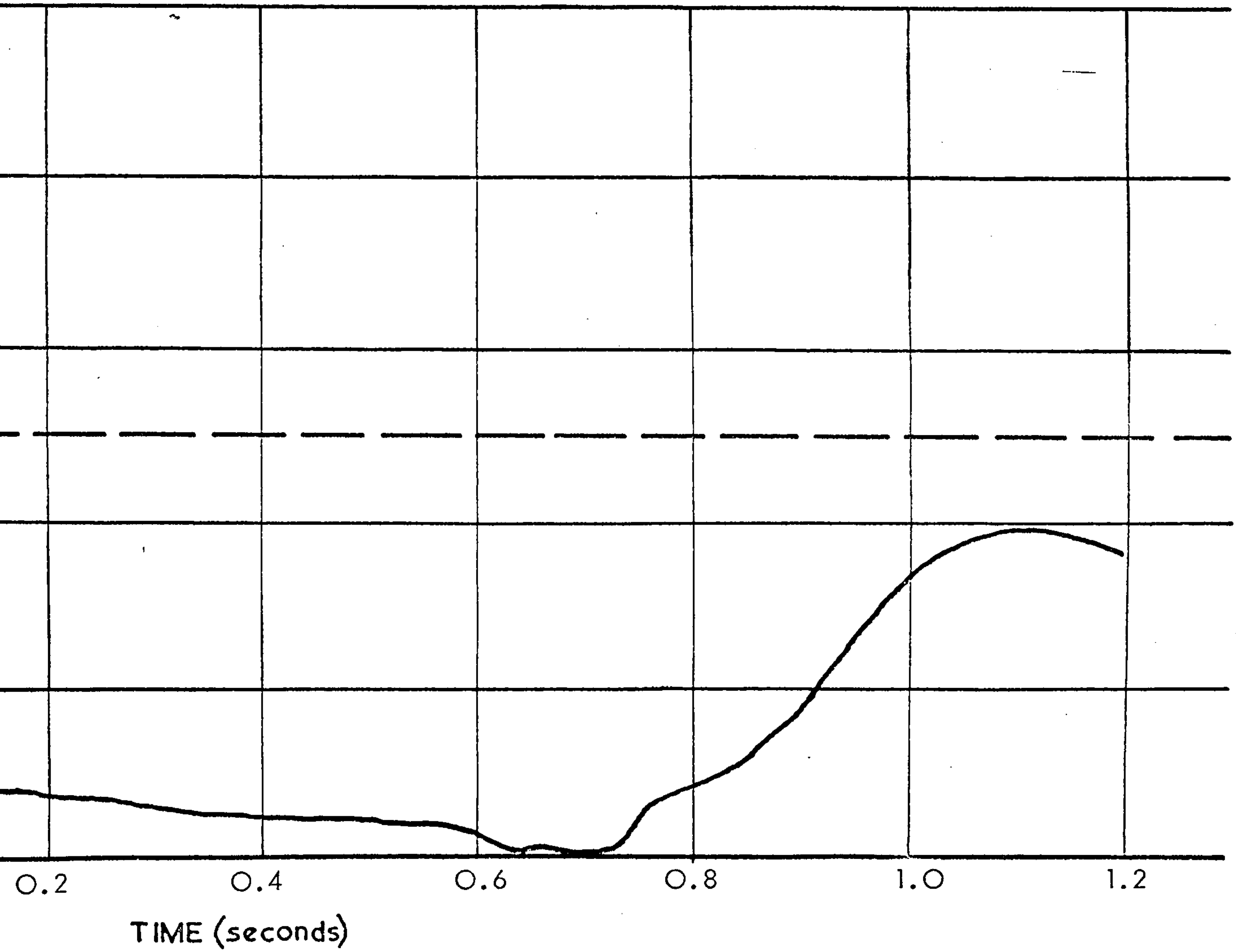


fig. VI.70



RESULTANT LOAD IN STANDING UP WITH U.C.B.

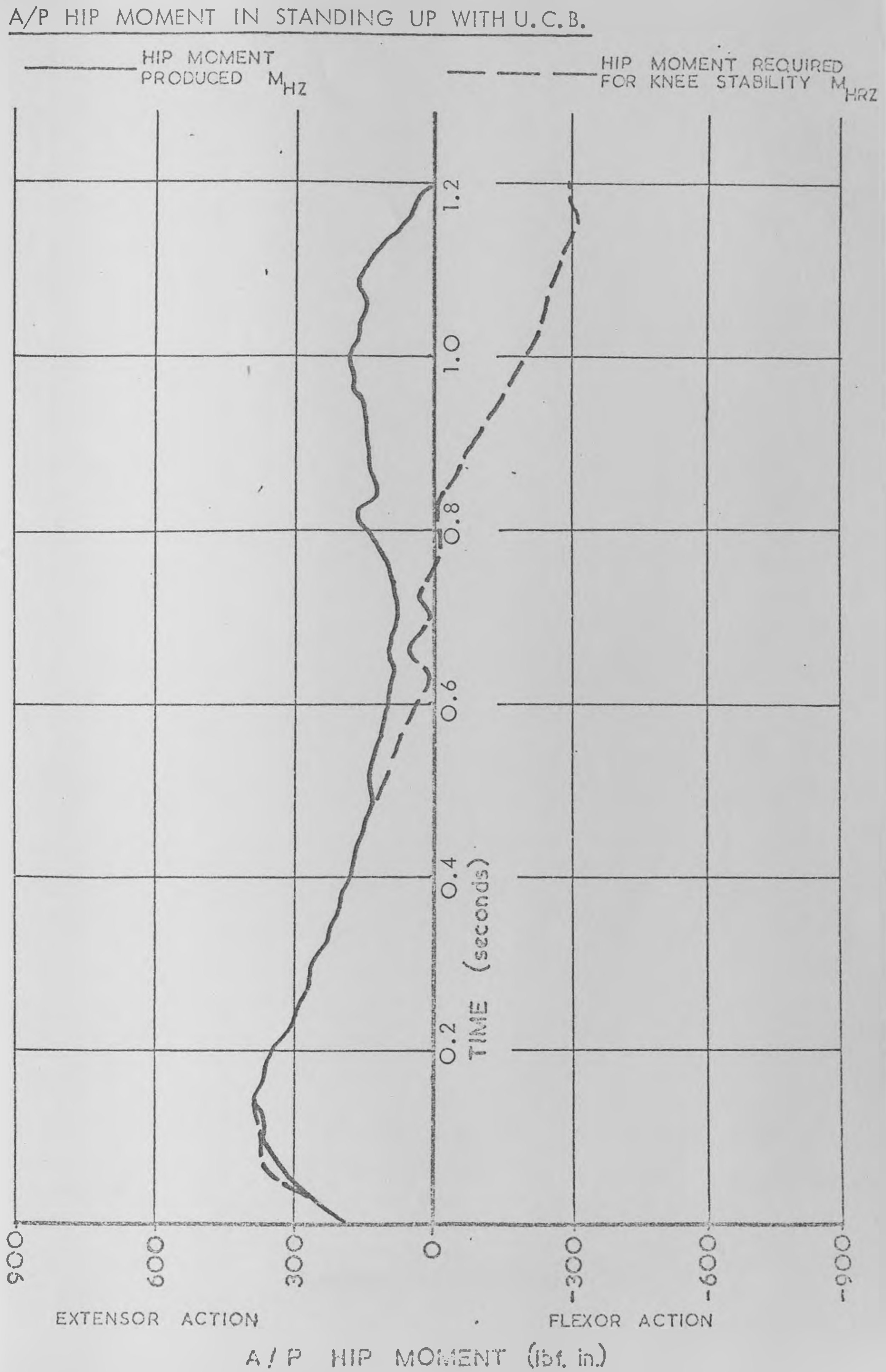

A/P HIP MOMENT IN STANDING UP WITH U.C.B.
HIP MOMENT PRODUCED M_{HZ}
HIP MOMENT REQUIRED FOR KNEE STABILITY M_{HRZ}
1.2
1.0
0.8
0.6
0.4
0.2
TIME (seconds)
900
600
300
0
-300
-600
-900
EXTENSOR ACTION
FLEXOR ACTION
A/P HIP MOMENT (lbf. in.)

fig. VI. 71

RESULTANT LOAD IN SITTING DOWN WITH U.C.B.

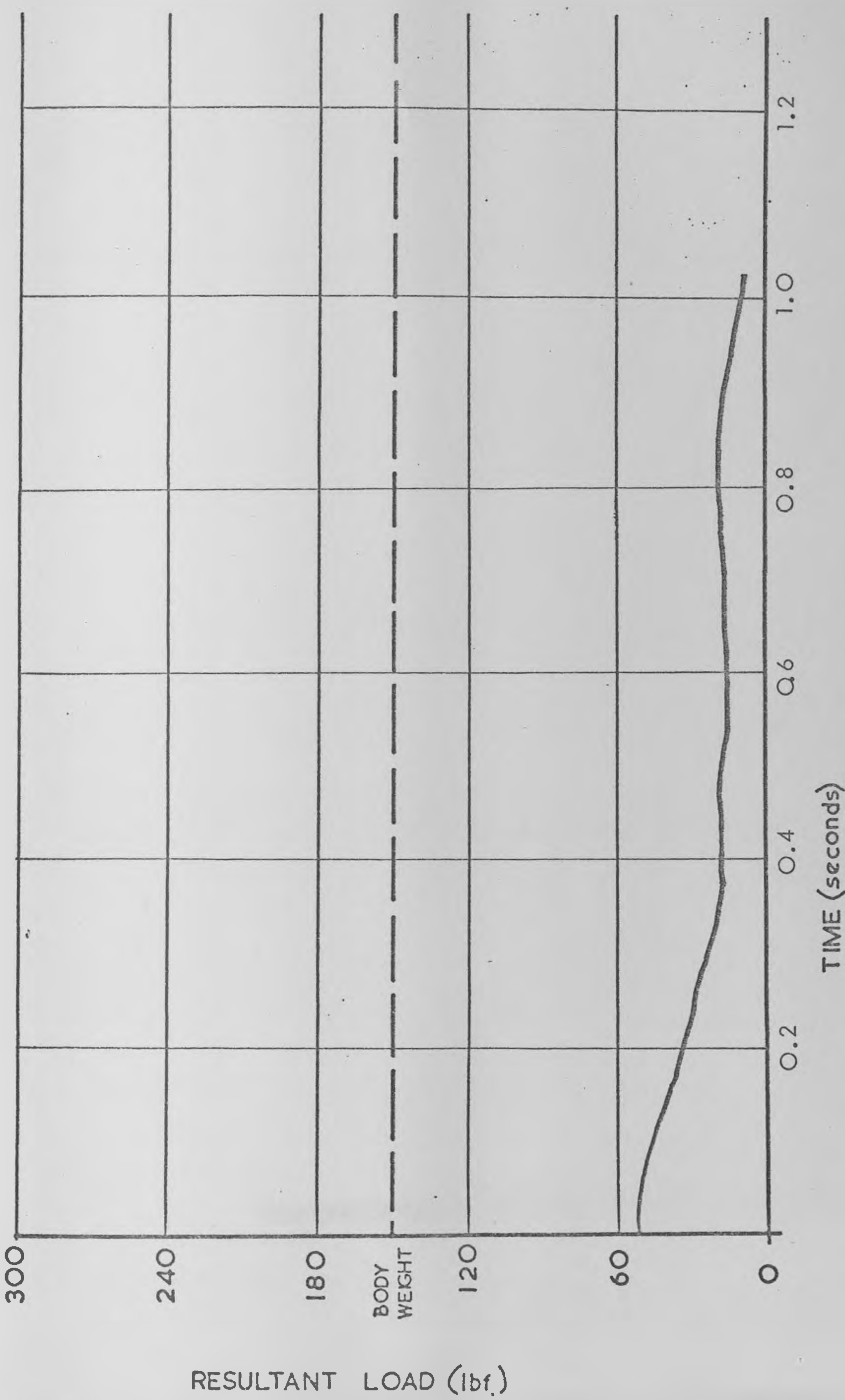


fig. VI. 72

A/P HIP MOMENT IN SITTING DOWN WITH U.C.B.

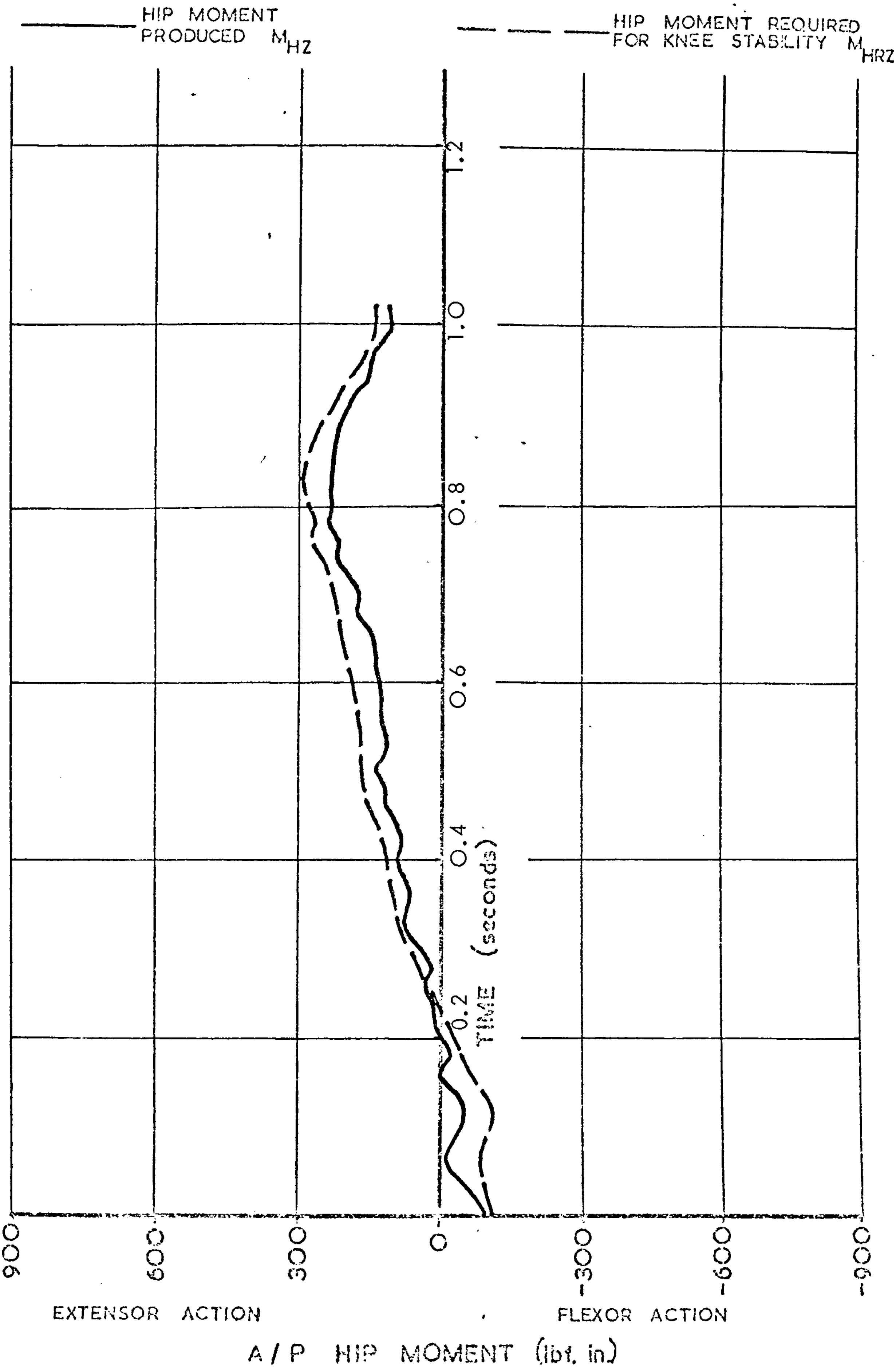


fig.VI.73

RESULTANT LOAD IN LIFTING AND LOWERING A WEIGHT WITH U.C.B.

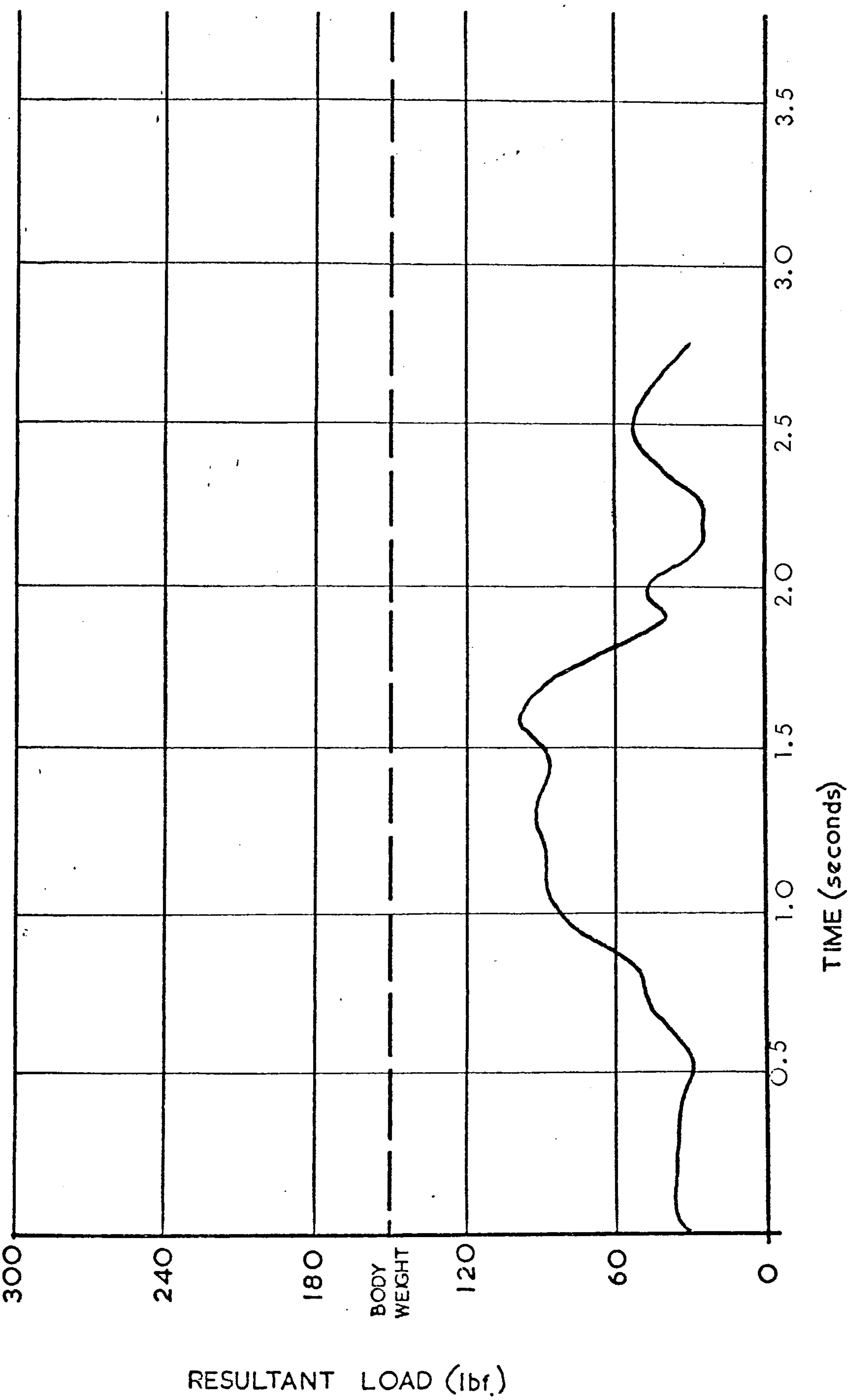


fig. VI.74

A/P HIP MOMENT IN LIFTING AND LOWERING A WEIGHT WITH U.C.B.

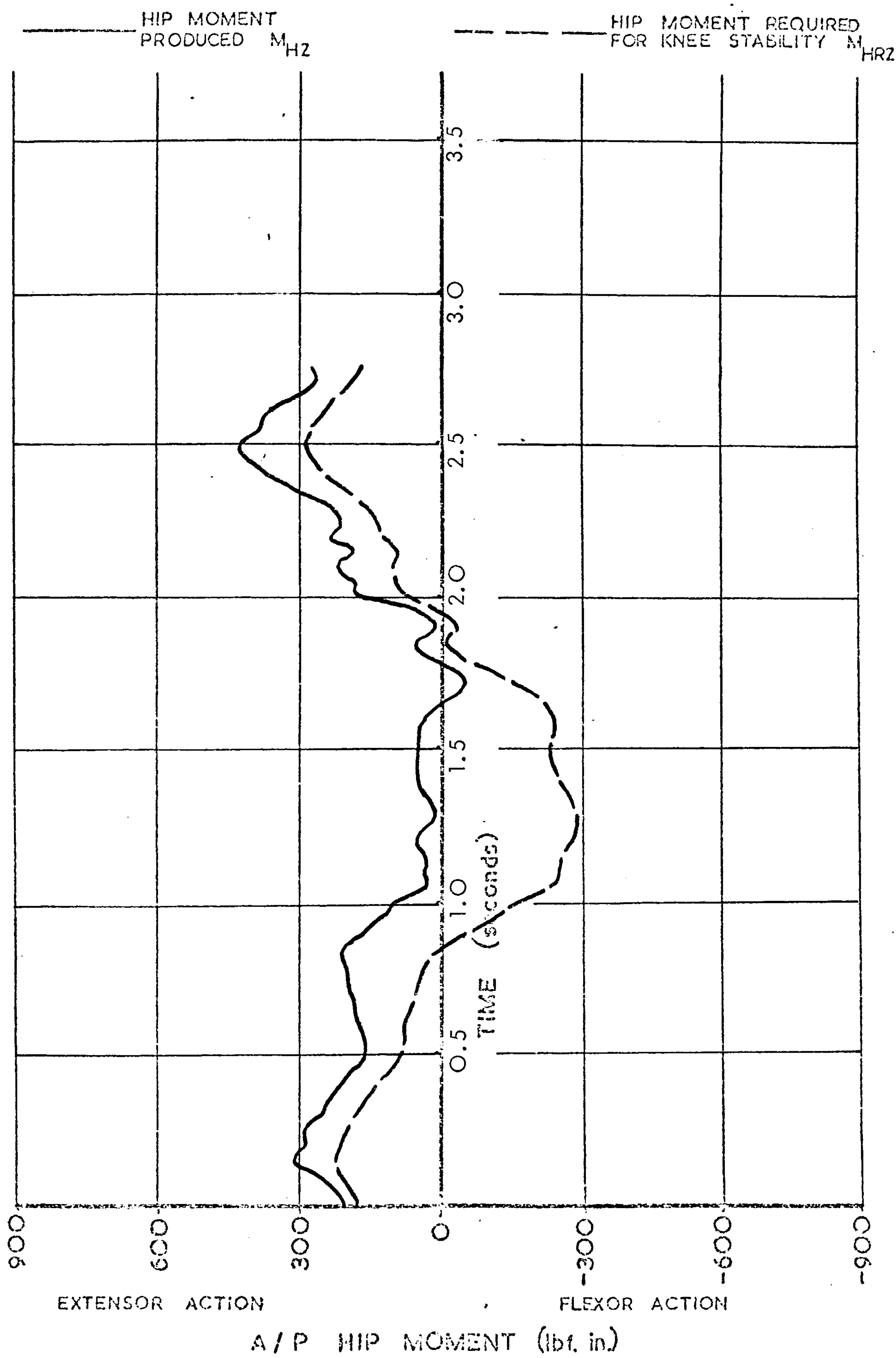


fig.VI.75

A/P HIP MOMENT IN LEVEL WALKING WITH L.A.

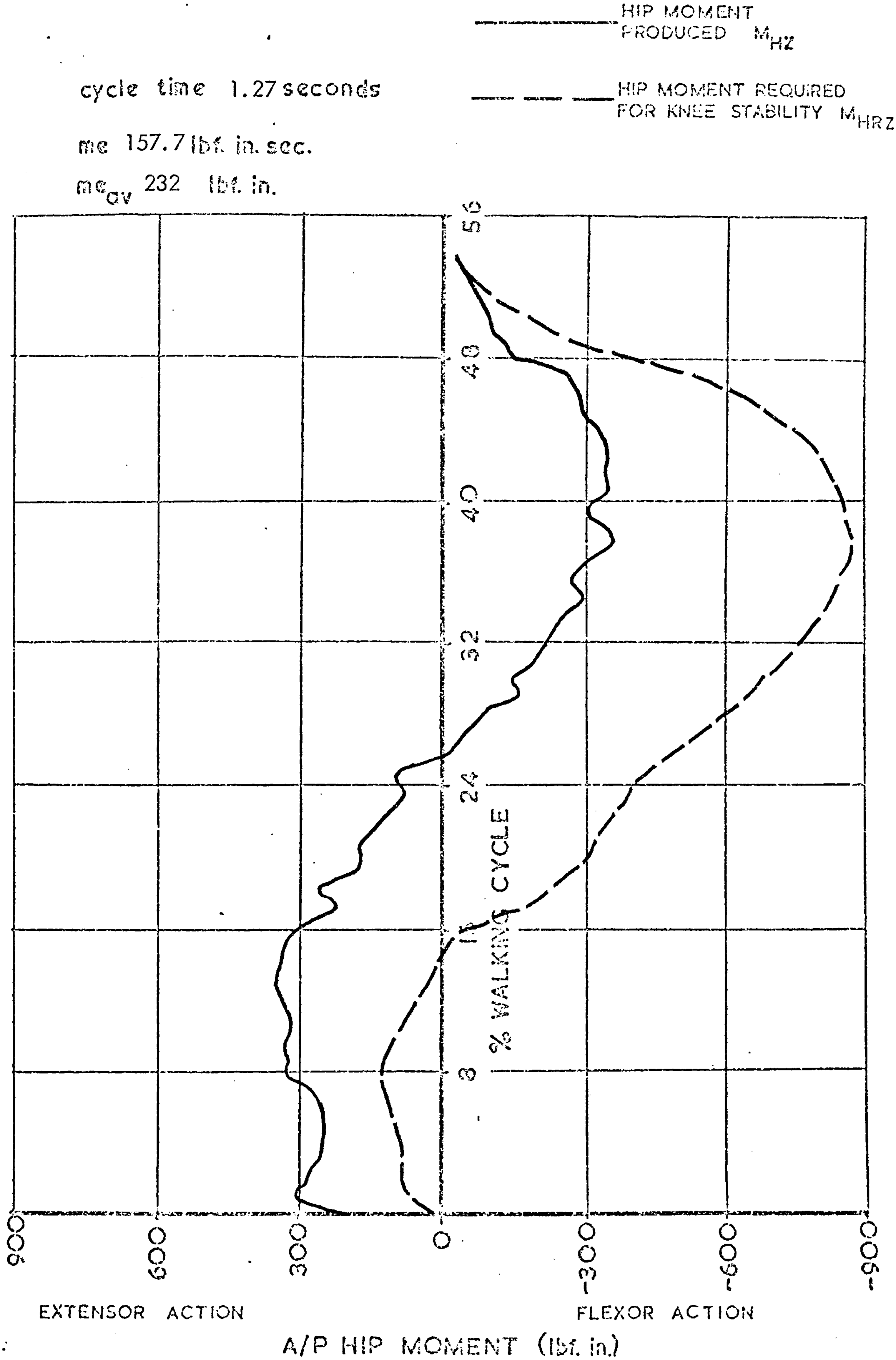


fig. VI.76

A/P HIP MOMENT IN WALKING UP RAMP WITH L.A.

fig.VI.77

A/P HIP MOMENT IN WALKING DOWN RAMP WITH L.A.

cycle time 1.26 seconds

me 134.2lbf. in. sec.

me_{av} 200 lbf. in.

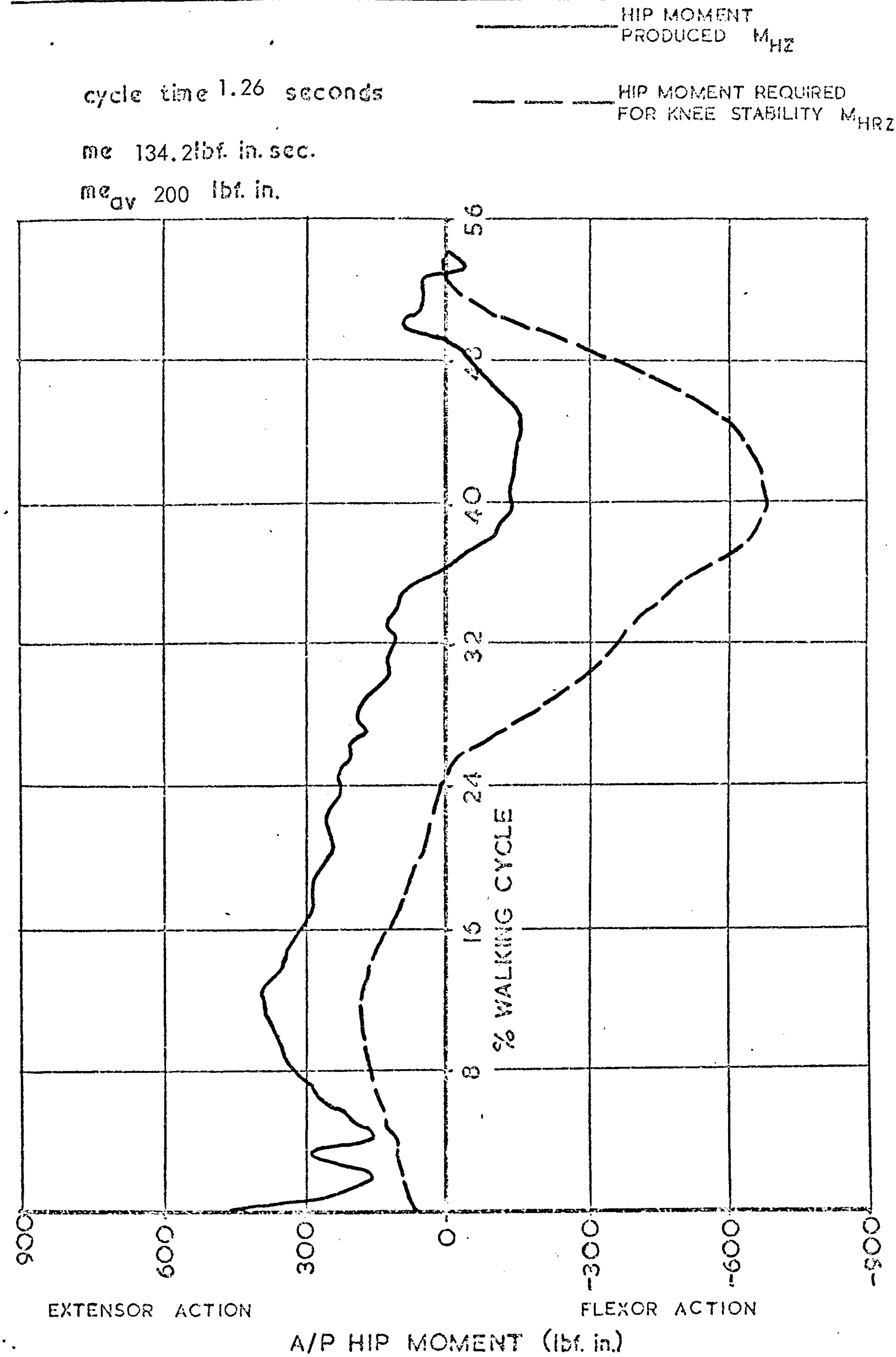


fig. VI.78

A/P HIP MOMENT IN WALKING UP STAIRS WITH L.A.

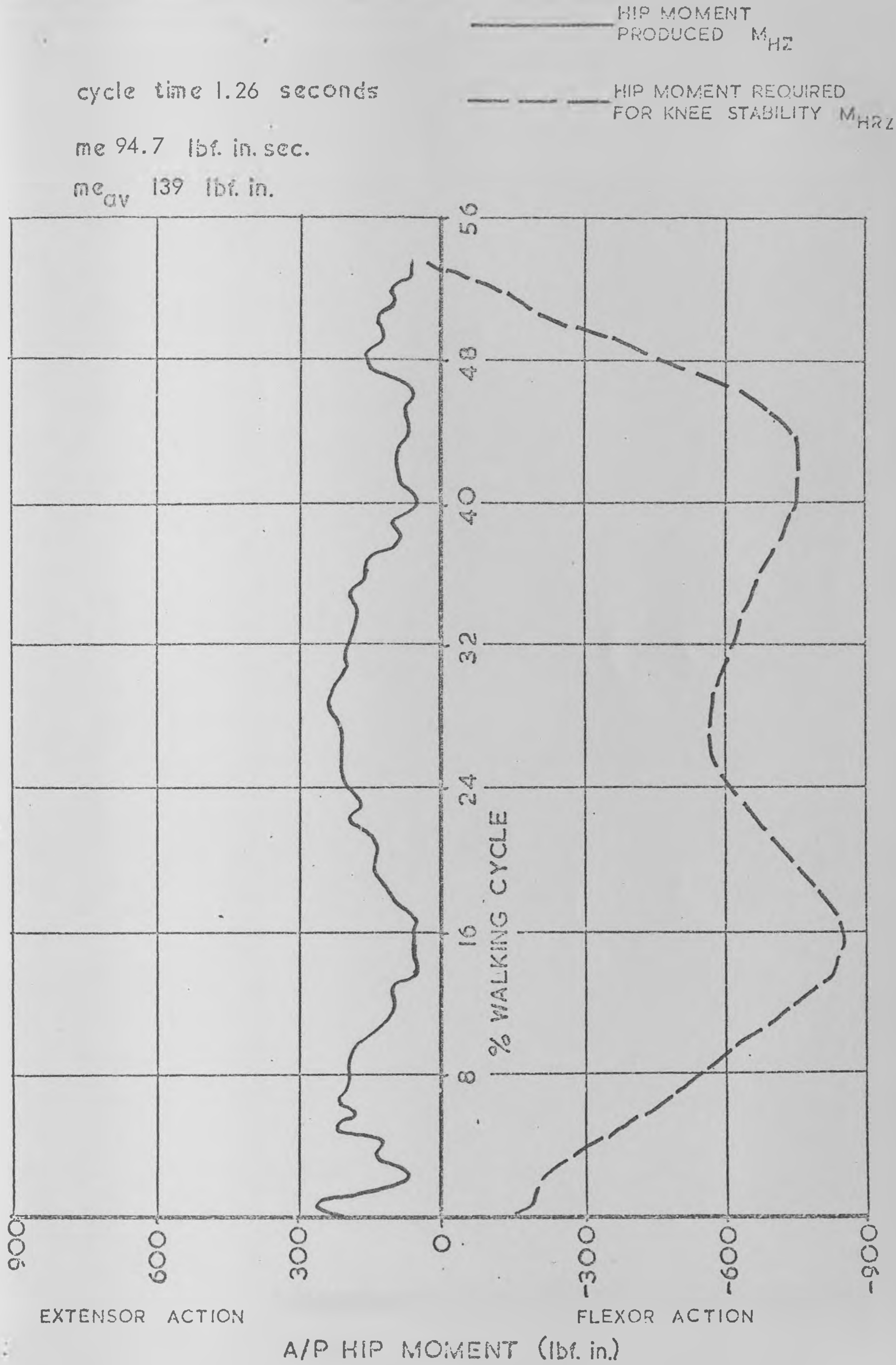


fig. VI.79

A/P HIP MOMENT IN WALKING DOWN STAIRS WITH L.A.

cycle time 1.12 seconds

me 143.1 lbf. in. sec.

me_{av} 270 lbf. in.

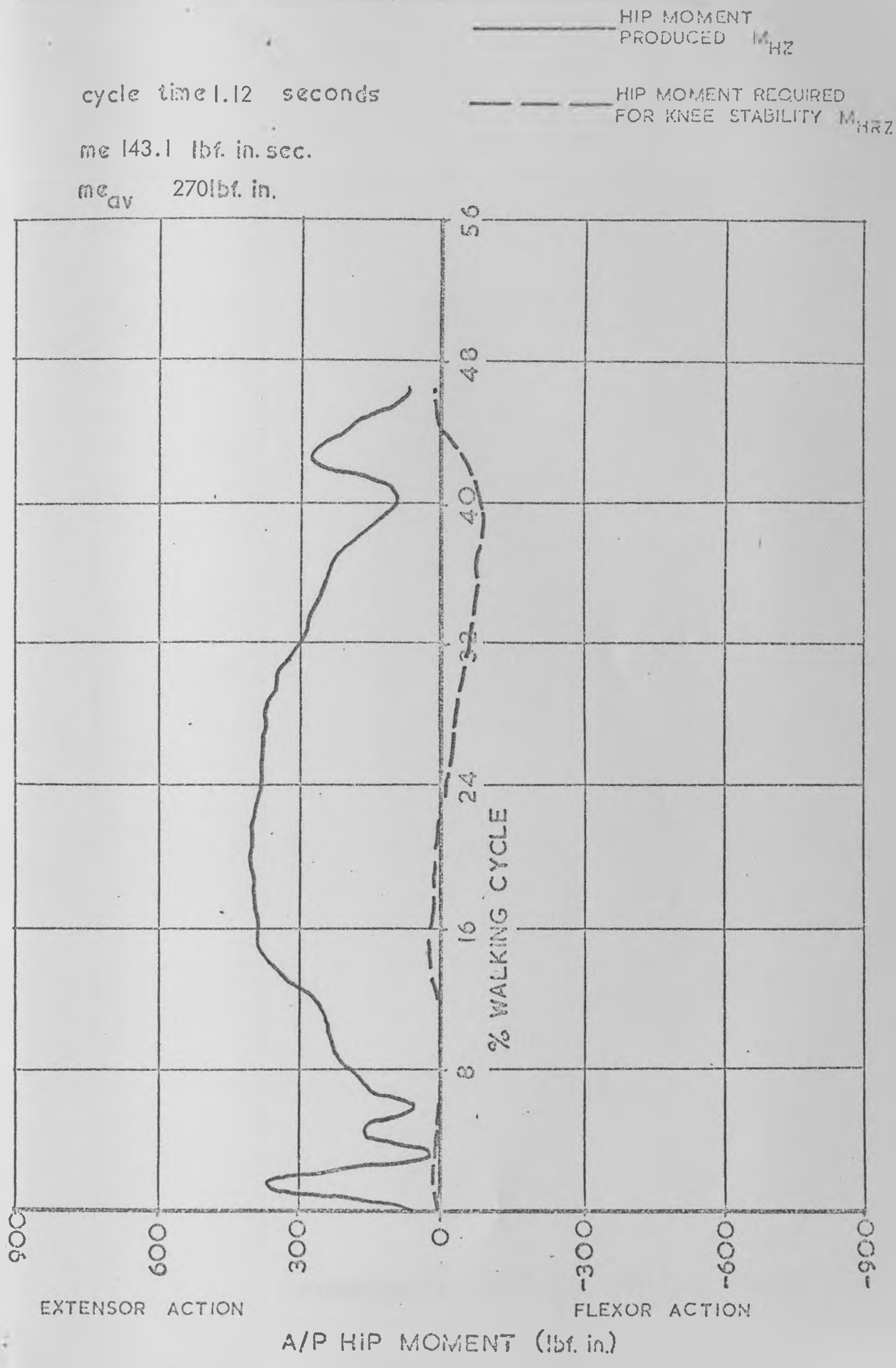


fig. VI. 80

A/P HIP MOMENT IN STEPPING OVER AN OBJECT (from a standing position) WITH L.A.

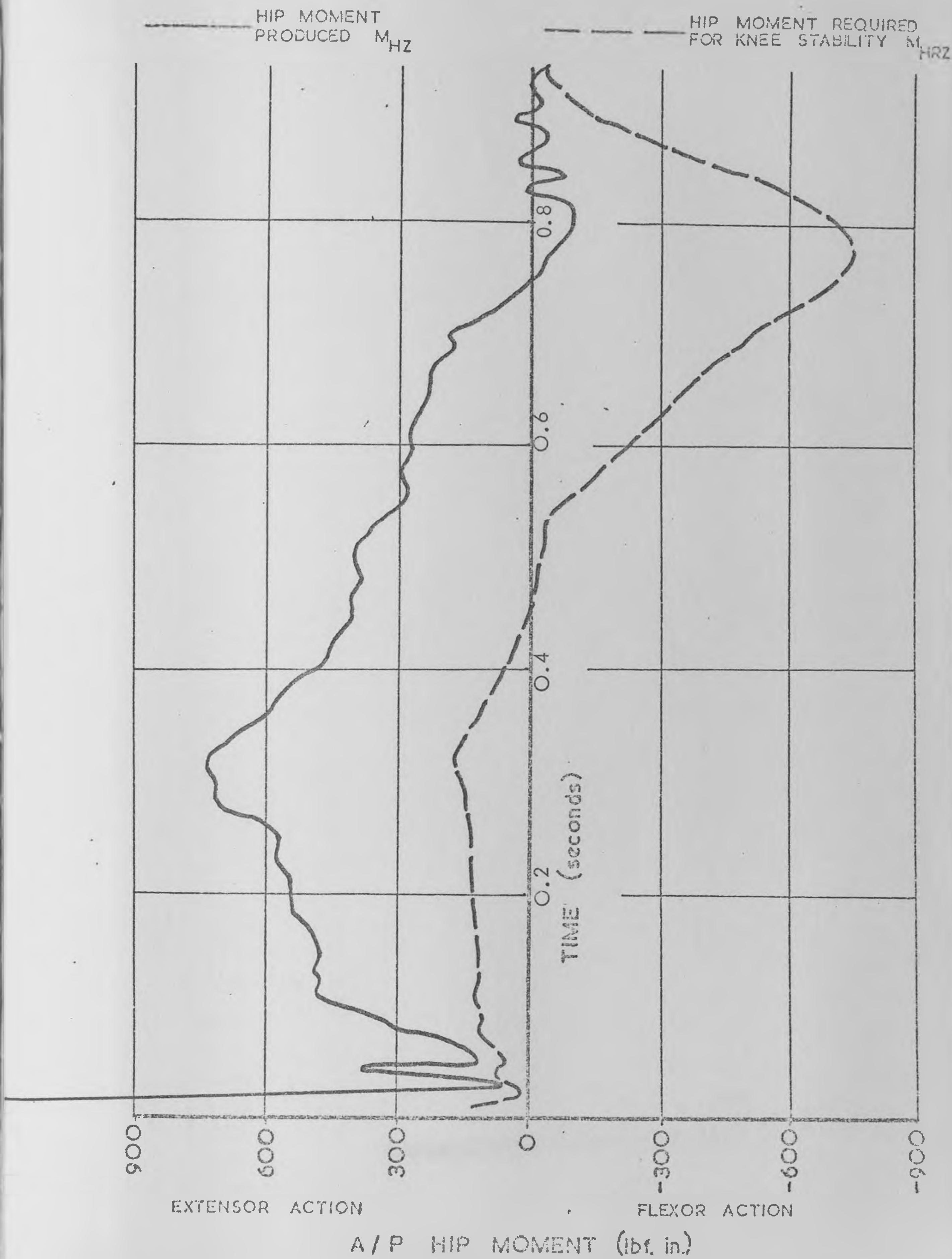
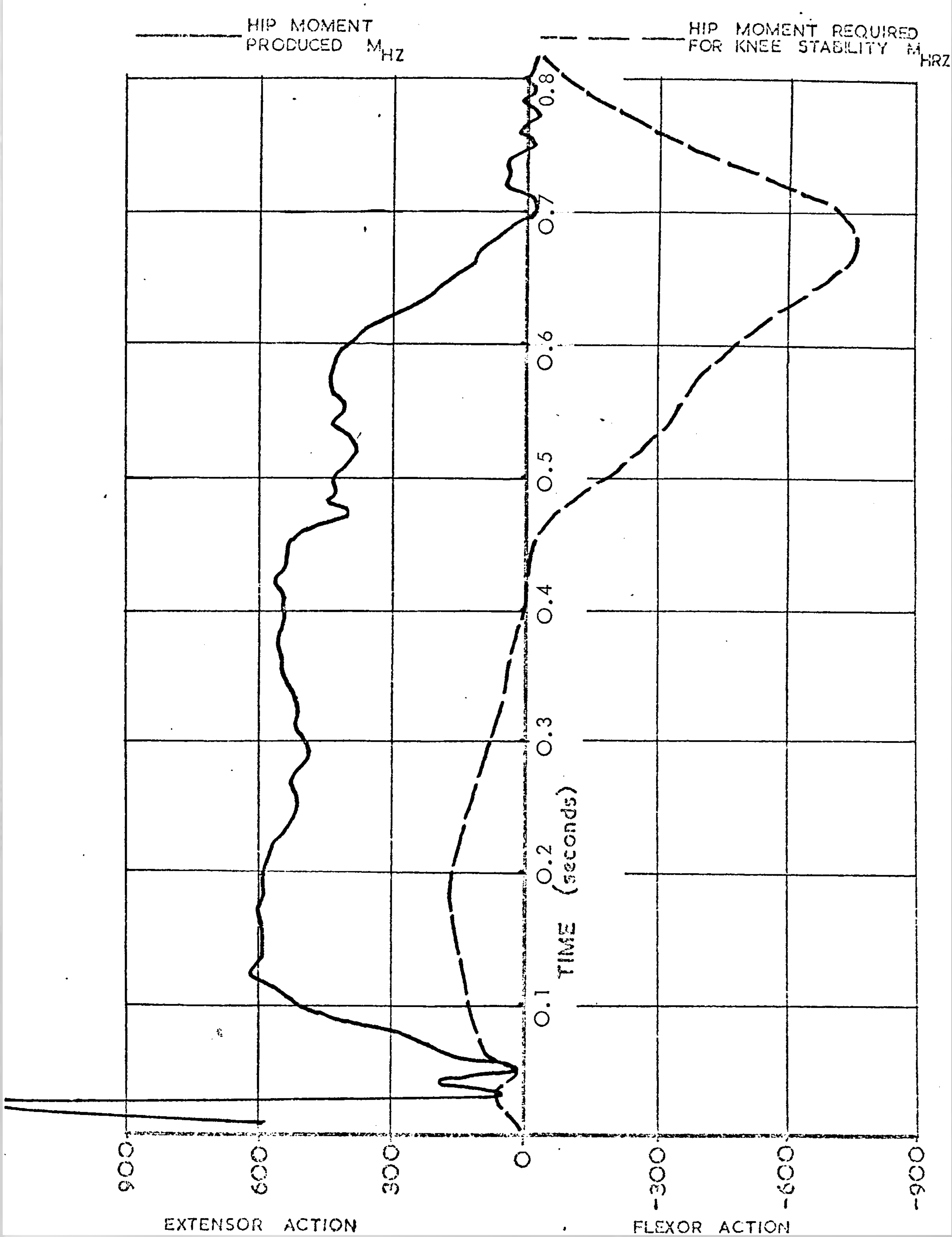


fig. VI. 81

A/P HIP MOMENT IN STEPPING OVER AN OBJECT (after walking up to it) WITH L.A.



A / P HIP MOMENT (lbf. in.)

fig. VI. 82

A/P HIP MOMENT IN WALKING SIDEWAYS (Prosthesis Leading) WITH L.A.

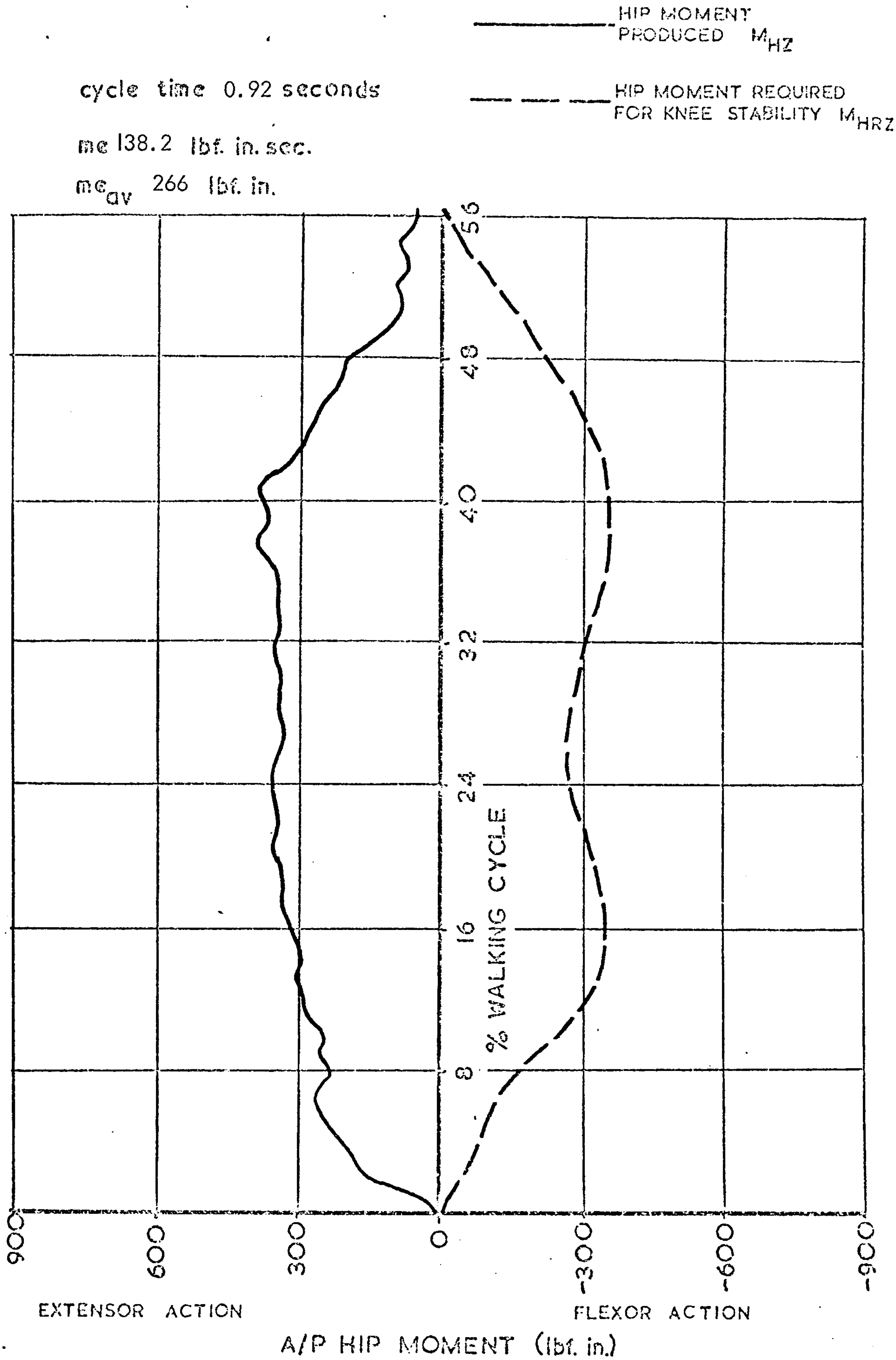


fig. VI. 83

A/P HIP MOMENT IN WALKING SIDEWAYS (Normal Leg Leading) WITH L.A.

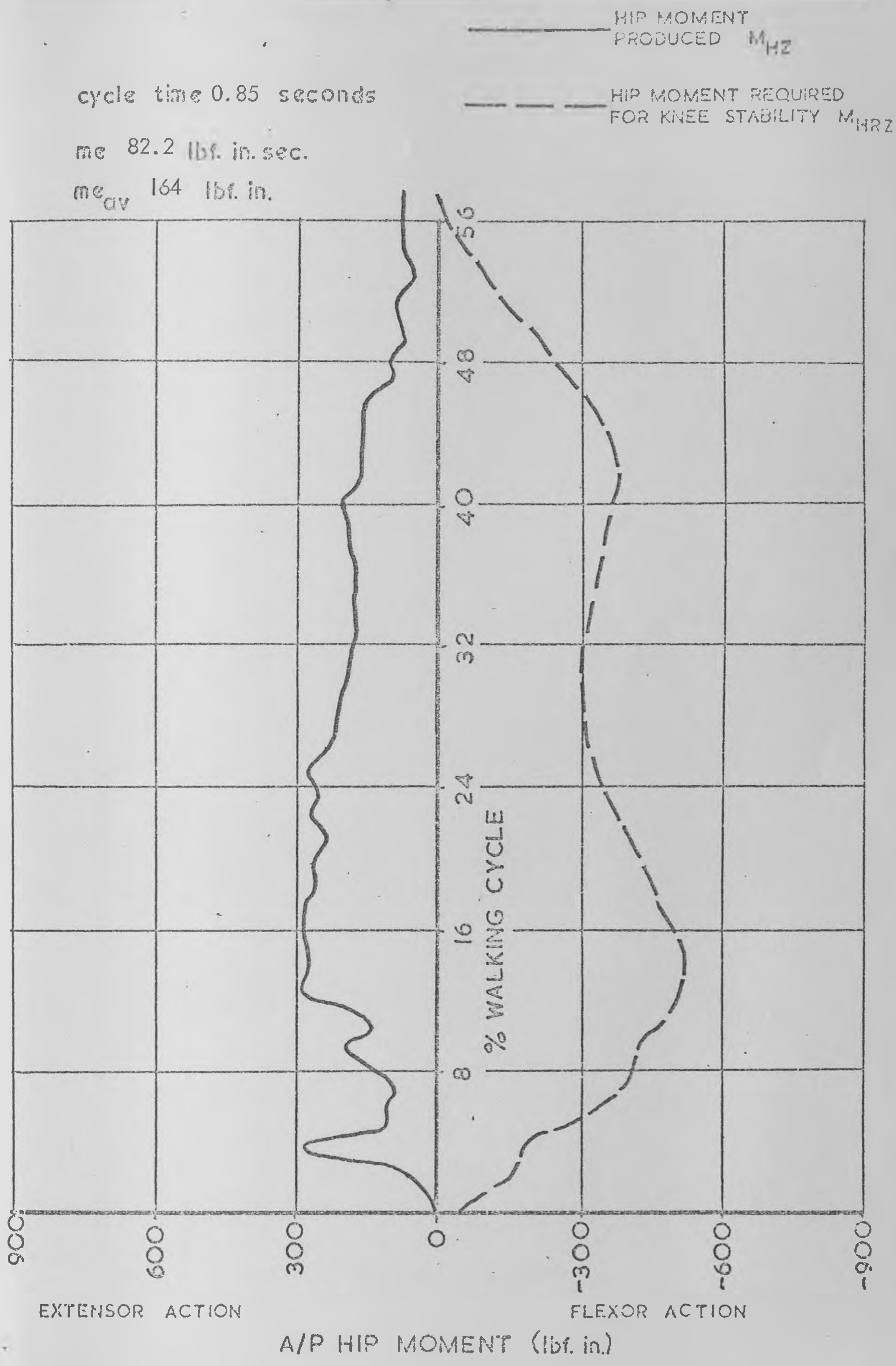
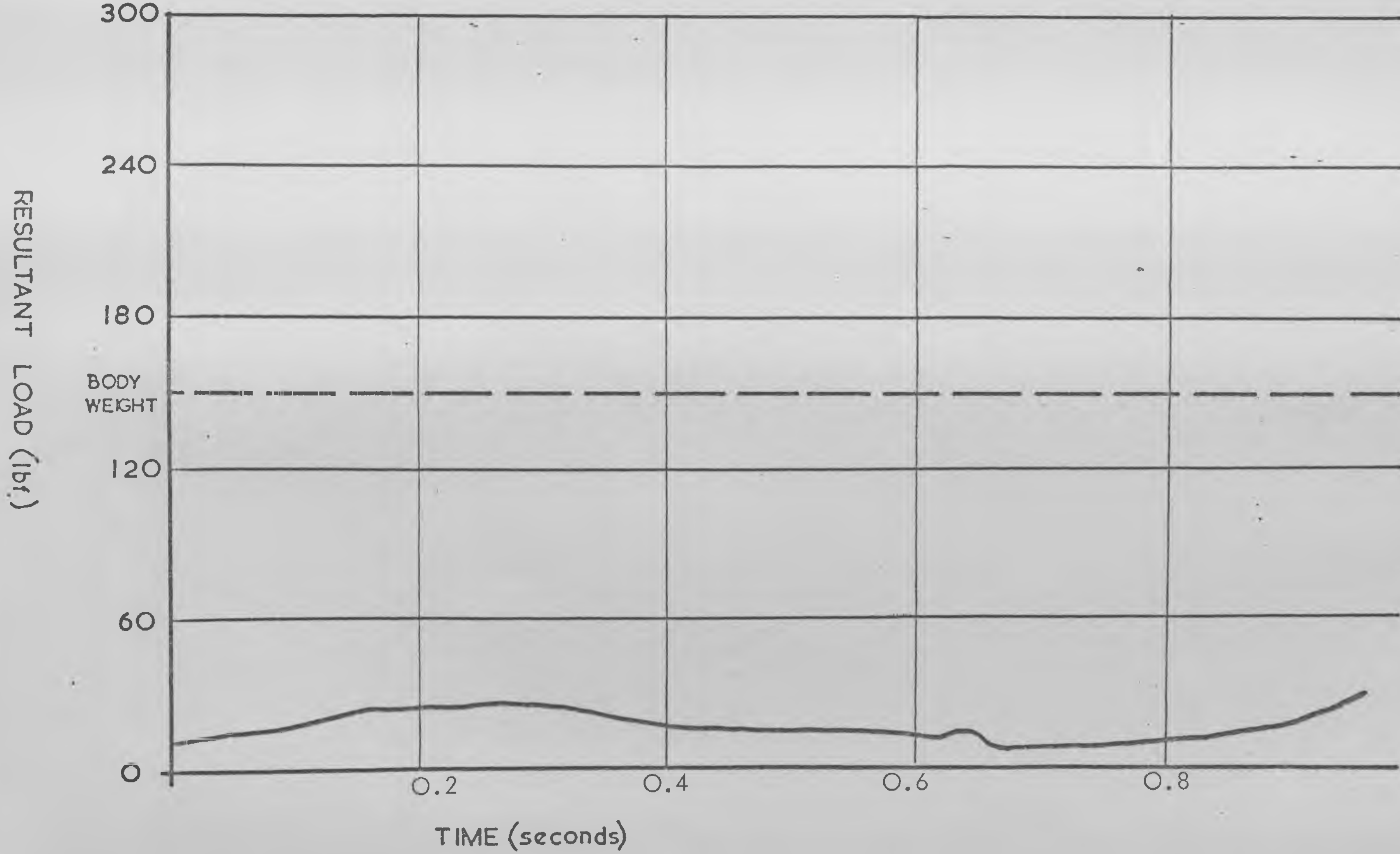


fig. VI. 84



RESULTANT LOAD IN STANDING UP WITH L.A.

fig. VI.85

A/P HIP MOMENT IN STANDING UP WITH L.A.

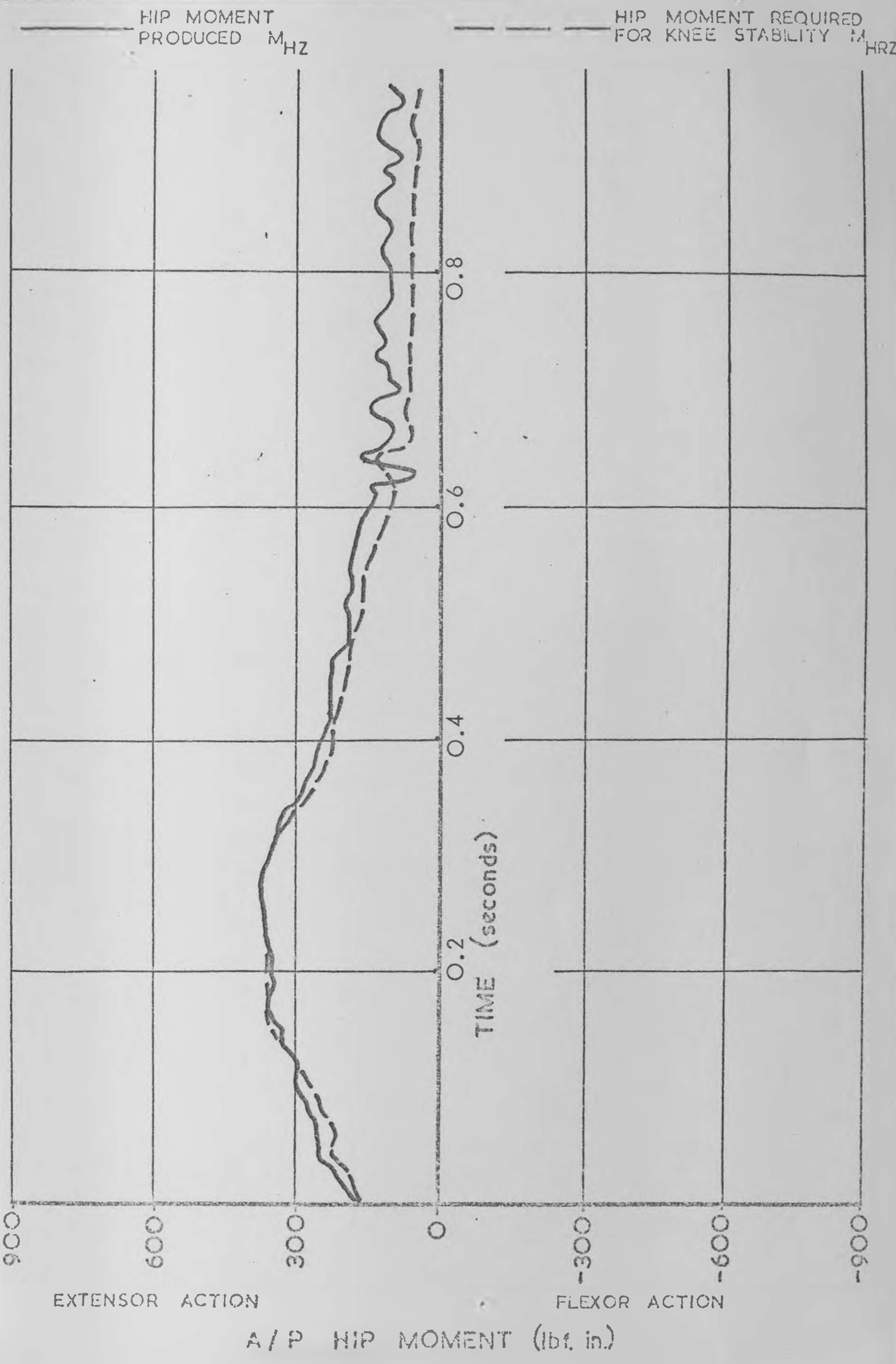


fig VI. 86

RESULTANT LOAD IN SITTING DOWN WITH L.A.

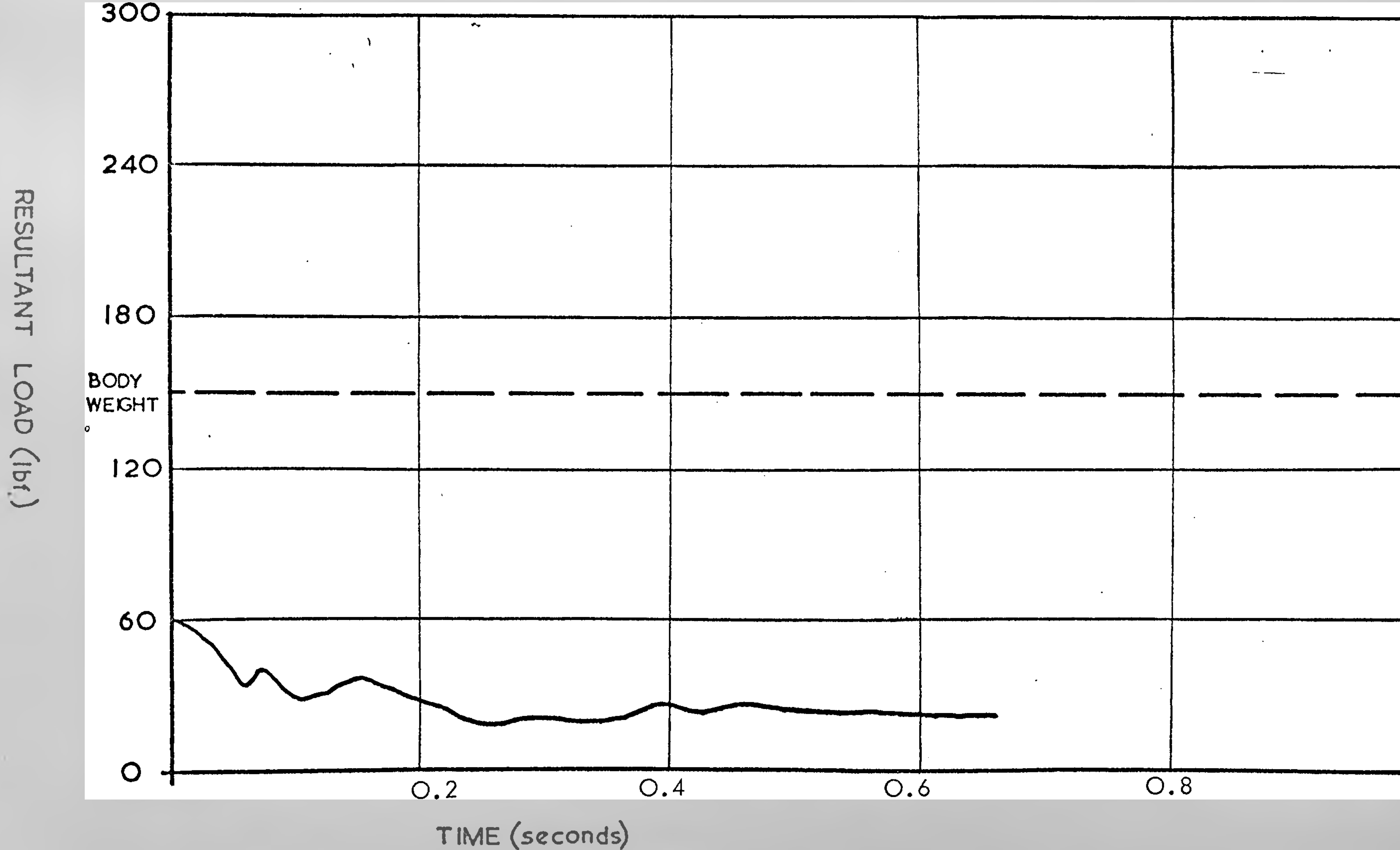


fig. VI.87

A/P HIP MOMENT IN SITTING DOWN WITH L.A.

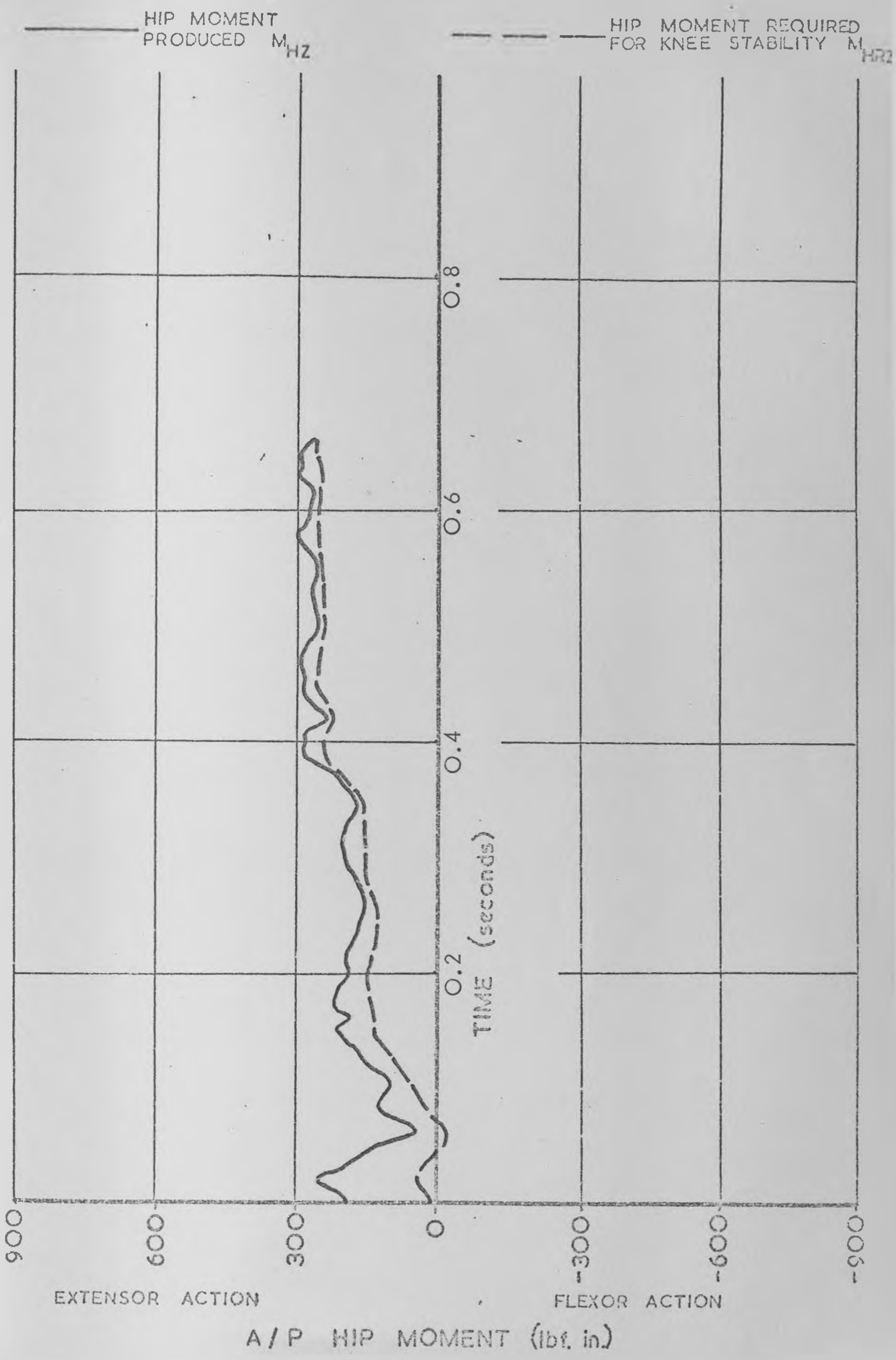


fig.VI.88

RESULTANT LOAD IN LIFTING AND LOWERING A WEIGHT WITH L.A.

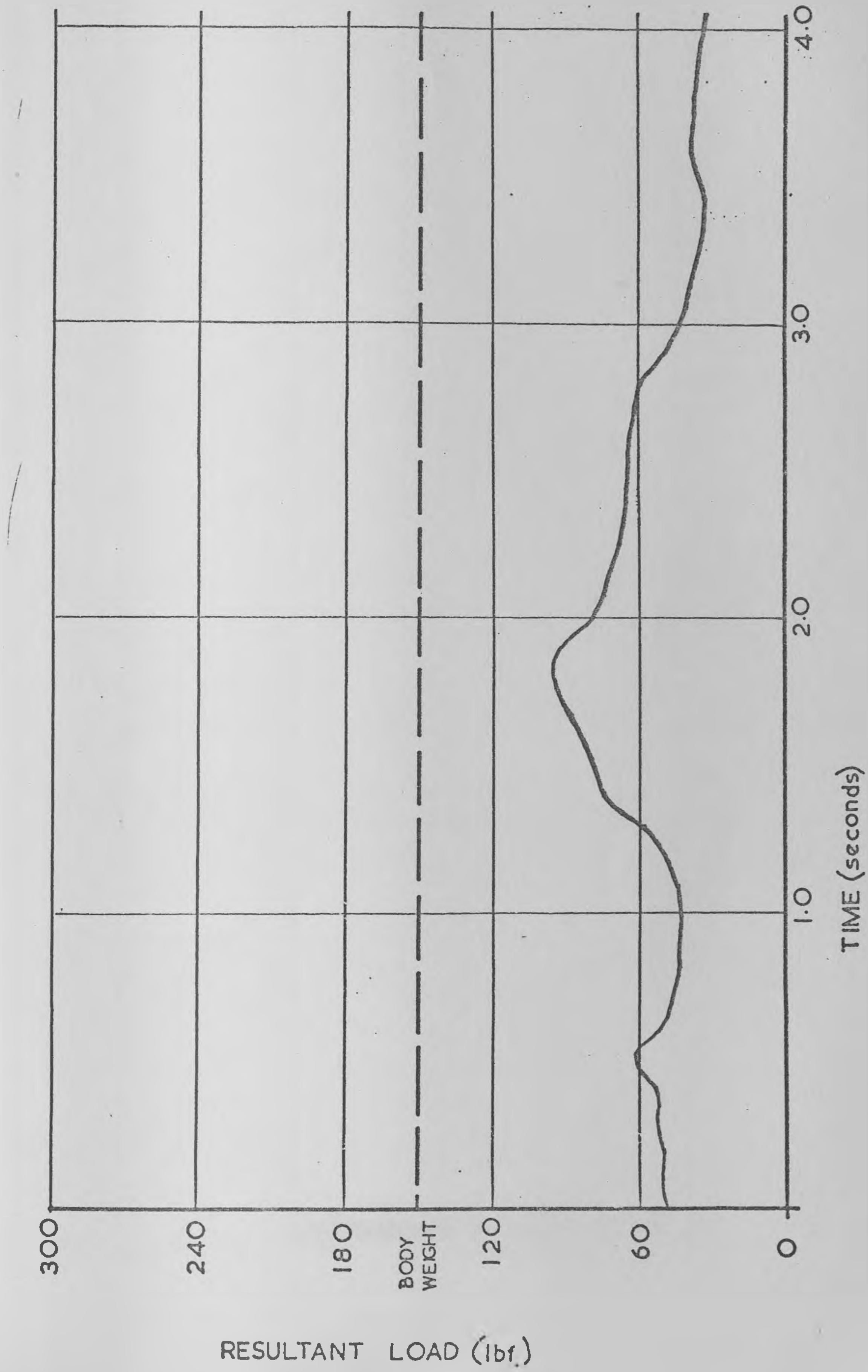


fig. VI. 89

A/P HIP MOMENT IN LIFTING AND LOWERING A WEIGHT WITH L.A.

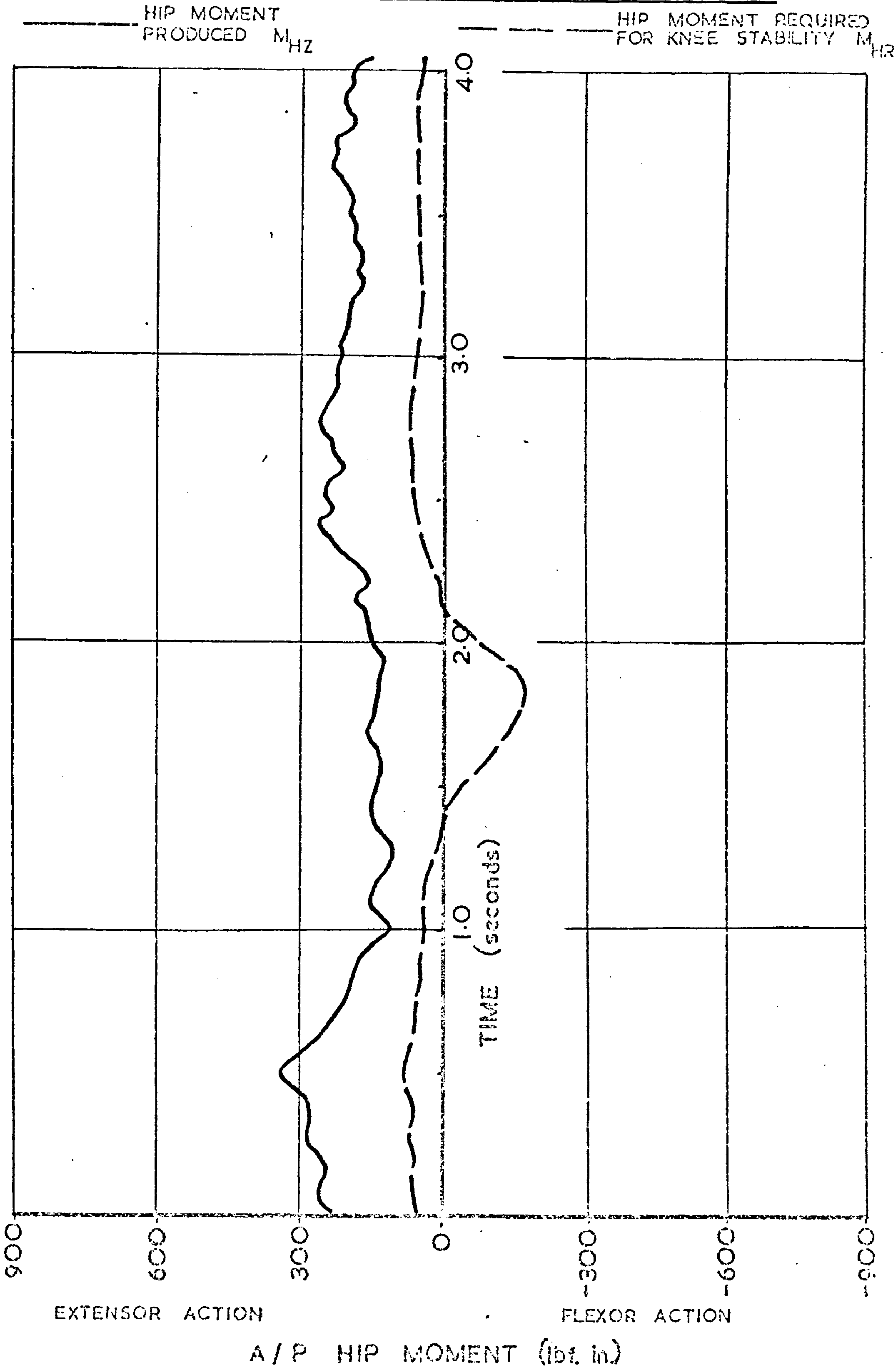


fig. VI.90

A/P KNEE MOMENT IN LEVEL WALKING WITH S.A.

cycle time 1.10 seconds

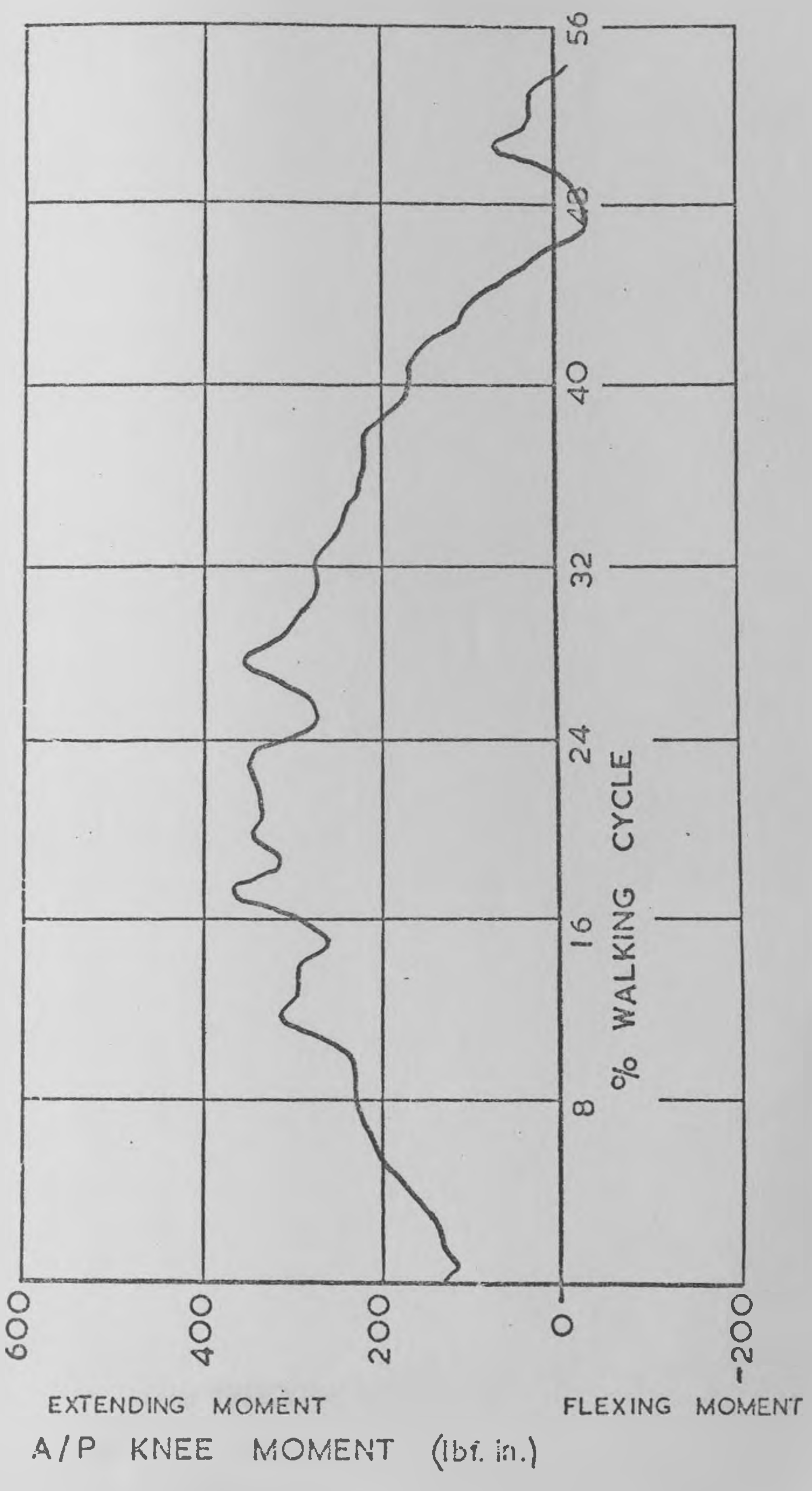


fig VI.91

A/P KNEE MOMENT IN WALKING UP RAMP WITH S.A.

cycle time 1.44 seconds

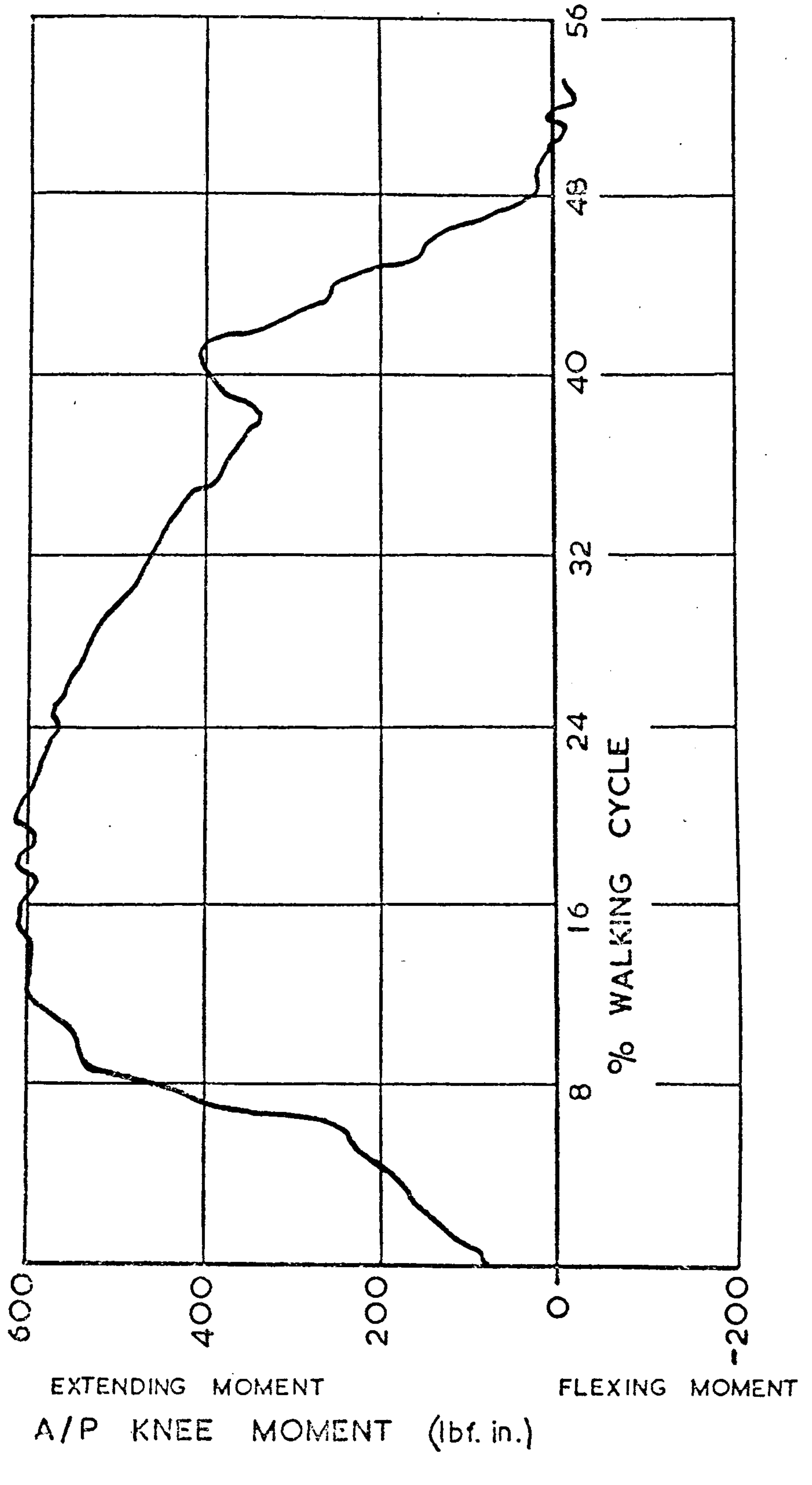


fig.VI.92

A/P KNEE MOMENT IN WALKING DOWN RAMP WITH S.A.

cycle time 1.14 seconds

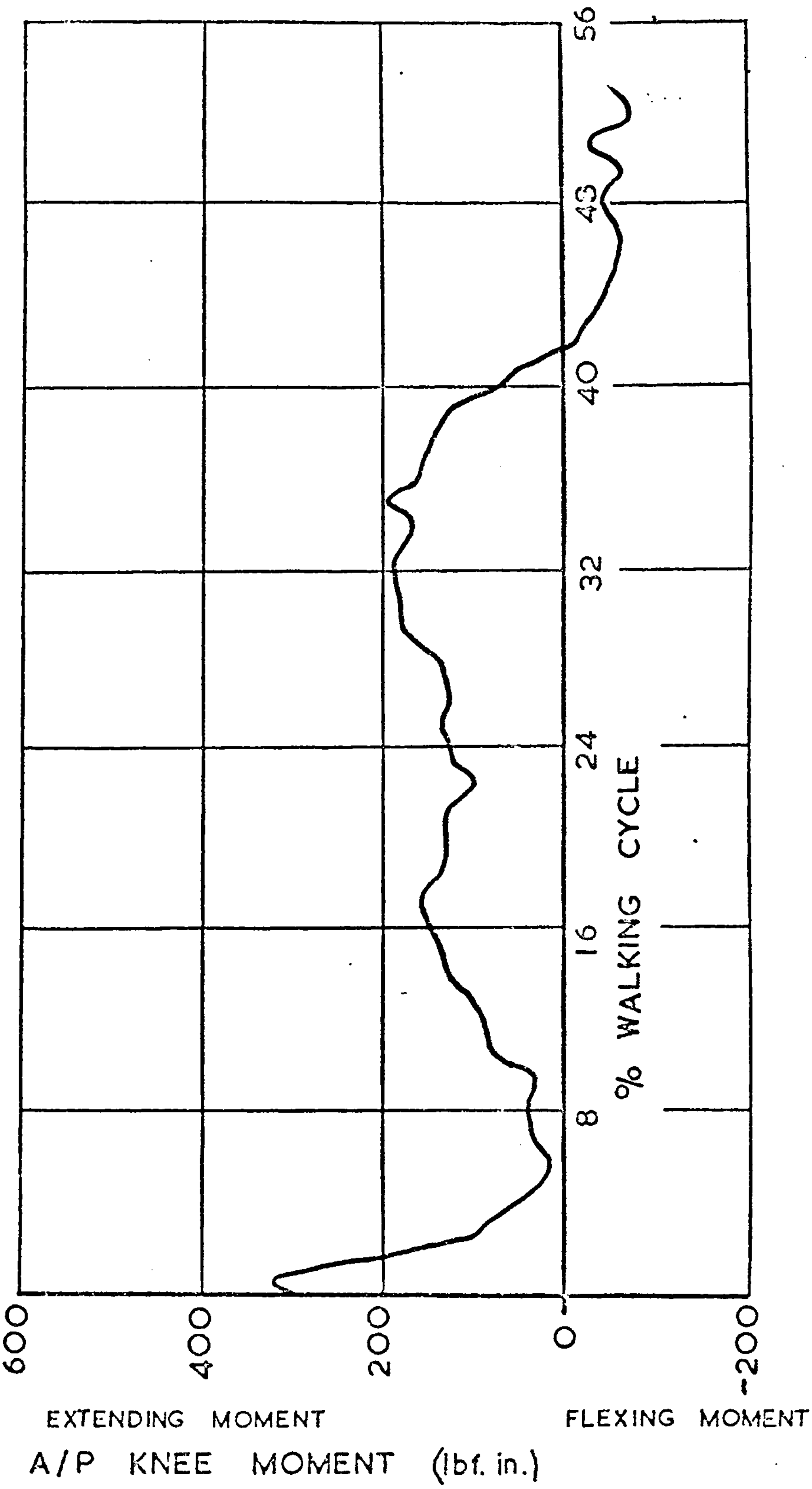


fig.VI.93

A/P KNEE MOMENT IN WALKING UP STAIRS WITH S.A.

cycle time 1.39 seconds

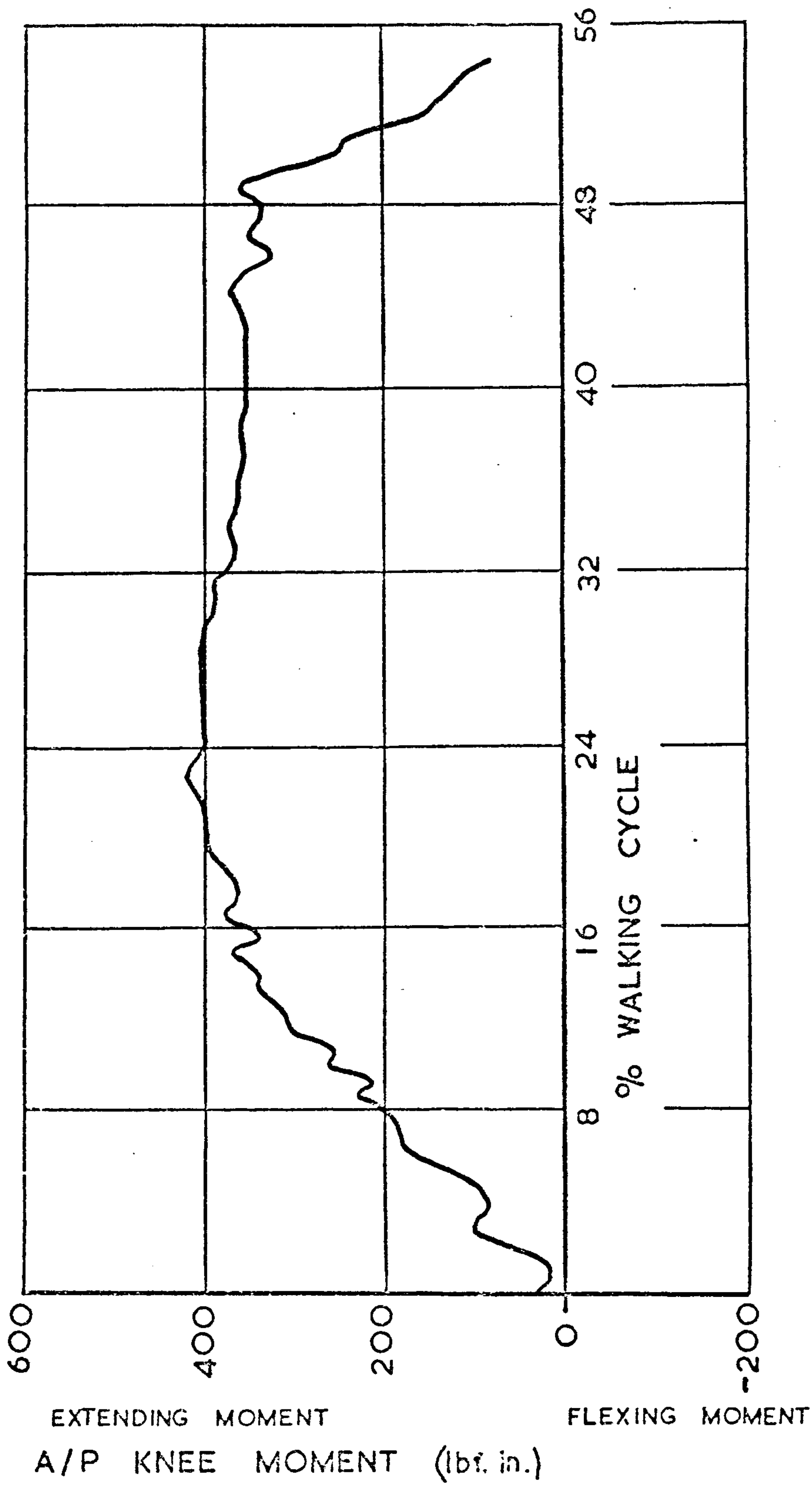


fig.VI.94

A/P KNEE MOMENT IN WALKING DOWN STAIRS WITH S.A.

cycle time 1.20 seconds

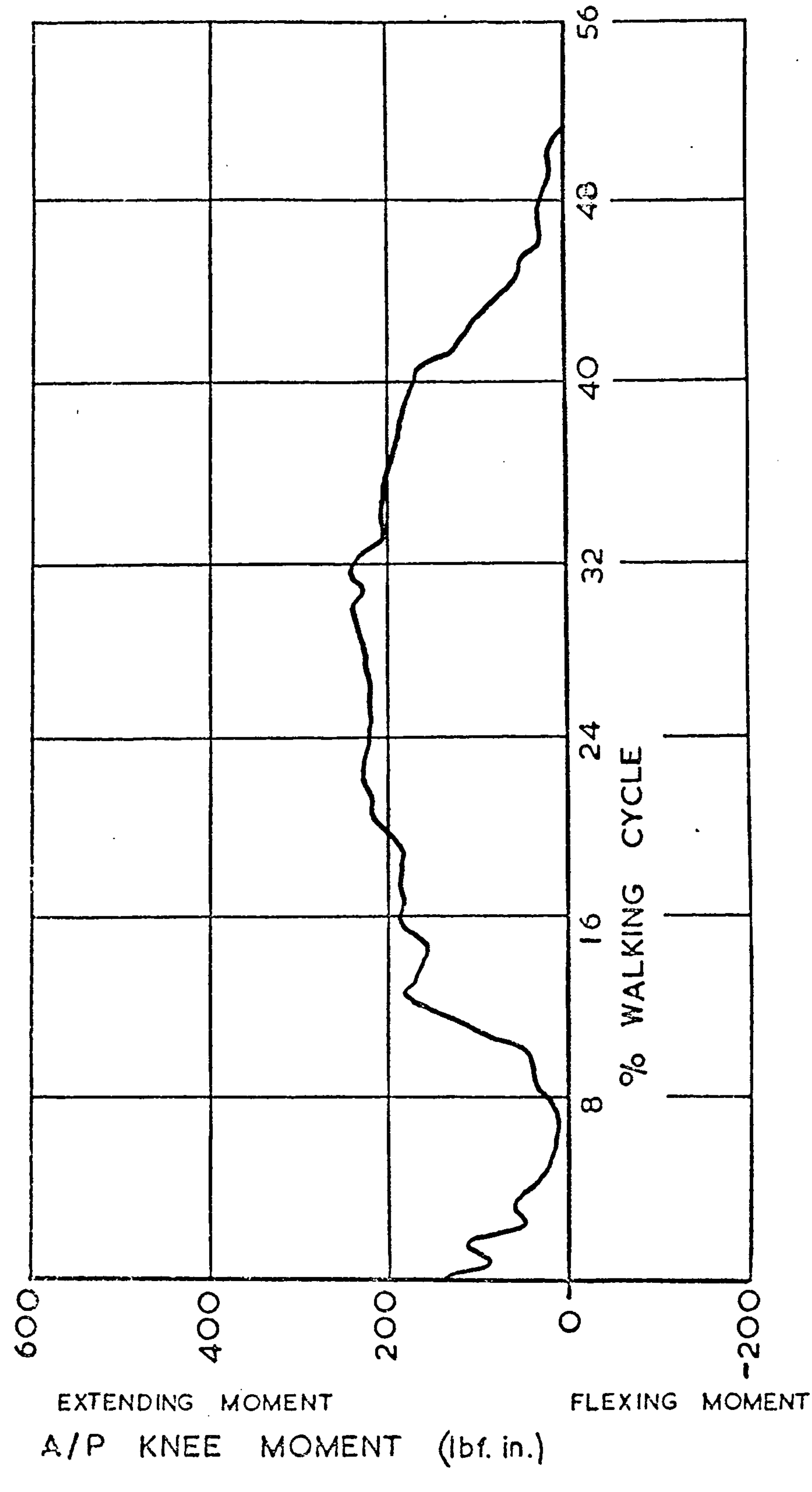


fig.VI.95

A/P KNEE MOMENT IN STEPPING OVER AN OBJECT (from a standing position) WITH S.A.

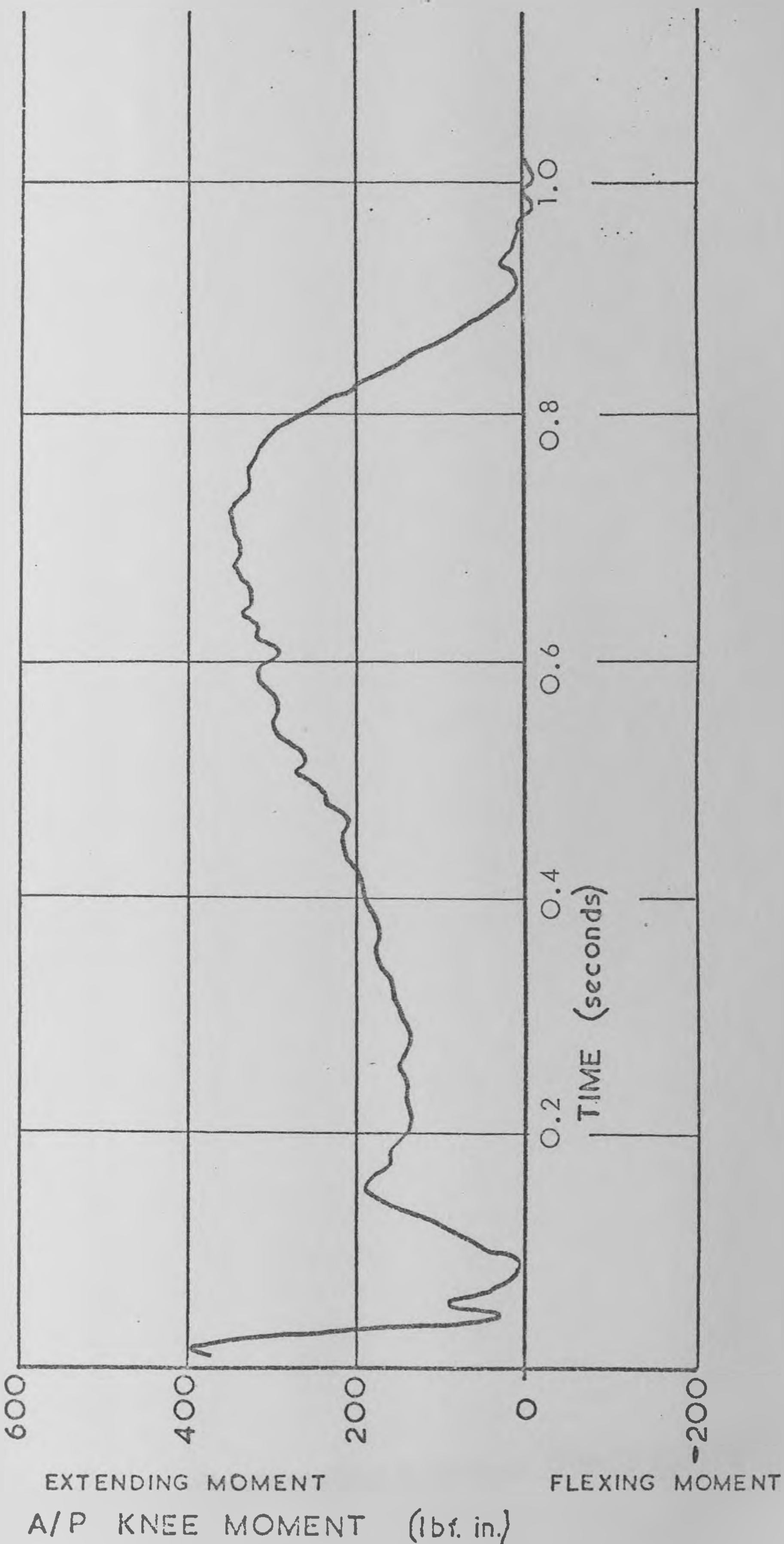


fig.VI. 96

A/P KNEE MOMENT IN STEPPING OVER AN OBJECT (after walking up to it) WITH S.A.

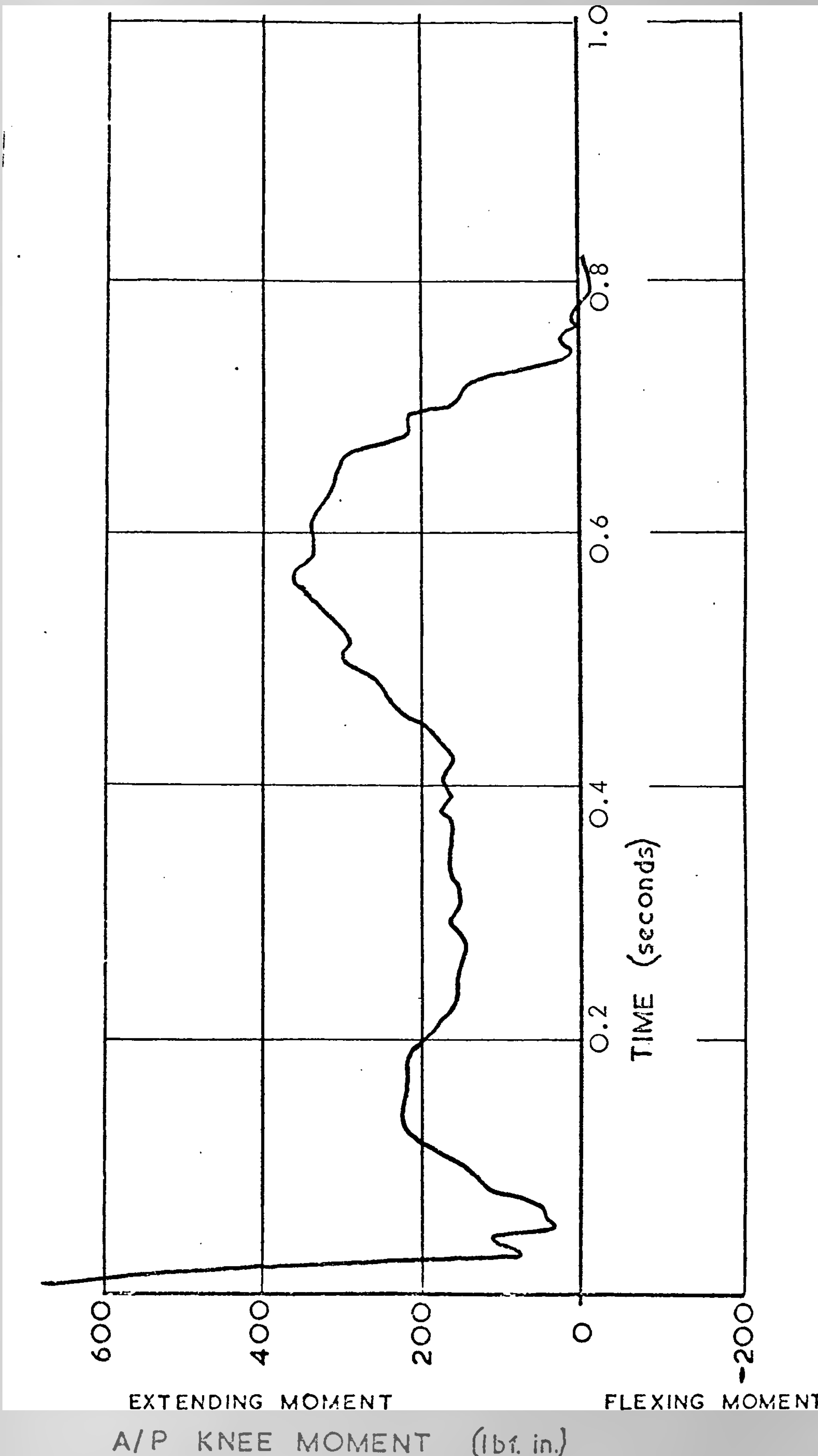


fig.VI.97

A/P KNEE MOMENT IN RUNNING WITH S.A.

cycle time 1.09 seconds

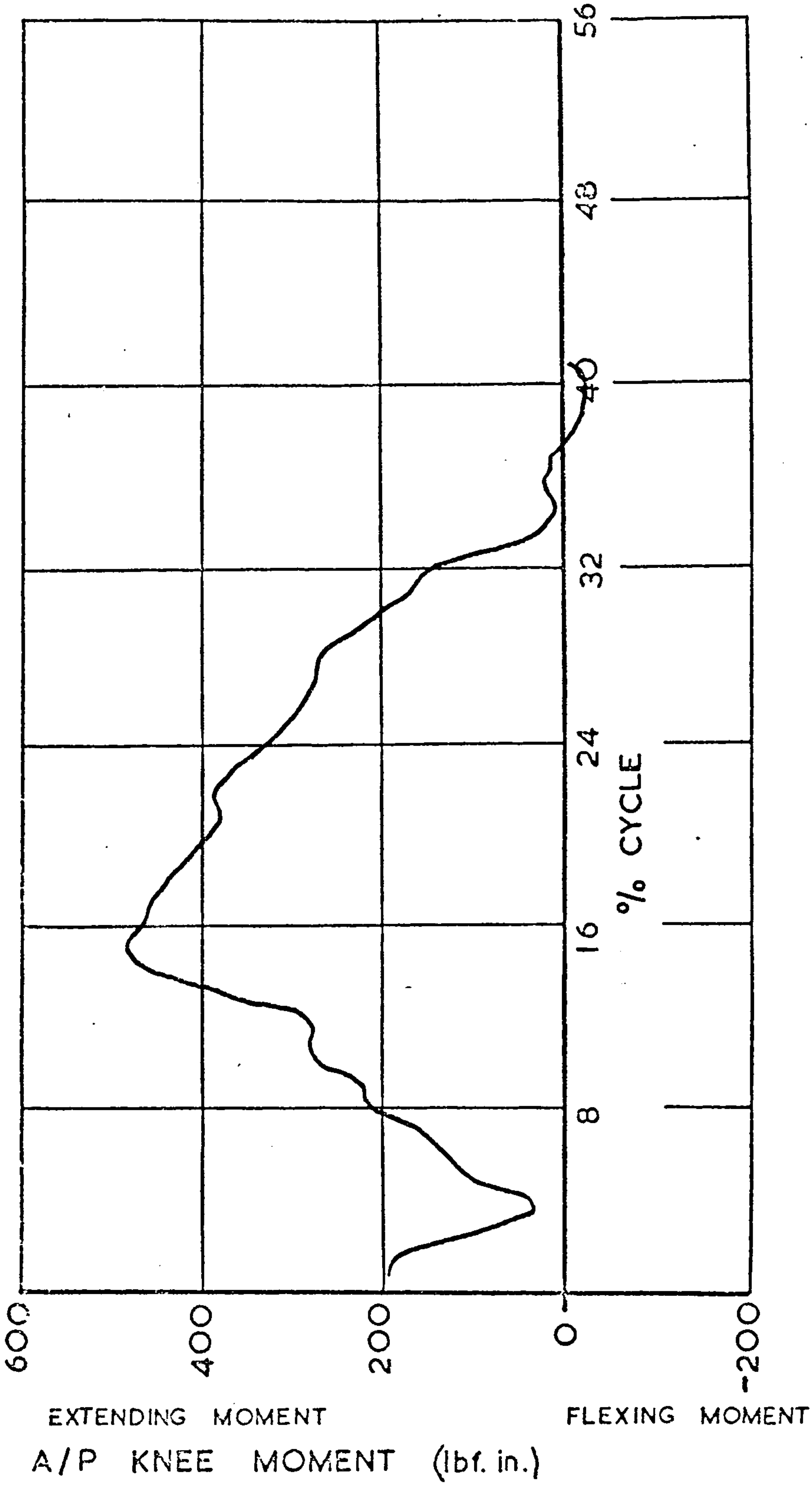


fig. VI. 98

A/P KNEE MOMENT IN WALKING SIDEWAYS (Prosthesis Leading) WITH S.A.

cycle time 1.00 seconds

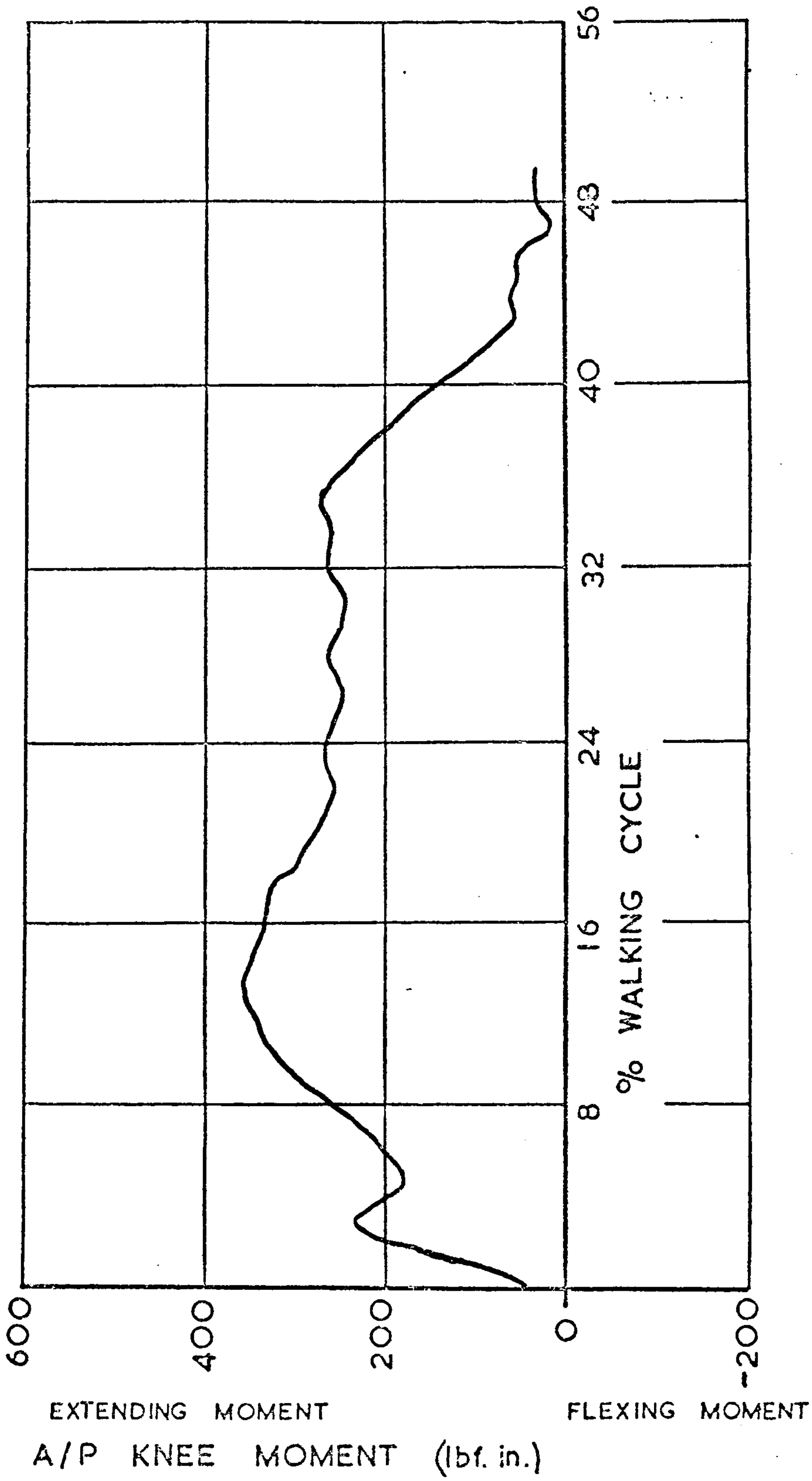


fig. VI. 99

A/P KNEE MOMENT IN WALKING SIDEWAYS (Normal Leg Leading) WITH S.A.

cycle time 0.82 seconds

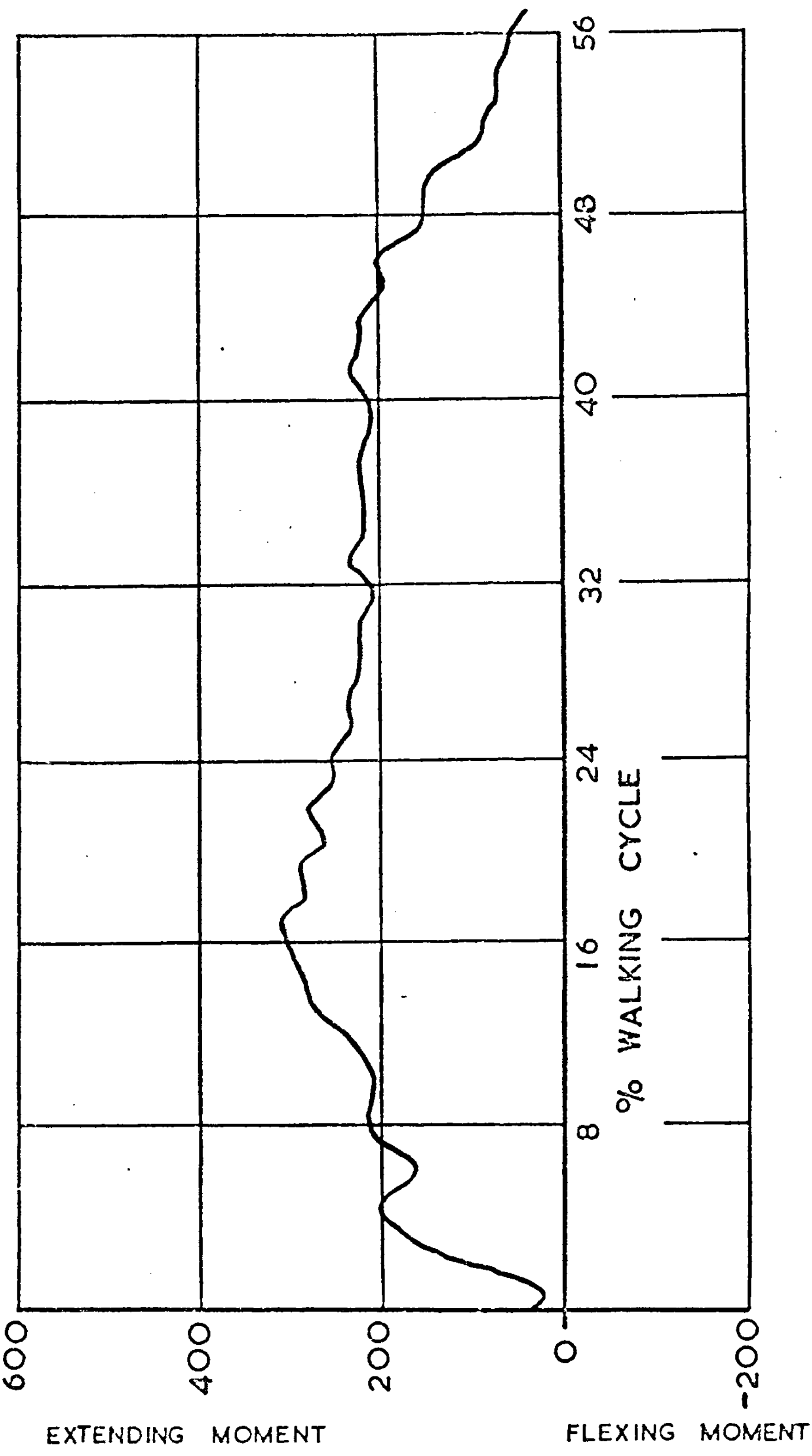


fig.VI.100

A/P ANKLE MOMENT IN LEVEL WALKING WITH S.A.

cycle time 1.10 seconds

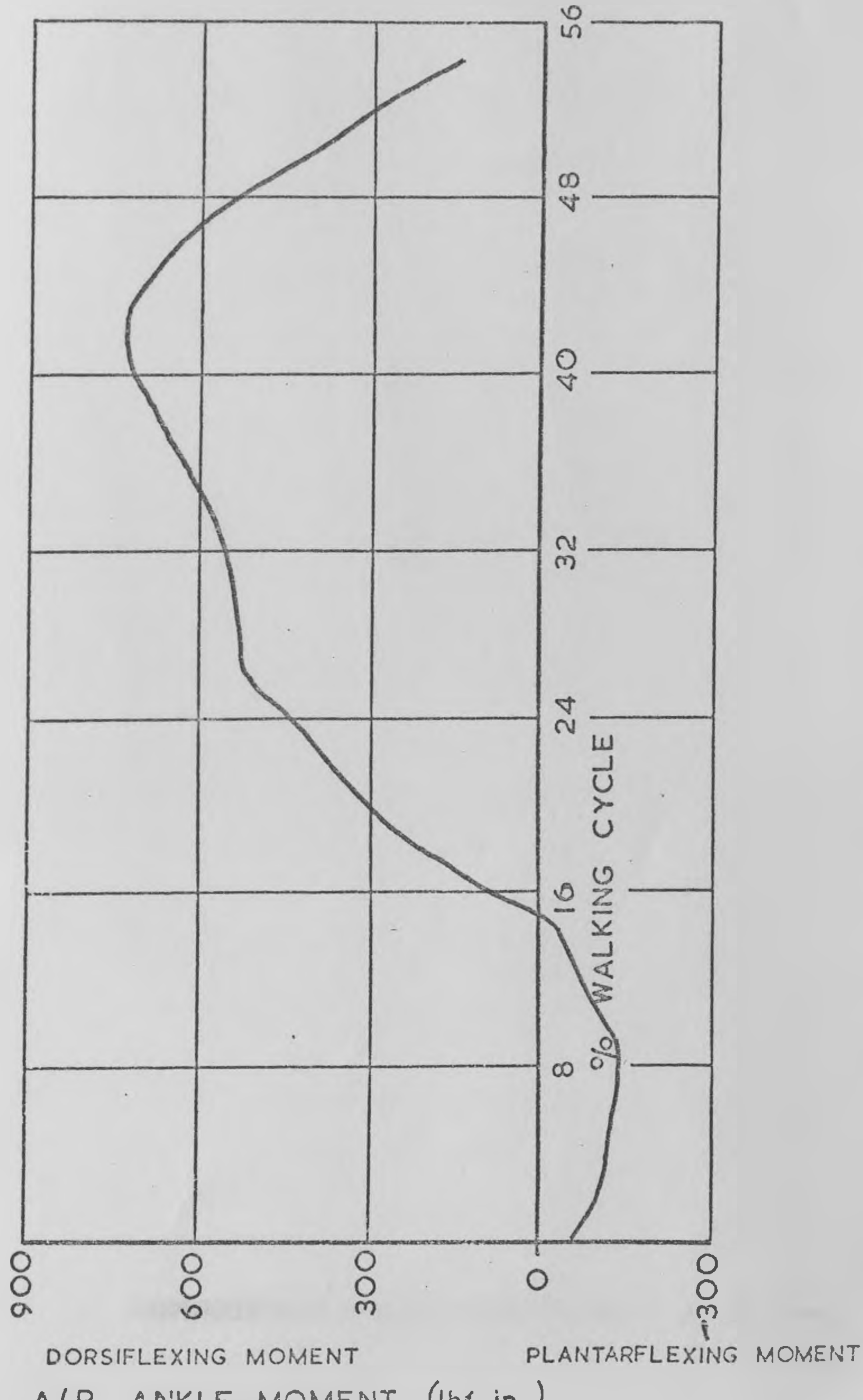


fig.VI.101

A/P ANKLE MOMENT IN WALKING UP RAMP WITH S.A.

cycle time 1.44 seconds

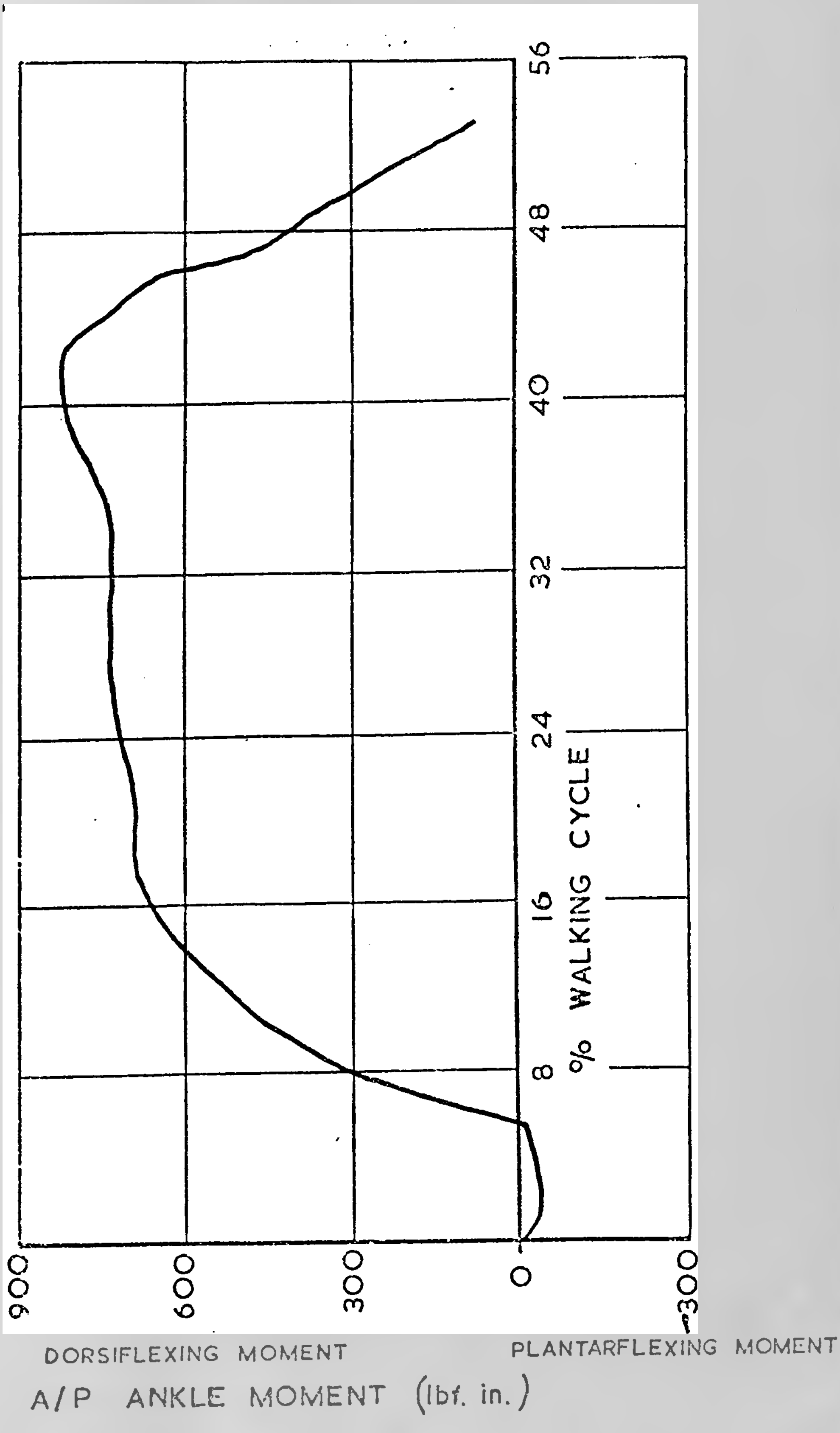
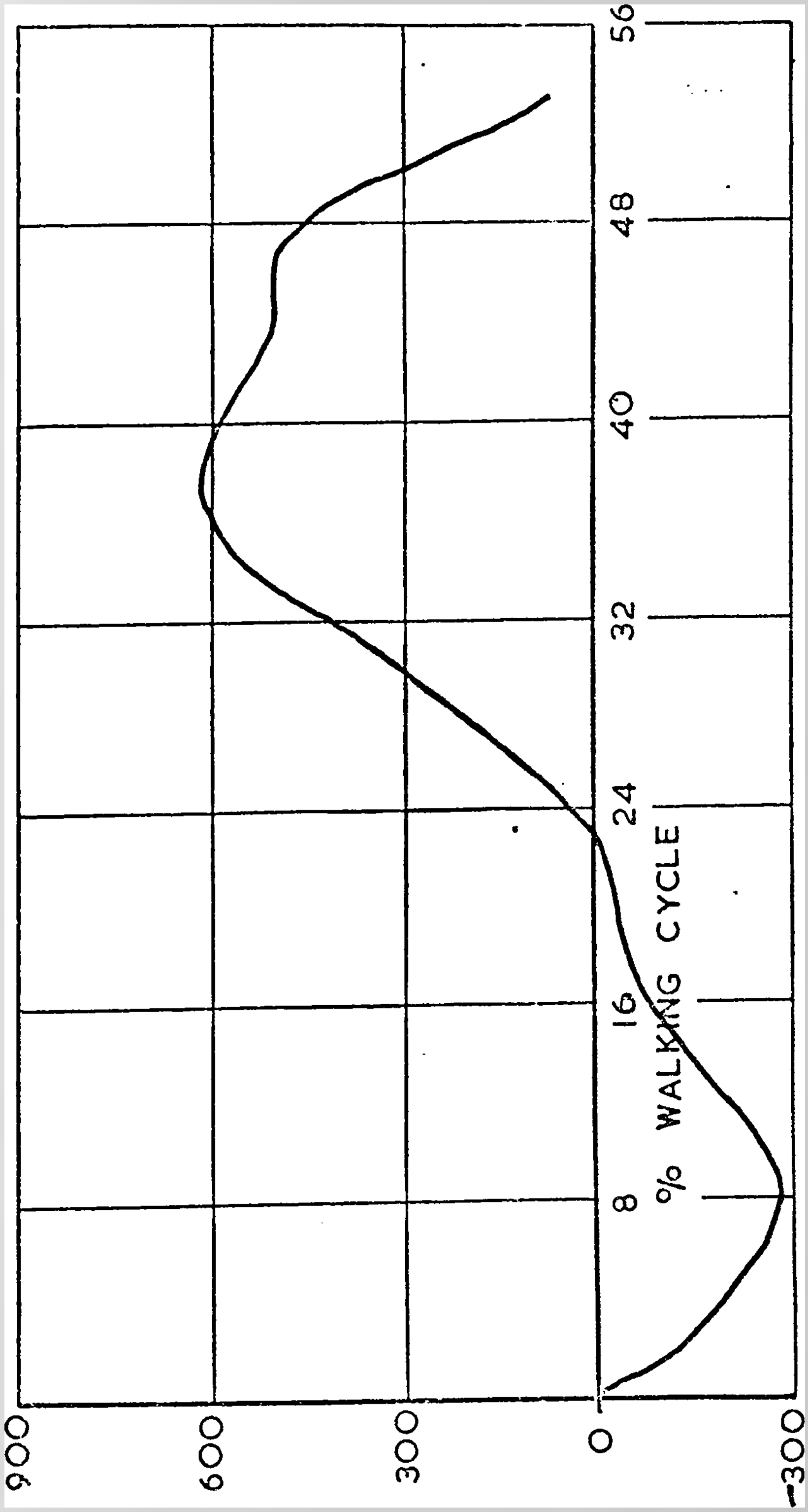


fig.VI.102

A/P ANKLE MOMENT IN WALKING DOWN RAMP WITH S.A.

cycle time 1.14 seconds



DORSIFLEXING MOMENT PLANTARFLEXING MOMENT

A/P ANKLE MOMENT (lbf. in.)

fig.VI.103

A/P ANKLE MOMENT IN WALKING UP STAIRS WITH S.A.

cycle time 1.39 seconds

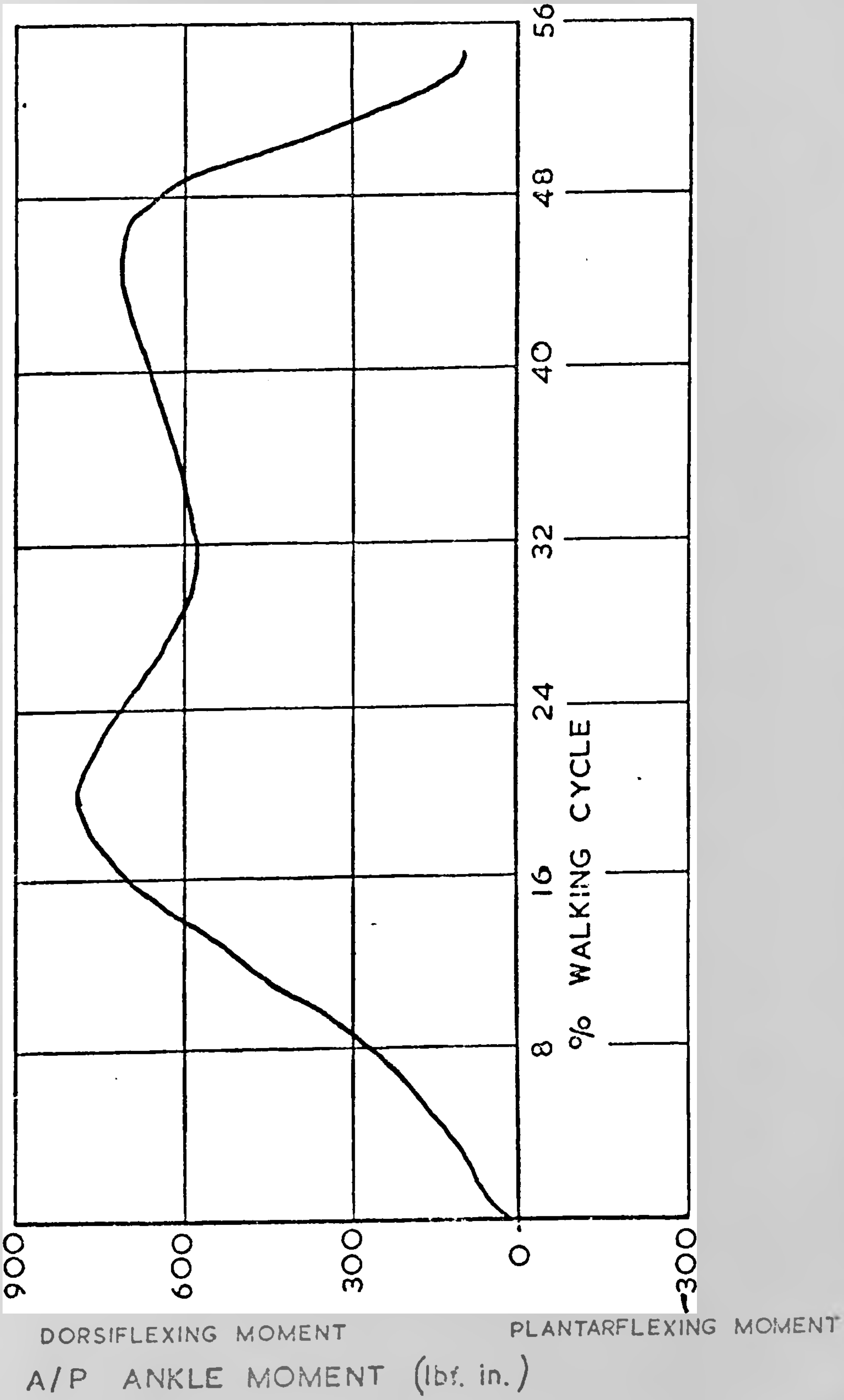


fig.VI.104

A/P ANKLE MOMENT IN WALKING DOWN STAIRS WITH S.A.

cycle time 1.20 seconds

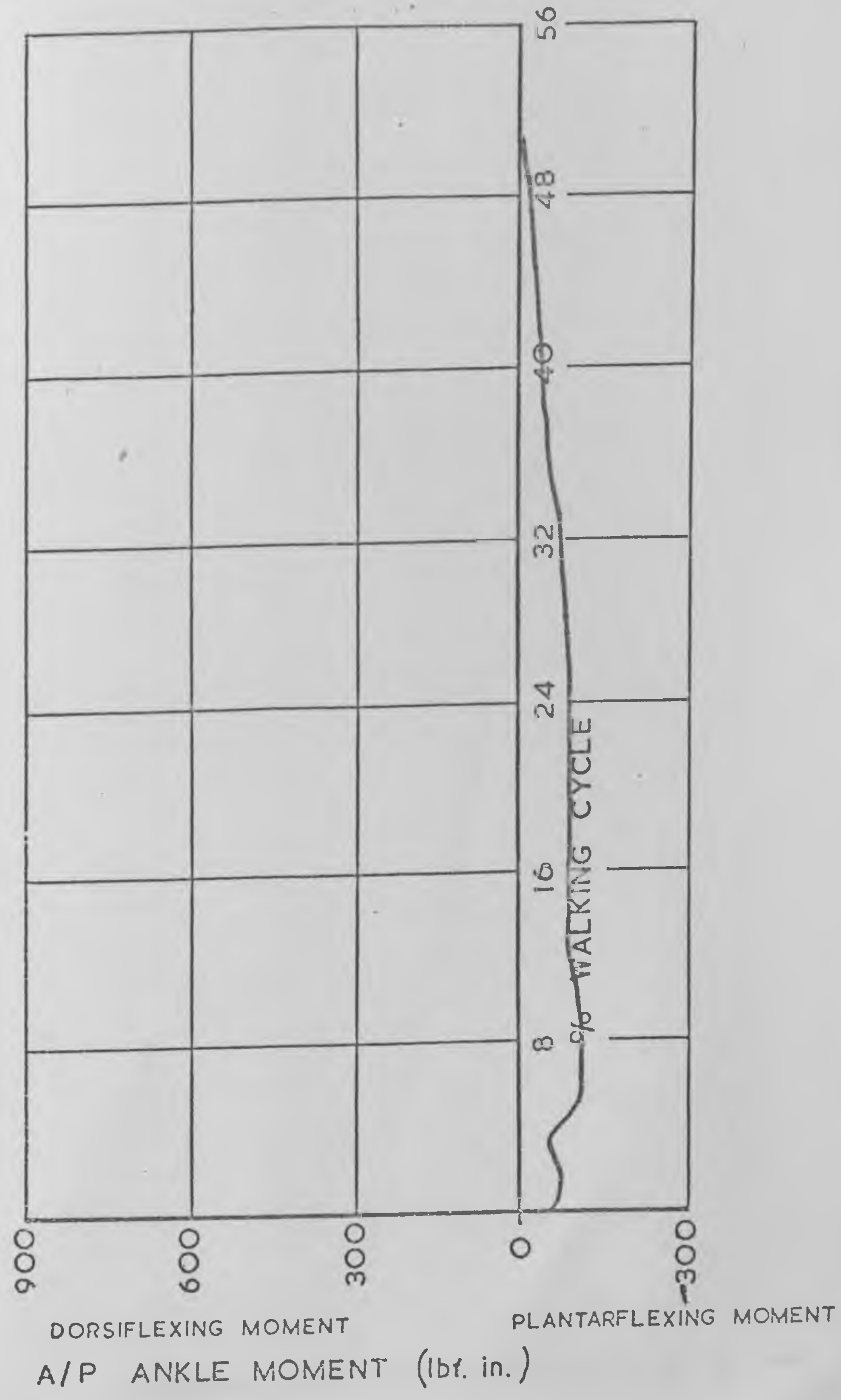
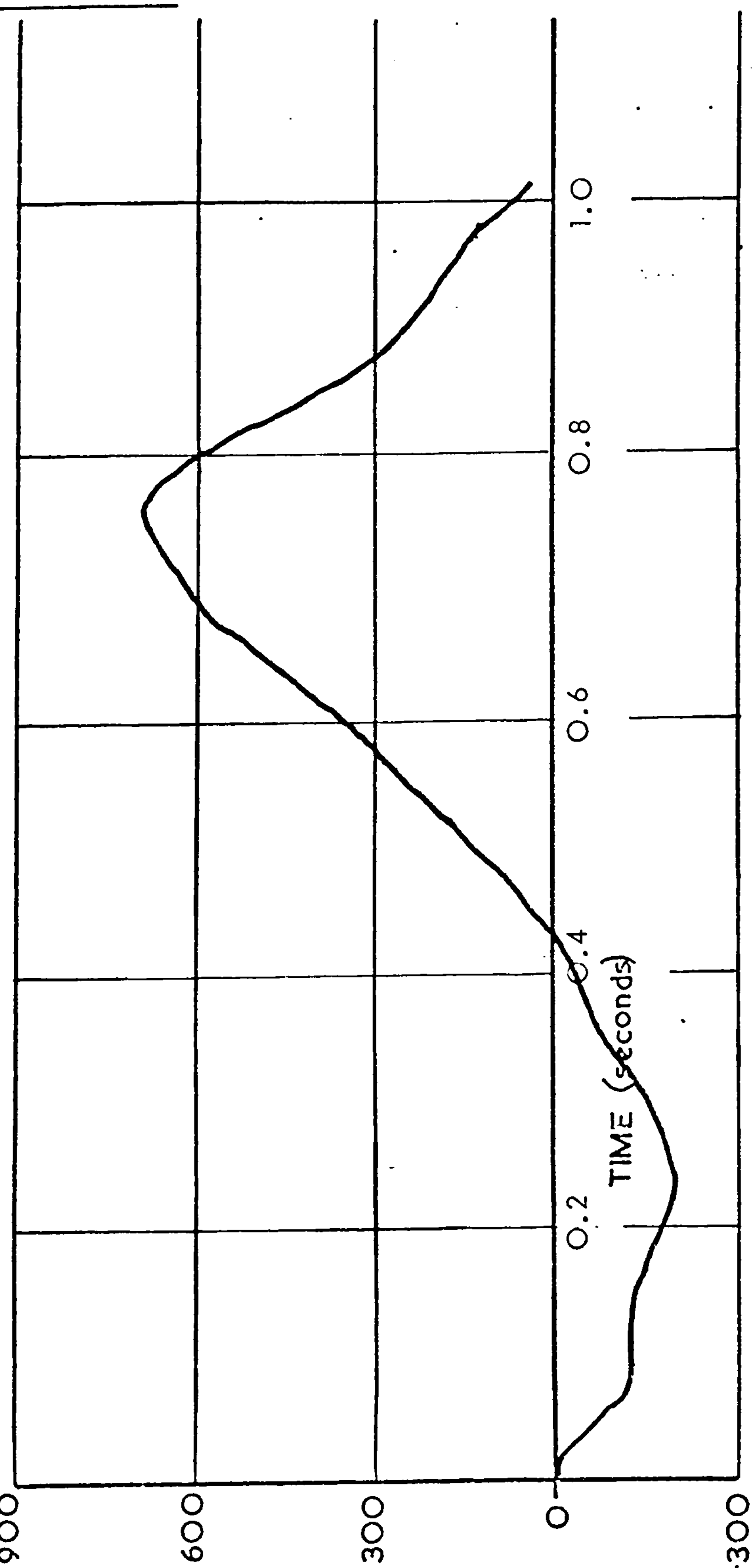


fig.VI.105

A/P ANKLE MOMENT IN STEPPING OVER AN OBJECT (from a standing position) WITH S.A.



DORSIFLEXING MOMENT PLANTARFLEXING MOMENT

A/P ANKLE MOMENT (lbf. in.)

A/P ANKLE MOMENT IN STEPPING OVER AN OBJECT (after walking up to it) WITH S.A.

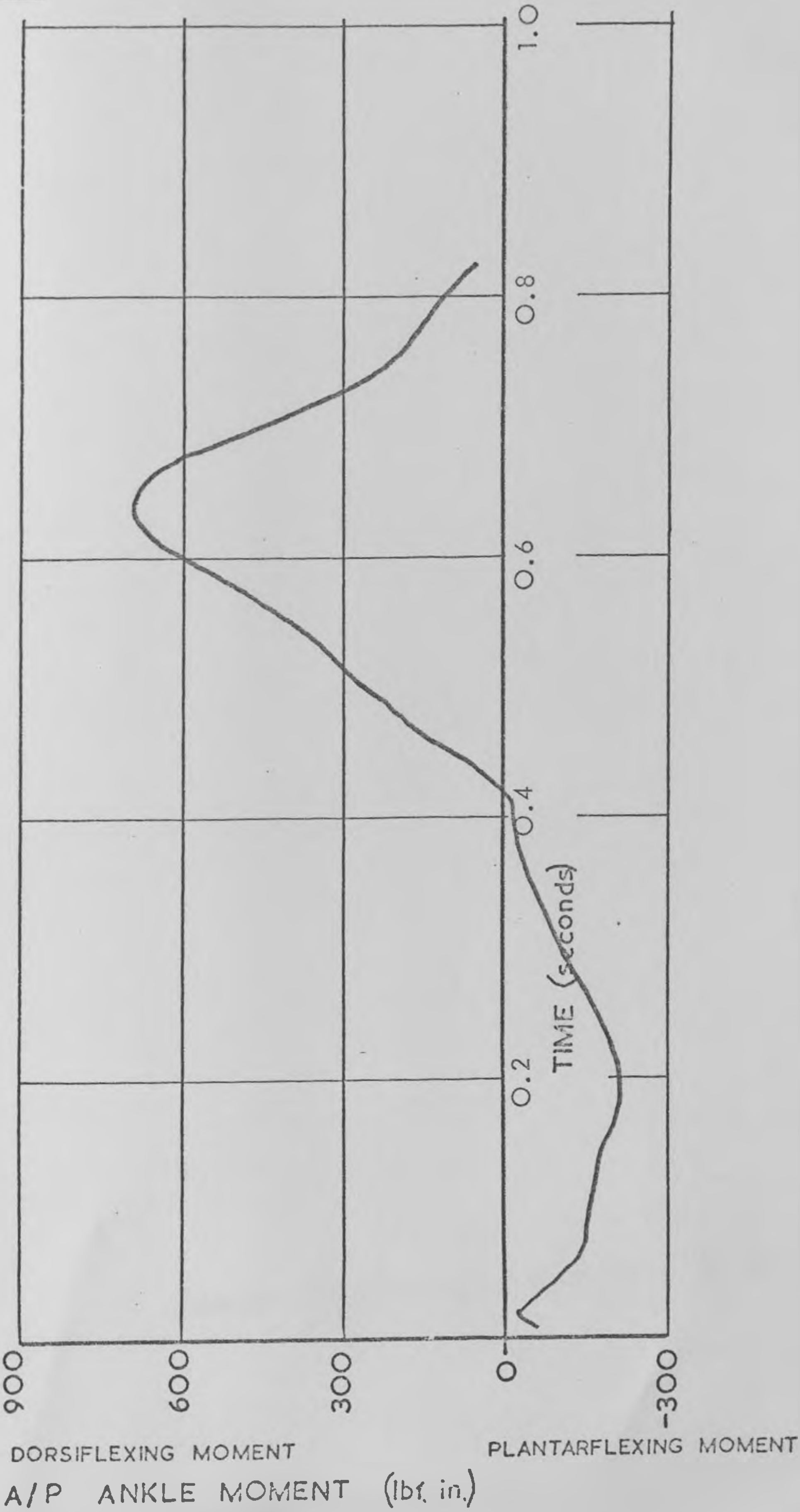


fig.VI.107

A/P ANKLE MOMENT IN RUNNING WITH S.A.

cycle time 1.09 seconds

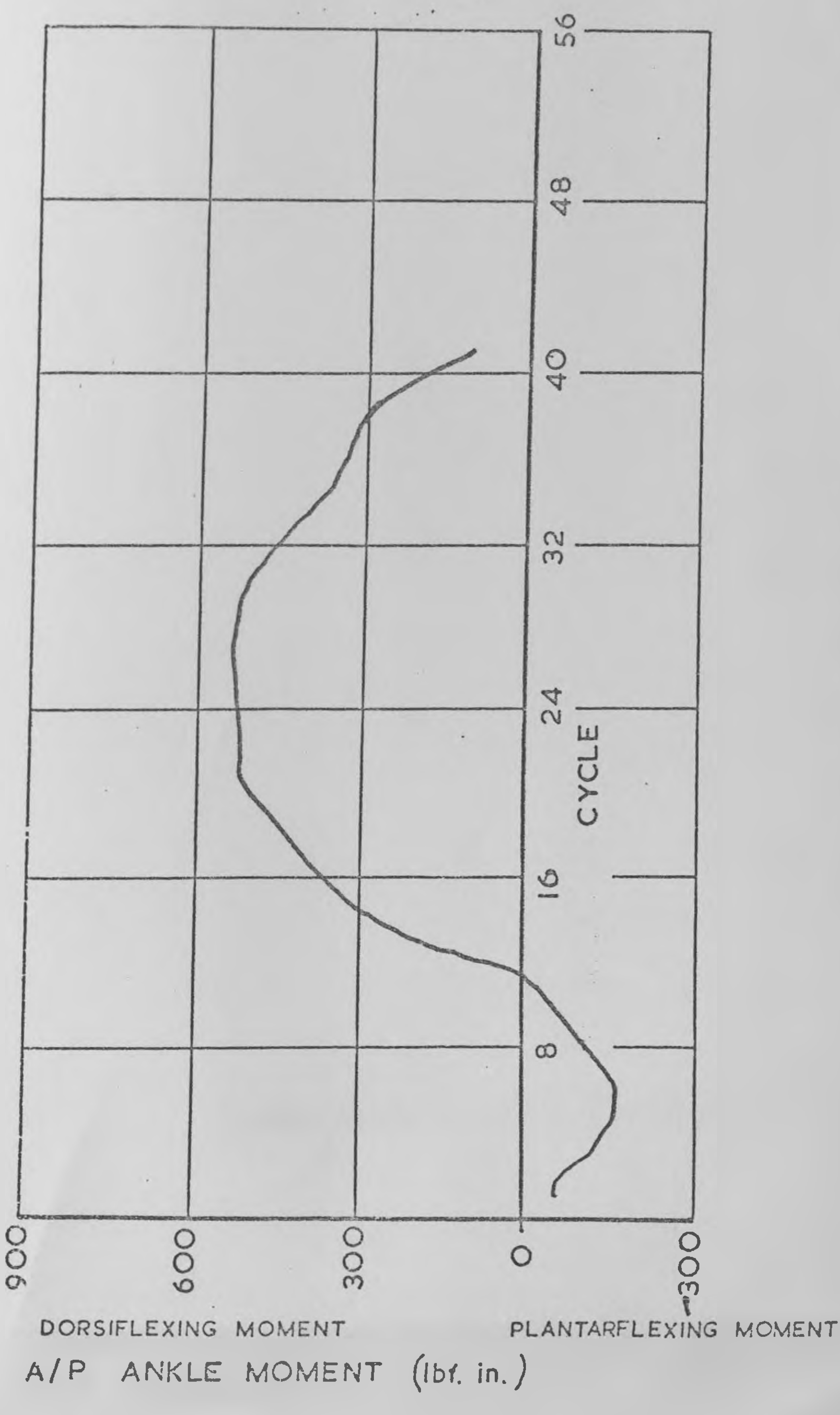


fig.VI.108

A/P ANKLE MOMENT IN WALKING SIDEWAYS (Prosthesis Leading) WITH S.A.

cycle time 1.00 seconds

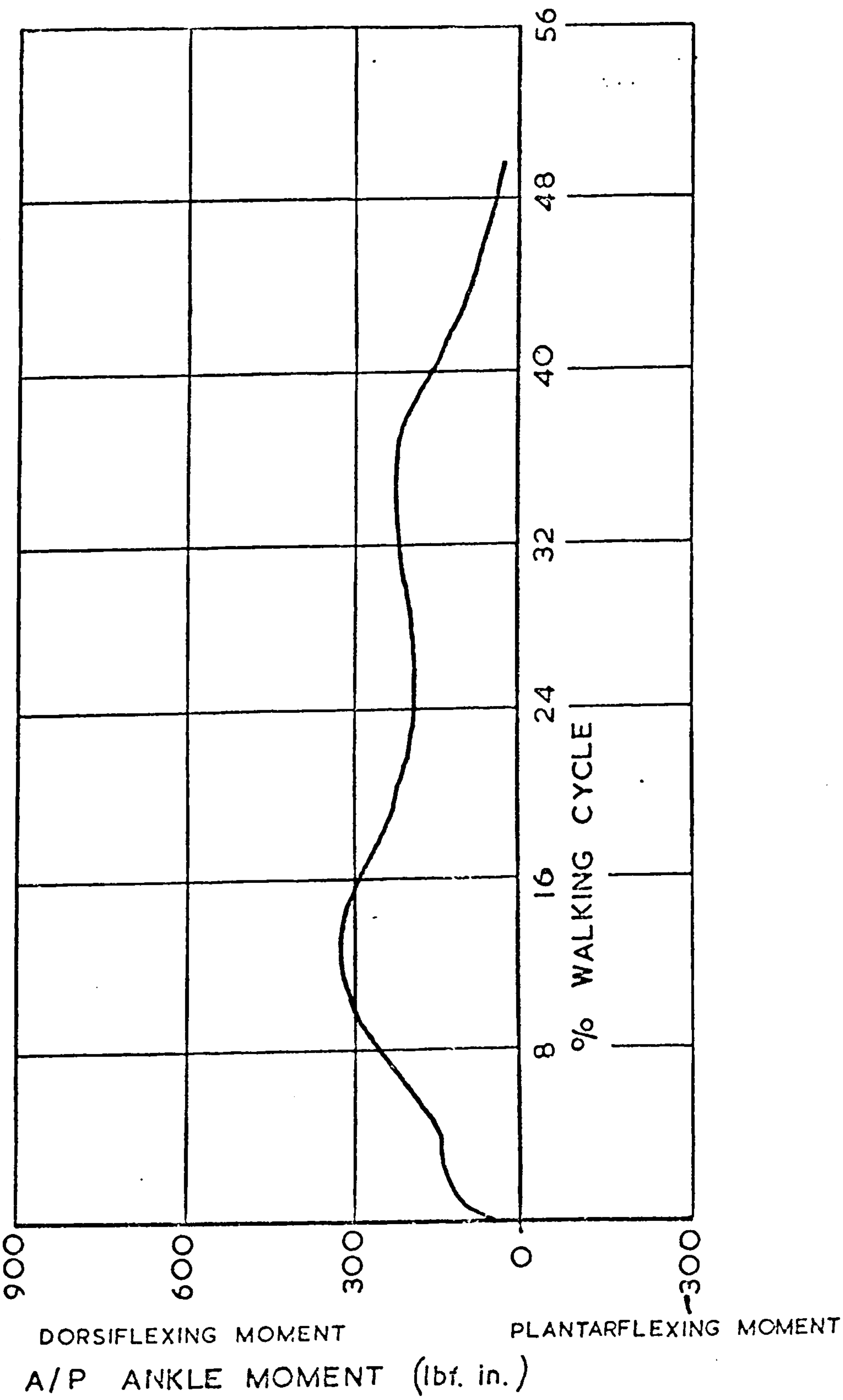
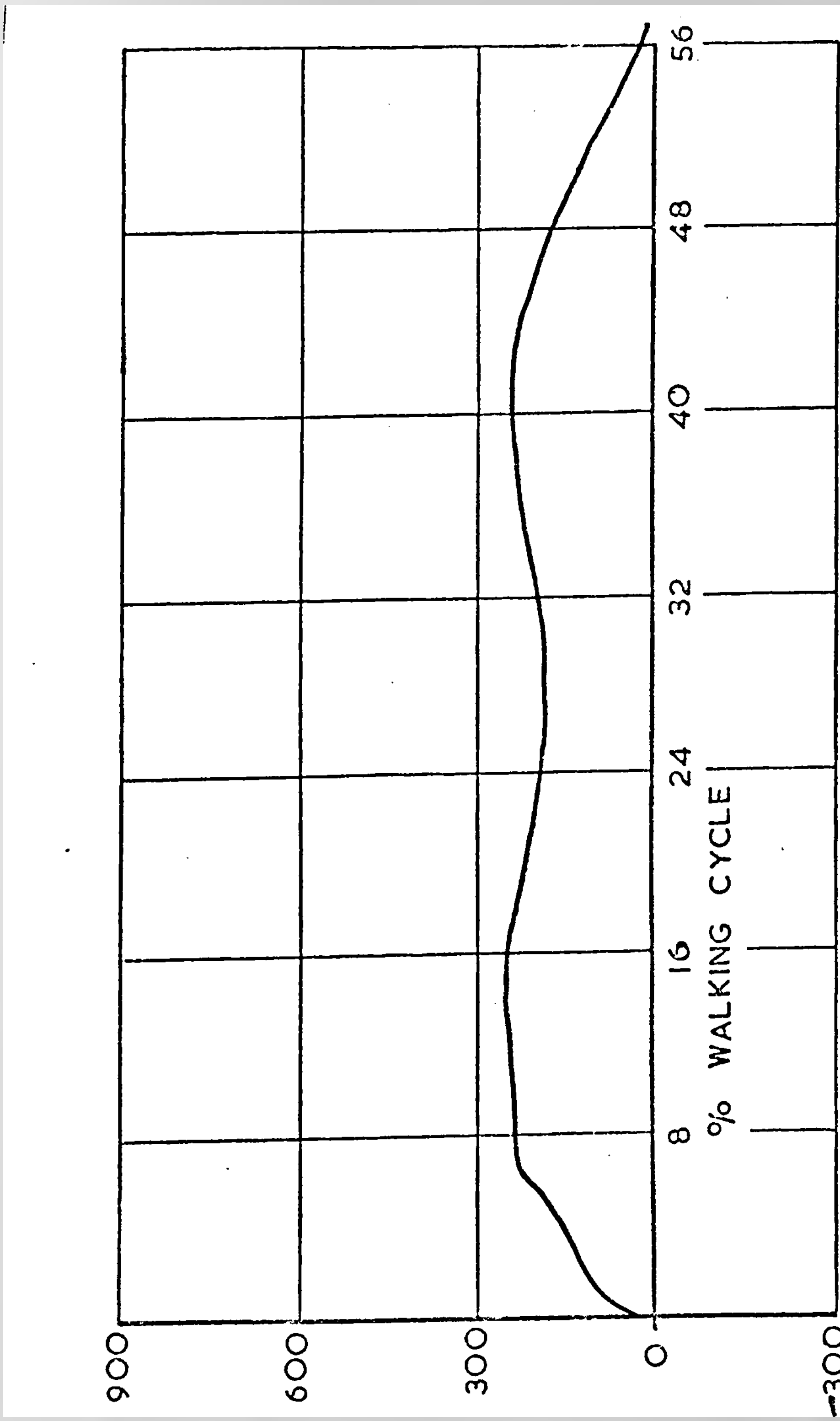


fig.VI.109

A/P ANKLE MOMENT IN WALKING SIDEWAYS (Normal Leg Leading) WITH S.A.

cycle time 0.82 seconds



DORSIFLEXING MOMENT PLANTARFLEXING MOMENT

A/P ANKLE MOMENT (lbf. in.)

fig.VI.110

M/L HIP MOMENT IN LEVEL WALKING WITH S.A.

cycle time 1.10 seconds

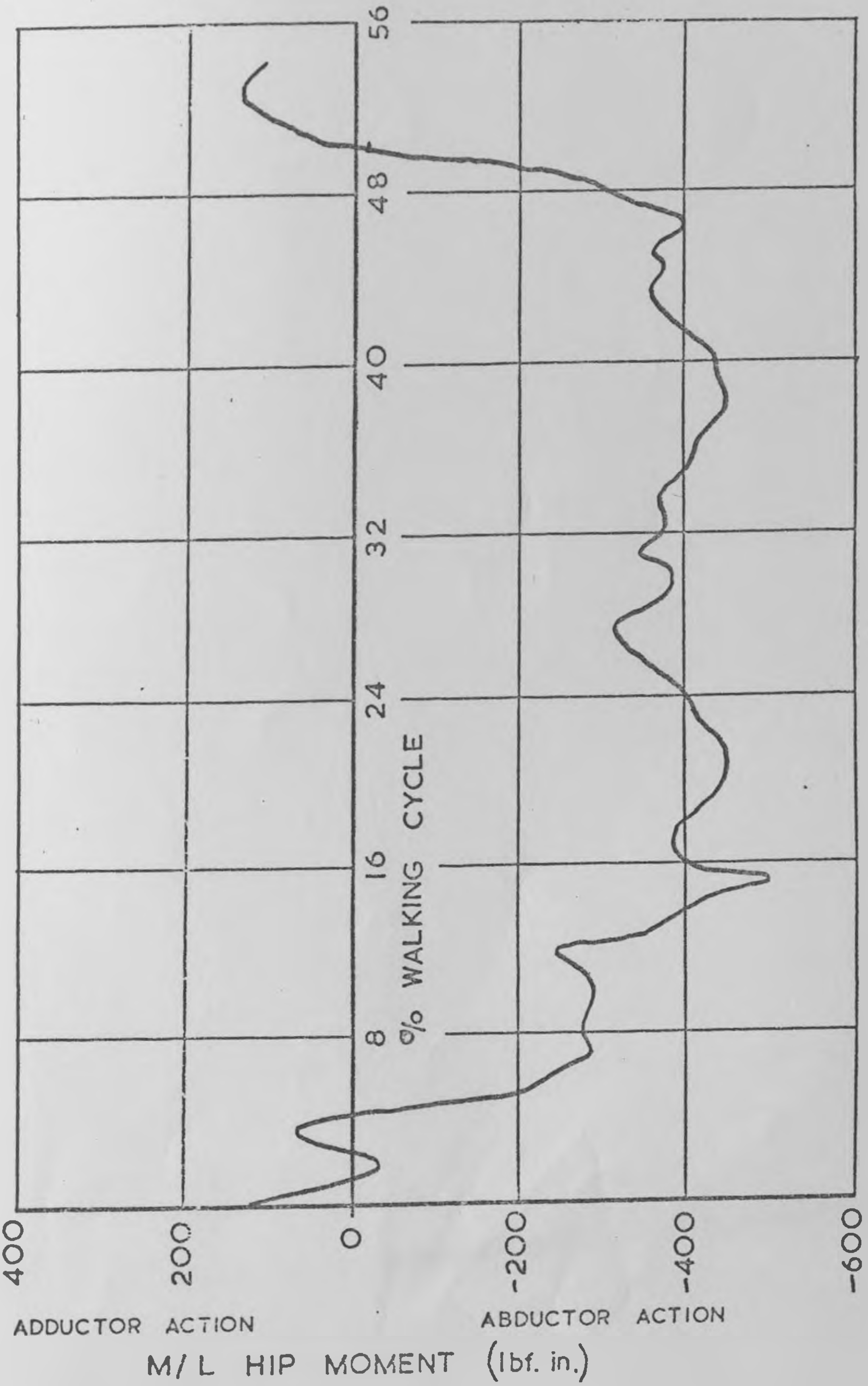


fig.VI.111

M/L HIP MOMENT IN WALKING UP RAMP WITH S.A.

cycle time 1.44 seconds

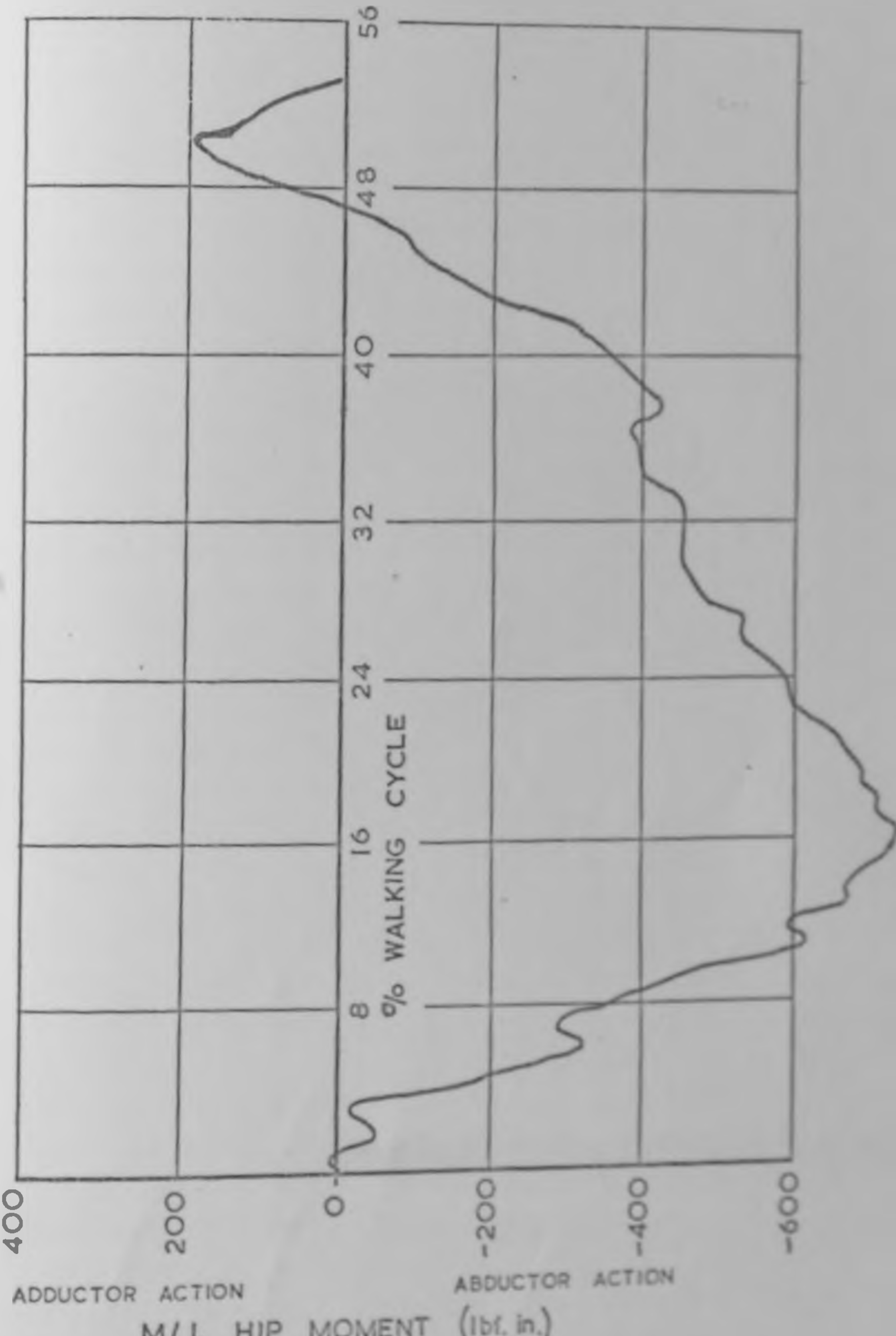


Fig VI. [illegible]

M/L HIP MOMENT IN WALKING DOWN RAMP WITH S.A.

cycle time 1.14 seconds

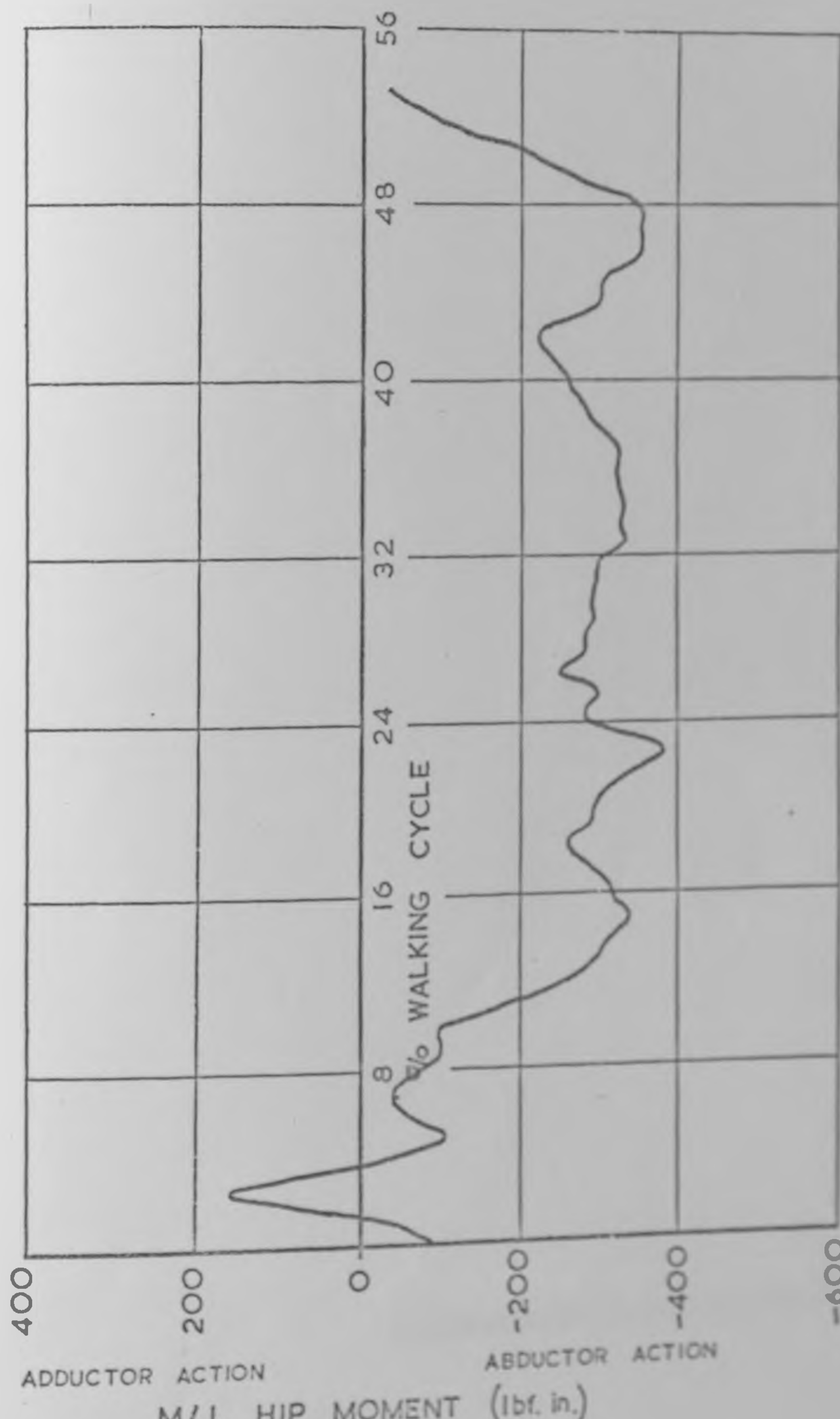


fig. VI. [illegible]

M/L HIP MOMENT IN WALKING UP STAIRS WITH S.A.

cycle time 1.39 seconds

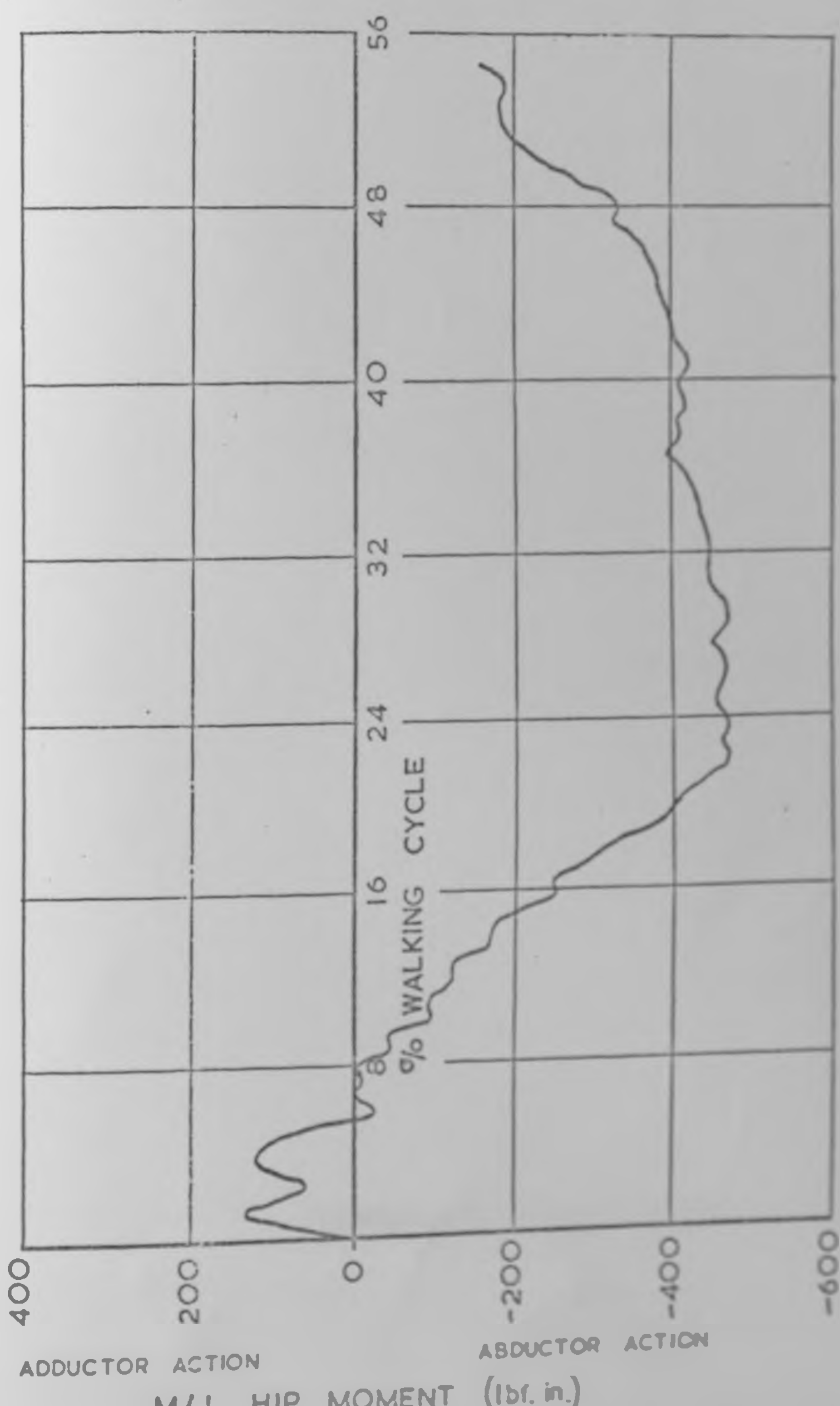


fig VI. 11c

M/L HIP MOMENT IN WALKING DOWN STAIRS WITH S.A.

cycle time 1.20 seconds

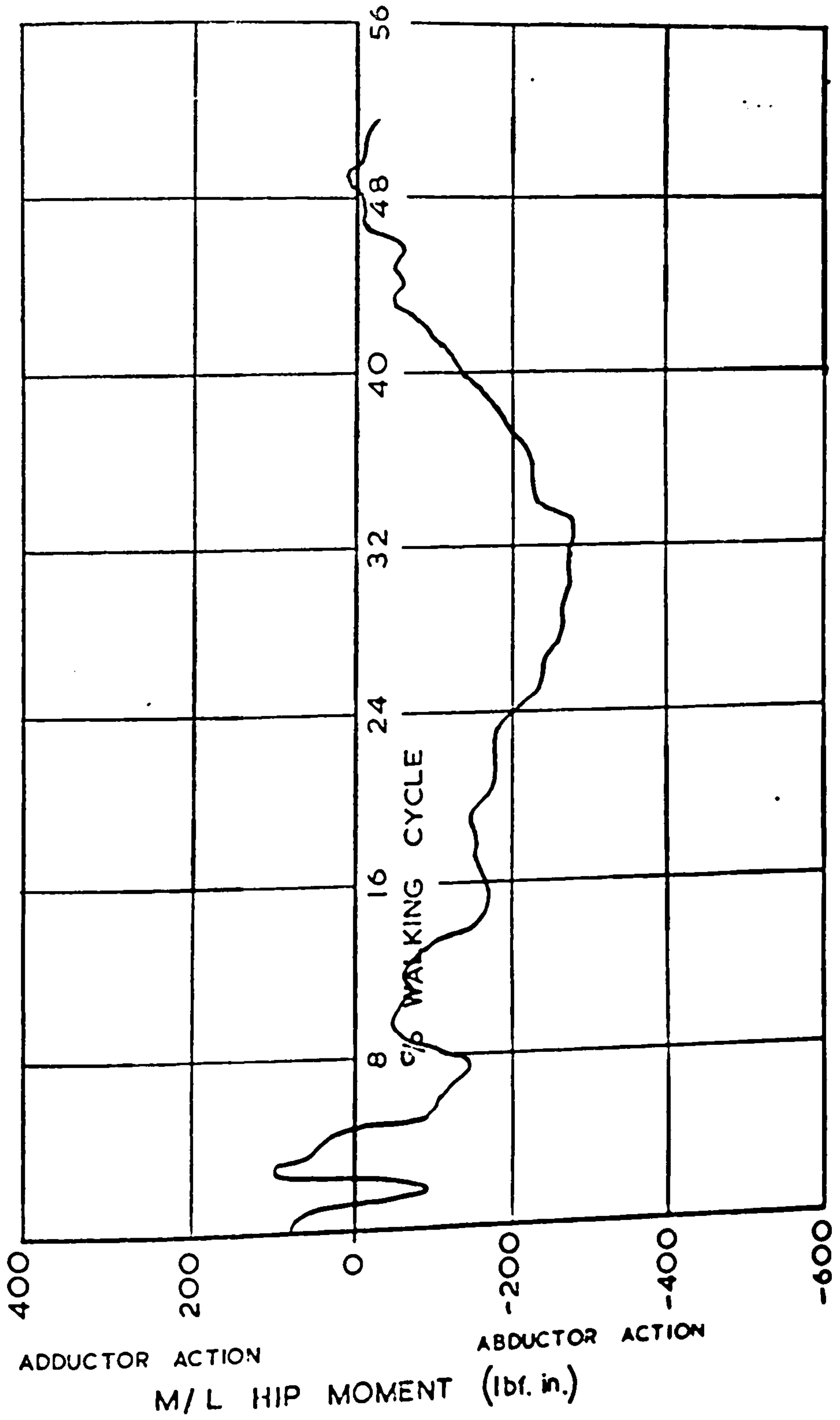


fig VI.115

M/L HIP MOMENT IN STEPPING OVER AN OBJECT (from a standing position) WITH S.A.

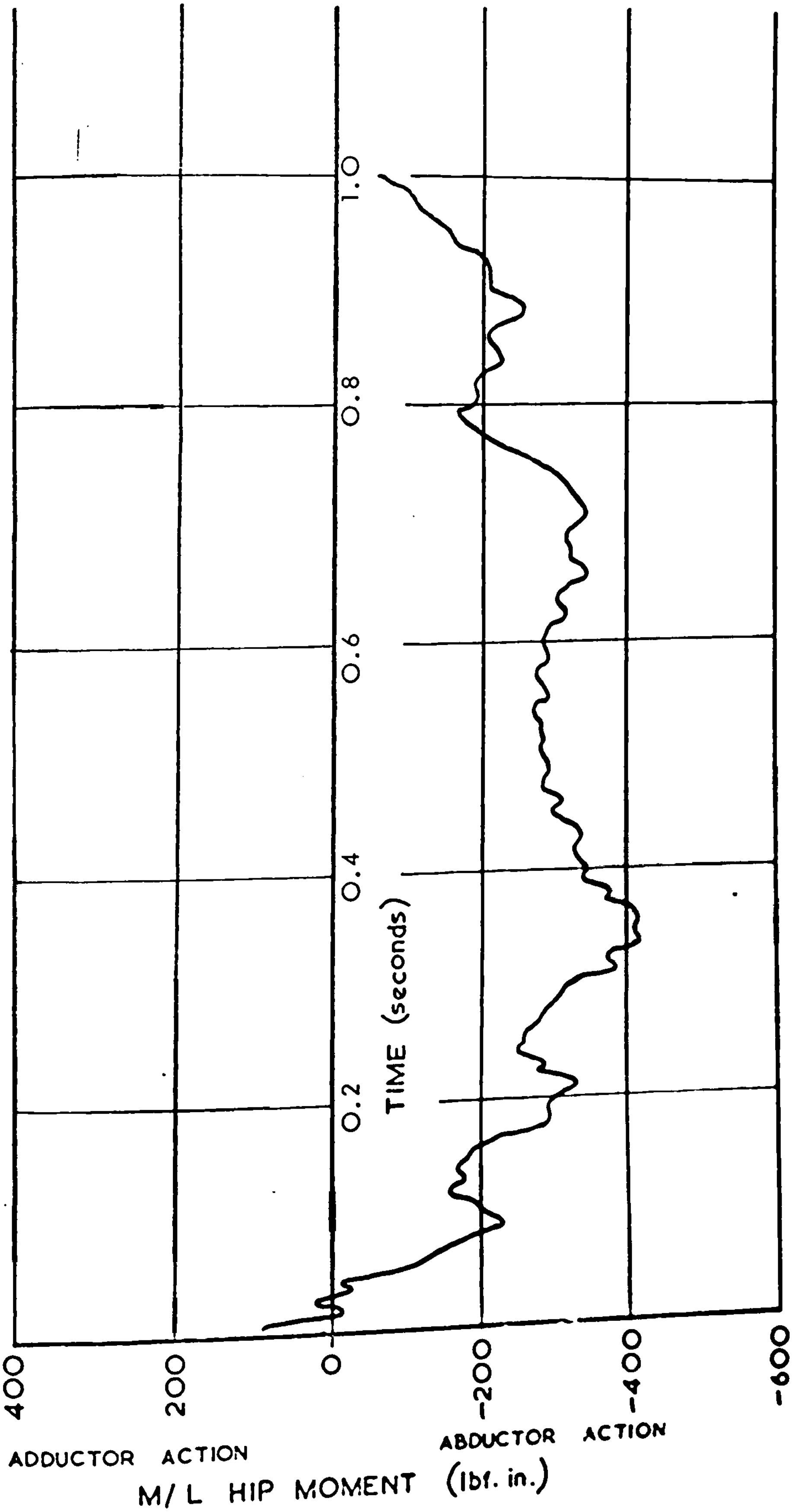


fig. VI. 116

M/L HIP MOMENT IN STEPPING OVER AN OBJECT (after walking up to it) WITH S.A.

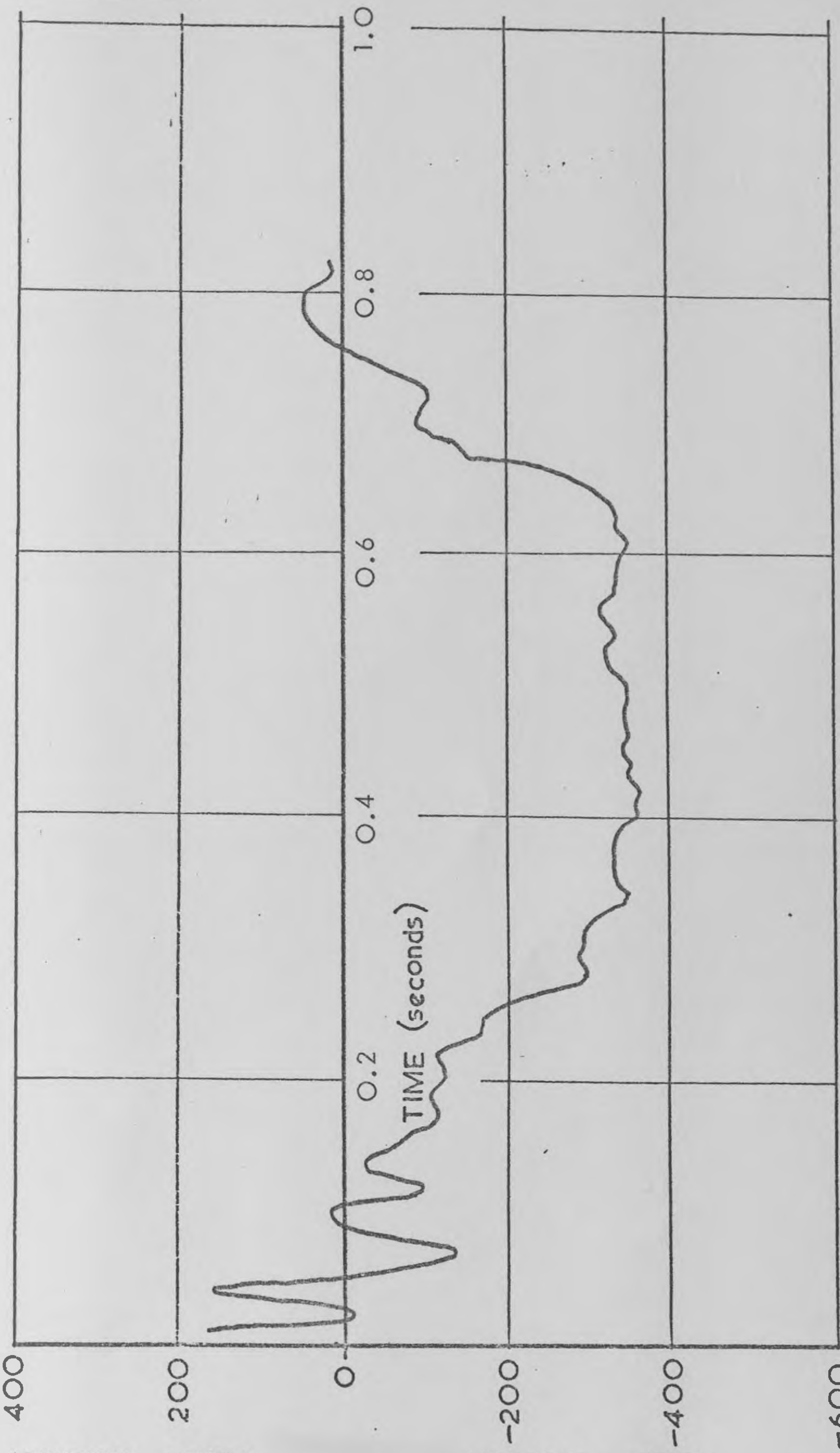


fig.VI.117

M/L HIP MOMENT IN RUNNING WITH S.A.

cycle time 1.09 seconds

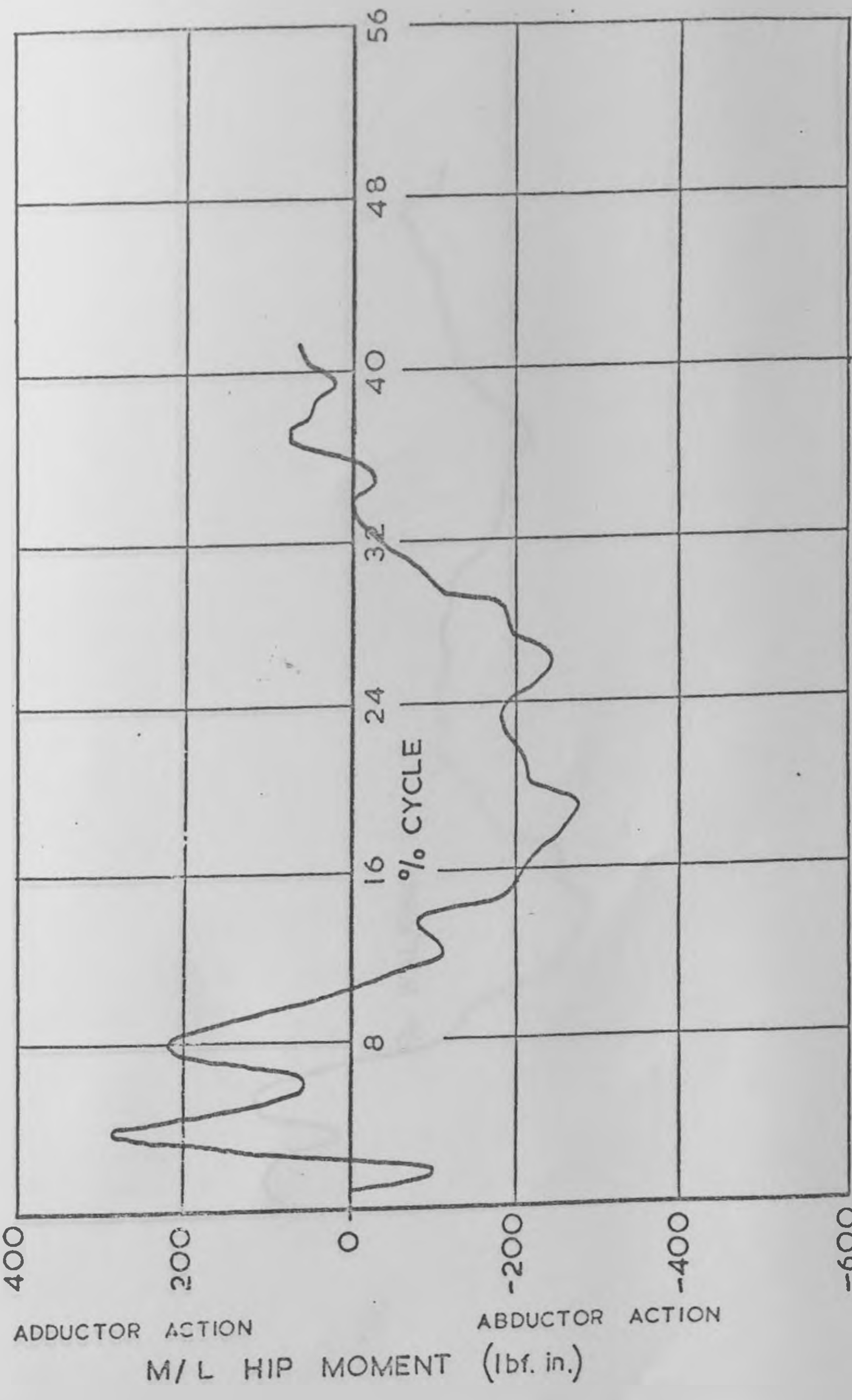


fig. VI. 118

M/L HIP MOMENT IN WALKING SIDEWAYS (Prosthesis Leading) WITH S.A.

cycle time 1.00 seconds

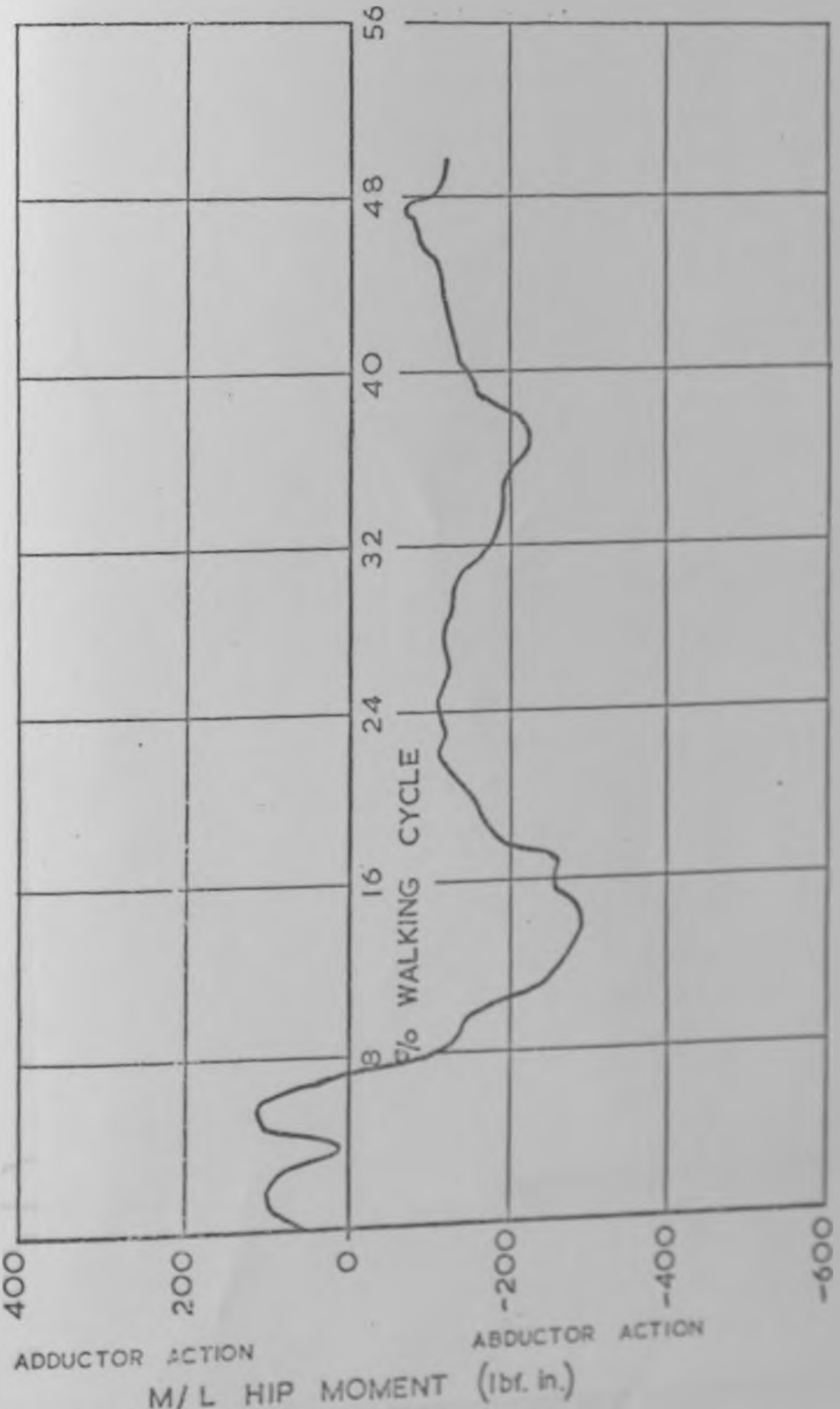


fig VI. 119

M/L HIP MOMENT IN WALKING SIDEWAYS (Normal Leg Leading) WITH S.A.

cycle time 0.82 seconds

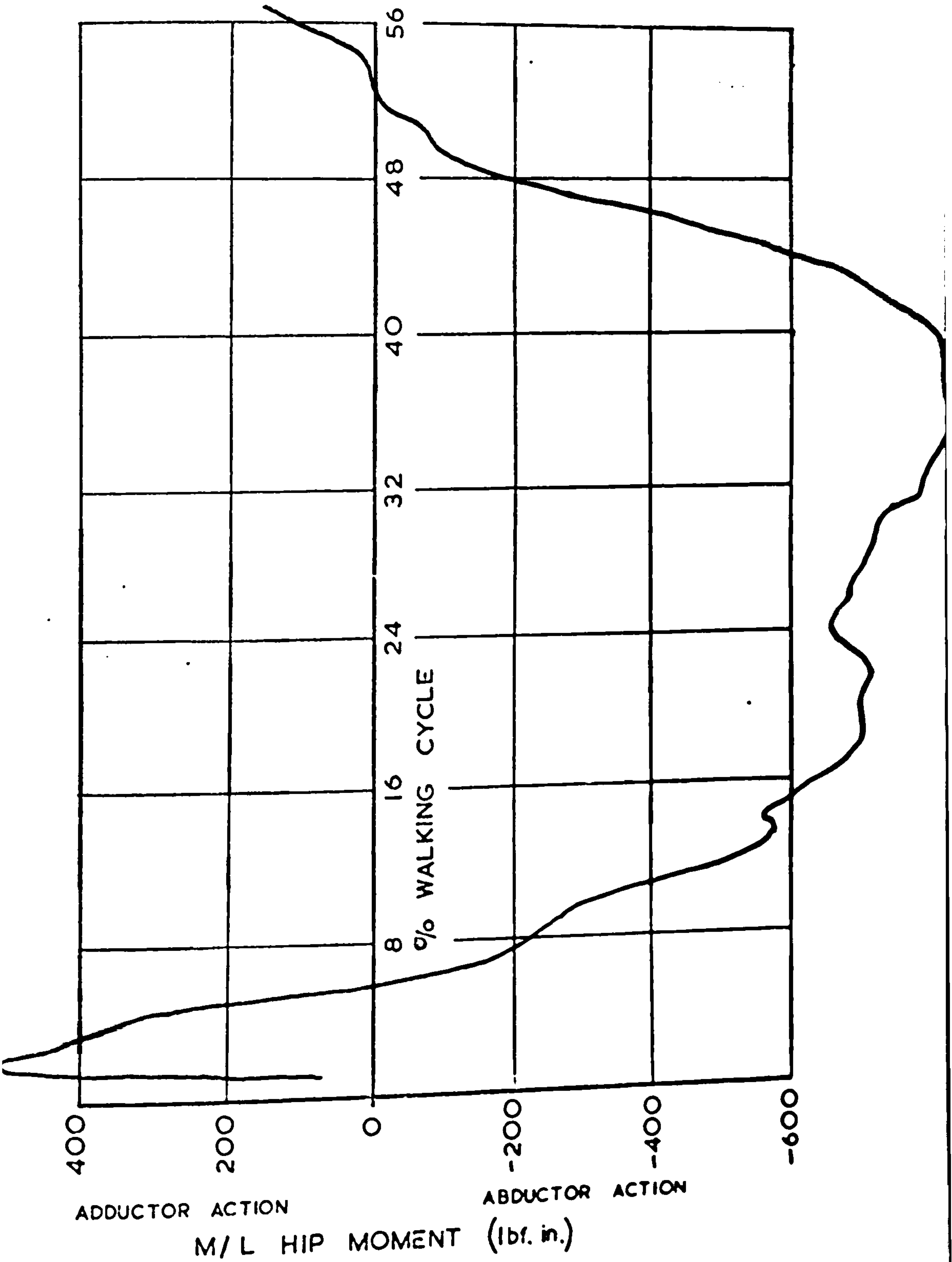


fig.VI.120

TORQUE IN LEVEL WALKING WITH S.A.

cycle time 1.10 seconds

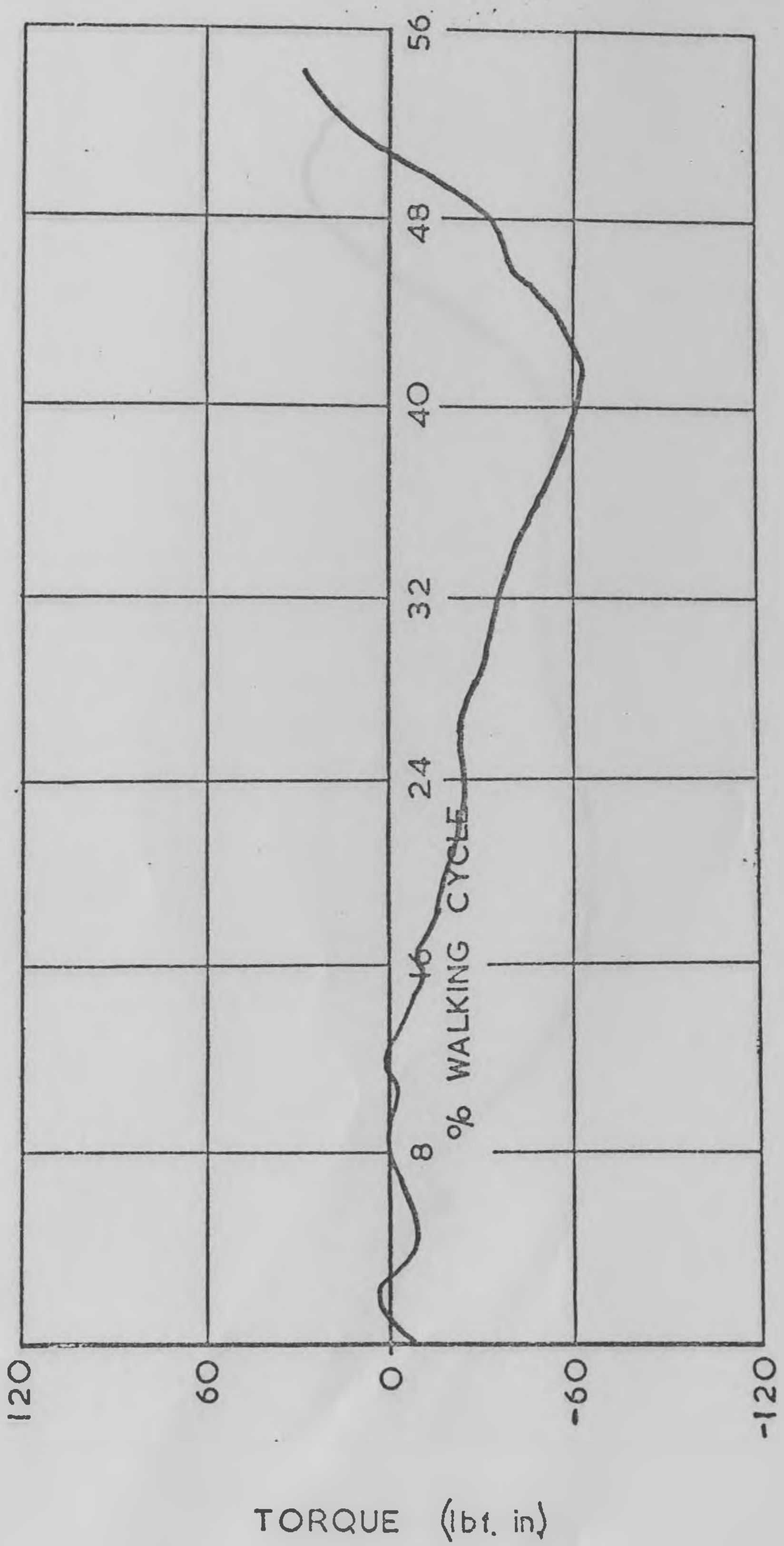


fig. VI.

TORQUE IN WALKING UP RAMP WITH S.A.

cycle time 1.44seconds

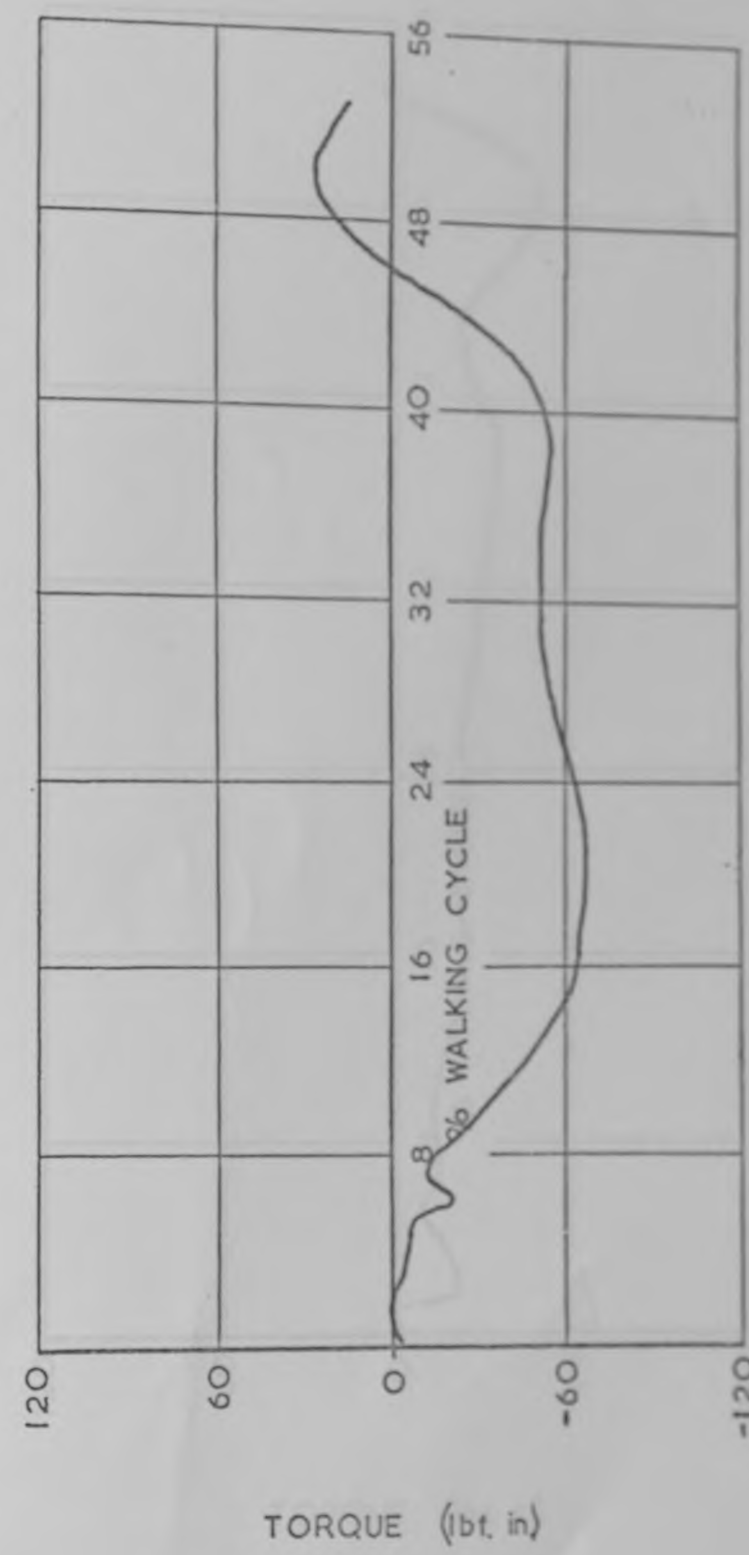


fig. VI
122

TORQUE IN WALKING DOWN RAMP WITH S.A.

cycle time 1.14 seconds

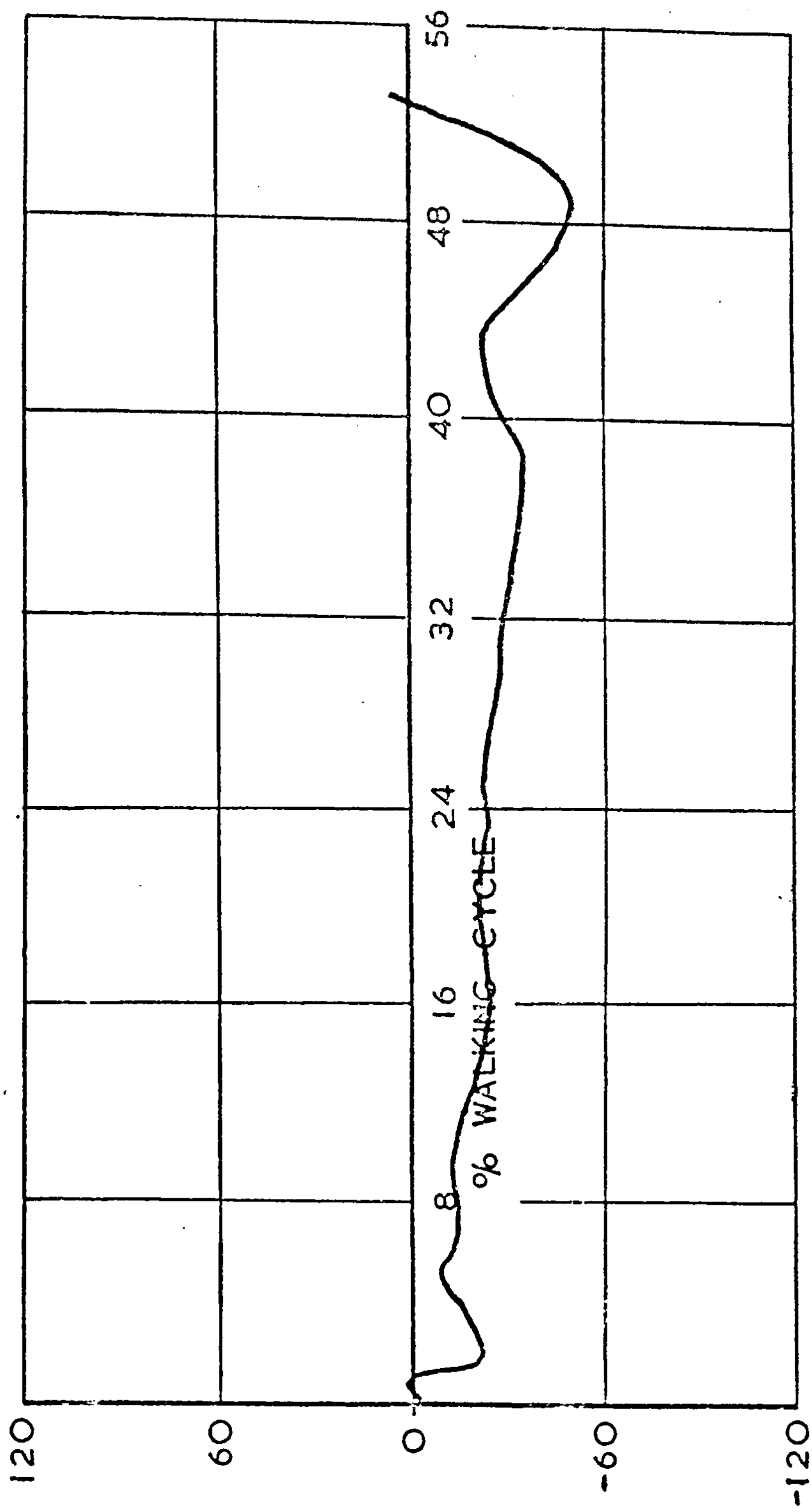
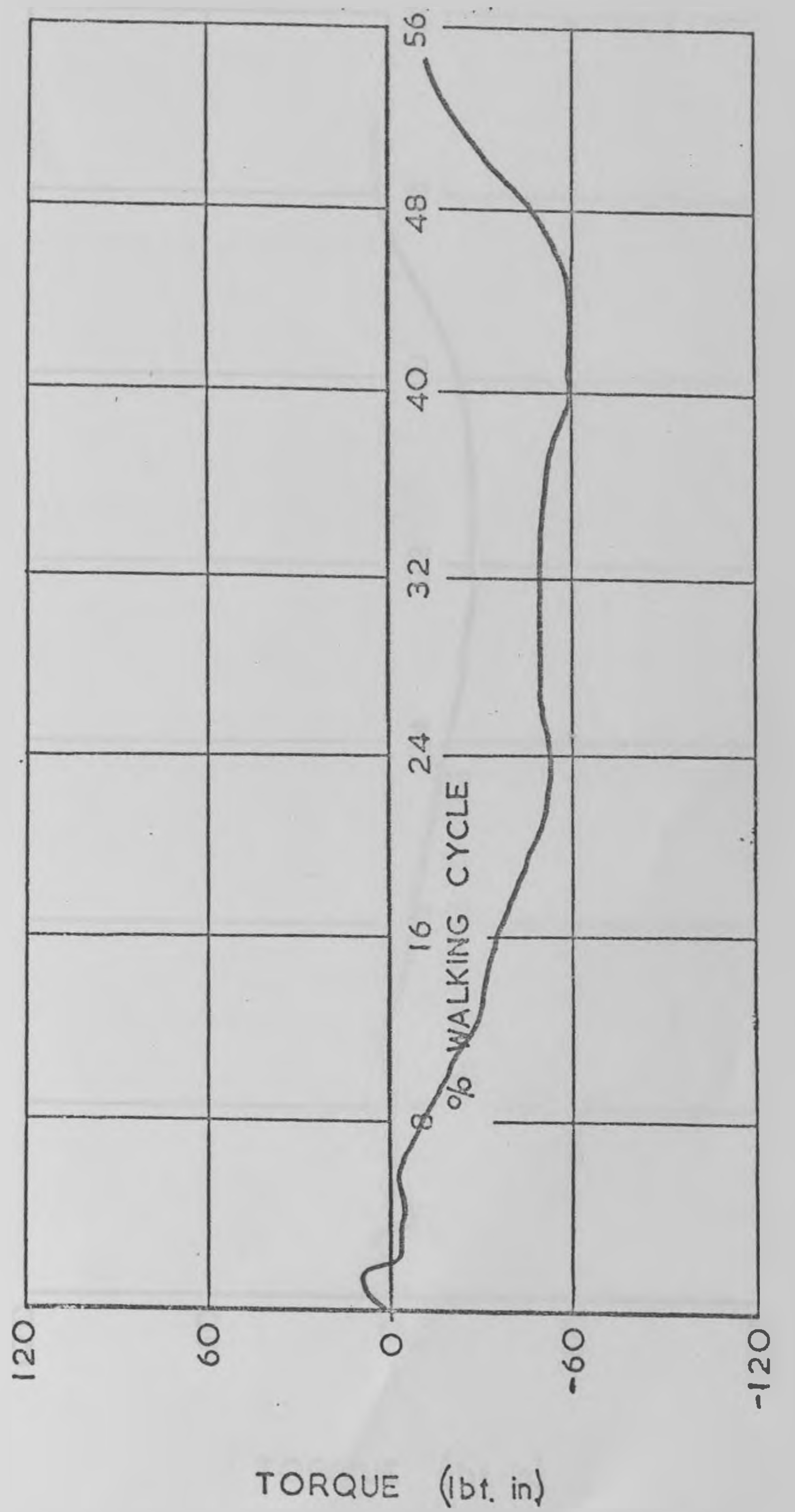


fig.VI.

TORQUE IN WALKING UP STAIRS WITH S.A.

cycle time 1.39 seconds



TORQUE IN WALKING DOWN STAIRS WITH S.A.

cycle time 1.20 seconds

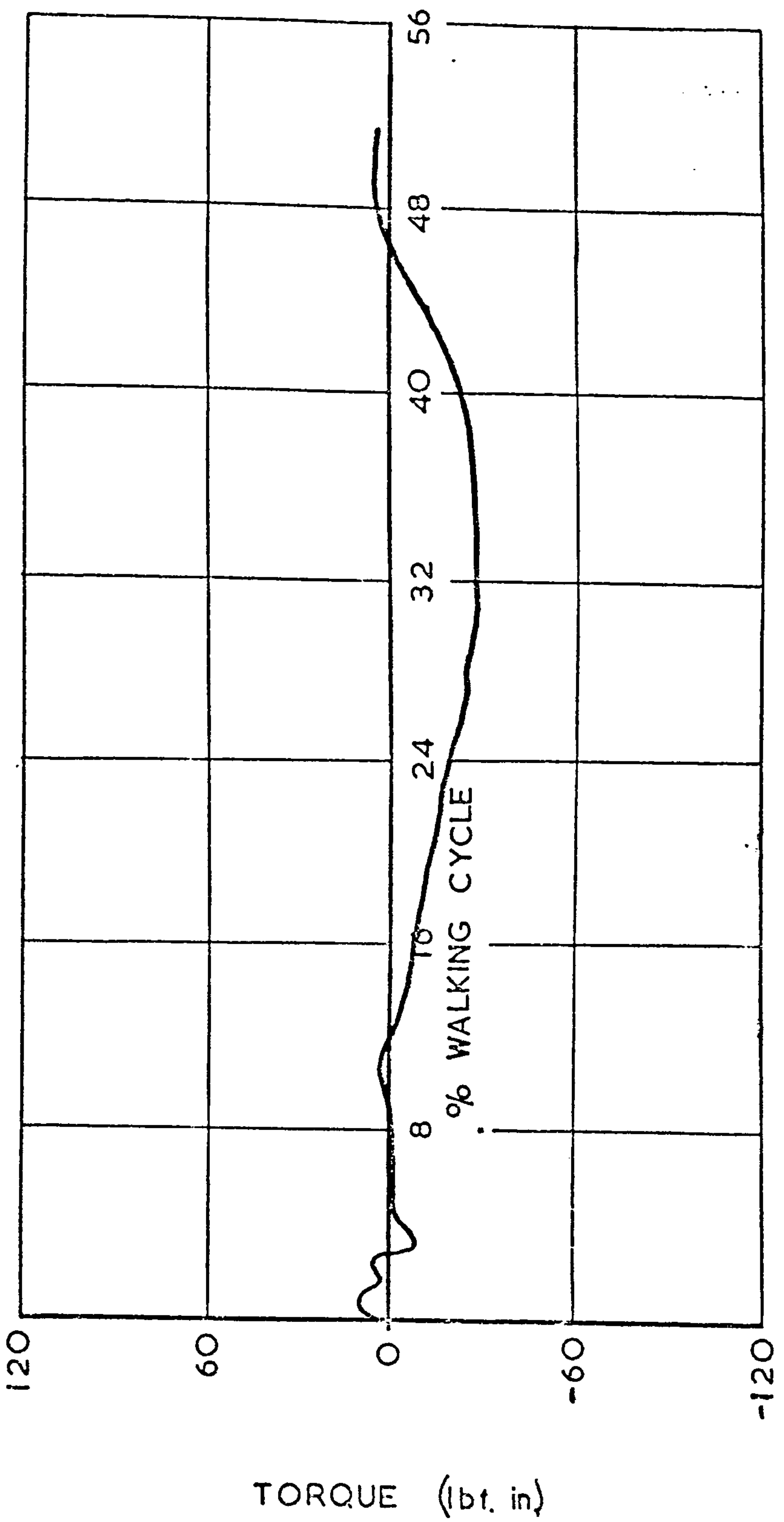


fig.VI

TORQUE IN STEPPING OVER AN OBJECT (from a standing position) WITH S.A.

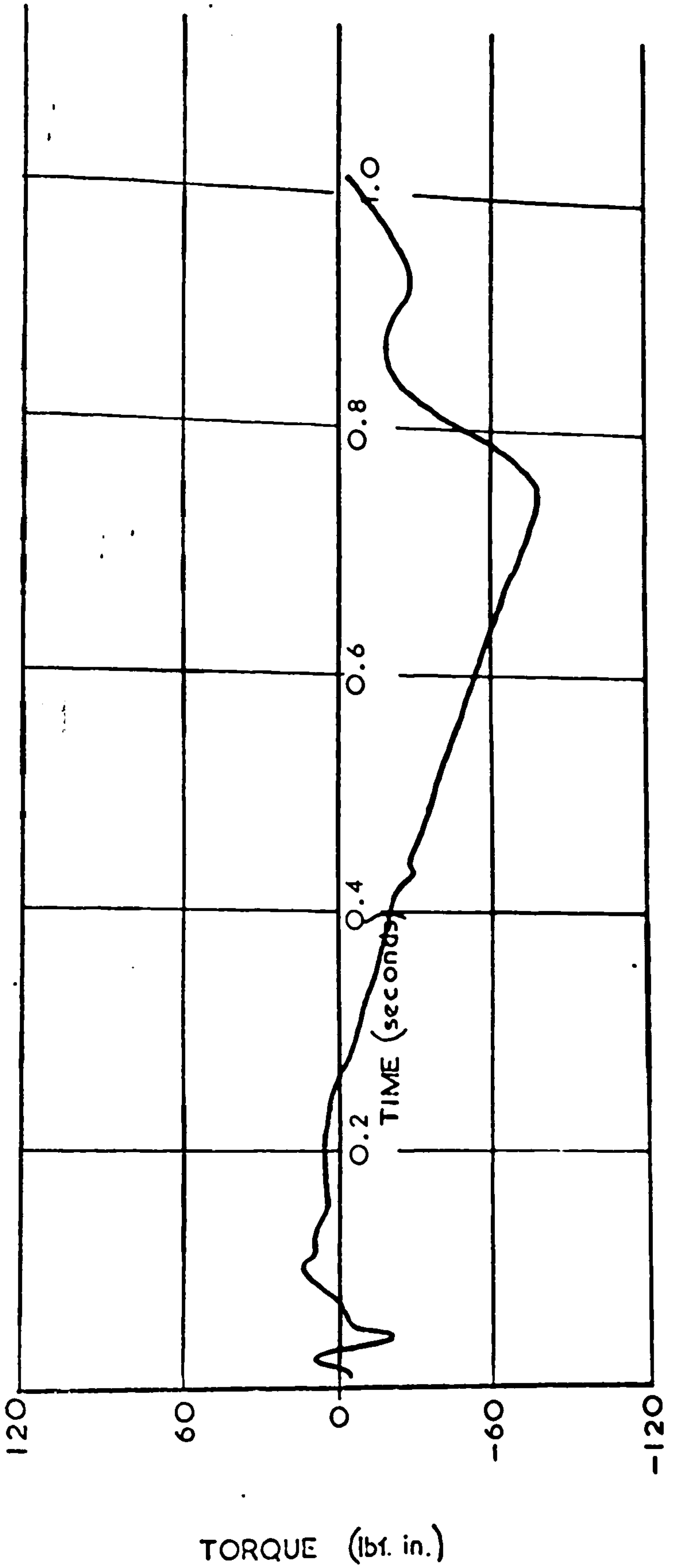


fig.VI

TORQUE IN STEPPING OVER AN OBJECT (after walking up to it)
WITH S.A.

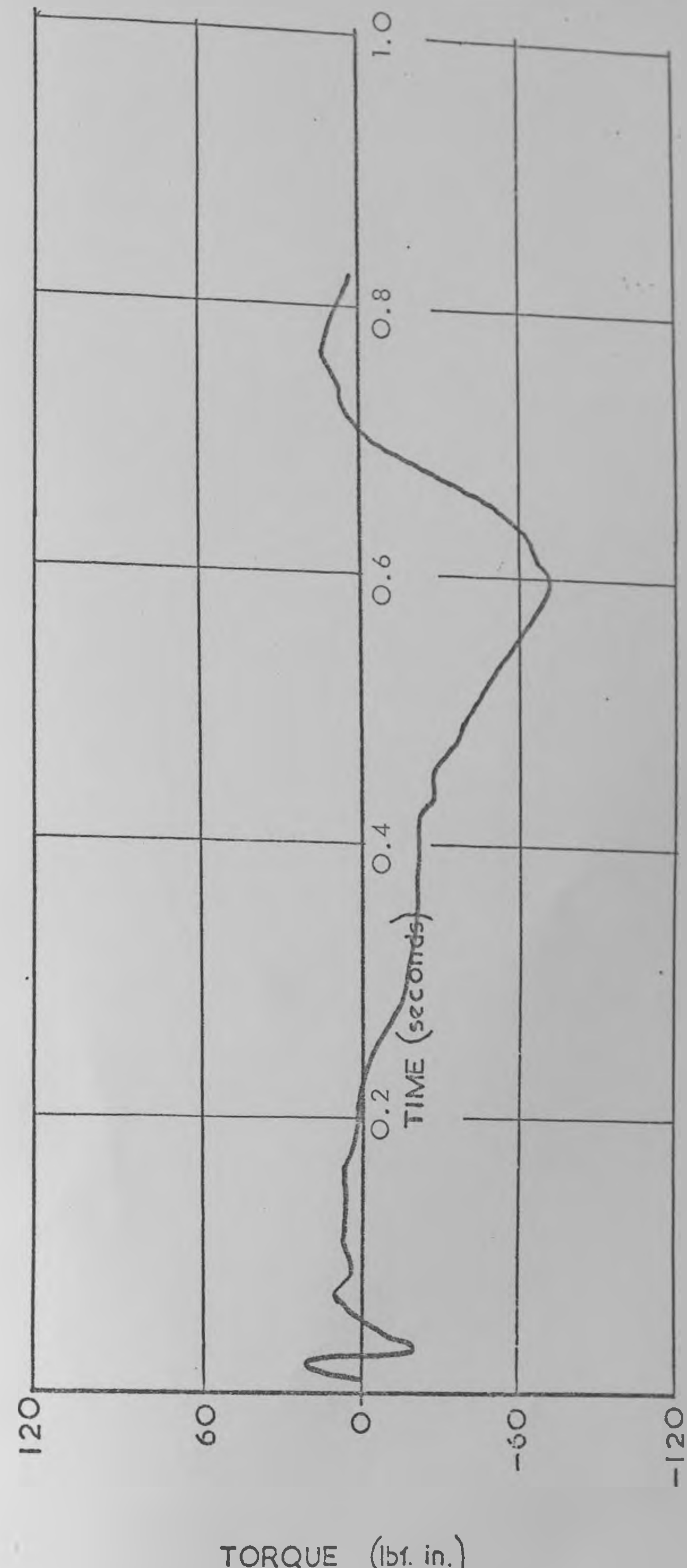


fig. VI

TORQUE IN RUNNING WITH S.A.

cycle time 1.09 seconds

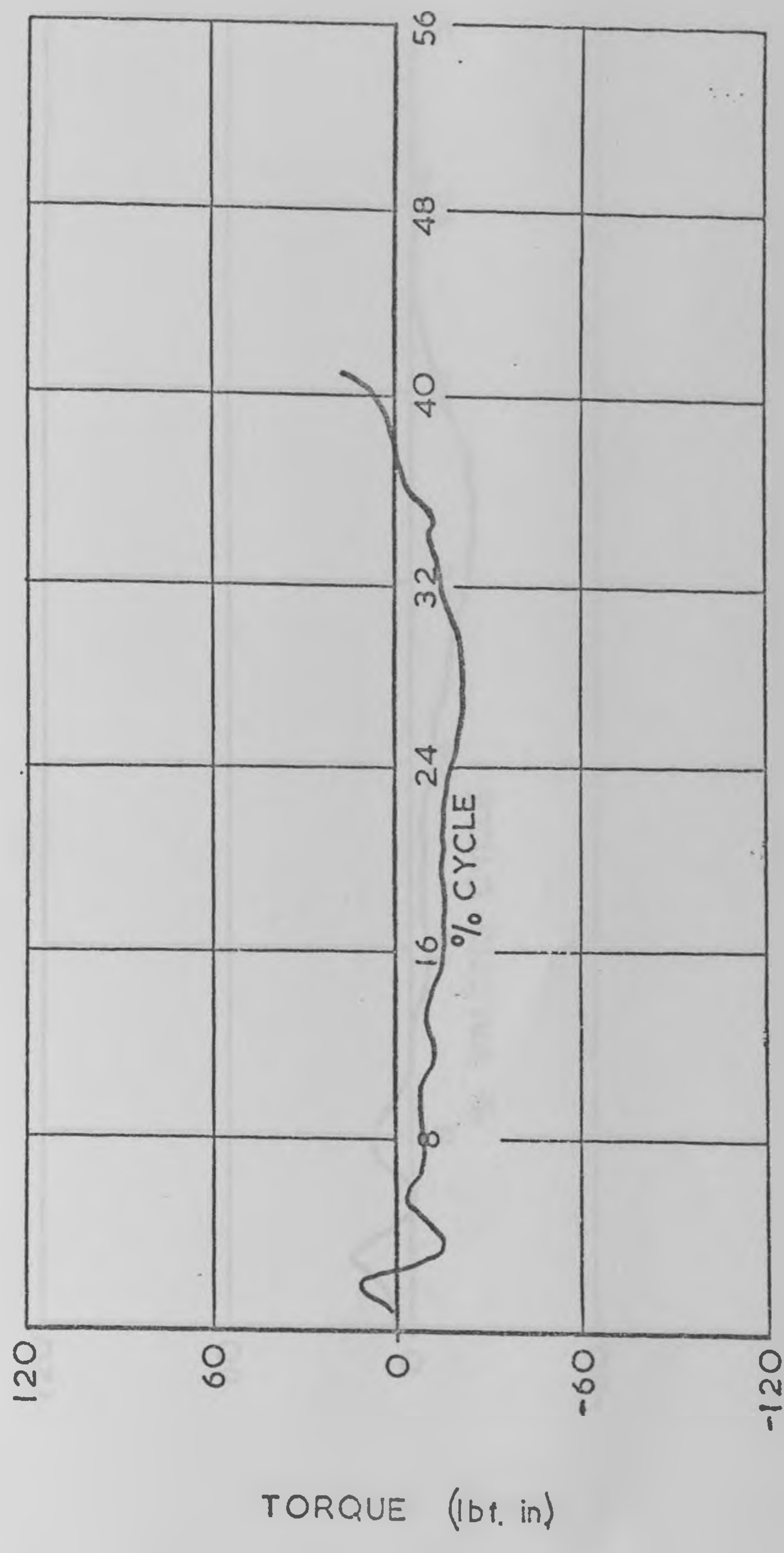


fig. VI

TORQUE IN WALKING SIDEWAYS (Prosthesis Leading) WITH S.A.

cycle time 1.00 seconds

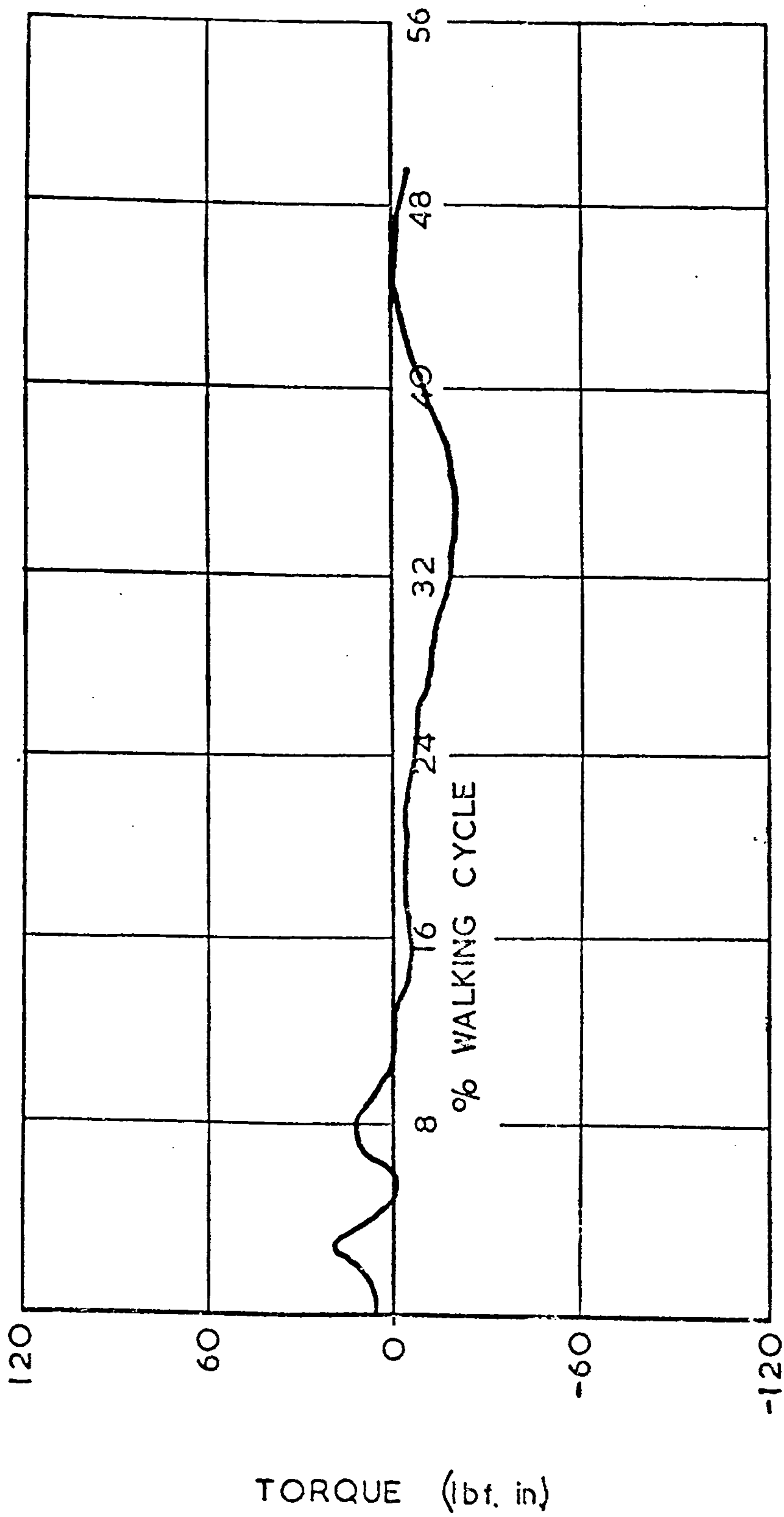
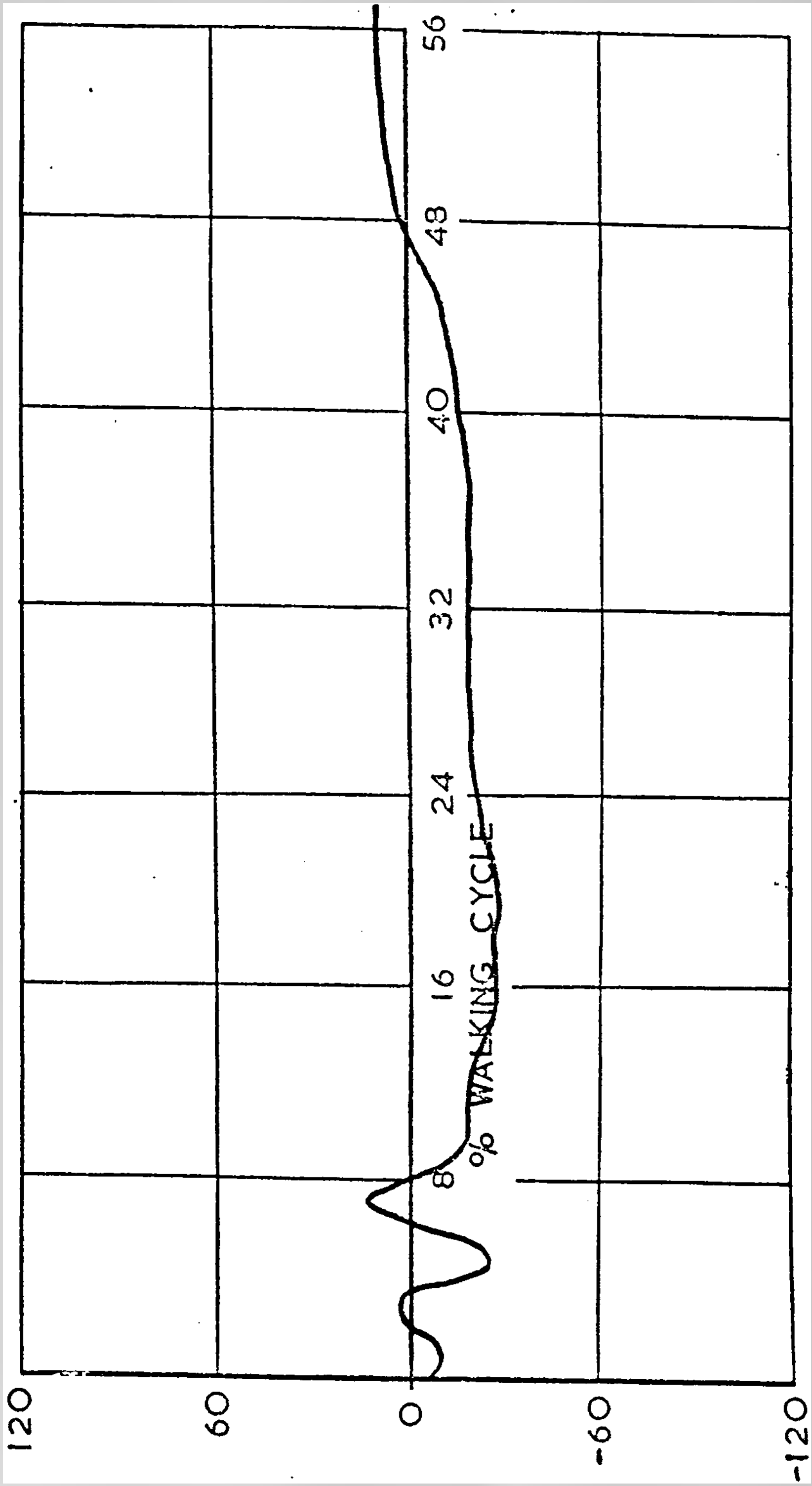


fig.VI

TORQUE IN WALKING SIDEWAYS (Normal Leg Leading) WITH S.A.

cycle time 0.82 seconds



TORQUE (lbt. in)

fig. VI

RESULTANT LOAD IN LEVEL WALKING WITH S.A.

cycle time 1.10 seconds

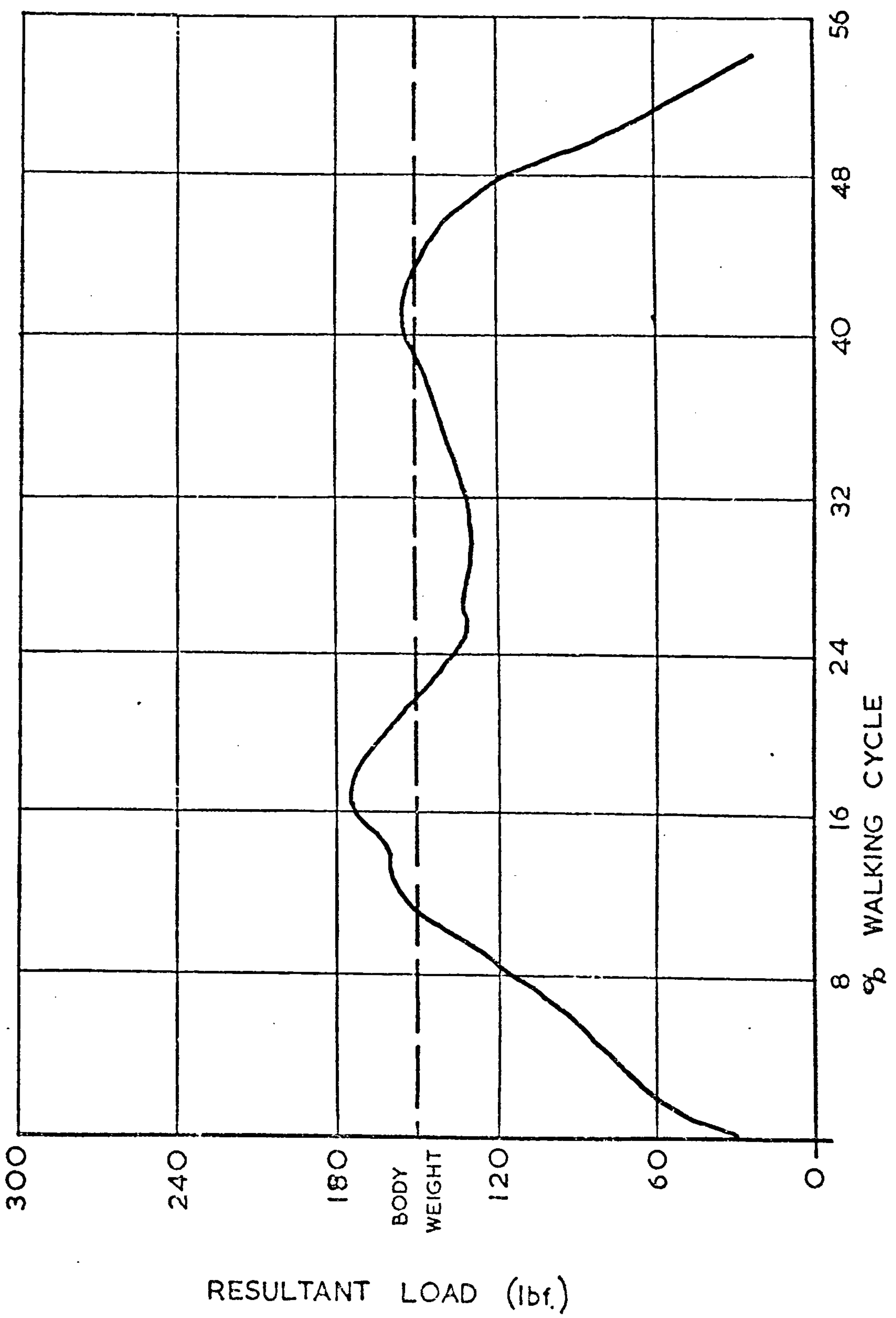


fig.VI

RESULTANT LOAD IN WALKING UP RAMP WITH S.A.

cycle time 1.44 seconds

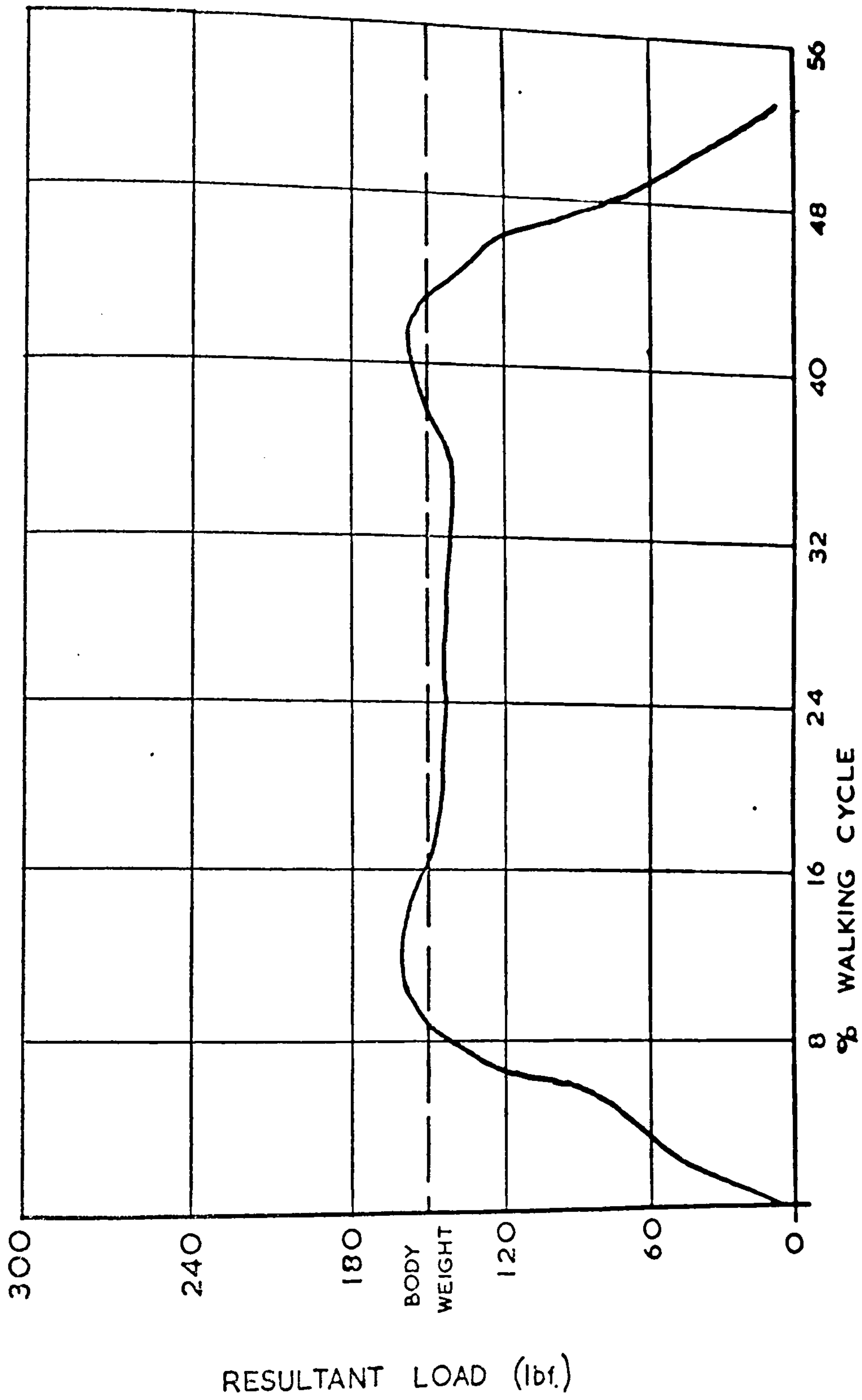


fig. VI

RESULTANT LOAD IN WALKING DOWN RAMP WITH S.A.

cycle time 1.14 seconds

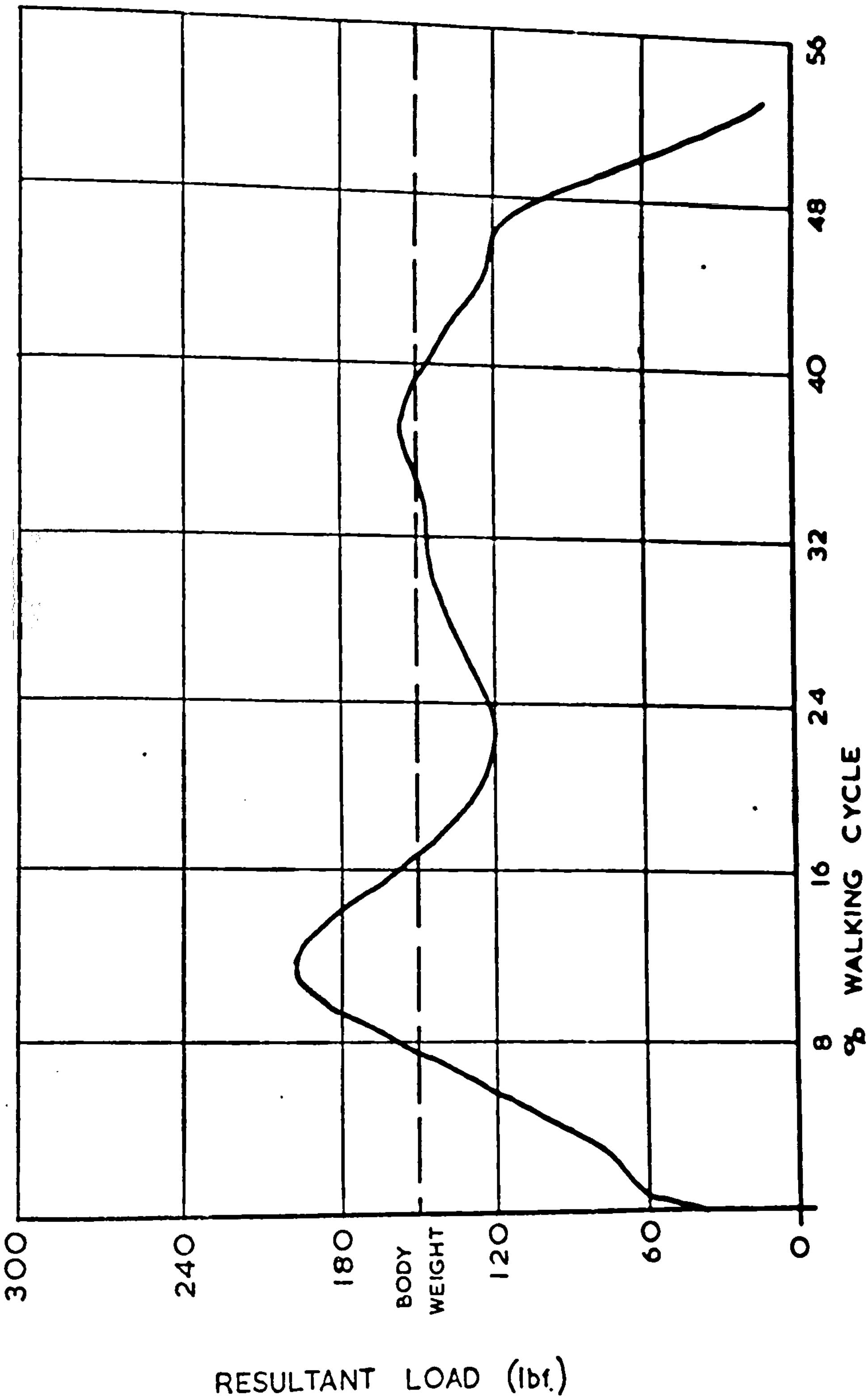
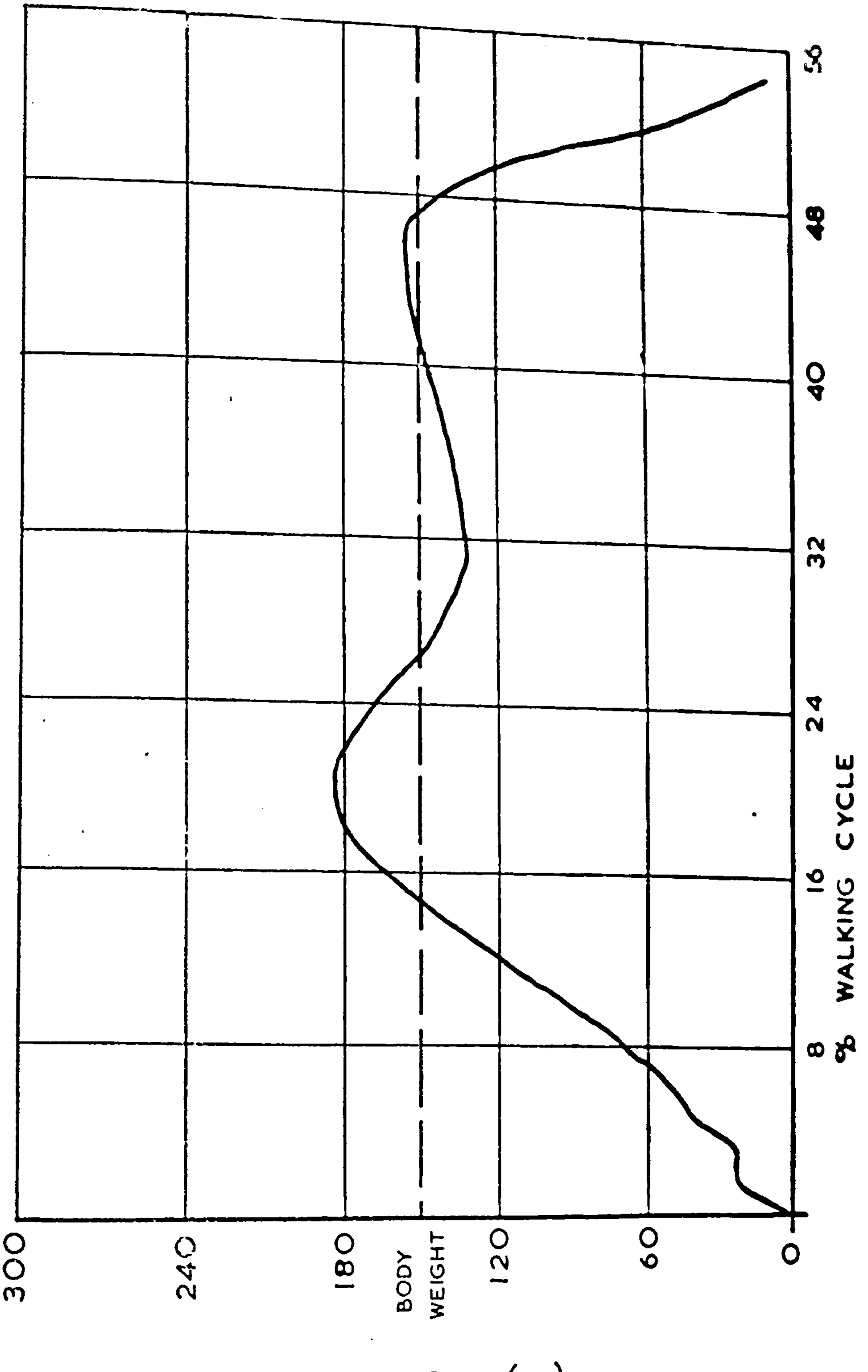


fig. VI

RESULTANT LOAD IN WALKING UP STAIRS WITH S.A.

cycle time 1.39 seconds



RESULTANT LOAD (lbf.)

fig.VI

RESULTANT LOAD IN WALKING DCWN STAIRS WITH S.A.

cycle time 1.20 seconds

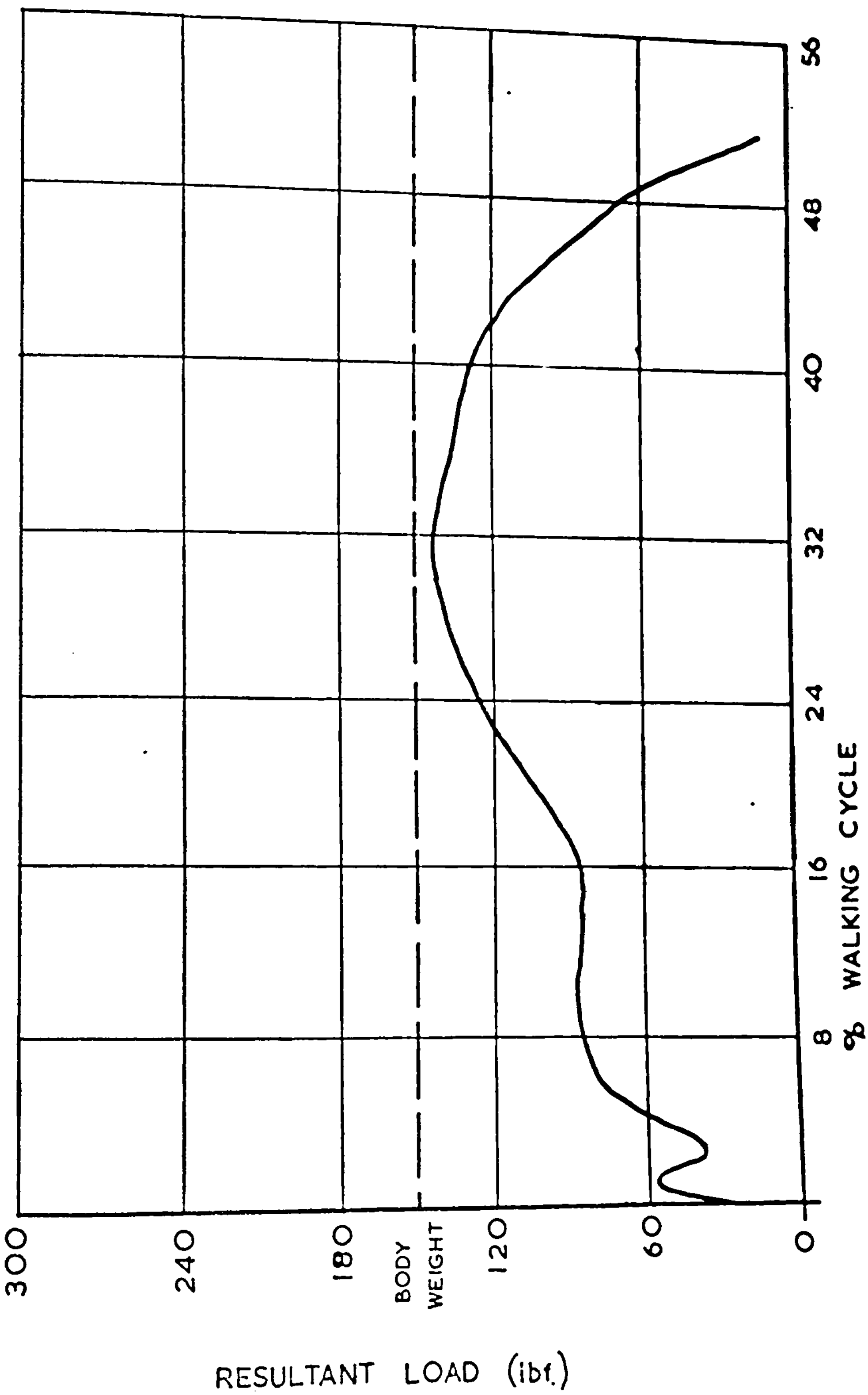


fig. VI

RESULTANT LOAD IN STEPPING OVER AN OBJECT (from a standing position) WITH S.A.

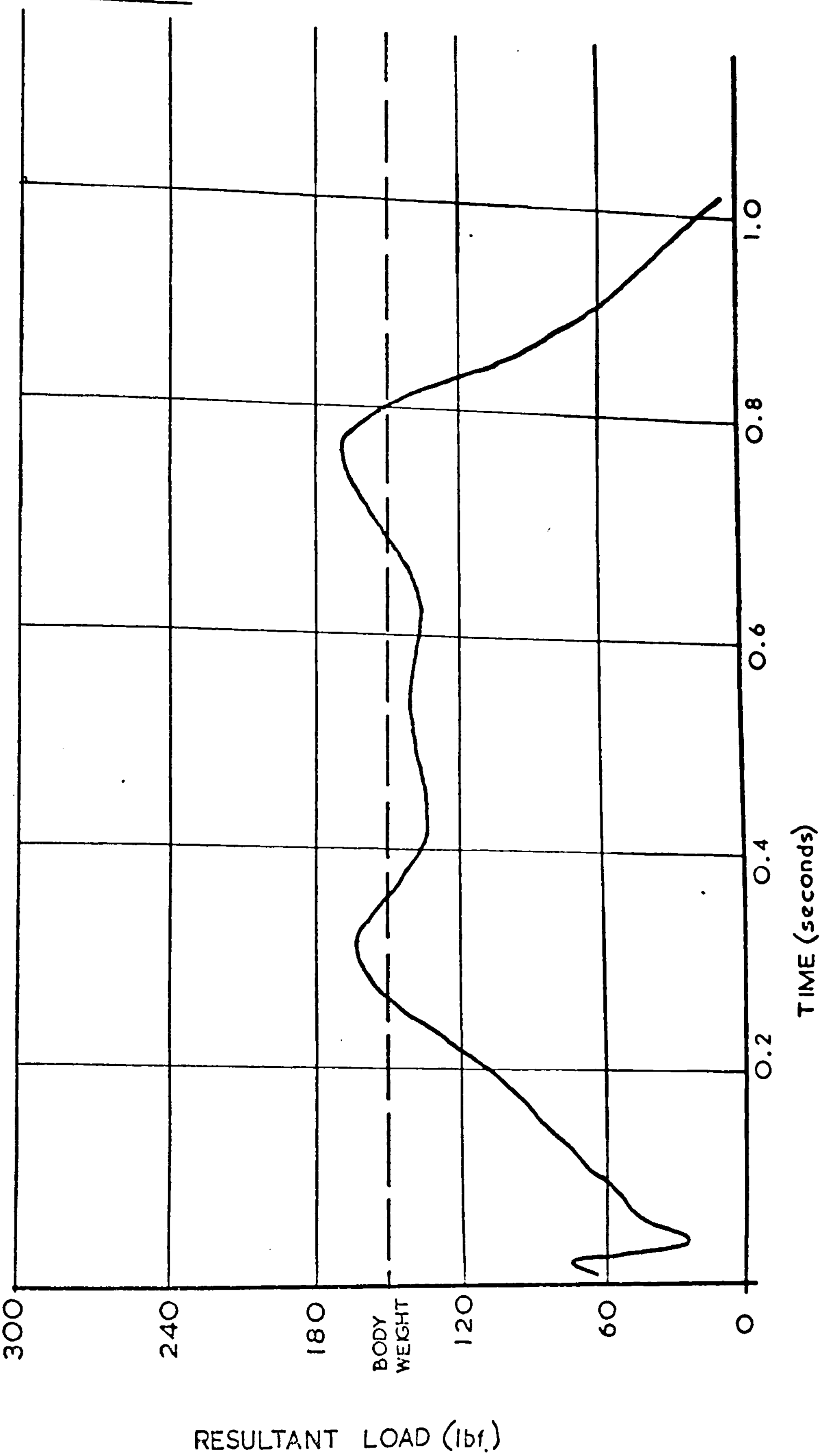


fig. VI

RESULTANT LOAD IN STEPPING OVER AN OBJECT (after walking up to it) WITH S.A.

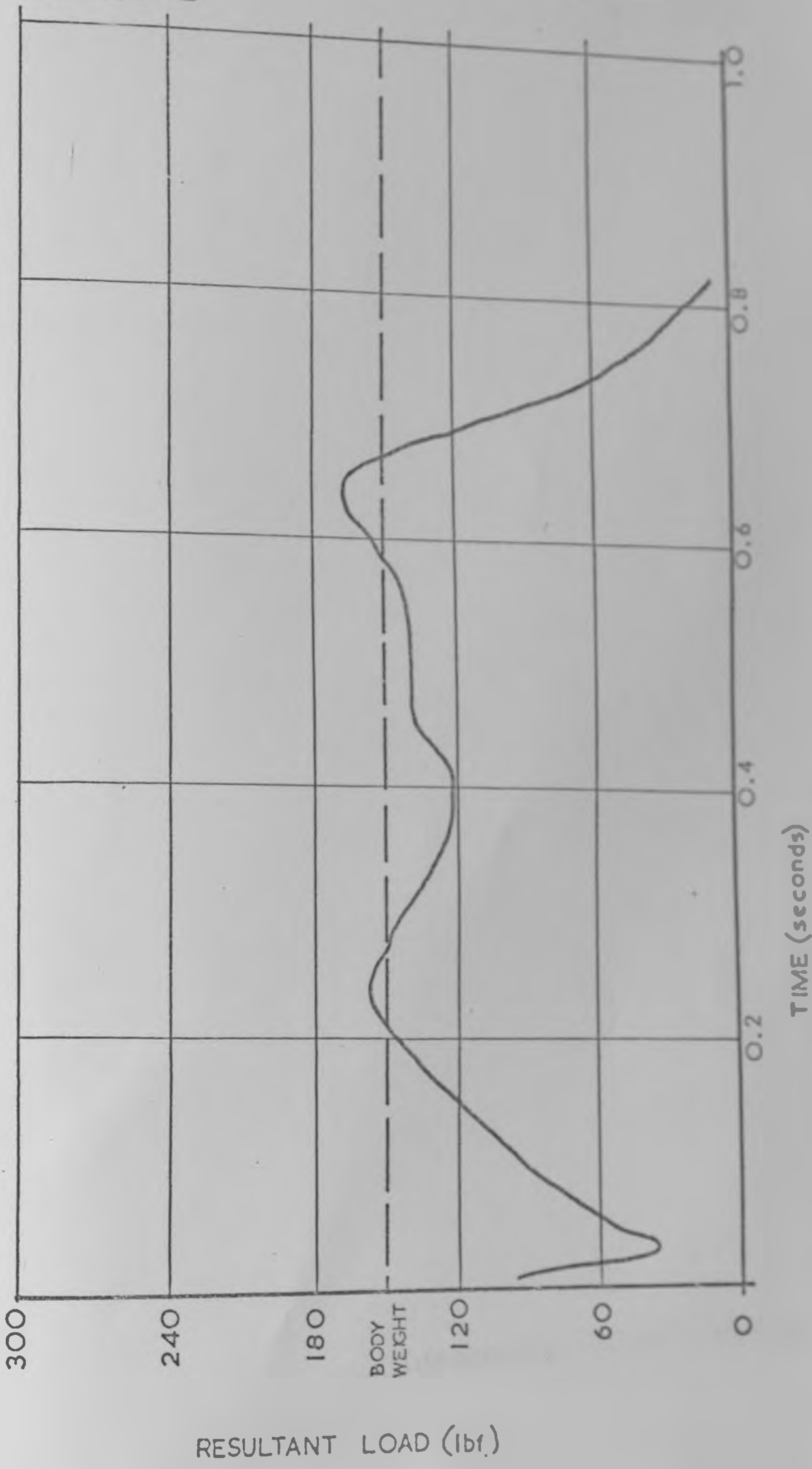


fig. VI

RESULTANT LOAD IN RUNNING WITH S.A.

cycle time 1.09 seconds

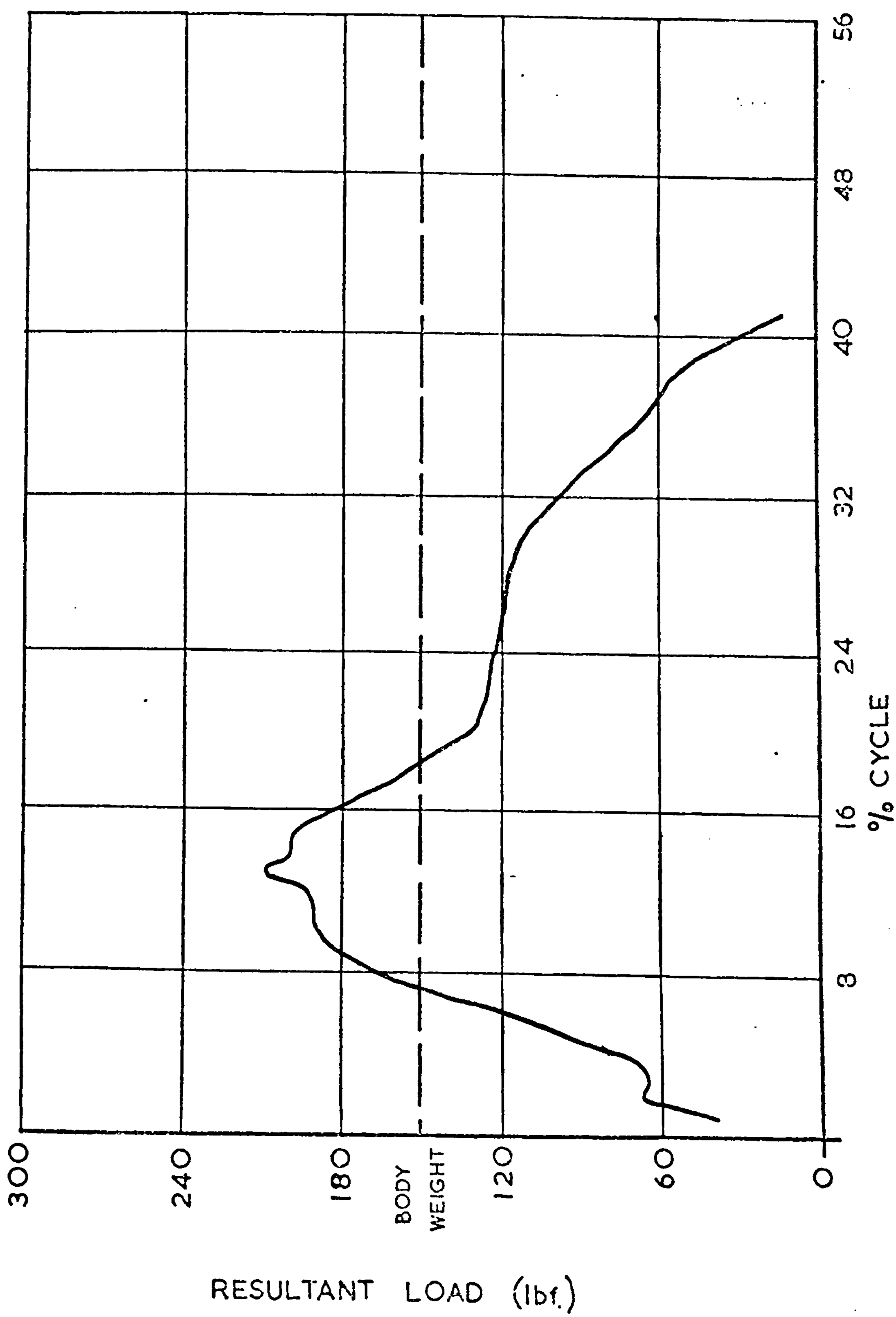


fig. VI

RESULTANT LOAD IN WALKING SIDEWAYS (Prosthesis Leading)
WITH S.A.
cycle time 1.00 seconds

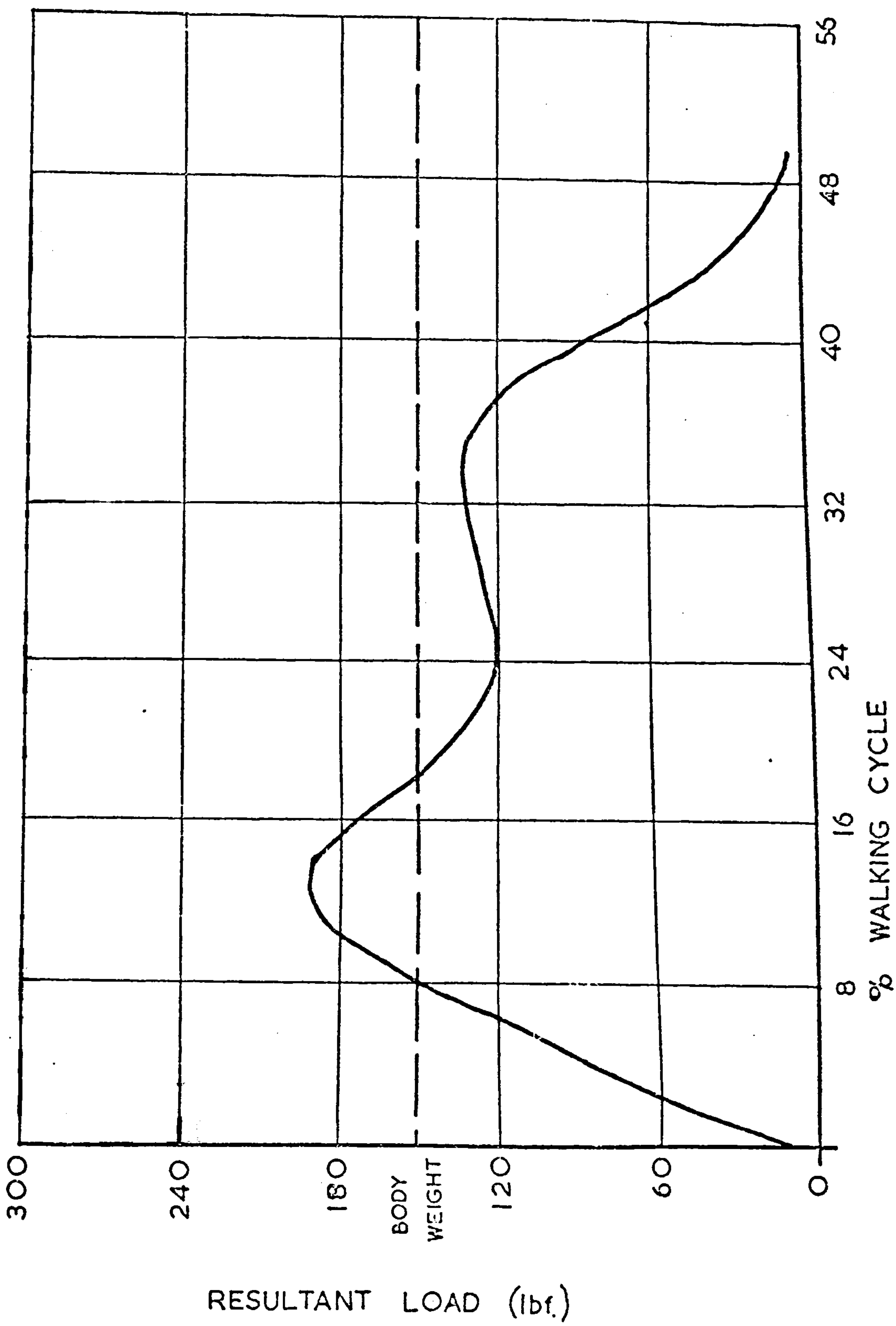


fig. VI

RESULTANT LOAD IN WALKING SIDEWAYS (Normal Leg Leading)

WITH S.A.

cycle time 0.82 seconds

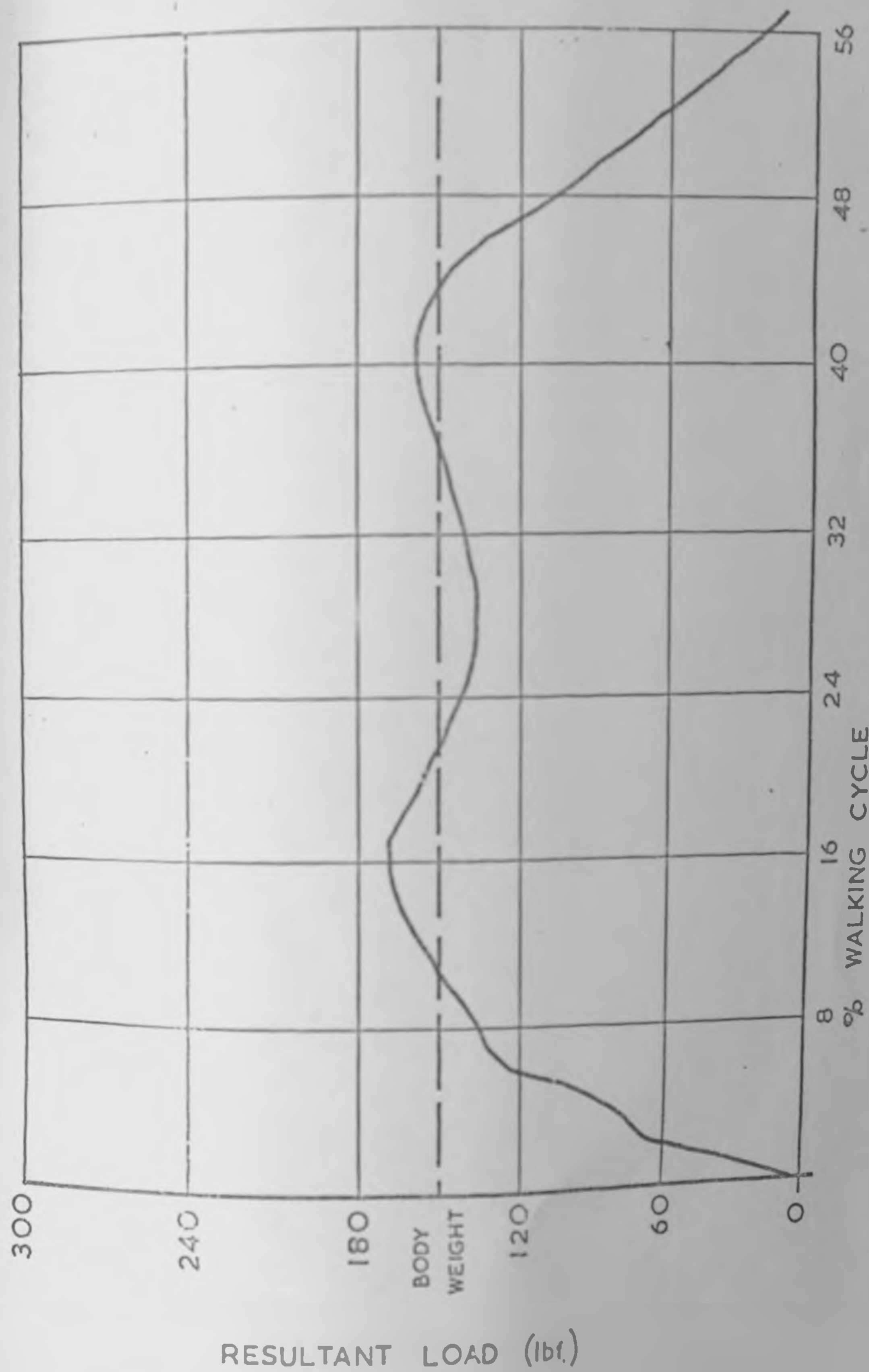


fig. VI