

ROCKFORD BALL SCREW

LINEAR GUIDE RAIL

SELECTING A LINEAR GUIDEWAY



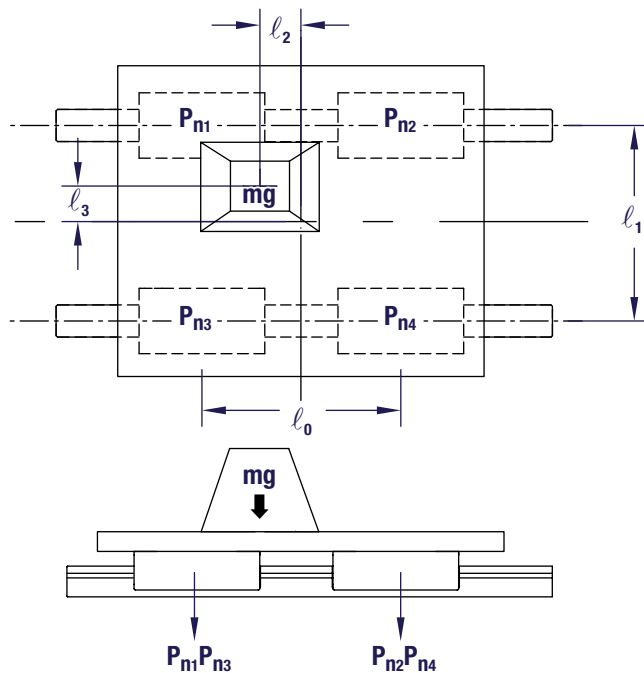
It's Your Move.™

LOAD CALCULATION

The loads acting on the a linear guide system vary according to the location of the center of gravity, the thrust, the load position, the moment loading due to acceleration and deceleration, the cutting forces and other external forces.

Below are some common guide system arrangements, please contact the factory if your application is not shown.

Horizontal Orientation



$$P_{n1} = \frac{1}{4}mg + \frac{l_2}{2l_0}mg + \frac{l_3}{2l_1}mg + \frac{l_2l_3}{l_0l_1}mg$$

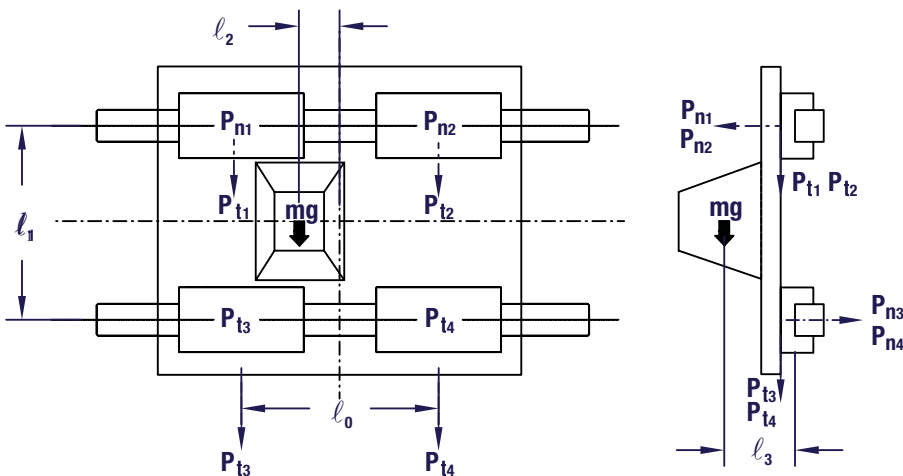
$$P_{n2} = \frac{1}{4}mg - \frac{l_2}{2l_0}mg + \frac{l_3}{2l_1}mg - \frac{l_2l_3}{l_0l_1}mg$$

$$P_{n3} = \frac{1}{4}mg + \frac{l_2}{2l_0}mg - \frac{l_3}{2l_1}mg - \frac{l_2l_3}{l_0l_1}mg$$

$$P_{n4} = \frac{1}{4}mg - \frac{l_2}{2l_0}mg - \frac{l_3}{2l_1}mg + \frac{l_2l_3}{l_0l_1}mg$$

$P_{n1, 2, 3, 4}$ = Resultant Normal Loads on Blocks
 m = Mass of Applied Load (kg)
 $g = 9.8 \text{ m/sec}^2$

Perpendicular Orientation (Wall Mount)



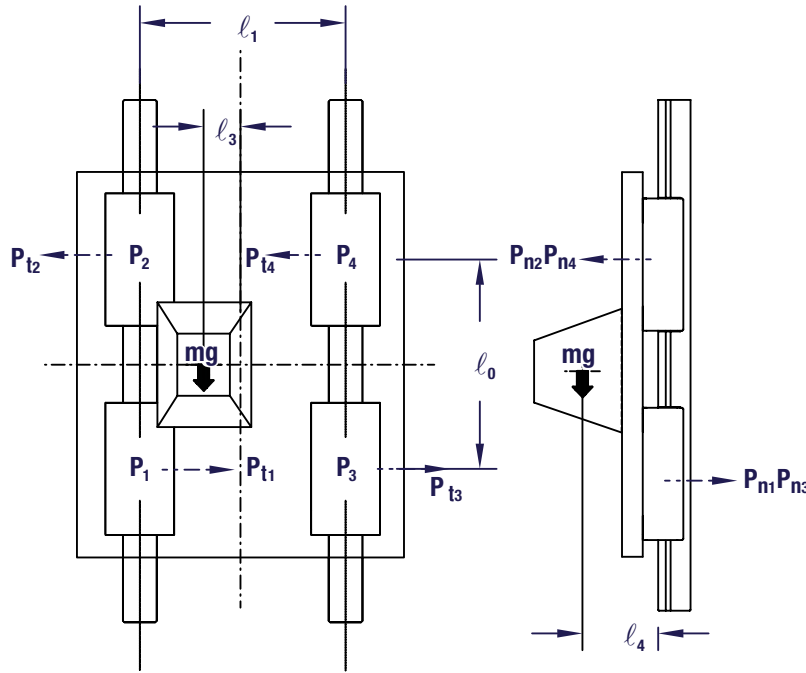
$$P_{n1} = P_{n2} = P_{n3} = P_{n4} = \frac{l_4}{2l_1}mg$$

$$P_{t1} = P_{t3} = \frac{1}{4}mg + \frac{l_2}{2l_0}mg$$

$$P_{t2} = P_{t4} = \frac{1}{4}mg - \frac{l_2}{2l_0}mg$$

$P_{n1, 2, 3, 4}$ = Resultant Normal Loads on Blocks
 $P_{t1, 2, 3, 4}$ = Resultant Transverse Loads on Blocks
 m = Mass of Applied Load (kg)
 $g = 9.8 \text{ m/sec}^2$

Vertical Orientation

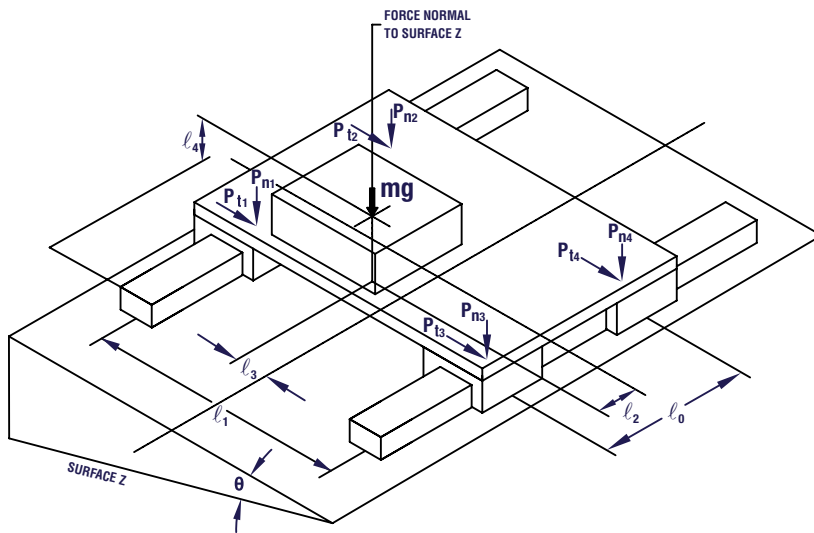


$$P_{n1} = P_{n2} = P_{n3} = P_{n4} = \frac{l_4}{2l_0} mg$$

$$P_{t1} = P_{t2} = P_{t3} = P_{t4} = \frac{l_3}{2l_0} mg$$

$P_{n1, 2, 3, 4}$ = Resultant Normal Loads on Blocks
 $P_{t1, 2, 3, 4}$ = Resultant Transverse Loads on Blocks
 m = Mass of Applied Load (kg)
 $g = 9.8 \text{ m/sec}^2$

Angled Orientation



$$P_{n1} = \frac{mg \cos \theta}{4} + \frac{mg \cos \theta l_2}{2l_0} + \frac{mg \cos \theta l_3}{2l_1} - \frac{mg \sin \theta l_4}{2l_1} + \frac{l_2 l_3}{l_0 l_1} mg \cos \theta$$

$$P_{n2} = \frac{mg \cos \theta}{4} - \frac{mg \cos \theta l_2}{2l_0} + \frac{mg \cos \theta l_3}{2l_1} - \frac{mg \sin \theta l_4}{2l_1} - \frac{l_2 l_3}{l_0 l_1} mg \cos \theta$$

$$P_{n3} = \frac{mg \cos \theta}{4} + \frac{mg \cos \theta l_2}{2l_0} - \frac{mg \cos \theta l_3}{2l_1} + \frac{mg \sin \theta l_4}{2l_1} - \frac{l_2 l_3}{l_0 l_1} mg \cos \theta$$

$$P_{n4} = \frac{mg \cos \theta}{4} - \frac{mg \cos \theta l_2}{2l_0} - \frac{mg \cos \theta l_3}{2l_1} + \frac{mg \sin \theta l_4}{2l_1} + \frac{l_2 l_3}{l_0 l_1} mg \cos \theta$$

$$P_{t1} = P_{t3} = \frac{mg \sin \theta}{4} + \frac{mg \sin \theta l_2}{2l_0}$$

$$P_{t2} = P_{t4} = \frac{mg \sin \theta}{4} - \frac{mg \sin \theta l_2}{2l_0}$$

$P_{n1, 2, 3, 4}$ = Resultant Normal Loads on Blocks
 $P_{t1, 2, 3, 4}$ = Resultant Transverse Loads on Blocks
 m = Mass of Applied Load (kg)
 $g = 9.8 \text{ m/sec}^2$
 θ = Angle of Incline

SELECTING A LINEAR GUIDEWAY

The following sizing example will be based on a common linear guide application beginning at the design consideration phase and ultimately resulting in product specification. The initial solution will assume that the allowed space does not constrain the design. However, an alternate subsequent solution will impose an assumed space constraint.

Several Free Body Diagrams (FBD) depicting some of the most common applications are shown on pages 2 & 3 for reference. However, each unique

application should be reviewed to determine the magnitude and direction of the forces involved (consult factory if assistance is required).

The sequence and calculations contained within this section are theoretical but describe a typical application.

Note: All calculations will be metric based as this is the universal base dimensioning for linear guide rail systems.

A. Design Considerations

- Initial Design Concept Sketch
- Required Life of System (L_{10}) in km of travel
- Space limitations such as allowable height, length, and width
- Velocity, acceleration, and time cycle requirements
- Stroke length required
- Duty cycle
- Orientation of system (horizontal, vertical, inclined...)
- Applied Loads to system (both magnitude and direction). A FBD might need to be developed.
- Preload and Accuracy requirements for the application (*pages 19-21 in Linear Guide Rail Product Catalog*)
- Environmental considerations (*page 25 in Linear Guide Rail Product Catalog*)

B. Establishing Service Life (L_{10})

- Identify operating conditions (Inputs)
- Develop FBD to calculate the effective loading, magnitude and direction on each block — Assume number of rails and number of blocks on each rail
- Calculate Applied Loads (P_n & P_t) and Equivalent Loads (P_e)
- Evaluate Design Safety Factor f_s (*page 15 in Linear Guide Rail Product Catalog*) and required minimum Basic Static Load Rating C_0 (*page 13 in Linear Guide Rail Product Catalog*)
- Calculate Mean Load P_m
- Determine block with greatest loading
- Select rail/block combination that satisfies required service life

Initial Design Considerations

The following design considerations are a representation of the information that is typically defined prior to performing the selection calculations. For this example, *Given Specifications* will be shown in Green, *Calculation Results* will be shown in Blue, and *Catalog Product Data* will be shown in Red.

■ = Given Specifications

■ = Calculation Results

■ = Catalog Product Data

Given Specifications

1. The device duty cycle parameters are as follows:

- a. Gross device cycle time = **30** seconds
- b. Time allocated for extending the device = **4.0** seconds
- c. Time allocated for retracting the device = **4.0** seconds
- d. Operating at **24** hours per day, **260** days per year, and at **85%** efficiency (uptime) for **10** years
- e. Each cycle consists of **2** travels; one extend and one retract stroke

2. Linear device travel for extending and retracting motions = **1335** mm respectively. The initial point of displacement = **0**.

3. The orientation of the device will be **horizontal** and preferably **bolted through the top of the block**.

4. The application will have **very little impact, vibration, or moment loading**.

5. The motion profile will be **trapezoidal** (*Fig. 5*) and have **equivalent acceleration and deceleration rates** as shown below:

- a. Acceleration $\alpha_1 = \mathbf{2.5 \text{ meters /sec}^2}$
- b. Deceleration $\alpha_3 = \mathbf{-2.5 \text{ meters/sec}^2}$
- c. Maximum Velocity (ω_m) = **.35 meters/sec**
- d. The initial velocity $\omega_i = \mathbf{0}$

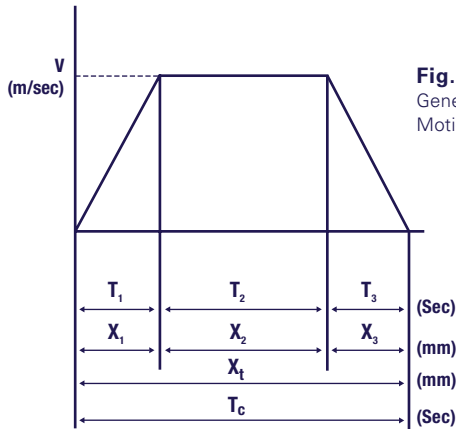


Fig. 5
General Trapezoidal
Motion Profile Diagram

STEP 1

Calculate the Required Service Life Based on the Design Considerations.

By definition, the service or L_{10} life is the amount of travel required during the expected life of the system. The information shown in **items 1 and 2** of the given specifications above will be used to calculate the service life requirement. The results from this calculation will be used in Step 7A.

1335 mm per travel*2 travels per cycle*2 cycles per minute*60 minutes per hour*24 hours per day*260 days per year*10 years of L_{10} life*85% efficiency/ 10^6 mm/km = 16,994 Km.

According to the calculation above, service life will be evaluated based on 17,000 Km of travel (This value has been rounded from 16,994 to 17,000).

STEP 2

Calculate the Extend, Retract, and Total Cycle Time based on Acceleration, Deceleration, and Maximum Velocity.

The extend, retract, and total cycle time will be calculated based on the information listed in item 5 of the given specifications. The total calculated cycle time will be evaluated to ensure conformity to the 4.0 second design objective. Additionally, it will be necessary to determine the validity of the specified acceleration rates as they will be used in Step 3 to determine the dynamic block loading.

2A The following linear motion variables and equations will be utilized:

- ω_m = Maximum Velocity
- ω_i = Initial Velocity
- α_i = Acceleration
- T_1, T_2, \dots = Time for cycle element 1,2,...
- T_C = Total Cycle Time
- X_i = Initial Starting Location / Position
- X_1, X_2, \dots = Displacement during time increment 1,2,...
- X_t = Total system displacement

Uniform Rectilinear Motion Equations:

Uniform rectilinear motion requires that the acceleration = **0** and the velocity = **constant**.

$$X_j = X_i + \omega_m * T_j$$

Uniformly Accelerated Rectilinear Motion Equations:

In uniformly accelerated rectilinear motion, the acceleration = **constant** and the velocity = **variable**

1. $\omega_m = \omega_i + \alpha_i * T_j$
2. $X_j = X_i + \omega_i * T_j + .5 * \alpha_i * T_j^2$
3. $\omega_m^2 = \omega_i^2 + 2 * \alpha_i * (X_j - X_i)$

2B Solve for T1, T3, X1 and X3 during the initial acceleration and final deceleration of the motion profile:

Using the equations above and the information in **item 5** of the given specifications, the time increment T_1 and the displacement X_1 will be solved. Given that the acceleration and deceleration rates are equivalent, the time increment T_3 will equal T_1 and the displacement X_3 will equal X_1 . (See previous motion profile diagram for $T_1, T_3, X_1,$ & X_3 . Fig. 5). The results from these calculations will be used in Steps 2C and 2D.

Calculate T_1 & T_3 :

- $\omega_m = .35$ meters / sec
- $\omega_i = 0$ (the system is stationary)
- $\alpha_i = 2.5$ meters / sec²
- $\alpha_3 = -2.5$ meters / sec²

$$\omega_m = \omega_i + \alpha_i * T_1 \text{ (substituting variables)}$$

$$.35 = 0 + 2.5 * T_1$$

$$T_1 = .14 \text{ Seconds}$$

$$T_3 = .14 \text{ Seconds}$$

Calculate X_1 & X_3 :

$$\omega_m = .35 \text{ meters/sec}$$

$$\omega_i = 0 \text{ (the system is stationary)}$$

$$X_i = 0 \text{ (the system initially starts from a 0 location)}$$

$$T_1 = .14 \text{ Seconds}$$

$$T_3 = .14 \text{ Seconds}$$

$$\alpha_1 = 2.5 \text{ meters/sec}^2$$

$$\alpha_3 = -2.5 \text{ meters/sec}^2$$

$$X_1 = X_i + \omega_i * T_1 + .5 * \alpha_1 * T_1^2$$

(substituting variables)

$$X_1 = 0 + 0 * .14 + .5 * 2.5 * .14^2$$

$$X_1 \text{ \& } X_3 = .025 \text{ meters (displacement during acceleration and deceleration)}$$

2C Solve for T_2 which occurs during the period of constant velocity for the motion profile:

The initial calculation will determine the displacement required (X_2) once the system has reached maximum velocity. Once the displacement required for period T_2 has been determined, the time required for the displaced distance will be solved. The information shown in **items 2 and 5** of the given specifications (page 4), as well as the results from *Step 2B* will be used to perform these calculations.

Determine X_t :

$$\omega_m = .35 \text{ meters/sec}$$

$$\alpha_2 = 0$$

$$X_1 = .025 \text{ meters (From Step 2B)}$$

$$X_3 = .025 \text{ meters (From Step 2B)}$$

$$X_t = 1335 \text{ mm} = 1.335 \text{ meters}$$

$$X_t = X_1 + X_2 + X_3 \text{ (substituting variables)}$$

$$1.335 = .025 + X_2 + .025$$

$$X_2 = 1.285 \text{ meters} = 1285 \text{ mm}$$

Calculate T_2 :

$$X_2 = \omega_m * T_2 \text{ (substituting variables)}$$

$$1.285 = .35 * T_2$$

$$T_2 = 3.671 \text{ seconds}$$

2D Solve for the Total Calculated Cycle Time:

The total cycle time will be the summation of the time periods T_1 , T_2 , and T_3 .

$$T_1 = .14 \text{ Seconds (From Step 2B)}$$

$$T_2 = 3.671 \text{ Seconds (From Step 2C)}$$

$$T_3 = .14 \text{ Seconds (From Step 2B)}$$

$$T_C = T_1 + T_2 + T_3$$

$$T_C = .14 + 3.671 + .14$$

$$T_C = 3.951 \text{ Seconds (slightly less than the 4.0 second objective)}$$

2E Design Concept & Loading Calculations:

The purpose of the following section is to populate the motion profile diagram with the values previously calculated above in *Step 2* and establish an initial geometric design concept. This concept will be utilized as the basis for calculating the applied loading to each guide block.

Motion Profile and Loading Data:

$$\text{Speed } \omega_m = .35 \text{ m/sec}$$

$$\text{Time } T_1 = .14 \text{ sec}$$

$$T_2 = 3.671 \text{ sec}$$

$$T_3 = .14 \text{ sec}$$

$$\text{Acceleration } \alpha_1 = 2.5 \text{ m/sec}^2$$

$$\alpha_2 = 0 \text{ m/sec}^2$$

$$\alpha_3 = -2.5 \text{ m/sec}^2$$

$$\text{Stroke } X_t = 1335 \text{ mm}$$

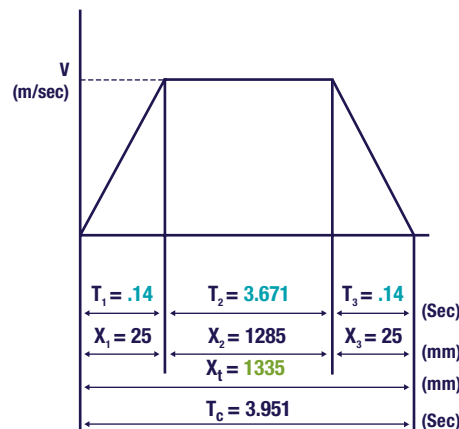


Fig. 6 Defined Trapezoidal Motion Profile Diagram

Given Resultant Catalog

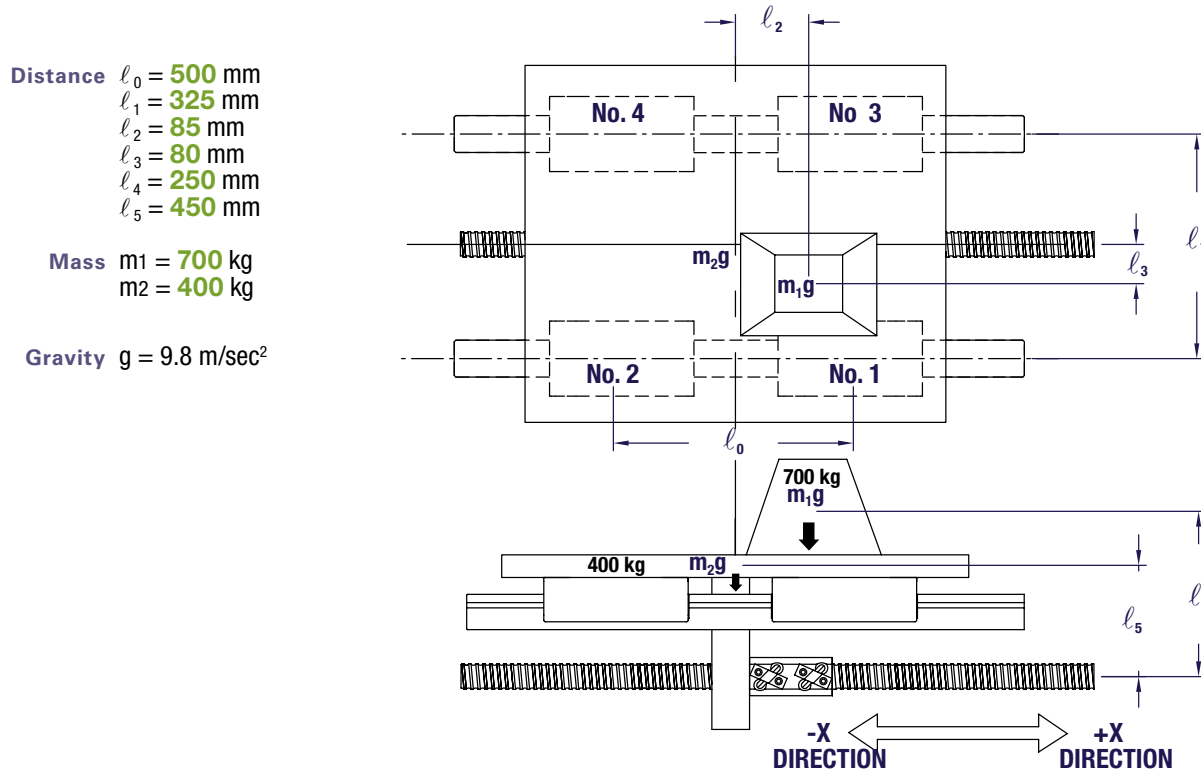


Fig. 7 Initial Design Concept Sketch

STEP 3

Calculate Individual Applied Block Loads.

In this step, the applied loads will be evaluated for the periods of acceleration and constant velocity. These subsequent equations will calculate loading in both the normal and transverse directions (See Fig. 9 from Step 4 on page 9).

Note: In general, linear motion system applications should always be evaluated with respect to the highest loaded block as it will be the first to reach the calculated design life limit.

3A Load During Constant Velocity:

Applied Load in the normal direction P_n
 (Use the information in Fig. 7 for the equations in Steps 3A-3E)

$$P_{n1} = \frac{1}{4} m_1 g + \frac{l_2}{2l_0} m_1 g + \frac{l_3}{2l_1} m_1 g + \frac{l_2 l_3}{l_0 l_1} m_1 g + \frac{1}{4} m_2 g = 4409 \text{ N}$$

$$P_{n2} = \frac{1}{4} m_1 g - \frac{l_2}{2l_0} m_1 g + \frac{l_3}{2l_1} m_1 g - \frac{l_2 l_3}{l_0 l_1} m_1 g + \frac{1}{4} m_2 g = 2669 \text{ N}$$

$$P_{n3} = \frac{1}{4} m_1 g + \frac{l_2}{2l_0} m_1 g - \frac{l_3}{2l_1} m_1 g - \frac{l_2 l_3}{l_0 l_1} m_1 g + \frac{1}{4} m_2 g = 2147 \text{ N}$$

$$P_{n4} = \frac{1}{4} m_1 g - \frac{l_2}{2l_0} m_1 g - \frac{l_3}{2l_1} m_1 g + \frac{l_2 l_3}{l_0 l_1} m_1 g + \frac{1}{4} m_2 g = 1555 \text{ N}$$

3B Load During X- Acceleration:

Applied Load in the Normal direction P_{nL_a} :

$$P_{nL_{a1}} = P_{n1} + \frac{m_1 \alpha_1 \ell_5}{2 \ell_0} + \frac{m_2 \alpha_1 \ell_4}{2 \ell_0} = 5447 \text{ N}$$

$$P_{nL_{a2}} = P_{n2} - \frac{m_1 \alpha_1 \ell_5}{2 \ell_0} - \frac{m_2 \alpha_1 \ell_4}{2 \ell_0} = 1632 \text{ N}$$

$$P_{nL_{a3}} = P_{n3} + \frac{m_1 \alpha_1 \ell_5}{2 \ell_0} + \frac{m_2 \alpha_1 \ell_4}{2 \ell_0} = 3184 \text{ N}$$

$$P_{nL_{a4}} = P_{n4} - \frac{m_1 \alpha_1 \ell_5}{2 \ell_0} - \frac{m_2 \alpha_1 \ell_4}{2 \ell_0} = 517 \text{ N}$$

Applied Load in the Transverse direction P_{tL_a} :

$$P_{tL_{a1}} = + \frac{m_1 \alpha_1 \ell_3}{2 \ell_0} = + 140 \text{ N}$$

$$P_{tL_{a2}} = - \frac{m_1 \alpha_1 \ell_3}{2 \ell_0} = - 140 \text{ N}$$

$$P_{tL_{a3}} = + \frac{m_1 \alpha_1 \ell_3}{2 \ell_0} = + 140 \text{ N}$$

$$P_{tL_{a4}} = - \frac{m_1 \alpha_1 \ell_3}{2 \ell_0} = - 140 \text{ N}$$

3C Load During X- Deceleration:

Applied Load in the Normal direction P_{nL_d} :

$$P_{nL_{d1}} = P_{n1} + \frac{m_1 \alpha_3 \ell_5}{2 \ell_0} + \frac{m_2 \alpha_3 \ell_4}{2 \ell_0} = 3372 \text{ N}$$

$$P_{nL_{d2}} = P_{n2} - \frac{m_1 \alpha_3 \ell_5}{2 \ell_0} - \frac{m_2 \alpha_3 \ell_4}{2 \ell_0} = 3707 \text{ N}$$

$$P_{nL_{d3}} = P_{n3} + \frac{m_1 \alpha_3 \ell_5}{2 \ell_0} + \frac{m_2 \alpha_3 \ell_4}{2 \ell_0} = 1109 \text{ N}$$

$$P_{nL_{d4}} = P_{n4} - \frac{m_1 \alpha_3 \ell_5}{2 \ell_0} - \frac{m_2 \alpha_3 \ell_4}{2 \ell_0} = 2592 \text{ N}$$

Applied Load in the Transverse direction P_{tL_d} :

$$P_{tL_{d1}} = + \frac{m_1 \alpha_3 \ell_3}{2 \ell_0} = - 140 \text{ N}$$

$$P_{tL_{d2}} = - \frac{m_1 \alpha_3 \ell_3}{2 \ell_0} = + 140 \text{ N}$$

$$P_{tL_{d3}} = + \frac{m_1 \alpha_3 \ell_3}{2 \ell_0} = - 140 \text{ N}$$

$$P_{tL_{d4}} = - \frac{m_1 \alpha_3 \ell_3}{2 \ell_0} = + 140 \text{ N}$$

3D Load During X+ Acceleration:

Applied Load in the Normal direction P_{nR_a} :

$$P_{nR_{a1}} = P_{n1} - \frac{m_1 \alpha_1 \ell_5}{2 \ell_0} - \frac{m_2 \alpha_1 \ell_4}{2 \ell_0} = 3372 \text{ N}$$

$$P_{nR_{a2}} = P_{n2} + \frac{m_1 \alpha_1 \ell_5}{2 \ell_0} + \frac{m_2 \alpha_1 \ell_4}{2 \ell_0} = 3707 \text{ N}$$

$$P_{nR_{a3}} = P_{n3} - \frac{m_1 \alpha_1 \ell_5}{2 \ell_0} - \frac{m_2 \alpha_1 \ell_4}{2 \ell_0} = 1109 \text{ N}$$

$$P_{nR_{a4}} = P_{n4} + \frac{m_1 \alpha_1 \ell_5}{2 \ell_0} + \frac{m_2 \alpha_1 \ell_4}{2 \ell_0} = 2592 \text{ N}$$

Applied Load in the Transverse direction P_{tR_a} :

$$P_{tR_{a1}} = - \frac{m_1 \alpha_1 \ell_3}{2 \ell_0} = - 140 \text{ N}$$

$$P_{tR_{a2}} = + \frac{m_1 \alpha_1 \ell_3}{2 \ell_0} = + 140 \text{ N}$$

$$P_{tR_{a3}} = - \frac{m_1 \alpha_1 \ell_3}{2 \ell_0} = - 140 \text{ N}$$

$$P_{tR_{a4}} = + \frac{m_1 \alpha_1 \ell_3}{2 \ell_0} = + 140 \text{ N}$$

3E Load During X+ Deceleration:

Applied Load in the Normal direction P_{nR_d} :

$$P_{nR_{d1}} = P_{n1} - \frac{m_1 \alpha_3 \ell_5}{2 \ell_0} - \frac{m_2 \alpha_3 \ell_4}{2 \ell_0} = 5447 \text{ N}$$

$$P_{nR_{d2}} = P_{n2} + \frac{m_1 \alpha_3 \ell_5}{2 \ell_0} + \frac{m_2 \alpha_3 \ell_4}{2 \ell_0} = 1632 \text{ N}$$

$$P_{nR_{d3}} = P_{n3} - \frac{m_1 \alpha_3 \ell_5}{2 \ell_0} - \frac{m_2 \alpha_3 \ell_4}{2 \ell_0} = 3184 \text{ N}$$

$$P_{nR_{d4}} = P_{n4} + \frac{m_1 \alpha_3 \ell_5}{2 \ell_0} + \frac{m_2 \alpha_3 \ell_4}{2 \ell_0} = 517 \text{ N}$$

Applied Load in the Transverse direction P_{tR_d} :

$$P_{tR_{d1}} = - \frac{m_1 \alpha_3 \ell_3}{2 \ell_0} = + 140 \text{ N}$$

$$P_{tR_{d2}} = + \frac{m_1 \alpha_3 \ell_3}{2 \ell_0} = - 140 \text{ N}$$

$$P_{tR_{d3}} = - \frac{m_1 \alpha_3 \ell_3}{2 \ell_0} = + 140 \text{ N}$$

$$P_{tR_{d4}} = + \frac{m_1 \alpha_3 \ell_3}{2 \ell_0} = - 140 \text{ N}$$

■ Given ■ Resultant ■ Catalog

STEP 4

Calculate the Equivalent Block Loads.

The individual equivalent block loads (also referred to as resultant load) are calculated by summing the absolute value of the normal and transverse loads applied to each block. The values used in the following equations were previously calculated in *Step 3*. The determined equivalent load values will then be used in the successive Mean Load Calculation (See *Step 6 on page 10*).

Equivalent Load Formula Diagram:

$$P_e \text{ (Equivalent Load)} = |P_n| + |P_t|$$

P_n = Normal Load

P_t = Transverse Load

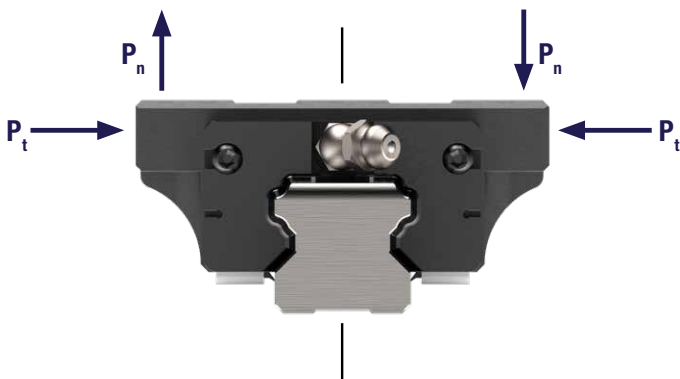


Fig. 9 Equivalent Load

4A Equivalent Load Calculation:

Use the values from Steps 3A-3E for these equations.

During Uniform Motion:

$$P_{e1} = P_{n1} = 4409 \text{ N}$$

$$P_{e2} = P_{n2} = 2669 \text{ N}$$

$$P_{e3} = P_{n3} = 2147 \text{ N}$$

$$P_{e4} = P_{n4} = 1555 \text{ N}$$

During X+ Acceleration:

$$P_{eR_{a1}} = |P_{nR_{a1}}| + |P_{tR_{a1}}| = 3512 \text{ N}$$

$$P_{eR_{a2}} = |P_{nR_{a2}}| + |P_{tR_{a2}}| = 3847 \text{ N}$$

$$P_{eR_{a3}} = |P_{nR_{a3}}| + |P_{tR_{a3}}| = 1249 \text{ N}$$

$$P_{eR_{a4}} = |P_{nR_{a4}}| + |P_{tR_{a4}}| = 2732 \text{ N}$$

During X- Acceleration:

$$P_{eL_{a1}} = |P_{nL_{a1}}| + |P_{tL_{a1}}| = 5587 \text{ N}$$

$$P_{eL_{a2}} = |P_{nL_{a2}}| + |P_{tL_{a2}}| = 1772 \text{ N}$$

$$P_{eL_{a3}} = |P_{nL_{a3}}| + |P_{tL_{a3}}| = 3324 \text{ N}$$

$$P_{eL_{a4}} = |P_{nL_{a4}}| + |P_{tL_{a4}}| = 657 \text{ N}$$

During X+ Deceleration:

$$P_{eR_{d1}} = |P_{nR_{d1}}| + |P_{tR_{d1}}| = 5587 \text{ N}$$

$$P_{eR_{d2}} = |P_{nR_{d2}}| + |P_{tR_{d2}}| = 1772 \text{ N}$$

$$P_{eR_{d3}} = |P_{nR_{d3}}| + |P_{tR_{d3}}| = 3324 \text{ N}$$

$$P_{eR_{d4}} = |P_{nR_{d4}}| + |P_{tR_{d4}}| = 657 \text{ N}$$

During X- Deceleration:

$$P_{eL_{d1}} = |P_{nL_{d1}}| + |P_{tL_{d1}}| = 3512 \text{ N}$$

$$P_{eL_{d2}} = |P_{nL_{d2}}| + |P_{tL_{d2}}| = 3847 \text{ N}$$

$$P_{eL_{d3}} = |P_{nL_{d3}}| + |P_{tL_{d3}}| = 1249 \text{ N}$$

$$P_{eL_{d4}} = |P_{nL_{d4}}| + |P_{tL_{d4}}| = 2732 \text{ N}$$

According to these calculations, **Block #1** has the highest maximum applied load of **5587 N** during acceleration in the X- direction and deceleration in the X+ direction. This information will be used in *Step 5*.

STEP 5

Evaluate Static Loading.

NOTE: The L_{10} Fatigue Life and Static Loading should be evaluated for each application to ensure proper product sizing.

Each variable in the following Static Loading equation will be isolated and quantified. The objective will be to calculate the minimum allowable Basic Static Load Rating (C_0). (See page 13 in *Linear Guide Rail Product Catalog* for additional information)

f_s (Design Safety Factor)= **2.0** (Conservative)

f_c (Contact Factor)= **1.0** (Assumes block spacing as shown on page 16 in *Linear Guide Rail Product Catalog*)

P_e (Equivalent Load)= **5587** N

Rearrange Equation, Substitute Values, and Calculate to solve for Basic Static load Rating (C_0):

$$f_s = \left(\frac{f_c * C_0}{P_e} \right)$$

$$(f_s * P_e) / f_c = C_0$$

$$(2.0 * 5587) / 1.0 = C_0$$

$$C_0 = \mathbf{11,174}$$
 N minimum

The product selection will need to have a minimum Basic Static Load Rating (C_0) of **11,174** N

Load Data for the RPG-HA Product:

(See product pages 5-6 in *Linear Guide Rail Product Catalog* for additional data)

Model No.	Basic Load Rating	
	(C_{50})	(C_0)
	N lbf	N lbf
RPG15HA	8336	13239
	1874	2976
RPG20HA	13729	23536
	3086	5291
RPG25HA	19123	31381
	4299	7055
RPG30HA	27949	47072
	6283	10582
RPG35HA	37756	60801
	8488	13669
RPG45HA	63743	102970
	14330	23149

Table 10

RPG-HA Static and Dynamic Load Ratings

The charted product load ratings (C_0) indicate that any size product would satisfy the **11,174** N minimum Static Load requirement. However before product selection can occur, the L_{10} Fatigue Life will need to be evaluated.

STEP 6

Evaluate Fatigue Life (L_{10}) and Select Product.

The main objective of this section will be to evaluate the effects of dynamic loading on product selection. Initially, this evaluation will begin by solving the Mean Load applied to each block. The Mean Load and other input factors will then be used to solve for the minimum required Dynamic Load Rating (C_{50}). At the end of this section, the appropriate product selection will be achieved based on the full scope of this application example.

Mean Load (P_m) Equation for cycles with Stepwise Load variation:

$$P_m = \sqrt[3]{\frac{1}{X_t} (P_{e1}^3 * X_1 + P_{e2}^3 * X_2 + \dots + P_{en}^3 * X_n)}$$

P_m = Mean Load (N)

$P_{e1}, P_{e2}, \dots, P_{en}$ = Equivalent Load (N)

X_t = Total Distance Traveled (mm)

X_1, X_2, \dots, X_n = Distance Traveled Under Load P_e (mm)

Calculate Applied Mean Load (P_m) per Block:

During the majority of all motion profile cycles, the resultant loading will vary as the system moves from point to point. These loads may vary for reasons such as mass acceleration (inertia), varying rates of acceleration, externally encountered forces, incrementally applied loads, or as a result of other factors. The following Mean Load Calculation transforms these varying cycle loads into a corresponding load of constant value. The block determined to have the maximum applied Mean Load will be the focus as it will have the shortest Fatigue Life (L_{10}). (Refer to page 14 in *Linear Guide Rail Product Catalog* for a complete explanation of Mean Load.)

NOTE: The previously calculated equivalent applied load values will be used to calculate the Mean Load. (Refer to Step 4A on page 9 for calculated equivalent load values)

Given Resultant Catalog

6A Solve for the Individual Mean Applied Load Per Block:

Block	Applied Load	Mean Load (P _m)
1	$P_{m1} = \sqrt[3]{\frac{1}{2 * Xt} \left[(PeLa1^3 * X1) + (Pe1^3 * X2) + (PeLd1^3 * X1) + (PeRa1^3 * X1) + (Pe1^3 * X2) + (PeRd1^3 * X3) \right]}$	$P_{m1} = 4424 \text{ N}$
	$P_{m1} = \sqrt[3]{\frac{1}{2 * 1335} \left[(5587^3 * 25) + (4409^3 * 1285) + (3512^3 * 25) + (3512^3 * 25) + (4409^3 * 1285) + (5587^3 * 25) \right]}$	
2	$P_{m2} = \sqrt[3]{\frac{1}{2 * Xt} \left[(PeLa2^3 * X1) + (Pe2^3 * X2) + (PeLd2^3 * X1) + (PeRa2^3 * X1) + (Pe2^3 * X2) + (PeRd2^3 * X3) \right]}$	$P_{m2} = 2690 \text{ N}$
	$P_{m2} = \sqrt[3]{\frac{1}{2 * 1335} \left[(1772^3 * 25) + (2669^3 * 1285) + (3847^3 * 25) + (3847^3 * 25) + (2669^3 * 1285) + (1772^3 * 25) \right]}$	
3	$P_{m3} = \sqrt[3]{\frac{1}{2 * Xt} \left[(PeLa3^3 * X1) + (Pe3^3 * X2) + (PeLd3^3 * X1) + (PeRa3^3 * X1) + (Pe3^3 * X2) + (PeRd3^3 * X3) \right]}$	$P_{m3} = 2172 \text{ N}$
	$P_{m3} = \sqrt[3]{\frac{1}{2 * 1335} \left[(3324^3 * 25) + (2147^3 * 1285) + (1249^3 * 25) + (1249^3 * 25) + (2147^3 * 1285) + (3324^3 * 25) \right]}$	
4	$P_{m4} = \sqrt[3]{\frac{1}{2 * Xt} \left[(PeLa4^3 * X1) + (Pe4^3 * X2) + (PeLd4^3 * X1) + (PeRa4^3 * X1) + (Pe4^3 * X2) + (PeRd4^3 * X3) \right]}$	$P_{m4} = 1588 \text{ N}$
	$P_{m4} = \sqrt[3]{\frac{1}{2 * 1335} \left[(657^3 * 25) + (1555^3 * 1285) + (2732^3 * 25) + (2732^3 * 25) + (1555^3 * 1285) + (657^3 * 25) \right]}$	

STEP 7

Determine the Dynamic Load Rating (C₅₀) and Select Product.

The Required Dynamic Load Rating (C₅₀) will be assessed for the block with the greatest Mean Load. This block theoretically will have the shortest Fatigue Life and will uniquely indicate the product selection. In this application example, **Block 1** has the greatest calculated Mean Load of **4424 N**.

NOTE: In general, linear motion system applications should always be evaluated with respect to the highest loaded block.

7A Solve for Minimum Required Dynamic Load Rating (C₅₀):

The L₁₀ life calculation, as found below and on page 13, will be rearranged to solve for the Required Dynamic Load Rating variable (C₅₀).

Original L₁₀ Equation:

$$L_{10} = \left(\frac{f_c}{f_w} * \frac{C_{50}}{P_m} \right)^3 * 50\text{km}$$

Calculate C₅₀ :

L₁₀ = **17,000 km** (See Step 1)

C₅₀ = Basic Dynamic Load Rating (N)

P_{m2} = **4424 N** (See Step 6A)

f_c = **1.0** (See Step 5)

f_w = **1.5** (Based on Maximum Velocity = **.35** meters/second
Refer to following Table 26A for factor value)

Load Factor (fw):

Vibration/Impact	Speed (V)	f _w
Faint 0 ≤ f _w < .25g	Hyper-slow V ≤ 0.25m/sec	1 - 1.2
Weak .25 ≤ f _w < .50g	Slow .25 < V ≤ 1m/sec	1.2 - 1.5
Moderate .50 ≤ f _w < 1.0g	Medium 1 < V ≤ 2m/sec	1.5 - 2
Strong 1.0 ≤ f _w < 2.0g	Fast V > 2m/sec	2 - 3.5

Table 12A Load Factor Table

Rearrange L₁₀ equation to isolate the C₅₀ variable:

$$\frac{\sqrt[3]{\frac{L_{10}}{50} * f_w * P_m}}{f_c} = C_{50}$$

Substitute values and solve for the minimum required Dynamic Load Rating (C₅₀):

$$\frac{\sqrt[3]{\frac{17000}{50} * 1.5 * 4424}}{1} = C_{50} = 46,319 \text{ N}$$

7B Select product based on the calculated Minimum Required Dynamic Load Rating (C50):

Based on the previously calculated minimum C₅₀ value of **46,319** Newtons (Step 7A) and the stated design consideration to use a RPG-HA style block, the RPG45HA is the only available size that would satisfy the minimum Dynamic Load Rating requirement. (Refer to the chart below for product selection)

Load Data for the RPGHA Product:

Model No.	Basic Load Rating	
	(C ₅₀)	(C ₀)
	N	N
RPG15HA	8336	13239
	1874	2976
RPG20HA	13729	23536
	3086	5291
RPG25HA	19123	31381
	4299	7055
RPG30HA	27949	47072
	6283	10582
RPG35HA	37756	60801
	8488	13669
RPG45HA	63743	102970
	14330	23149

Table 12B
Basic Load Rating
for RPGHA

7C Solve for the L10 life expectation (based on the RPG45HA product):

$$L_{10} = \left(\frac{f_c}{f_w} * \frac{C_{50}}{P_m} \right)^3 * 50\text{km}$$

L₁₀ = Nominal Life Expectation

C₅₀ = **63743** (N) (See Step 7B)

P_{m2} = **4424** N (See Step 6A)

f_c = **1.0** (See Step 5)

f_w = **1.5** (See Given Information in Step 7A)

$$L_{10} = \left(\frac{1}{1.5} * \frac{63743}{4424} \right)^3 * 50\text{km} = 44,307\text{km}$$

7D Re-evaluate the selected size for Static Safety Factor (fs):

The static safety factor will be evaluated based on selecting the RPG45HA product.

Static Safety Factor Equation:

$$f_s = \left(\frac{f_c * C_0}{P_e \text{ max}} \right)$$

f_c = **1.0** (See Step 5)

C₀ = **102970** (N)

P_e = **5587** N (See Step 4A)

f_s = ((1***102970**)/**5587**) = **18.4** (substitute values and solve)

Operating Conditions	Loading Conditions	Minimum f _s
At Rest	Impact Load is small, little or no vibration	1.0 - 1.7
	Impact, Moment Loads or vibration present	1.7 - 3.0
During Motion	Impact Load is small, little or no vibration	1.0 - 2.0
	Impact, Moment Loads or vibration present	2.0 - 5.0

Table 12C Reference Values for Static Safety Factor

The calculated Static Safety Factor (f_s) certainly exceeds the value necessary for the application. Therefore, the RPG45HA model is a viable selection choice.

■ Given ■ Resultant ■ Catalog

STEP 8

Alternative Solution for the Application.

As the design drawings were being created, the designer realized that the 45 mm product selection was too large for the machine envelope. As a contingency plan, the designer considers using the style RPGH-AL blocks which are a longer, higher capacity version of the “A” style blocks.

Load Data for the RPGH-AL Product:

Model No.	Basic Load Rating	
	(C ₅₀)	(C ₀)
	N lbf	N lbf
RPG20HAL	16181	29420
	3638	6614
RPG25HAL	25497	45111
	5732	10141
RPG30HAL	35304	62763
	7937	14110
RPG35HAL	47072	81395
	10582	18298
RPG45HAL	75511	127486
	16976	28660

Table 13A
Basic Load Rating
for RPGH-AL

8A Reference Load Rating Data for the RPGH-AL Blocks:

Referring back to the previously calculated minimum Required Dynamic Load Rating (C₅₀) of **46,319** Newtons, the RPG35H-AL product is selected. It is determined that this product not only meets the minimum stated Required Dynamic Load Rating (C₅₀) but also will fit within the work envelope.

8B Solve for the L10 life expectation based on the RPG35HAL product:

$$L_{10} = \left(\frac{f_c}{f_w} * \frac{C_{50}}{P_m} \right)^3 * 50\text{km}$$

L₁₀ = Nominal Life Expectation

C₅₀ = **47072** (N) (see *Basic Load Rating Chart* above)

P_{m2} = **4424** N (See *Step 6A*)

f_c = **1.0** (See *Step 5*)

f_w = **1.5** (See *Given Information* in *Step 7A*)

$$L_{10} = \left(\frac{1}{1.5} * \frac{47072}{4424} \right)^3 * 50\text{km} = \mathbf{17,842\text{km}}$$

The RPG35HAL meets the Fatigue Life requirements (L₁₀) that were calculated in *Step 1* and is appropriate to use for this application.

Effect of Change in Parameters

Increase In	Effects	How
Number of Blocks on Each Rail	Load per Block	Decreases
	Contact Factor f _c (distance between blocks decreases)	Decreases
Distance Between Blocks on Rail	Contact Factor f _c	Increases
	Rated Life	Increases
Length of Block	Load Carrying Capacity	Increases
	Static Load Rating	Increases
Accuracy of Rail	Mounting Accuracy Requirement	Increases
	Cost	Increases
Preload	Allowable Mounting Error	Decreases
	Stiffness & Rigidity	Increases
Velocity of Motion	Load Factor f _w	Increases
	Suggested Preload	Decreases
Impacts or Vibrations	Minimum Static Safety Factor	Increases
	Life	Decreases

Table 13B Effect of Change in Parameters Table