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USAAMRDL TECHNICAL REPORT 72-36

DESIGN GUIDE FOR LOAD SUSPENSION POINTS, SLINGS, AND AIRCRAFT HARD POINTS

By

Walter E. Huebner

July 1972

EUSTIS DIRECTORATE
U. S. ARMY AIR MOBILITY RESEARCH AND DEVELOPMENT LABORATORY
FORT EUSTIS, VIRGINIA

CONTRACT DAAJ02-71-C-0016
SIKORSKY AIRCRAFT
DIVISION OF UNITED AIRCRAFT
STRATFORD, CONNECTICUT

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U. S. ARMY MATERIEL COMMAND

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DOCUMENT CONTROL DATA - R & D		
(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)		
1. ORIGINATING ACTIVITY *(Corporate author)* Sikorsky Aircraft Division United Aircraft Corporation North Main Street, Stratford, Connecticut	2a. REPORT SECURITY CLASSIFICATION Unclassified 2b. GROUP	
3. REPORT TITLE DESIGN GUIDE FOR LOAD SUSPENSION POINTS, SLINGS, AND AIRCRAFT HARD POINTS		
4. DESCRIPTIVE NOTES *(Type of report and inclusive dates)* Final Report		
5. AUTHOR(S) *(First name, middle initial, last name)* Walter E. Huebner		
6. REPORT DATE July 1972	7a. TOTAL NO. OF PAGES 103	7b. NO. OF REFS 7
8a. CONTRACT OR GRANT NO. DAAJ02-71-C-0016 b. PROJECT NO. 1F162203AA33 c. d.	9a. ORIGINATOR'S REPORT NUMBER(S) USAAMRDL Technical Report 72-36 9b. OTHER REPORT NO(S) *(Any other numbers that may be assigned this report)* Sikorsky Engineering Report SER-50769	
10. DISTRIBUTION STATEMENT Approved for public release; distribution unlimited.		
11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY Eustis Directorate U.S. Army Air Mobility R&D Laboratory Fort Eustis, Virginia	

13. ABSTRACT

This design guide provides criteria and procedures to be used for the design of:

1. Lift points on a piece of Army equipment.
2. The sling system used to suspend material as an external helicopter load.
3. The aircraft hard points to which the sling is attached.

Hardware components designed in accordance with the criteria and procedures in this text in the three design areas listed above will be compatible with each other and with existing and future helicopters.

DD FORM 1 NOV 65 1473 REPLACES DD FORM 1473, 1 JAN 64, WHICH IS OBSOLETE FOR ARMY USE.

Unclassified
Security Classification

Unclassified

Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Load suspension points Lift points Hard points Sling system Helicopter loads						

1b

Unclassified

Security Classification

7832-72

DEPARTMENT OF THE ARMY
U. S. ARMY AIR MOBILITY RESEARCH & DEVELOPMENT LABORATORY
EUSTIS DIRECTORATE
FORT EUSTIS, VIRGINIA 23604

This report was prepared by Sikorsky Aircraft, a Division of United Aircraft Corporation, under the terms of Contract DAAJ02-71-C-0016. It offers general criteria for use by the designer of load suspension points, slings, and aircraft hard points.

The objective of this contractual effort was to refine the data that resulted from two previous programs. The first of these was USAAMRDL House Task AS 70-11, "Effects of Helicopter External Loads on Sling Properties." The second was USAAMRDL Contract DAAJ02-70-C-0021, "Criteria for Externally Suspended Helicopter Loads." The data from these programs were combined to develop the criteria presented in this design guide.

The design criteria presented herein are considered to be a great improvement over existing criteria. The design guide offers a sound approach by which a designer can derive criteria suited to a particular case.

The design criteria contained herein are concurred with by this Directorate.

The technical monitor for this contract was Mr. Gene A. Birocco, Aircraft Subsystems and Equipment Division.

Project 1F162203AA33
Contract DAAJ02-71-C-0016
USAAMRDL Technical Report 72-36
July 1972

DESIGN GUIDE FOR LOAD SUSPENSION POINTS, SLINGS, AND AIRCRAFT HARD POINTS

Final Report

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SUMMARY

This design guide provides criteria and procedures to be used for the design of:

1. Lift points on a piece of Army equipment.
2. The sling system used to suspend materiel as an external helicopter load.
3. The aircraft hard points to which the sling is attached.

Hardware components designed in accordance with the criteria and procedures in this text in the three design areas listed above will be compatible with each other and with existing and future helicopters.

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DESIGN GUIDE FOR

LOAD SUSPENSION POINTS

BASIC DATA REQUIREMENTS

In order to design the lift points on a piece of equipment to be carried as an external helicopter load, the following basic data must be available to the designer. The data are divided into two classes: those relating to the piece of equipment and those relating to the helicopter(s) which may be expected to lift and carry the equipment.

Equipment data are supplied by the equipment designer and consist of:

1. Weight and center-of-gravity location in the loaded conditions.

2. Information relating to outline and external shape.

3. Information relating to the location and strength of substructure.

Helicopter data consist of:

1. The design load (limit load) factor for the helicopter(s) expected to carry the piece of equipment.

2. The type of suspension system used by those helicopters capable of carrying the load (Refer to Appendix 1).

Having gathered the basic information described above, the designer may proceed with the design of lift points using the criteria and procedures described in this section.

"Materiel," as used in this design guide, means any and all equipment procured by the Army which could be carried as an externally suspended helicopter load. Some typical examples are:

1. Vehicles of all sorts, including trailers and trailer-mounted equipment, trucks of all sizes, engineer equipment, self-propelled guns, tanks, howitzers and recovery vehicles, fork lift trucks, aircraft support vehicles, fixed-wing and rotary-wing aircraft.

2. Stationary equipment including generators, refrigeration units, searchlights, radio and radar sets, communications huts, shop van boxes, pallets, cargo containers, missile cans, machinery, laundry and bath units, control towers and shelters, large fuel containers and cargo nets.

MATERIEL TO BE CARRIED BY HELICOPTERS WITH SINGLE-POINT SUSPENSION SYSTEMS

NUMBER OF LIFT POINTS

Four lift points are to be provided. For compatibility with sling suspension systems and safety of flight considerations, four lift points will be provided where possible.

In cases where the nature and geometry of the materiel are unusual, four lift points may not be feasible or practical. In these cases, and with the approval of the procuring agency, three, two, or one lift point may be provided.

LOCATION OF LIFT POINTS

In order to achieve stability in flight and to be compatible with the slings used to suspend the materiel, the following procedures governing the location of lift points must be adhered to.

Location In The Vertical Plane

For the four-point and the three-point lift configurations, it is desirable for all lift points to be located above the center of gravity of the materiel, in both the empty and the fully loaded condition. If this requirement cannot be met, the center of gravity must be located within a triangle whose apex angle is 120° and whose base leg is formed by the lift points. Figure 1 illustrates the relationship between the center of gravity and the lift points on the materiel.

For the two-point and the single-point lift configurations, the lift points must be located above the center of gravity of the materiel, at a height such that at least 60 percent of the maximum projected vertical area lies below the lift point(s).

Location In The Horizontal Plane

All lift points are to be located as far apart as possible inside a circle, in the horizontal plane, whose diameter is 28 feet with the materiel center of gravity location as its center. See Figure 1.

All lift points are to be located symmetrically about a longitudinal axis and a lateral axis, both axes passing through the materiel center of gravity. If exact symmetry cannot be achieved, limited asymmetry is permissible provided the following requirement is met. Using the asymmetrical geometry, calculate the vertical static forces at each lift point. The ratio of the largest vertical force to the smallest vertical force must not exceed 1.2. For those cases where other operational conditions preclude the use of these criteria (e.g. containers), lift points shall be designed for the most severe conditions. Lift point locations which do not meet all of the requirements set forth above must

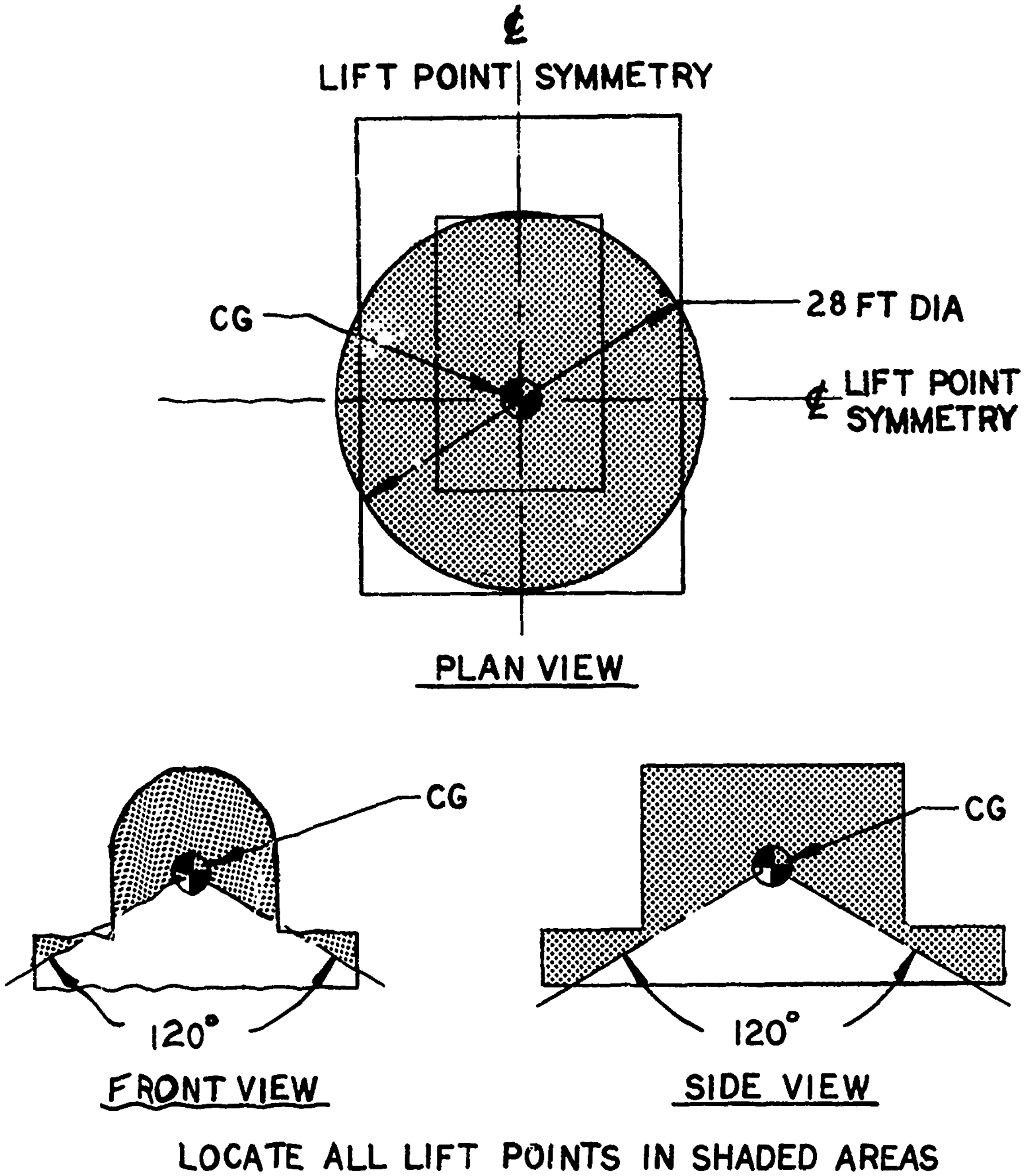


Figure 1. Lift Point CG Relationship, Four-Point and Three-Point Lift Configurations.

be approved by the procuring agency.

Sling Leg/Materiel Clearance

Lift points are to be located so that there is a minimum clearance of 8 inches between the centerline of the sling leg and the materiel. This clearance is required to allow for the width of twisted textile sling legs and the aerodynamic flapping of the sling legs in flight. Any contact between the sling leg and the materiel, even if the surface is smooth, can result in premature failure of textile sling legs due to chafing caused by vibratory loads in the sling leg.

To evaluate the sling leg/materiel clearance for a given lift point configuration, the path of the centerline of each sling leg must be established with respect to the materiel. The upper ends of the sling legs meet in a common apex. The length of each leg is adjustable from a minimum of 18 feet to a maximum of 22 feet. Using a scale layout of the materiel, locate the apex of the sling vertically above the center of gravity of the materiel at a height such that each sling leg, when attached to its lift point, will have a length that falls between 18 and 22 feet.

If adequate clearance cannot be obtained, the following methods should be explored to obtain the required clearance:

1. Relocate the lift points.

2. Remove or relocate the offending part on the materiel.

3. Investigate the use of spreader bars. Refer to Figures 2 and 3. Any lift point configuration that requires the use of spreader bars must have the approval of the procuring agency.

4. Investigate the use of three, two or one lift point configurations.

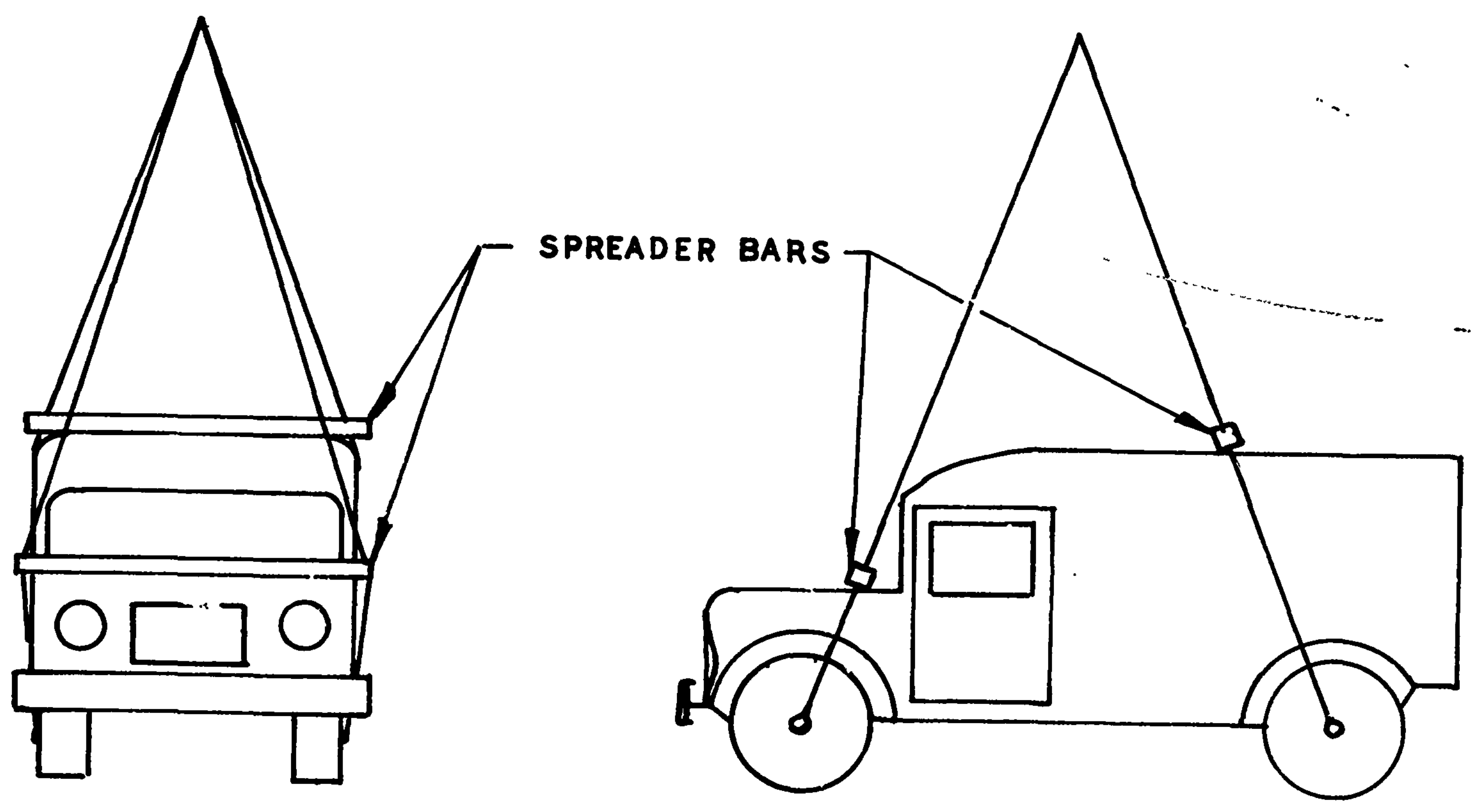


Figure 2. Spreader Bar Installation on 1-1/4-Ton Ambulance.

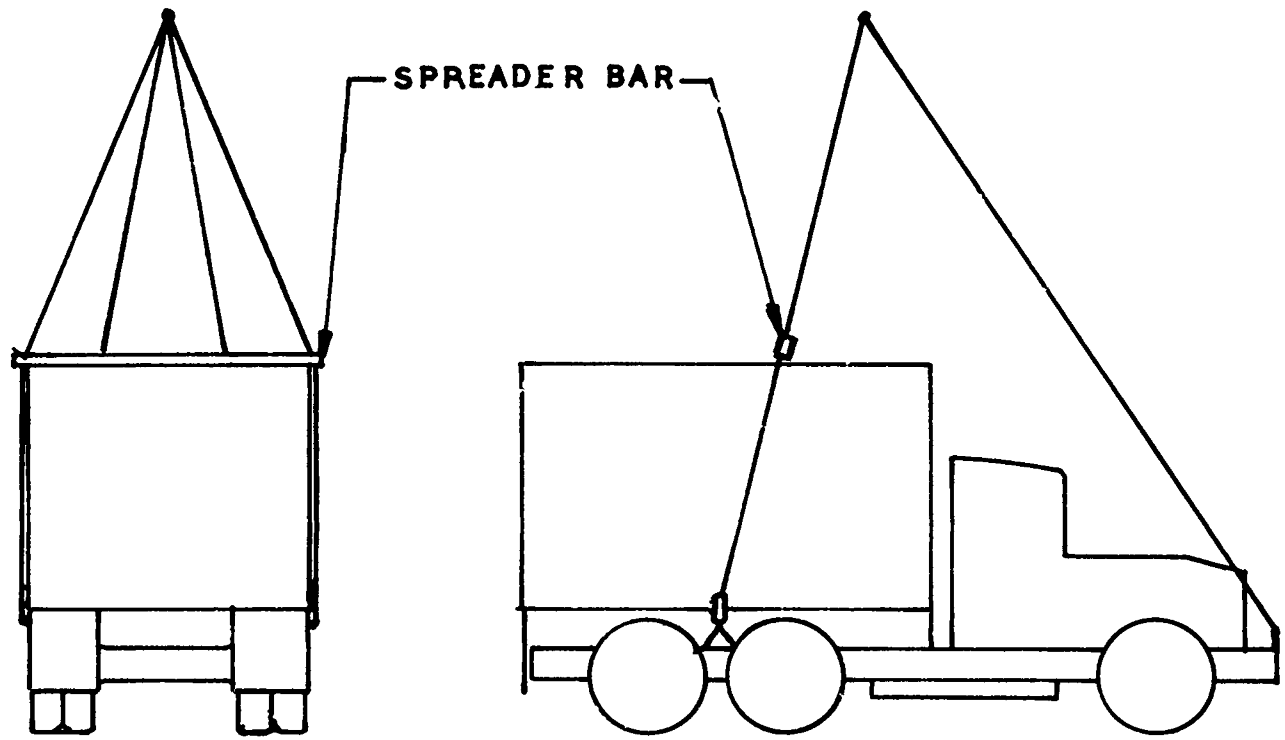


Figure 3. Spreader Bar Installation on 2-1/2-Ton Van Truck.

STRENGTH OF LIFT POINTS

In order to determine the strength requirements of the lift points it is necessary to have the data called for under the Basic Data Requirements section, and the location of the lift points.

General Procedure

The static forces on the lift points are calculated. The materiel classification is made. Then using the classification and the helicopter design load factor, the lift point load factors are determined. From these, the ultimate strength requirements for the lift point and their substructure are determined, using the factor of safety of 1.5.

Static Loads Calculation - Four-Point Lift Configuration

Assuming the materiel is suspended from a four-legged sling whose legs are 20 ± 2 feet in length, calculate the vertical (V) and the horizontal (H) components of the sling leg static tension at each of the lift points. Refer to Figure 4. Select the largest values of V and H (even if they do not occur at the same lift point) to serve as the basis for design.

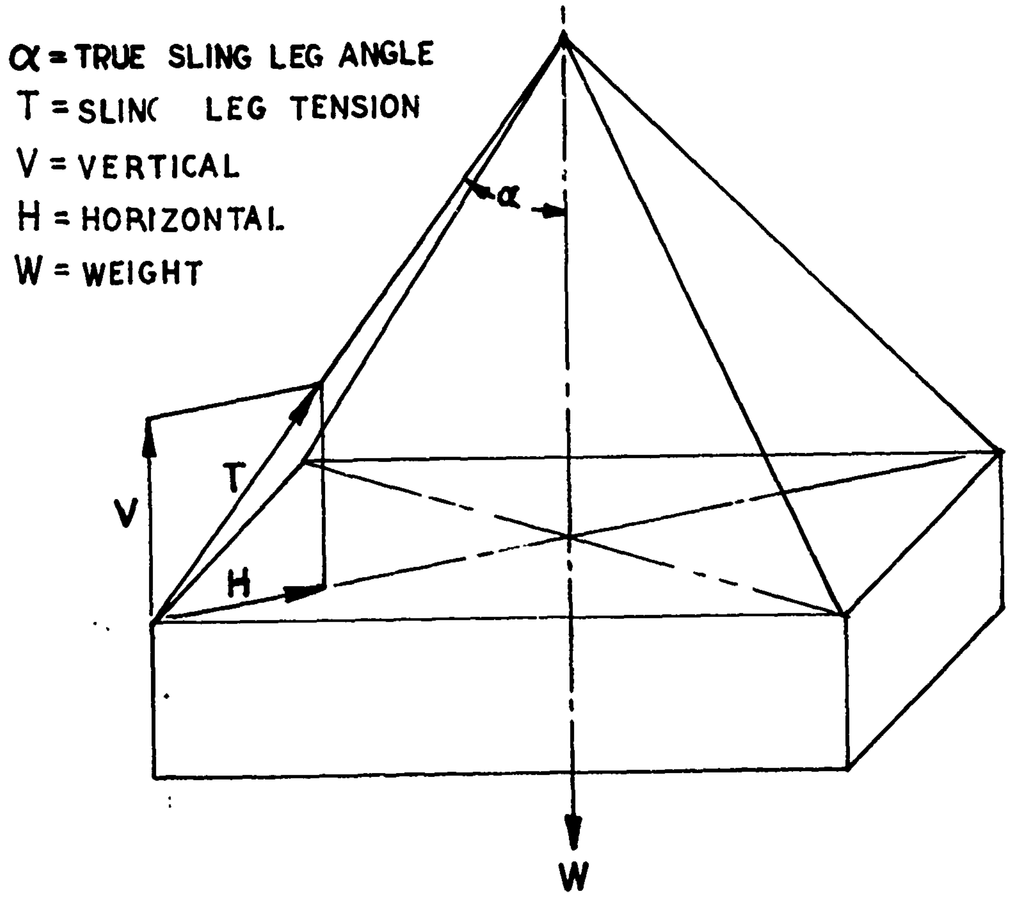


Figure 4. Four-Legged Sling Geometry.

Static Loads Calculation - Three-Point Lift Configuration

Assuming the materiel is suspended from a three-legged sling whose legs are 20 ± 2 feet in length, calculate the vertical (V) and the horizontal (H) components of the sling leg static tension for each of the three lift points. Refer to Figure 5. Select the largest values of V and H even if they do not occur at the same lift point.

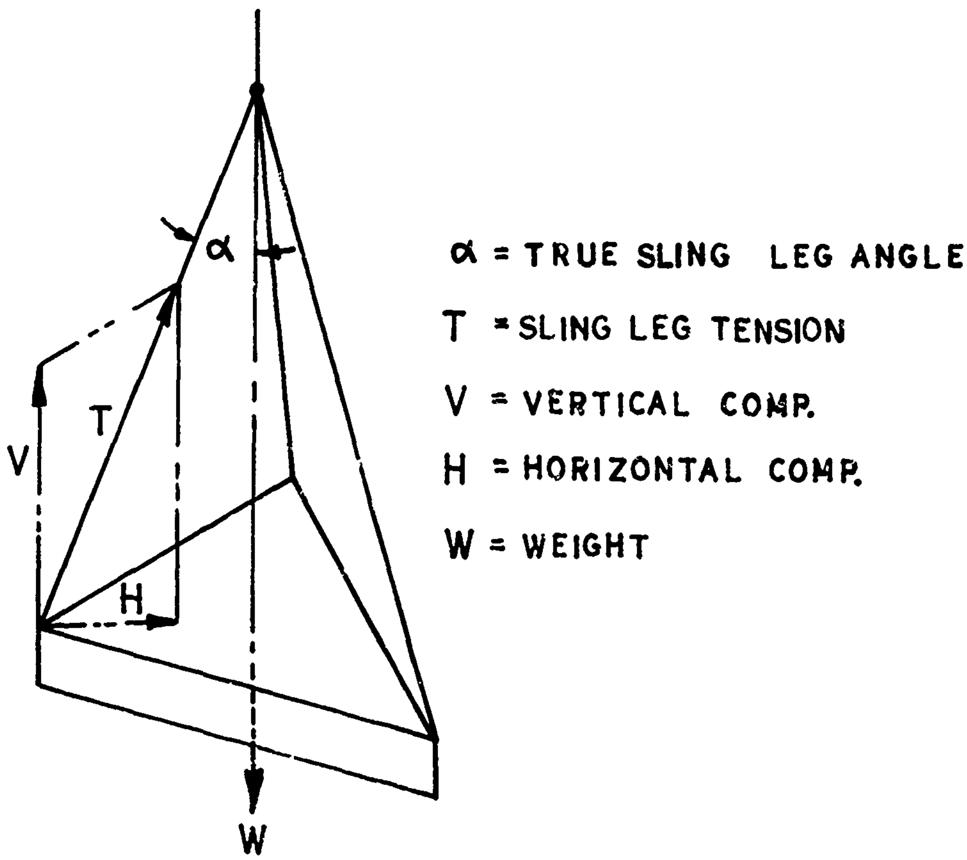


Figure 5. Three-Legged Sling Geometry.

Static Loads Calculation - Two-Point Lift Configuration

Assuming the materiel is suspended from a two-legged sling whose legs are 20 ± 2 feet in length, calculate the vertical (V) and the horizontal (H) components of the sling leg static tension for each of the two lift points. Refer to Figure 6. Select the largest values of V and H even if they do not occur at the same lift point.

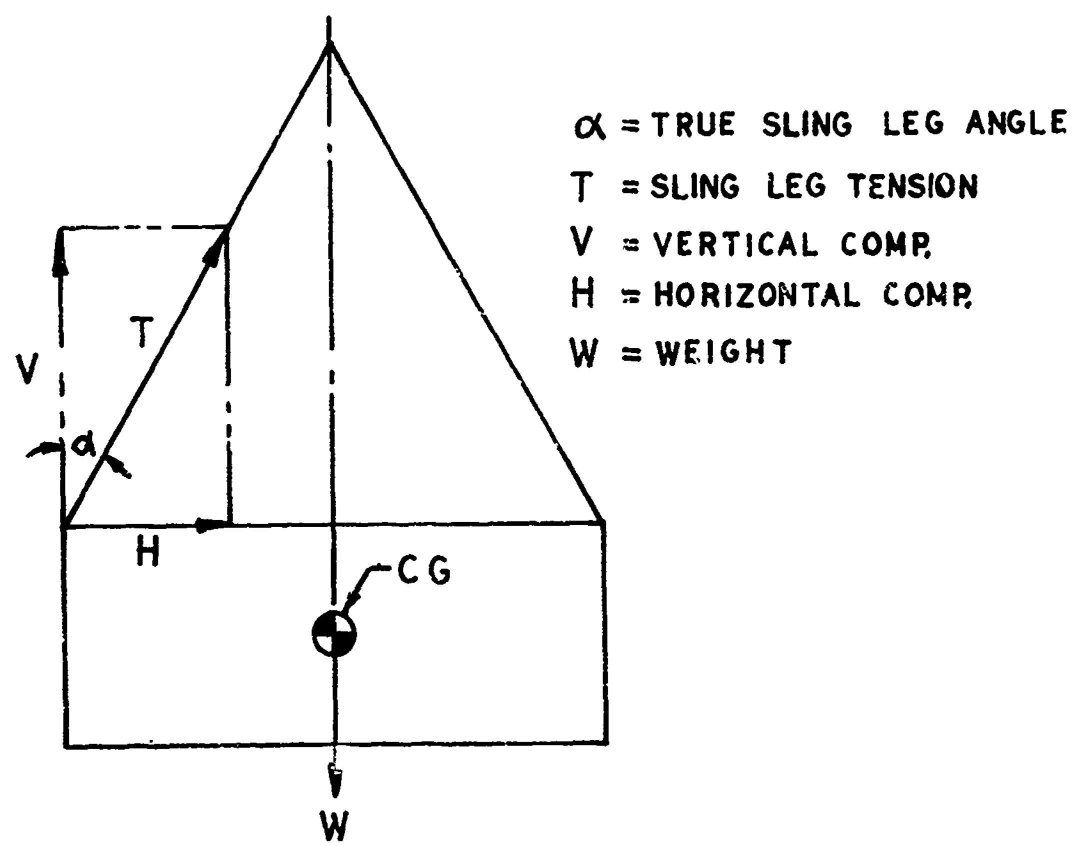


Figure 6. Two-Legged Sling Geometry.

Static Loads Calculation - Single-Point Lift Configuration

Use the weight of the materiel as the static load.

Helicopter Load Factor

The design load factor for the helicopter(s) which will carry the materiel is a major factor in determining the lift point structural requirements. This factor may be determined by consulting Appendix I which lists helicopters presently in the U. S. Army Inventory with their respective design load factors and their load lifting capabilities. If more than one type of helicopter has the required capability to carry the materiel, the highest load factor should be used.

Materiel Classification

Using the materiel classification chart shown in Appendix V, determine the materiel load type.

Lift Point Load Factor

With the materiel load type and the helicopter load factor established, the materiel lift point load factor may be determined from Figure 8. Apply this factor to the vertical (V) and horizontal (H) loads previously calculated to obtain the design limit loads.

Each lift point must react the design limit load without any permanent set taking place. It must also be capable of withstanding an ultimate load of 1.5 times the design limit load without failure.

Strength of the lift points must also conform to the requirements of MIL-STD-209 (Reference 4). In case the requirements of this document conflict with those of MIL-STD-209, use the higher load requirements to design the lift points.

Example: Assume a 19,000 pound piece of equipment measuring 8 feet by 20 feet with the CG on the centerline, but located 9.5 feet from the front (see Figure 7).

Step 1. Determine the vertical reaction (V) at each lift point.

$$V_f = \frac{10.5}{20} \quad \frac{19,000}{2} = 4,987 \text{ lb}$$

$$V_r = \frac{9.5}{20} \quad \frac{19,000}{2} = 4,512 \text{ lb}$$

Step 2. Calculate the horizontal force (H_f) using the sling geometry.

$$h_f = \sqrt{(4)^2 + (9.5)^2} = 10.31 \text{ ft}$$

$$K = \sqrt{(20)^2 - (h_f)^2} = \sqrt{(20)^2 - 106.25} = 17.14 \text{ ft}$$

$$\text{Sling Tension } (T) = V \frac{t}{K}$$

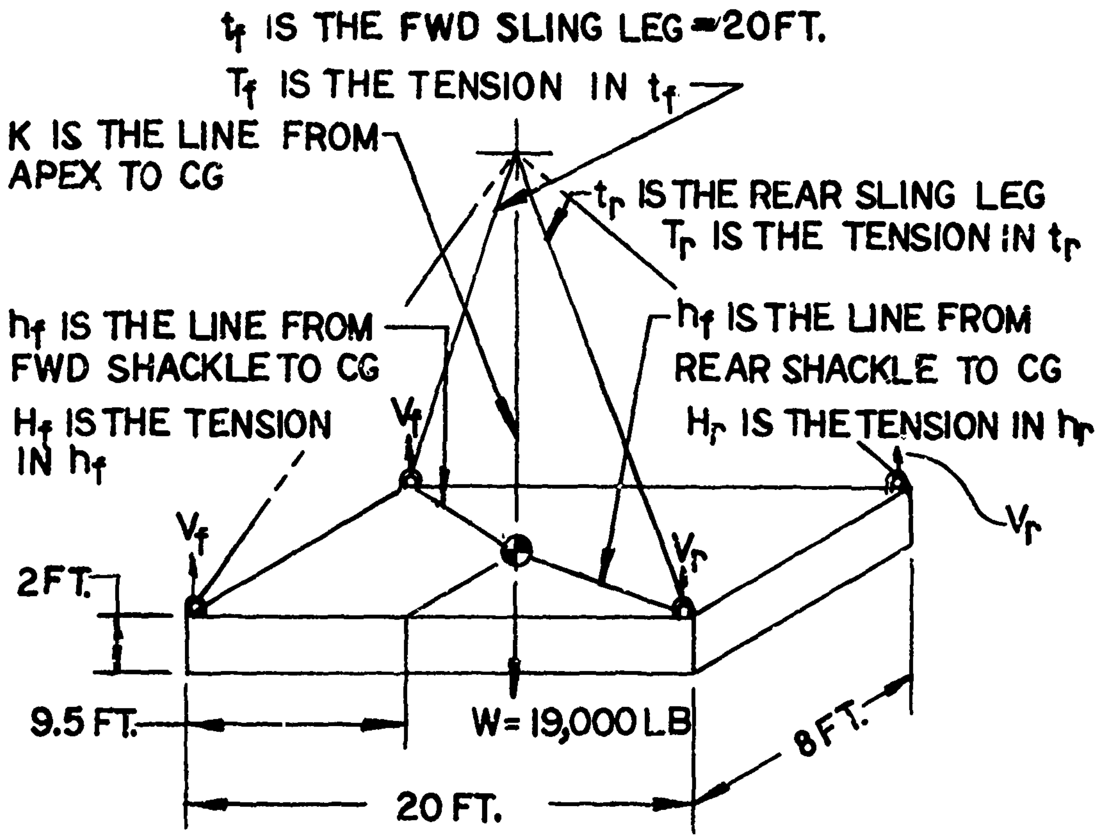


Figure 7. Four-Point Asymmetrical Sling Geometry

Horizontal Force $(H) = T\,\frac{h}{t}$

Substituting $(H) = V\,\frac{h}{K}$

$$H_f = V_f\,\frac{h_f}{K} = (4{,}987) \times \frac{10.31}{17.14} = 3{,}000 \text{ lb}$$

In similar fashion, calculate (H_R)

Use K from previous calculation.

$$h_r = \sqrt{(10.5)^2 + (4)^2} = 11.24 \text{ ft}$$

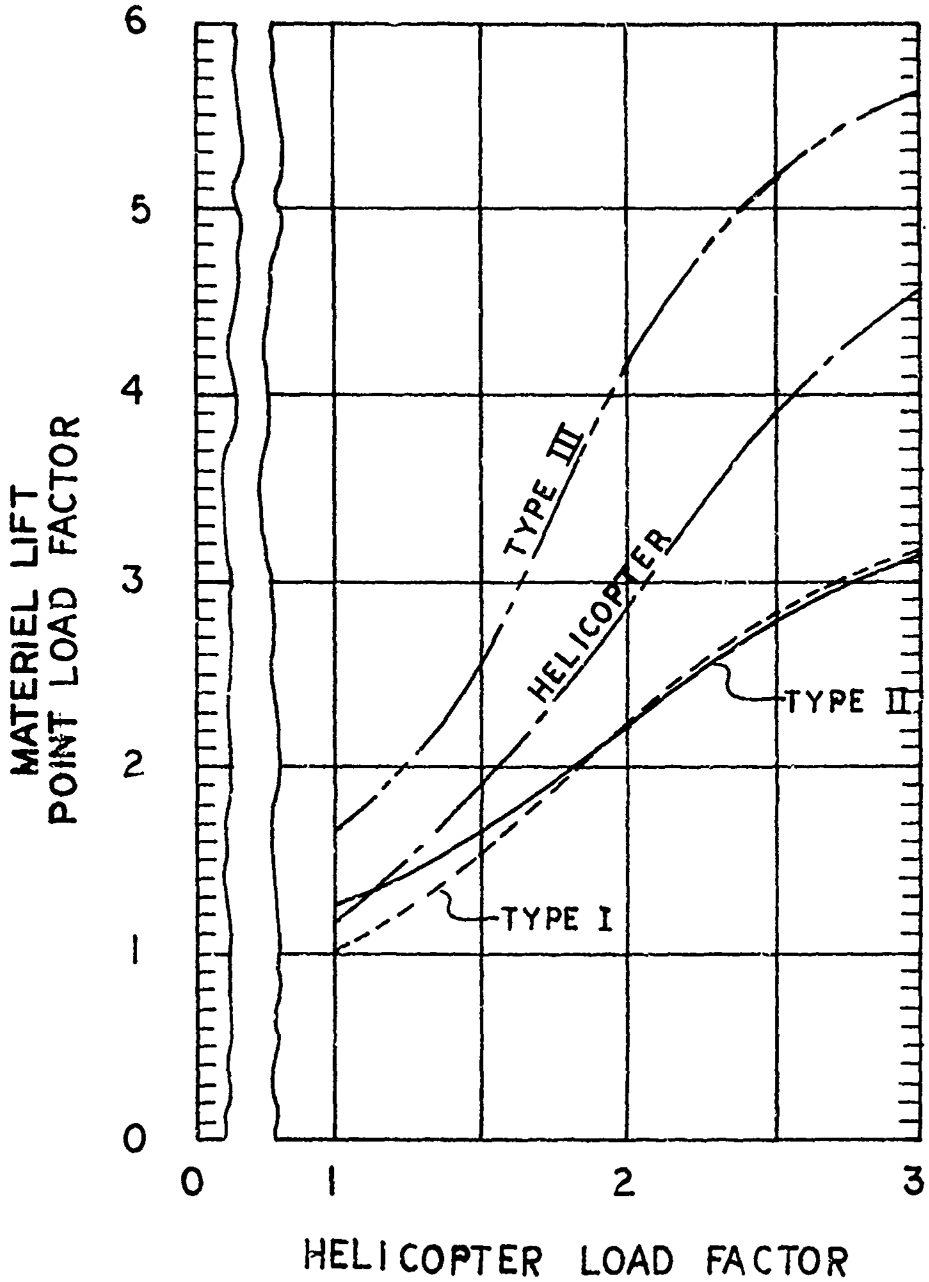


Figure 8. Materiel Lift Point Load Factor Variation With Helicopter Load Factor.

$$\text{Horizontal Force } (H_r) = V_r \frac{h_r}{K} = (4{,}512)\ \frac{11.24}{17.14} = 2{,}959 \text{ lb}$$

$V_F = 4{,}987$ lb and $H_F = 3{,}000$ lb are the largest values.

The load classification is made from Appendix V. The largest frontal area occurs when the diagonal is presented to the airstream. This area is

$\sqrt{(8)^2 + (20)^2}\ (2) = 43$ square feet. 19,000 lb/43 sq ft = 442 lb/sq ft.

This is a Type I load.

From Appendix I this load could be carried by a CH-47B at a load factor of 2.56. All others are less severe.

The lift point load factor from Figure 8 is 2.87.

Each lift point must react (4,987 lb) x 2.87 = 14,312 lb vertically and (3,000 lb) x 2.87 = 8,610 lb horizontally without permanent deformation and must withstand an ultimate load of (4,987 lb) x (2.8) x (1.5) = 21,468 lb vertically and (3,000 lb) x (2.87) x (1.5) = 12,915 lb horizontally.

GEOMETRIC CHARACTERISTICS OF LIFT POINTS

In order to be compatible with the sling systems used to suspend the materiel, the required geometric characteristics of the lift points have been established.

Shackle Requirements

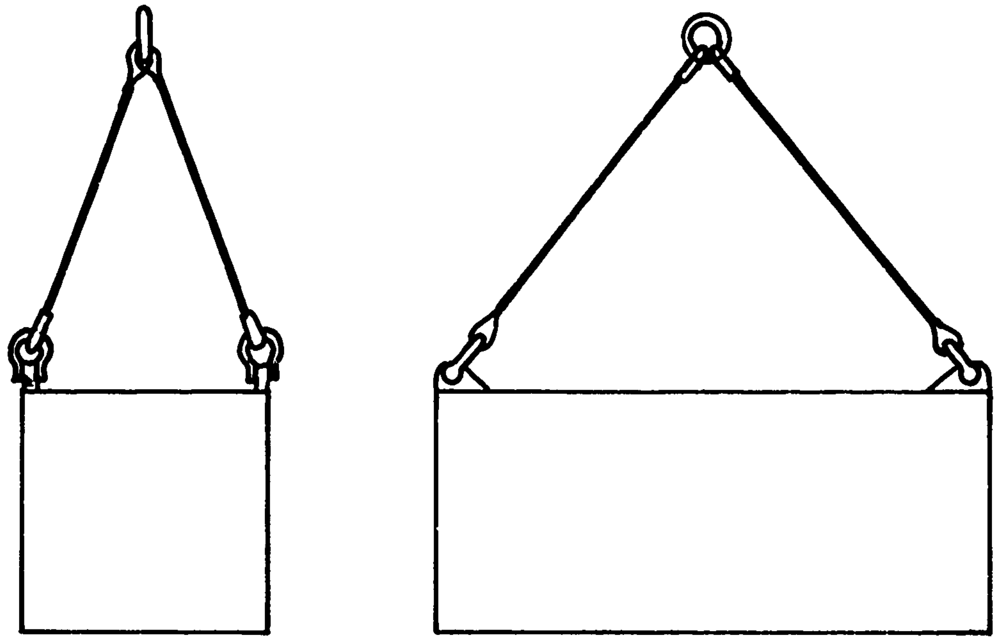
A shackle which conforms to or exceeds the structural requirements of Federal Specification RR-C-271a, Type IV, Class 4 is to be provided at each lift point. Use flat bar shackle if possible. This does not apply to specialized equipment such as milvan containers which have special lifting point fittings. The breaking strength requirement of the shackle is computed by two methods. The higher of the two values is the required breaking strength.

Method 1. Break Strength = R x Weight of Materiel

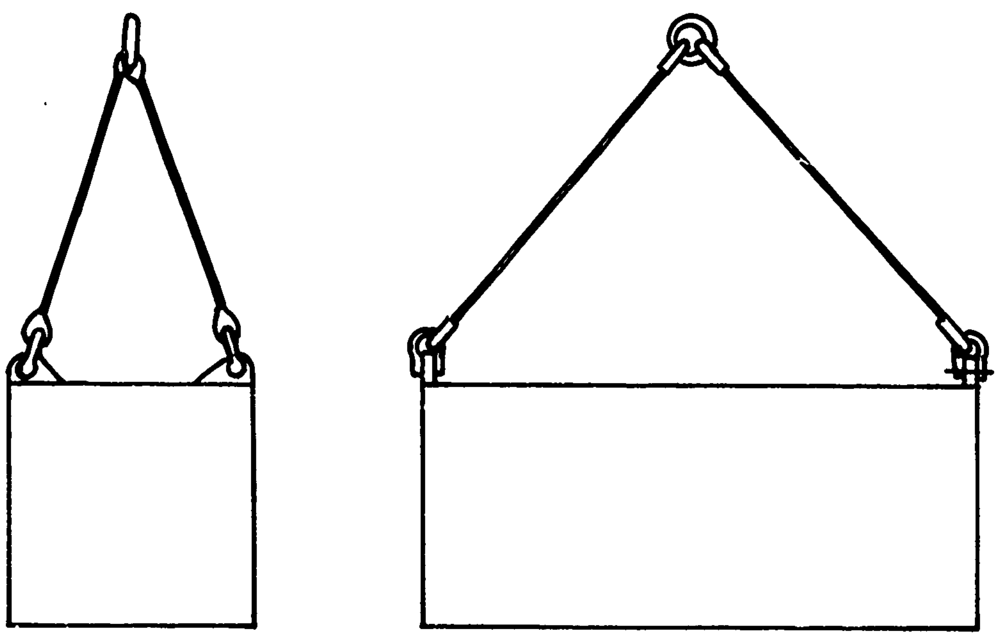
When the number of lift points is 4, R = 1.75

Number of lift points	R
4	1.75
3	2.33
2	3.50
1	5.0

Method 2. Break Strength = Static Load in Sling Leg x Lift Point Load Factor x 1.5



CORRECT ORIENTATION OF SHACKLES



INCORRECT ORIENTATION OF SHACKLES

Figure 9. Shackle Orientation Requirements.

Shackles are to be orientated so that bending loads on the shackle are kept to a minimum. Refer to Figure 9. Clearances around shackles shall permit easy installation of the appropriate attachment devices.

Alternate Lift Point Fittings

Blade or U-bolt type fittings may be used if it is impossible to provide shackles, provided the following requirements are met:

1. Fittings must be structurally adequate.
2. Fittings must be properly orientated (See Figure 10).
3. Fittings must be of the proper size to permit use of attach devices (See Figures 11, 12, 13, 14).

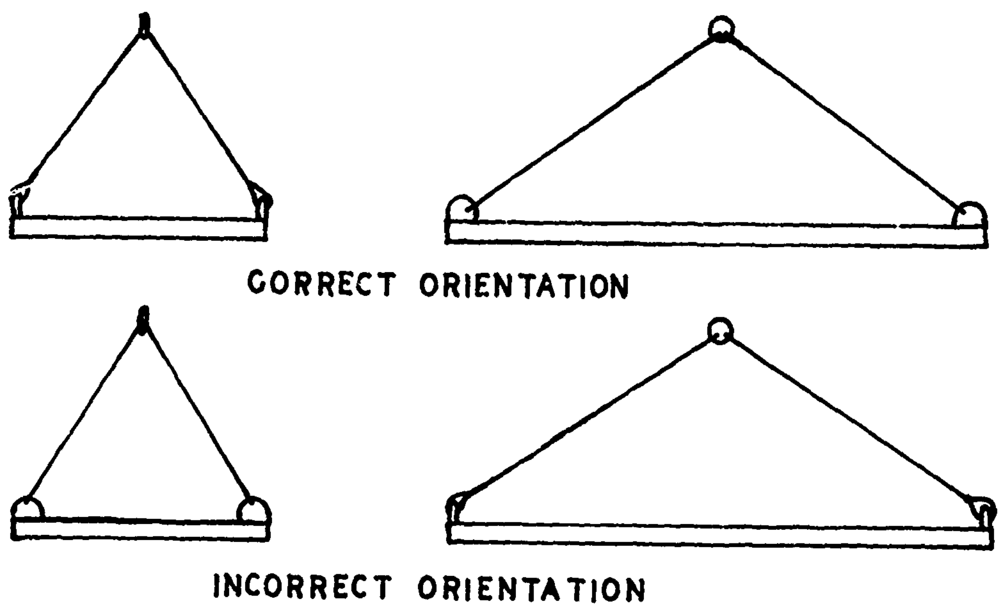
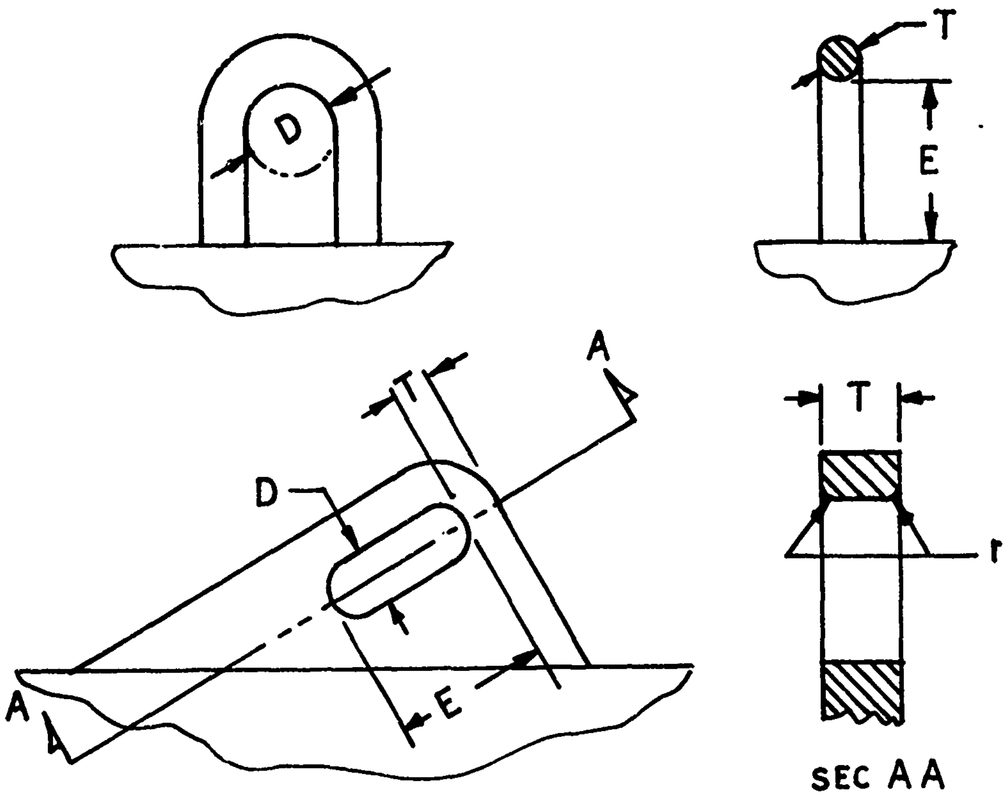
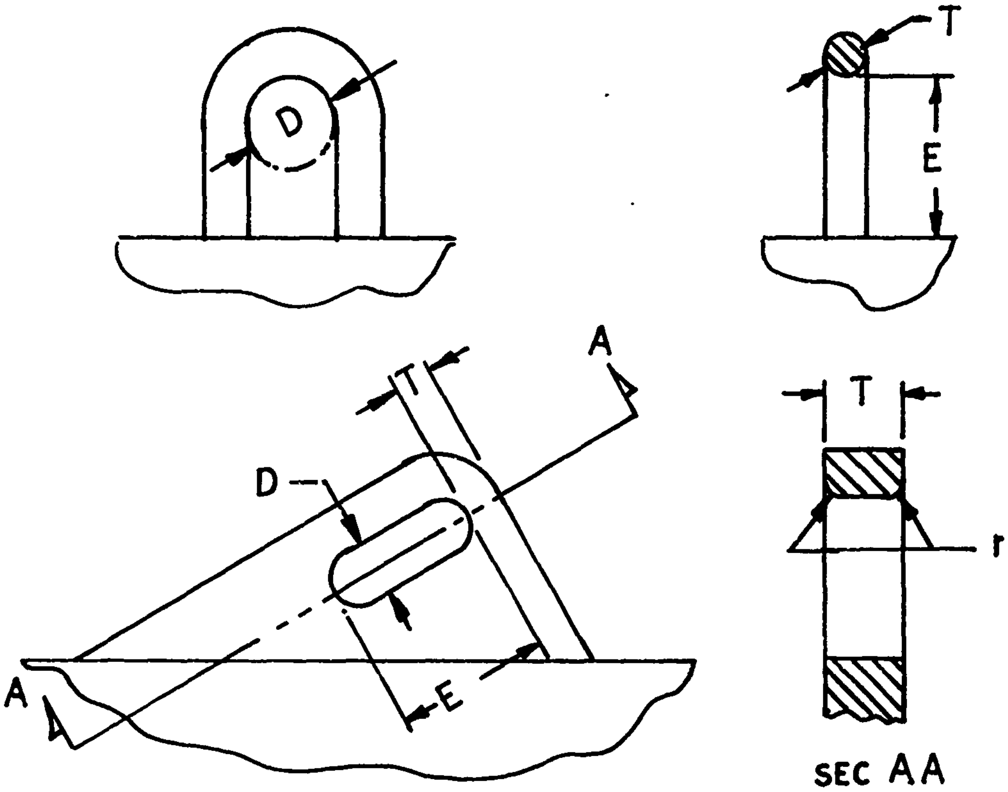


Figure 10. Fitting Orientation Requirements.



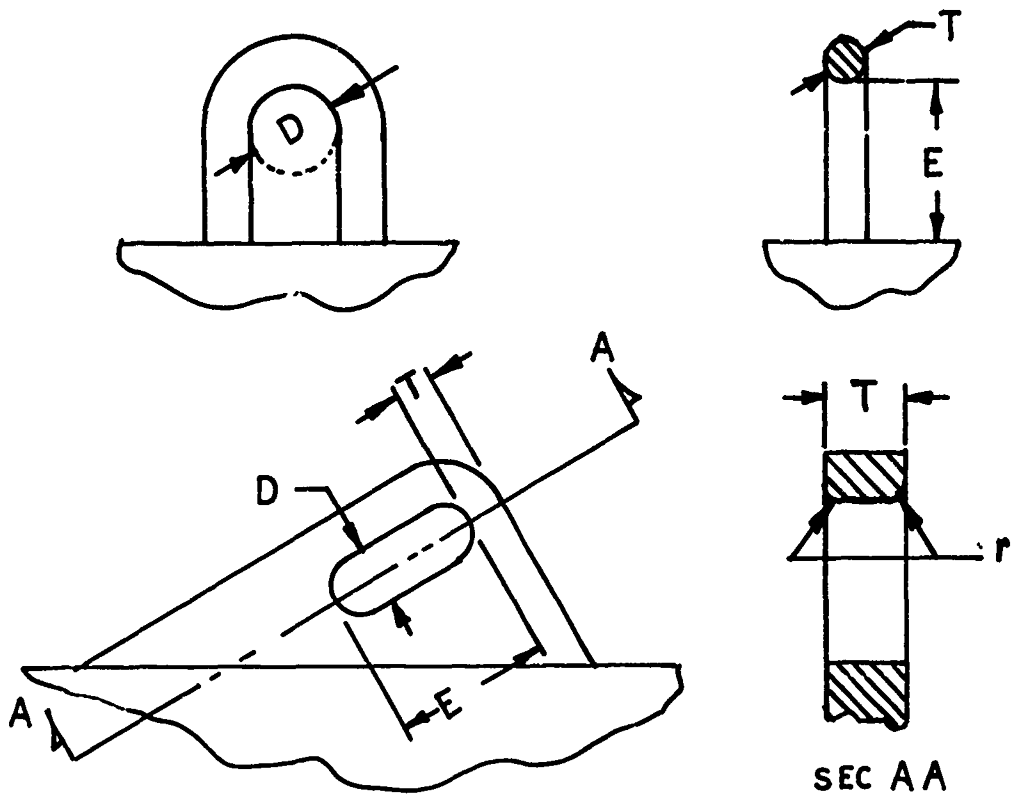
Weight Range of Materiel, lb	D_{min}	E_{min}	T_{max}	r_{min}
Up to 11,200	1-1/4	1-7/8	15/16	3/16
11,200 to 22,400	1-3/4	2-13/16	1-7/16	5/16
22,400 to 49,280	2-7/8	3-3/8	1-3/4	3/8
49,280 to 101,000	4	6	2-7/8	5/8

Figure 11. Fitting Dimensional Requirements - Four Lift Points.



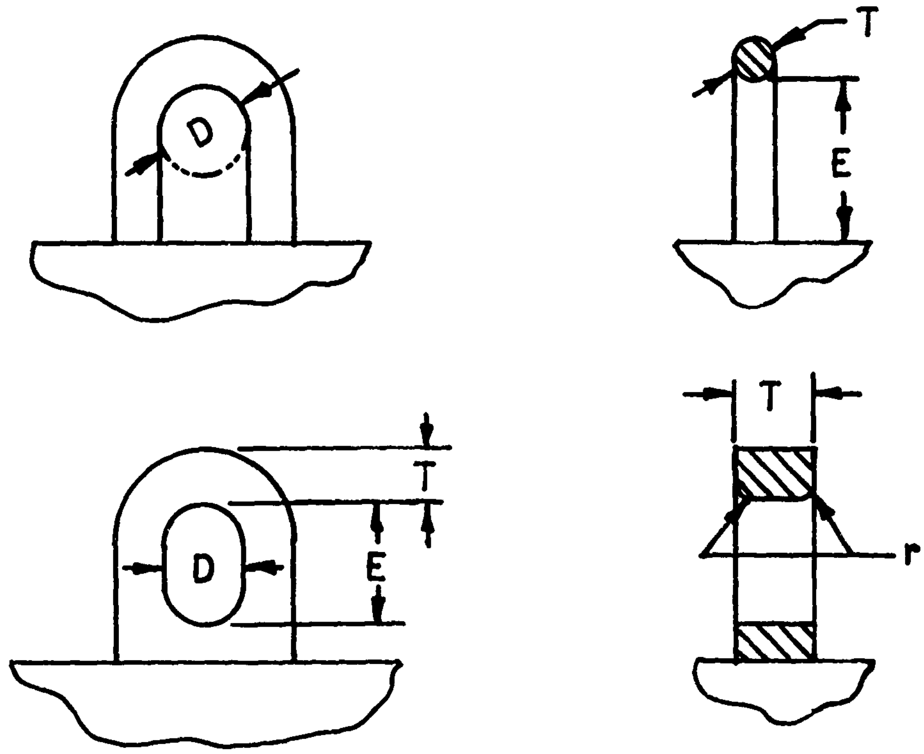
Weight Range of Materiel, lb	D_{min}	E_{min}	T_{max}	r_{min}
Up to 11,200	1-3/4	2-1/16	1-1/4	1/4
11,200 to 22,400	2-3/8	2-13/16	1-7/16	5/16
22,400 to 49,280	3-7/16	3-3/4	1-7/8	3/8
49,280 to 101,000	4-7/16	6-7/8	3-1/4	11/16

Figure 12. Fitting Dimensional Requirements - Three Lift Points.



Weight Range of Materiel, lb	D_{min}	E_{min}	T_{max}	r_{min}
Up to 11,200	2	2-3/8	1-5/8	3/8
11,200 to 22,400	3-1/8	2-3/4	1-15/16	3/8
22,400 to 49,280	4-1/8	4	2-7/8	5/8
49,280 to 101,000	6	6	4	3/4

Figure 13. Fitting Dimensional Requirements - Two Lift Points.



Weight Range of Materiel, lb	D_{min}	E_{min}	T_{max}	r_{min}
Up to 11,200	2-3/8	2-9/16	1-7/16	1/4
11,200 to 22,400	3-7/16	3-15/16	1-7/8	3/8
22,400 to 49,280	5-7/16	6-7/8	3-3/16	5/8
49,280 to 72,000	5-13/16	7-9/16	3-13/16	3/4

Figure 14. Fitting Dimensional Requirements - One Lift Point.

MATERIAL TO BE CARRIED BY HELICOPTERS WITH

MULTIPOINT SUSPENSION SYSTEMS

The multipoint suspension systems differ from the single-point suspension systems previously discussed in that the materiel is attached to the helicopter at more than one point. The CH-54A and the CH-54B are the only two helicopters presently in the U.S. Army inventory equipped with multipoint suspension systems. The design criteria and procedures described in this section are directly applicable to these two aircraft models. It is anticipated that future heavy lift helicopters will have multipoint suspension systems and that the criteria and design procedures in this section can be readily adapted to the future configurations.

LOCATION OF LIFT POINTS

In order to achieve stability in flight and to be compatible with the aircraft suspension system, the following procedures governing the location of the four lift points must be adhered to.

Location In The Vertical Plane

It is desirable for all four lift points to be located above the center of gravity of the materiel, in both the empty and the fully loaded condition. If this requirement cannot be met, the center of gravity must be located within a triangle whose apex angle is 120° and whose base leg is formed by the lift points. Figure 15 illustrates the relationship between the center of gravity and the four lift points on the materiel.

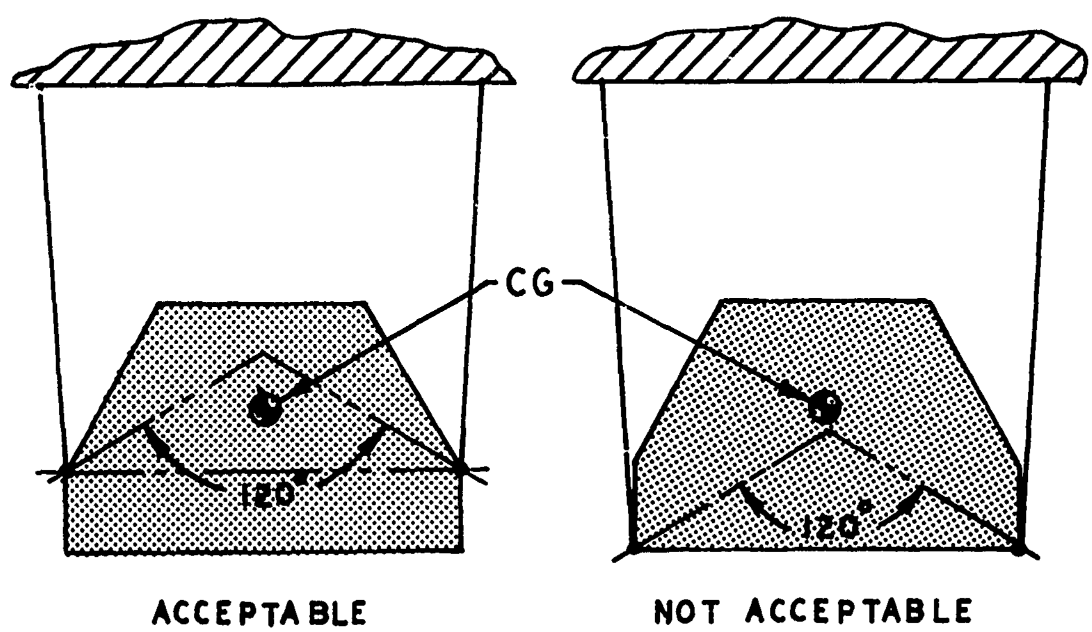


Figure 15. Lift Point CG Relationship - Multipoint Suspension System.

Location In The Horizontal Plane

All lift points are to be located symmetrically about a longitudinal axis and a lateral axis, both axes passing through the materiel center of gravity. If exact symmetry cannot be achieved, limited asymmetry is permissible provided the following requirement is met. Using the asymmetrical geometry, calculate the vertical static forces at each lift point. The ratio of the largest vertical force to the smallest vertical force must not exceed 1.2 (see Figure 16). This does not apply to specialized equipment such as milvan containers which have special lift point fittings.

The four lift points are to be located so that the tension member fleet angle, which is the angle between the vertical and the line of action, does not exceed 20° when the materiel is lifted clear of the ground.

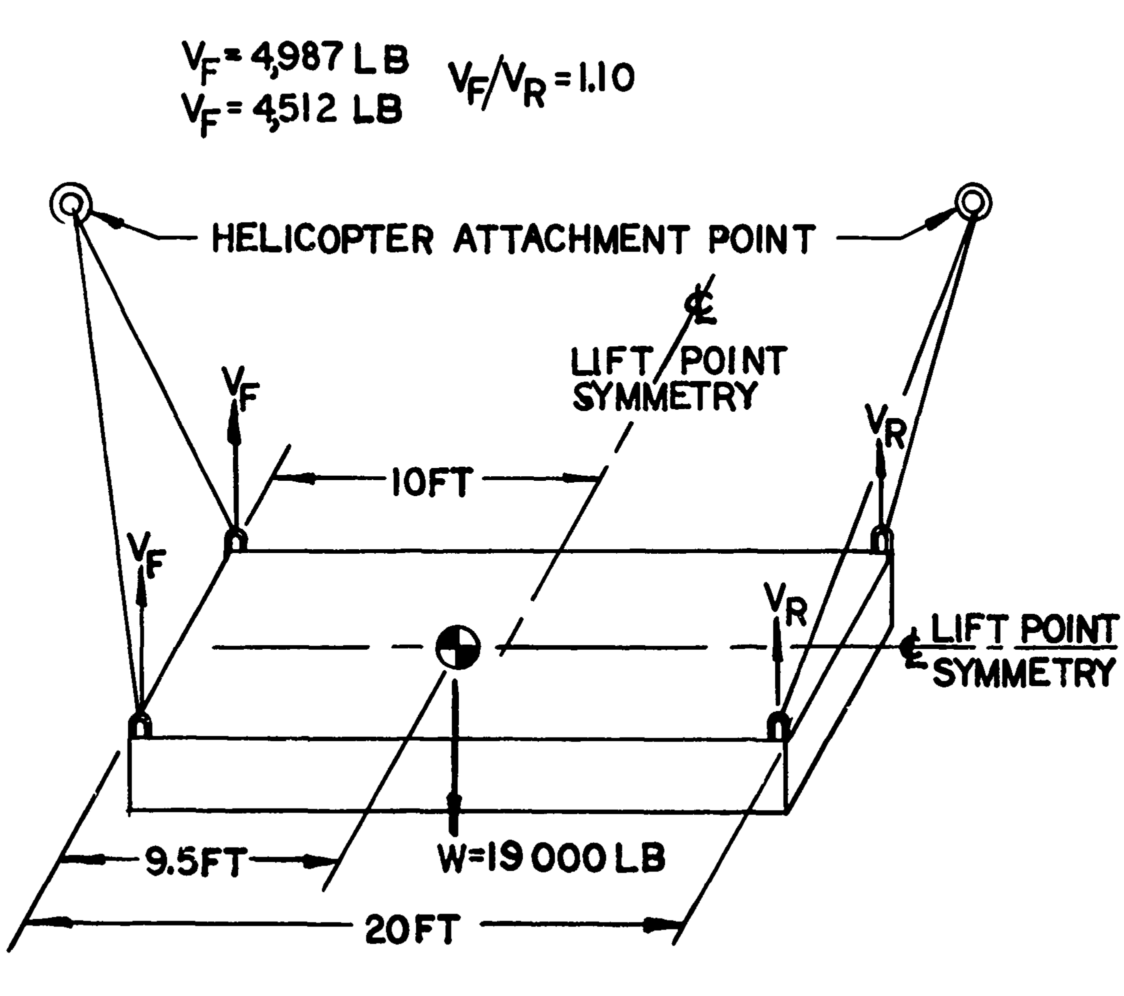


Figure 16. Four-Point Asymmetrical Sling Geometry With Two Helicopter Lift Points.

Clearance Requirements

The four lift points are to be located so that there is at least 6 inches of clearance between the centerline of the tension member and the materiel, when the materiel is freely suspended. If the required clearance cannot be obtained, it may be necessary to remove or relocate the offending part on the materiel.

STRENGTH OF LIFT POINTS

In order to determine the strength requirements of the lift points, it is necessary to have the data called for under the Basic Data Requirements section and the location of the four lift points.

General Procedure

First, the static forces on the lift points are calculated. The materiel classification is made. Then, using the classification and the helicopter design load factor, the lift point load factors are determined. From these, the ultimate strength requirements for the lift points and their substructure are determined.

Static Loads Calculation

With the materiel suspended from a multipoint suspension system calculate the vertical (V) and horizontal (H) components of the suspension leg tension at each of the lift points. Select the largest values of V and H (even if they do not occur at the same lift point) to serve as the basis for design. Figure 17 shows the basic geometry of two-point and four-point suspension systems.

Materiel Classification

The materiel classification, as established by a frontal area to weight ratio parameter, must be determined. With a multipoint suspension system the materiel is not permitted to rotate about a vertical centerline; hence the true frontal area, in square feet, divided by the materiel weight, in the fully loaded condition may be used in conjunction with Appendix V to determine the materiel type.

Lift Point Load Factor

With the materiel load type and the helicopter load factor established, the materiel lift point load factor may be determined from Figure 8. Apply this factor to the maximum values of V and H previously calculated. The resultant values represent the design limit loads for all four lift points. Each lift point must react these loads without permanent set and must also be capable of withstanding an ultimate load of 1.5 times the design limit load without failure.

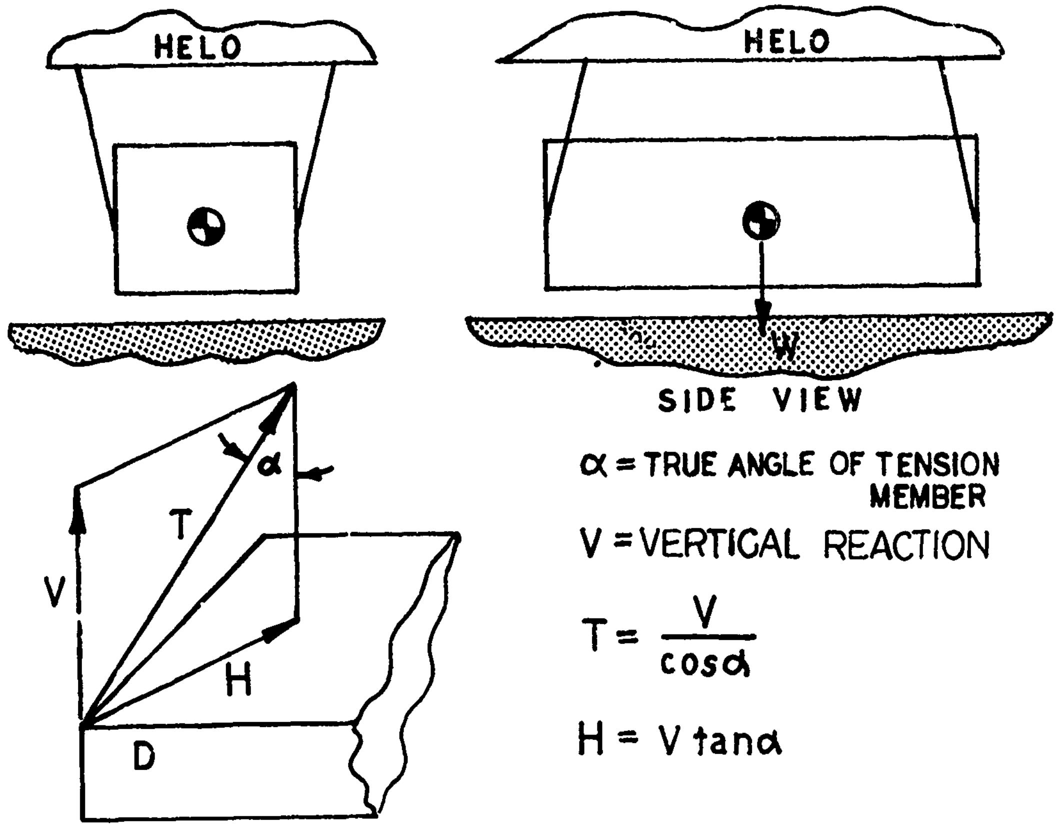


Figure 17. Basic Geometry of a Two-Point and a Four-Point Suspension System.

If the materiel is also to be carried using a sling, consult the standard lift point configuration section for strength requirements for that type of lift. In addition, the strength of the lift points must also conform to the requirements of MIL-STD-209 (Reference 4). In case the strength requirements of this document conflict with those of MIL-STD-209, use the higher values for the final structural requirements.

GEOMETRIC CHARACTERISTICS OF LIFT POINTS

In order to be compatible with the sling system used to suspend the materiel, the required geometric characteristics of the lift points have been established.

Shackle Requirements

A shackle which conforms to or exceeds the structural requirements of Federal Specification RR-C-271a, Type IV, Class 4 is to be provided at each lift point. The breaking strength requirement of the shackle is computed by two methods. The higher of the two values is the required breaking strength.

Method 1. Break Strength = 1.75 x weight of the materiel (4 pt.)

Break Strength = 3.50 x weight of the materiel (2 pt.)

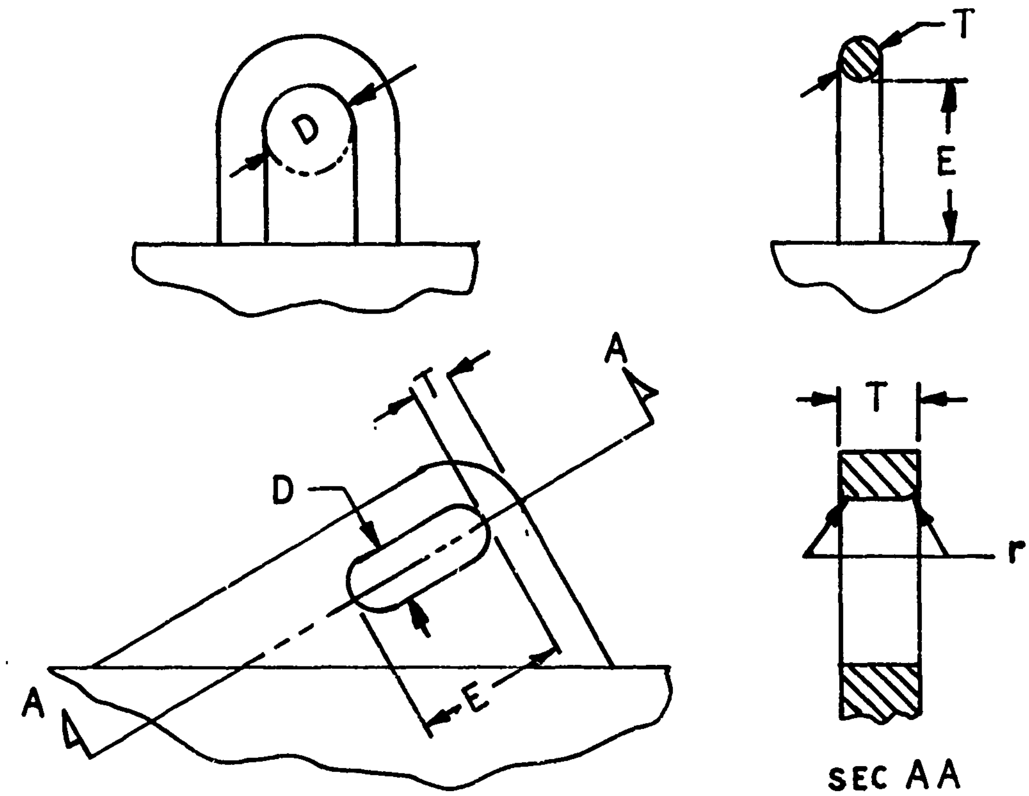
Method 2. Break Strength = Static load in sling leg x lift point load factor x 1.5

Shackles are to be orientated so that bending loads on the shackles are kept to a minimum. Refer to Figure 9.

Alternate Lift Point Fittings

Blade or U-bolt type fittings may be used if it is impossible to provide shackles, provided the following requirements are met:

1. Fittings must be structurally adequate.
2. Fittings must be properly orientated (see Figure 10).
3. Fittings must be of the proper size to permit the use of attachment devices (see Figure 18).



Weight Range of Materiel, lb	D_{min}	E_{min}	T_{max}	r_{min}
Up to 11,200	1-1/4	1-1/2	7/8	3/16
11,200 to 22,400	1-3/4	2-1/8	1-1/8	1/4
22,400 to 49,280	2-3/8	3-1/4	1-11/16	3/8
49,280 to 110,000	3-7/16	4-1/2	2-9/16	1/2

Figure 18. Fitting Dimensional Requirements - Four-Point Suspension.

HUMAN FACTORS CONSIDERATIONS

ACCESSIBILITY

All lift points must be readily accessible. Where feasible, they shall be within reach of personnel on the ground. When this is impossible, consideration shall be given to the provisions of integral steps, hand holds etc. to permit personnel to reach the lift points and to attach the sling leg without the necessity of obtaining a ladder or similar aid.

SLING-HELICOPTER ATTACH POSITION

A location shall be provided wherever possible to permit the hookup man to stand erect on the materiel when attaching the apex fitting to a helicopter hovering overhead. Means must also be provided to permit him to rapidly reach the ground after the hookup has been made.

FRAGILE MATERIALS

Glass and other brittle or fragile materials shall not be located in areas swept by the sling legs (areas from slack leg position to fully loaded position). If design considerations make it impossible to eliminate these materials, special provisions must be made to protect them from damage.

FOULING OF SLING LEGS

Care must be taken to ensure that sling legs do not foul or snag any part of the materiel when the legs are repositioned from the slack to the fully taut condition.

LABELING

All lift points must be clearly labeled. Letters shall be at least 1 inch high and shall be visible to personnel on the ground.

ROTOR DOWNWASH

Materiel shall be capable of resisting rotor downwash velocities as high as 60 mph without damage. Nonstructural materials, such as canvas covers must be firmly attached to prevent them from coming loose under these conditions. Such loose materials can be ingested into a helicopter's engine(s), possibly resulting in engine failure.

DESIGN GUIDE FOR SLINGS

BASIC DATA REQUIREMENTS

In order to design a sling system to be used for the external transport of material by helicopter, the following basic data must be available to the de igner. The data are divided into two classes: those relating to the helicopter(s) which are expected to be used with the sling and those relating to the materiel to be suspended from the sling.

Helicopter Data:

1. The design (limit load) factor for the helicopter(s) to be used with the sling system.

2. The maximum payload capability of the helicopter(s) to be used with the sling system.

3. The characteristics of the helicopter attachment point relating to distance below the fuselage, type (fixed or variable), and swivelling.

Suspended Materiel Data:

A definition of the spectrum of materiel to be supported by the sling system.

THE SLING SYSTEM

A sling system consists of all those items necessary to make the physical connection between the lift points on the materiel and the aircraft attachment point, usually a hook. Sling systems differ in the number and types of components, depending upon the functions required of the sling system. The two basic types of sling systems are illustrated schematically in Figures 19 and 20. Figure 19 illustrates the sling system with a pendant, and Figure 20 illustrates the sling system without a pendant.

Sling System With Pendant

The sling system with pendant is used on helicopters whose attachment point or cargo hook is mounted in the bottom of the fuselage and cannot be raised or lowered by means of a hoist or other mechanism. It consists of a sling and a pendant. In a typical externally slung transport operation, the sling is attached to the lift points of the materiel. The hookup man stands on the materiel and holds the apex of the sling. The helicopter approaches with the pendant suspended from the aircraft hook and hovers over the materiel so that the lower end of the pendant is within reach of the hookup man, who then connects the apex of the sling to the lower end of the pendant. The hookup man moves off and the materiel is lifted. In this system the basic functions of the pendant are:

1. To provide clearance between the bottom of the helicopter and the hookup man while hovering during hookup.

2. To provide clearance between the materiel and the aircraft in flight to avoid portions of the materiel striking the aircraft during flight maneuvers or due to load oscillations.

3. To provide, or help provide, the decoupling action between the slung load and the aircraft required to avoid objectionable vertical bounce oscillations.

In this system the basic function of the sling is to suspend the materiel from the end of the pendant in such a manner as to provide as much in-flight stability to the materiel as possible.

Sling System Without Pendant

The sling system without pendant is used on helicopters whose attachment point, or cargo hook, can be raised or lowered from the aircraft by means of a hoist or other device. Helicopters with cargo hoists have decouplers built into the hoist installations to provide the required decoupling action. This feature, plus the ability to lower the cargo hook to any desired position, does away with the requirements for a pendant.

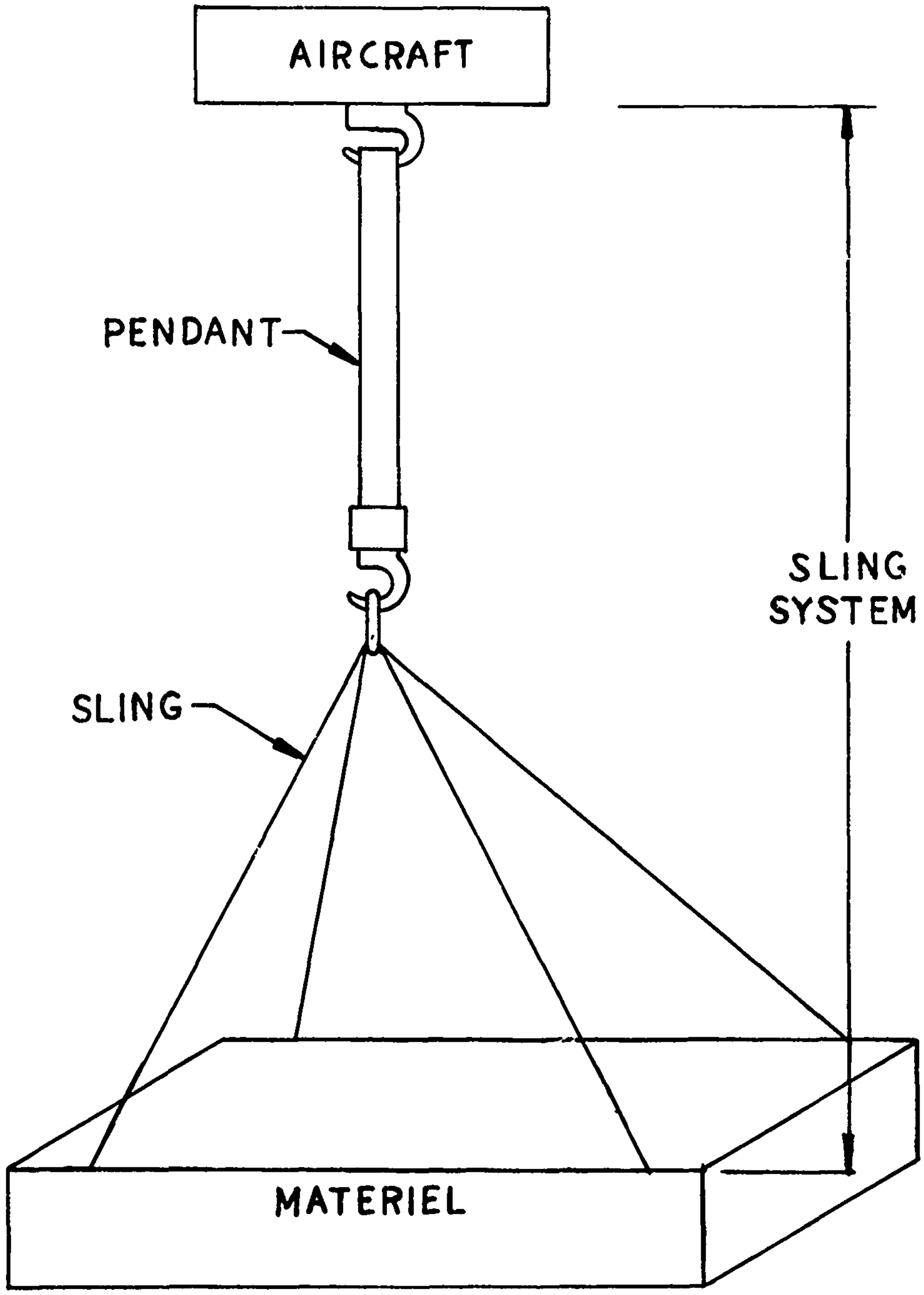


Figure 19. Sling System With Pendant.

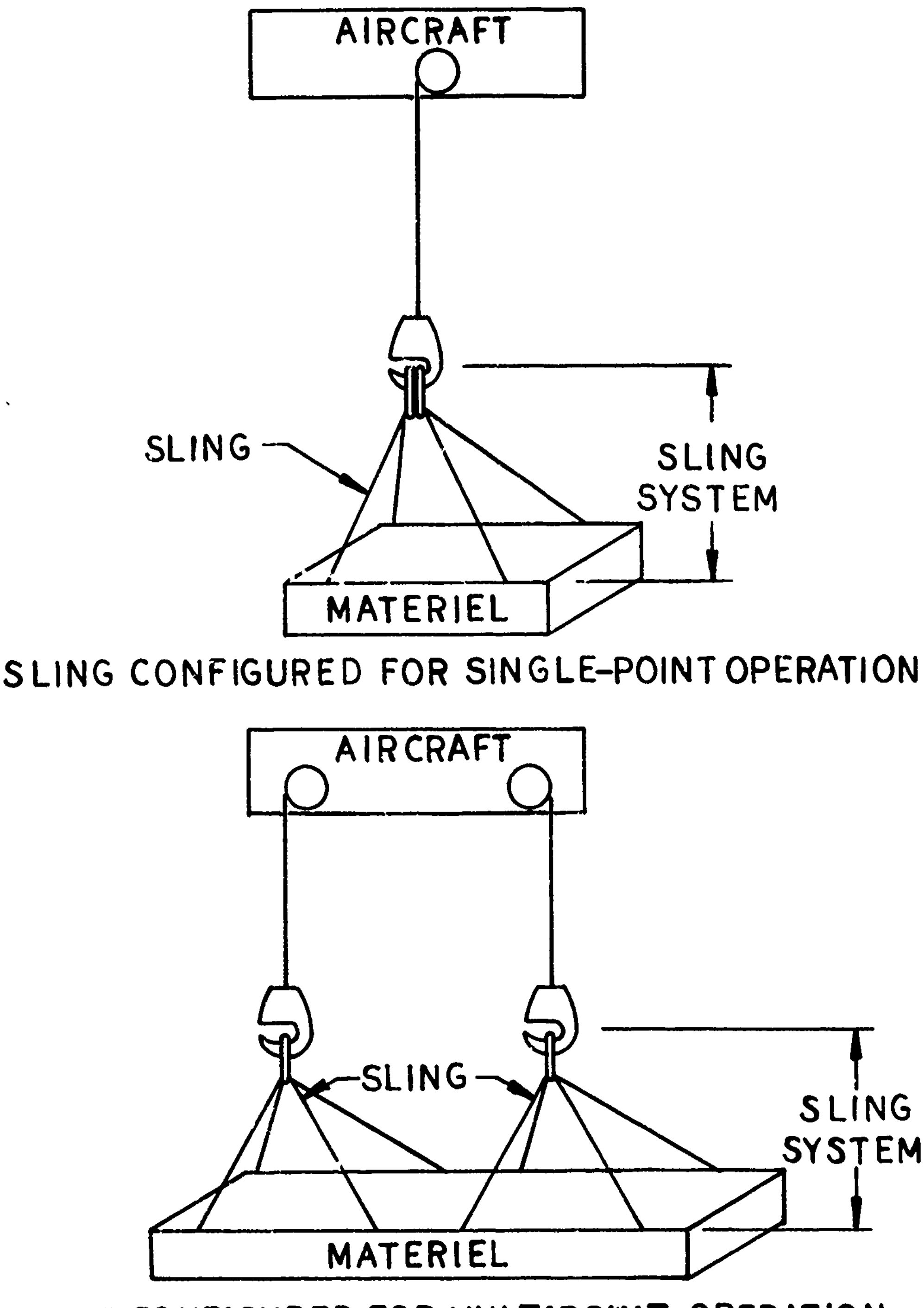


Figure 20. Sling System Without Pendant.

MATERIALS

Many materials can be used in the design of slings. Appendix II identifies and describes the mechanical and physical properties of some materials which could be used in the design of slings and pendants. The materials included in Appendix II are generally those for which sufficient test data have been generated to establish quantitative physical properties. The designer is not limited to the materials described in Appendix II, provided that quantitative data on the effects of environment are available for any sling material chosen.

REDUCED ULTIMATE STRENGTHS

Sling materials are subjected to a variety of detrimental effects during manufacturing and during their normal use. Each of these effects reduces the ultimate strength of the basic sling material. Table I lists the reduced ultimate strength factors for various sling materials for various environmental effects. These factors are applied to the breaking strength of the new material (see Apeendix II).

The reduced ultimate strength of a given sling material can be determined by multiplying its breaking strength by all of the factors listed for that material in Table I.

Exposure occurs when materials are subjected to weathering conditions. The single most destructive agent is ultraviolet light. When textile materials are exposed to the effects of ultraviolet light for long periods of time (up to a year) significant loss of strength occurs. Protection against the detrimental effects of ultraviolet light can be provided by the designer by using urethane or polymer coatings over the textile sling members. Sleeves over sling legs help screen out ultraviolet light. If the textile material is suitably protected against ultraviolet light by one or more of these methods, the exposure factor found in Table I may be raised to 0.9. Slings should be stored away from strong sunlight when not being used. The designer can provide a light-tight bag for sling storage.

Tempterature variation means the material is subjected to -65° F to 160° F at 95% relative humidity.

Sea water immersion means the material is soaked in sea water for periods up to 24 hours and then washed off in fresh water. The use of waterproof coatings on textiles by the designer and the prompt and thorough washing by the user will reduce the detrimental effects of sea water.

Sand: No quantitative strength reduction factor is given in Table I. Exposure to sand means that significant quantities of sand have been worked into the weave of the material, such as when a wet sling is dragged across a sandy beach. When this occurs, the reduction in strength is prohibitively high for textile materials. Therefore, textiles must be protected from the detrimental effects of sand, both in design and in usage. Urethane or polymer coatings which fill in the pores between the strands of a textile material will keep sand out of the weave. Zippered sleeves and

storage bags will help prevent the sling materials from impregnation by sand particles.

Pin diameter refers to the size of the pin over which textile materials are wrapped to form an end loop. Significant strength losses occur when pin diameters go below 1.25 inches.

TABLE I. REDUCED ULTIMATE STRENGTH FACTORS

Material	1 Year Exposure	Temperature Variation	Sea Water Immersion	Sand	Pin Diameter 1-1/4 and Up	Pin Diameter 1.00	Pin Diameter .750
Wire Rope	1.00	1.00	1.00	.96	Not Applicable		
Type X Nylon	.90		.85		1.00	.90	.80
Type XIX Nylon	.79	1.00	.91	Protection From	1.00	.92	.79
Type XXVI Nylon	.54	.93	.90	Sand Must	1.00	.91	.81
Type V Dacron	.62	1.00	1.00	Be Provided	1.00	.91	.81
Type VI Dacron	.90	.94	1.00		1.00	.91	.81

SLING SYSTEM DESIGN

Design criteria and procedures for sling system design have been separated into two areas: sling design and pendant design. Sling systems designed to these criteria will be compatible with Army helicopters and with the materiel to be carried by the sling.

SLING DESIGN

Sling design criteria and procedures have been divided into three areas corresponding to the three major portions of a sling:

1. The apex fitting.

2. The main body of the sling.

3. The materiel attachment point fittings.

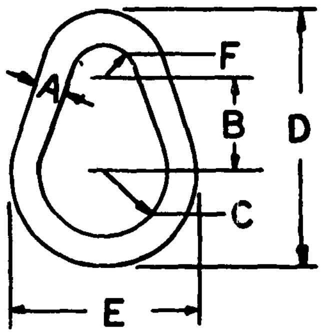
The Apex Fitting

The apex fitting is located at the top of the sling. Its function is to gather the legs of the sling together and make the connection to the aircraft or pendant load attachment point. When the sling is used without a pendant it will attach directly to the aircraft hook which can be raised or lowered and can swivel. On aircraft with fixed hooks, a pendant with a swivel is required and the sling will attach to the end of the pendant. The apex fitting should be dimensionally stable under load so that it does not tighten itself on the aircraft hook and interfere with the smooth release of the slung load when the hook is opened. Therefore, the apex fitting should be a pear shaped link, an oblong link or a ring in that order of preference. The link or ring should be as shown in Figure 21.

Note that commercially produced links or rings are of two types: welded and forged. The forged links are about 75 percent stronger than the welded links for a given size and therefore weigh less for a given strength requirement. The weight of the apex link should be kept to a minimum because the man standing on the materiel has to lift the apex fitting and part of the weight of the main body of the sling during hookup.

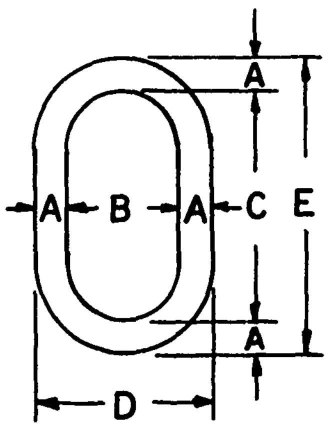
Apex Fitting Strength Requirements

To determine the ultimate strength requirement of the apex fitting, it is necessary to know the static load capacity of the sling being designed and the design load factor for the helicopter(s) with which the sling will be used. This factor may be obtained from Appendix I which lists design load factors for helicopters presently in U.S. Army inventory. The designer should select the highest design load factor, based on Appendix I.



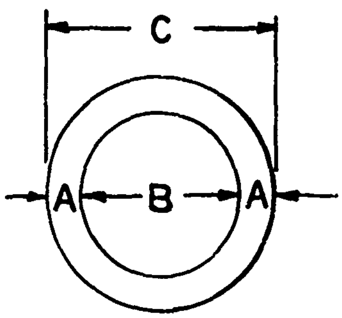
FORGED STEEL - HEAT TREATED

Stock Dia. A in.	B in.	C in.	D in.	E in.	F in.
7/8	2.63	1.75	7.00	5.25	0.88
1	3.00	2.00	8.00	6.00	1.00
1-1/4	4.00	2.50	10.25	7.50	[illegible]
1-3/8	4.13	2.75	11.00	8.25	1.38



FORGED ALLOY STEEL - HEAT TREATED

Stock Dia. A in.	B in.	C in.	D in.	E in.
3/4	2.75	5.50	4.25	7.00
1	3.50	7.00	5.50	9.00
1-1/4	4.38	8.75	6.88	11.25
1-1/2	5.25	10.50	8.25	13.50
1-3/4	6.00	12.00	9.50	15.50
2	7.00	14.00	11.00	18.00



FORGED STEEL - HEAT TREATED

Stock Dia. A in.	B in.	C in.
7/8	4.00	5.75
7/8	5.50	7.25
1	4.00	6.00
1-1/8	6.00	8.25
1-1/4	5.00	7.50
1-3/8	6.00	8.75

Figure 21. Apex Fittings.

Apex Fitting Load Factor

With the helicopter design load factor established, the apex fitting load factor may be determined from Figure 22. Multiply the apex fitting load factor by 1.5 times the static load capacity of the sling to obtain the required ultimate strength of the apex fitting.

Ultimate strength of Apex Fitting = 1.5 (Static Load Capacity) x (Apex Fitting Load Factor)

The value of the apex fitting load factor (From Figure 22) depends upon the type of loads the sling is to carry. If the heaviest Type III load is ≥ 0.5(static rating of sling) then slings should be designed using a Type III load factor. If the heaviest Type III load is <0.5 (static rating of sling) then slings should be designed using Type I or II load factors. Refer to Appendix V for load classification.

The Main Body of The Sling

The main body of the sling consists of the tension members that comprise the sling legs.

Number of Sling Legs

The usual sling configuration has four sling legs. If a nonstandard sling is to be designed, the procuring agency should specify the required number of legs. Materiel suspended by slings with fewer than four legs will undergo severe changes in attitude during flight if one leg is separated.

Length of Sling Legs

The length of each sling leg shall be adjustable between 18 and 22 feet. The length of a sling leg is measured from where it joins the apex fitting to where it engages the lift point on the materiel. Sling legs which can be adjusted to lengths shorter than 18 feet may have angles with the vertical of more than 45° with resultant high tensile loads in the sling leg.

Strength of Sling Legs

In order to determine the required ultimate strength of each sling leg, it is necessary to know the static load capacity of the sling and the highest design load factor for the helicopters with which the sling will be used.

Using the helicopter design load factor, the sling leg tension factor is determined from Figure 23. The ultimate strength requirements for each sling leg are given by the following equations where

U_L = Required ultimate strength for each sling leg (lb)

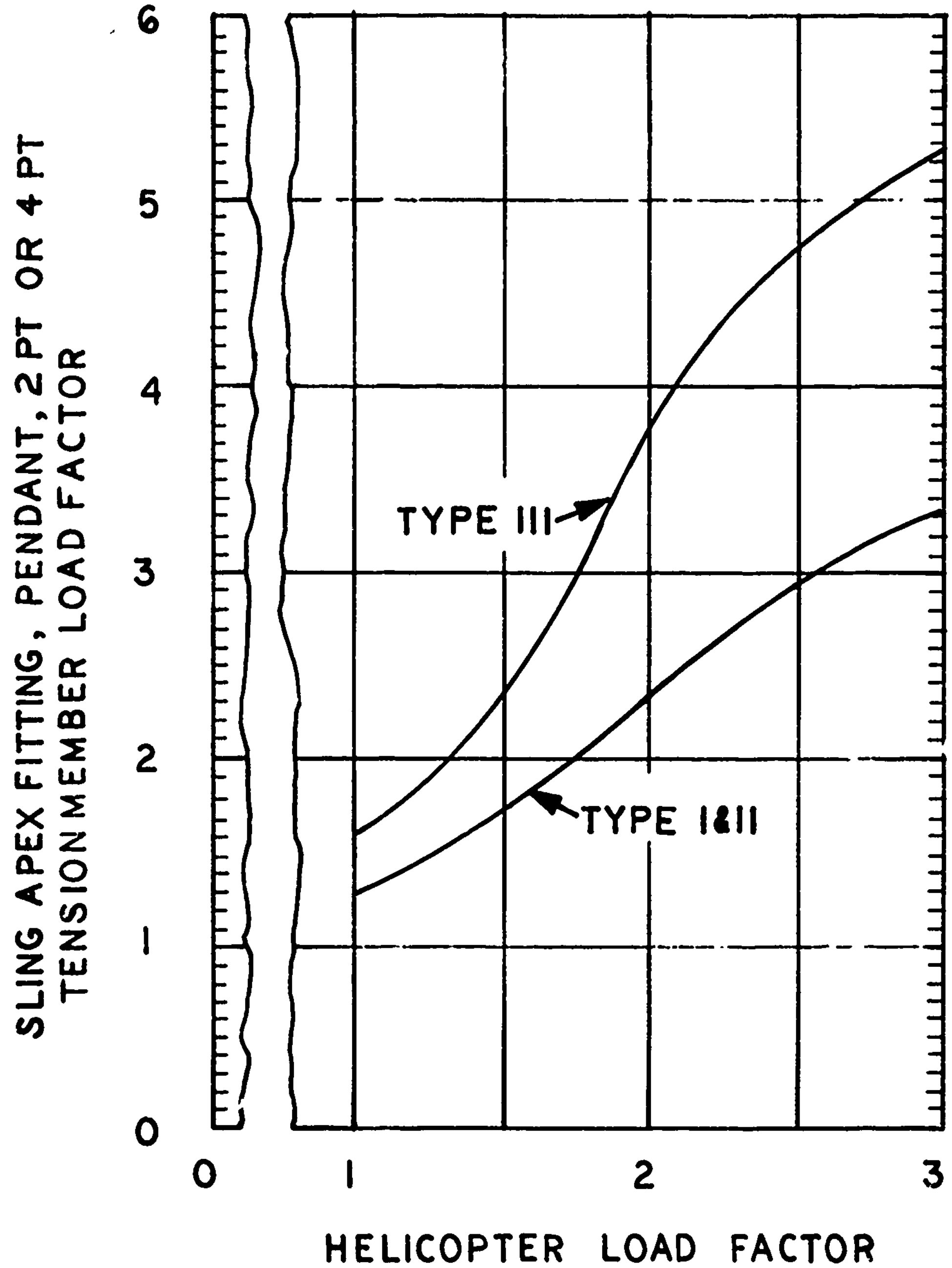


Figure 22. Sling Apex Fitting, Pendant, Two-Point or Four-Point Tension Member Load Factor Variation With Helicopter Load Factor.

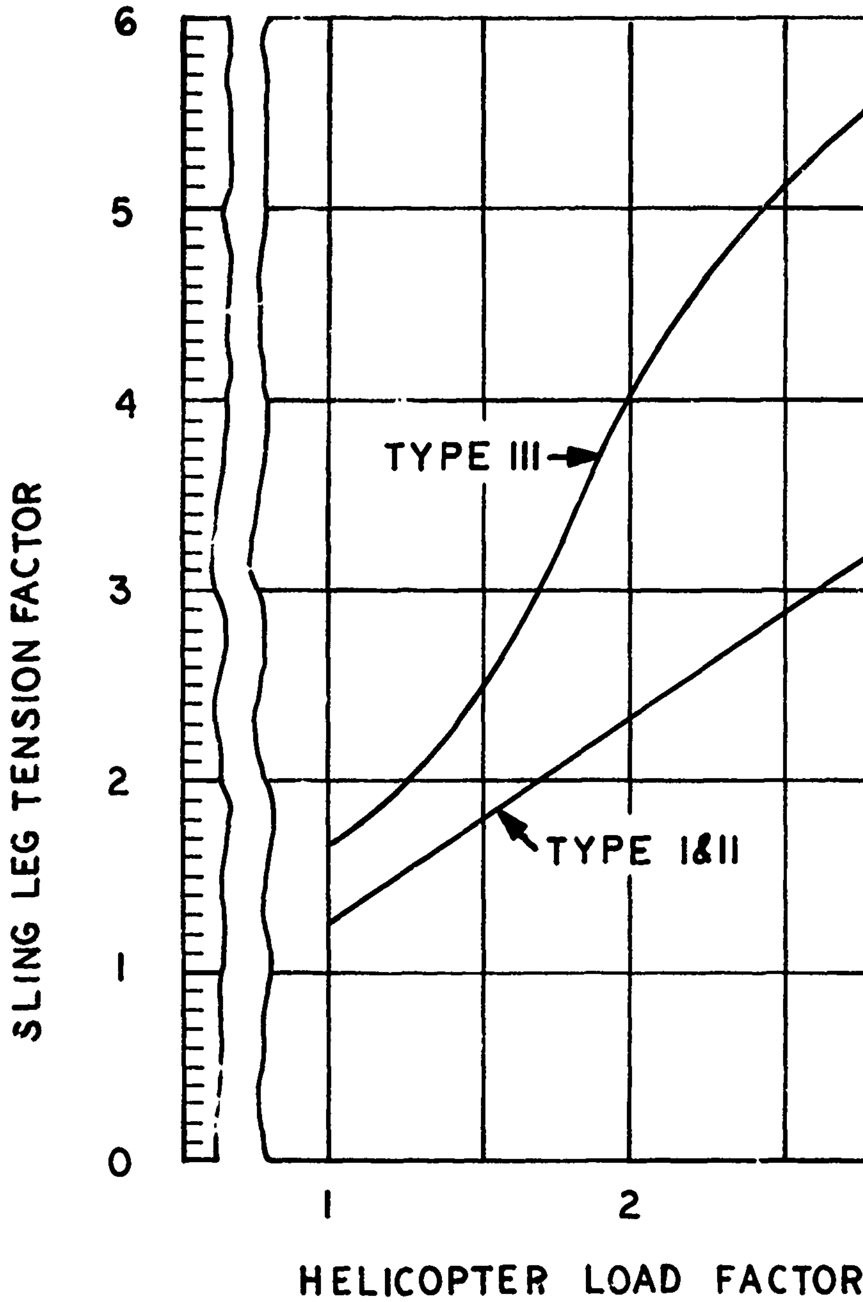


Figure 23. Sling Leg Tension Factor Variation With Helicopter Load Factor.

W = Static load capacity of the sling (lb)

K = Sling leg tension factor (from Figure 23)

For a four-legged sling, $U_L = 0.6\ (W)(K)$

For a three-legged sling, $U_L = 0.787\ (W)(K)$

For a two-legged sling, $U_L = 1.148\ (W)(K)$

For a single-legged sling, $U_L = 1.5\ (W)(K)$

The required ultimate strength for each sling leg (U_L) is compared to the reduced ultimate strength for the particular sling leg material chosen.

The value of K, which comes from Figure 23, depends upon the type of loads the sling is to carry. If the sling will carry the heaviest Type III loads ≥ 0.5 (static capacity of the sling) then the sling should be designed using a Type III load factor. If the heaviest Type III load is < 0.5 (static capacity of the sling) then the sling should be designed using Type I or II load factors. Refer to Appendix V for load classification.

For example: Assume a four-legged sling, with a static load capacity of 20,000 lb, is to be designed using Type XXVI nylon webbing in the sling legs. The sling is to be used for Type II loads, with helicopters having a maximum of a 2.5G design load factor then W = 20,000 lb, K = 2.86 and

$$U_L = .6\ (20{,}000)(2.86) = 34{,}320 \text{ lb}$$

From Tables I and IV the reduced ultimate strength for a single ply of Type XXVI nylon webbing is (assuming good pin design)

$$16{,}368\ (.540)(.932)(.903) = 7438.6 \text{ lb}$$

Five plies of Type XXVI nylon webbing are required in each leg of the sling.

Sling Leg Attachments

When textile webbing or wire rope are bent to form a loop, loss of strength occurs unless the following design practices are followed.

Wire Rope

Wire rope sling legs formed into a loop at the ends should have a heavy-duty thimble loop with a press sleeve, or a swaged end fitting as shown in Appendix III. These terminals will develop the rated breaking strength of the wire rope.

Wire rope clips, although convenient, are not to be used in sling design because of the chance of improper installation and torquing and the subsequent loosening as the rope stretches under load. Under ideal conditions and properly installed, a wire rope clip loop will only develop 80 percent of the basic rope strength.

Appendix III illustrates several types of wire rope terminals suitable for use in sling design. Typical dimensions for each terminal type are listed on the figures. Dimensions listed may vary slightly depending upon the manufacturer.

Textile Webbing

Textile webbing sling legs whose ends are formed into a loop over a pin, as shown in Figure 24, shall have a wear pad sewn on the inside of the loop where it passes over the pin. The pin diameter shall be 1-1/4 inches or larger so that no significant strength loss is incurred. If a pin diameter smaller than 1-1/4 inches is used, consult Table II for the appropriate reduced ultimate strength factor. In any case, pin diameters less than 3/4 may not be used.

Since a multi-ply webbing sling is thicker and heavier at the loop end due to the pin and associated hardware, severe local abrasion occurs when the sling is dragged across the ground. To prevent loss of strength, a wear pad shall be provided as shown in Figure 24.

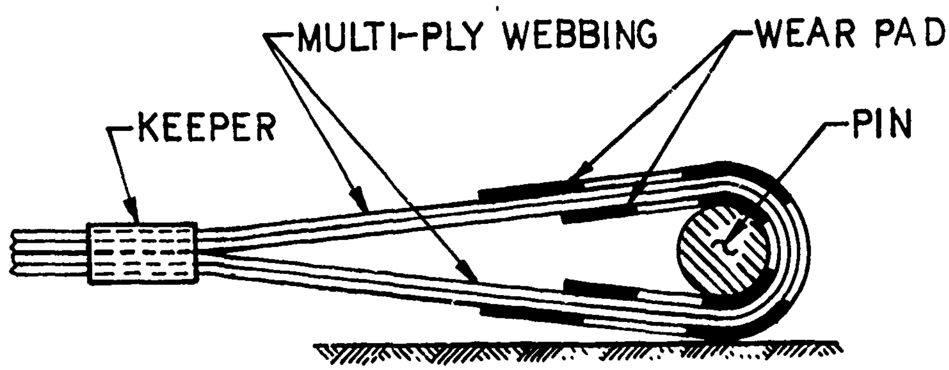


Figure 24. Textile Webbing Terminal.

The pins over which the webbing is wrapped shall be smooth to 125 micro-inches RMS. Part numbers, raised or indented, shall not appear on the surface of the pin. Part numbers may be rubber stamped on the pin surface or may appear on tags attached to the pin.

Figure 25 shows a typical sling leg end treatment for a synthetic rope sling.

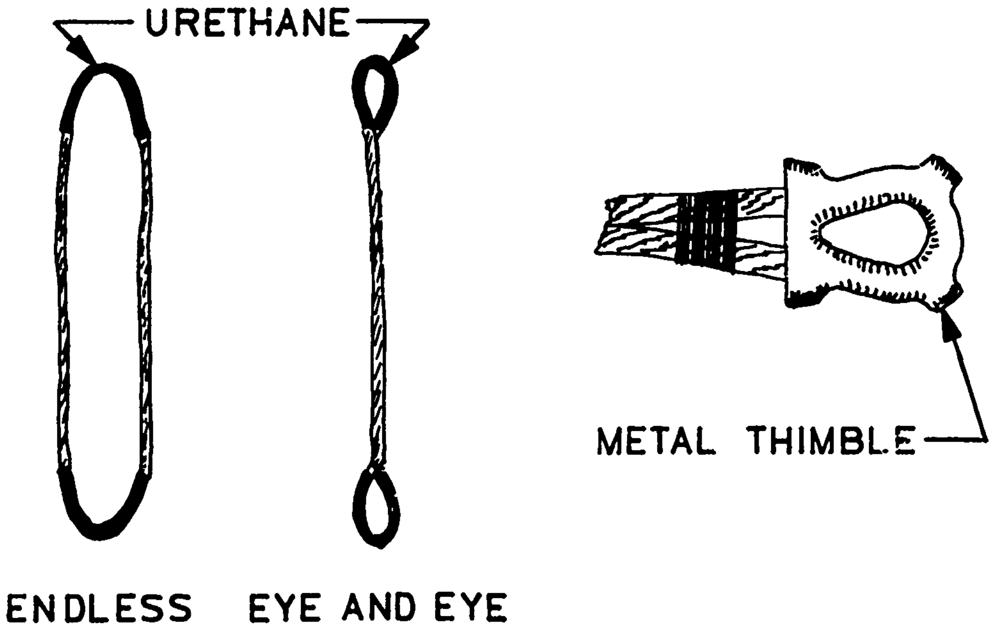


Figure 25. Synthetic Rope Sling Terminal.

Length Adjustment

Each sling leg shall be adjustable in length from 18 to 22 feet. Any device or method of adjustment is acceptable provided:

1. Such adjustment can be made by one man, in cold weather, wearing gloves.

2. The device allows adjustments in intervals of 2 inches or less in sling leg length.

3. The device meets the structural requirements of the sling leg.

4. The adjustment will not slip under any loads up to the required ultimate strength of the sling leg.

5. If the sling is to be designed integral to a piece of equipment, there is no requirement for adjustability.

Two methods of adjusting sling leg length are as follows:

1. The Chain Leg End. The chain leg end may be used with any sling leg material. It consists of a grab link attached to a length of chain. Refer to Figure 26.

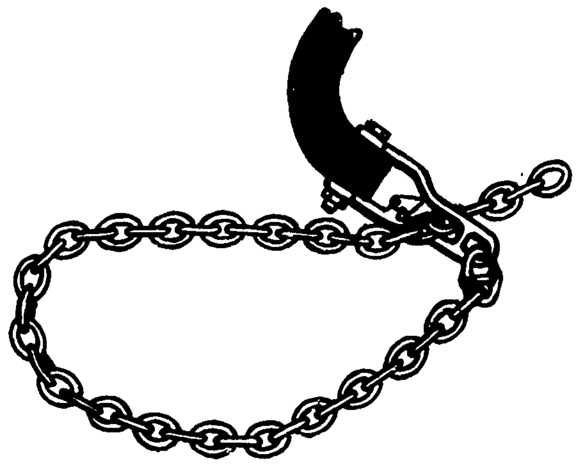


Figure 26. Chain Leg End.

The length of the chain is twice the amount of sling leg adjustment required. The grab link has a narrow throat guarded by a spring loaded keeper. When a link of the chain is engaged in the throat of the grab link, the adjacent links, oriented 90° from the engaged link, cannot pass through the grab link throat. When a chain link is engaged in the grab link, a loop of chain is formed. This loop of chain passes through the lift point on the load, and its length depends upon which link of chain is engaged.

The links are numbered consecutively from the free end. A rigging procedures manual tells the rigger which link to engage on each sling leg so that the load will be suspended properly. The advantages of the chain leg adjustment method are:

a. It provides a positive lock on the chain loop.

b. The chain can be used with all types of lift points on loads, and can be wrapped around suitable structure in the absence of formal lift points.

c. The length of the chain loop can be quickly and simply set.

d. The sling leg material does not come in contact with sharp or abrasive portions of the load.

e. The link by link arrangement allows the sling leg length to vary in small increments.

f. The operation of the chain and grab link is not hampered seriously by the presence of dirt or mud.

The principal disadvantage of the chain leg end is its weight. Depending upon the material chosen for the sling leg, the chain and grab links can account for as much as 40 percent of the total sling weight. In high capacity slings, this means increased difficulty in handling the slings.

2. The Webbing Gripper. The webbing gripper is a buckle-like device that uses a sliding wedge to snub the webbing and keep it from slipping. Refer to Figure 27.

The webbing gripper is used on slings whose legs are made from textile webbing. It is attached to a single ply of the webbing and by pulling the free end of the webbing through the gripper jaw, the sling leg length can be adjusted. Usually the webbing in the sling leg is marked at discrete intervals to allow the rigger to set the proper sling leg length. When used with a sling leg containing eight plies of webbing, the plies may not be sewn together. Since the gripper is attached to only one ply of material 8 feet of free end webbing must be pulled through to shorten the sling leg 1 foot. The remaining load-carrying portion of the webbing must be redistributed evenly to permit equal load sharing in the eight plys. There is a tendency for the wedge of the gripper to abrade the webbing under load. Repeated application of the webbing gripper to the same area of webbing could result in premature loss of strength in the sling leg. The rigger must be careful to see that the wedge is seated properly on the webbing. The presence of dirt or mud could cause the wedge to seat improperly and allow the webbing to slip. The gripper is relatively light in weight and low in cost.

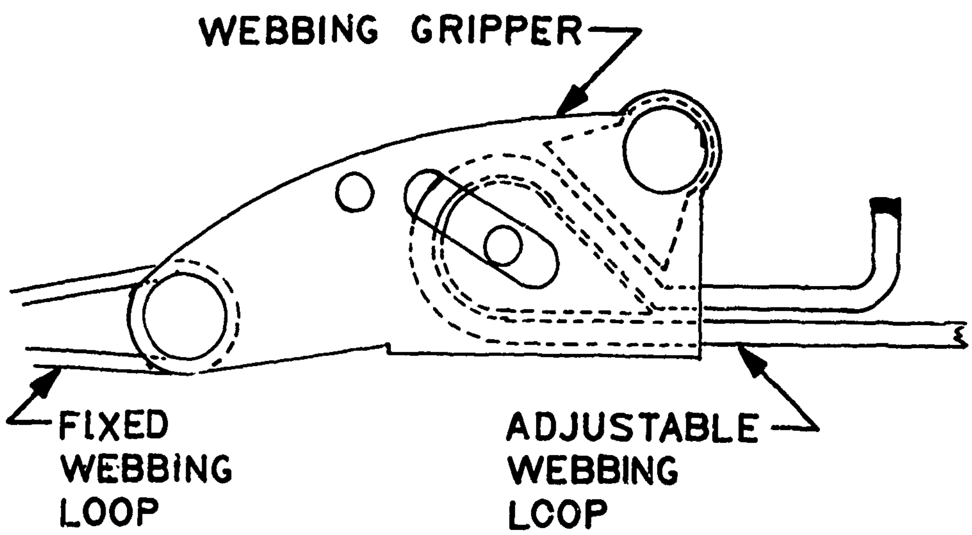


Figure 27. The Webbing Gripper.

Of the two methods described, the chain end method is preferred, especially in higher capacity slings.

Materiel Attachment Fittings

The materiel attachment fittings are located at the ends of the sling legs and are used to make the attachment to the lift points on the material.

Strength

The ultimate strength requirement for the materiel attachment fittings at the end of each sling leg is the same as for the entire sling leg.

Geometric Characteristics

The materiel attachment fittings must be capable of being attached to the lift point fittings on the materiel being suspended by the sling. Lift point fittings on materiel are usually shackles conforming to the requirements of Federal Specification RR-C-271a, Type IV, Class 4. Blade or U-bolt type fittings are also used on materiel. See Figures 11, 12, 13 or 14 for the basic dimensions of these fittings.

Operating Characteristics

The materiel attachment fittings may be of any type provided they meet the following requirements:

1. They are compatible with the lift point fittings on all materiel within the static capacity range of the sling.

2. Attachment to the materiel can be made by one man, preferably without tools.

3. The time required to attach or remove each sling leg from the materiel shall be less than 2 minutes, preferably less than 30 seconds.

4. The fittings do not become jammed in an improper position during the transition between the sling leg slack and the sling leg taut positions during lift-off.

5. The fittings make a positive attachment to the lift points on the materiel and cannot slip off during the transition from the sling leg slack to the sling leg taut position during hookup and cannot slip off due to the action of aerodynamic forces in flight.

PENDANT DESIGN

The pendant, as part of the sling system illustrated in Figure 19, is used on helicopters whose attachment point, or cargo hook, is mounted in the bottom of the fuselage and cannot be raised or lowered by means of a hoist or other mechanism. The basic functions of the pendant are:

1. To provide clearance between the bottom of the helicopter and the hookup man while hovering during hookup.

2. To provide clearance between the materiel and the aircraft in flight to avoid portions of the materiel striking the aircraft during flight maneuvers or due to load oscillations.

3. To provide, or help provide, the decoupling action between the slung load and the aircraft required to avoid objectionable vertical bounce oscillations.

The pendant must contain a swivel, so that if the slung materiel spins, neither the sling nor the pendant will twist upon itself and break.

Spring Rate

A pendant is required in sling systems to be used with the UH-1H and the CH-47 aircraft. In order to provide enough decoupling action to avoid objectionable vertical bounce oscillations, the spring rate of the pendant shall be less than:

1. 2000 pounds per inch for slung loads weighing from 2500 to 4000 pounds. This requirement is for pendants to be used with the UH-1 aircraft.

2. 4000 pounds per inch for slung loads weighing from 8000 pounds to 19000 pounds. This requirement is for pendants to be used with the CH-47 aircraft.

If future aircraft are built which require pendants with load isolating properties, the procuring agency shall specify the required spring rate.

Appendix IV provides a discussion of the phenomenon referred to as vertical bounce and establishes spring rate criteria for the avoidance of objectionable vertical bounce in the UH-1 and CH-47 aircraft.

Length

In order to satisfy the clearance-providing functions of the pendant, its length shall be a minimum of 10 feet. Its length beyond 10 feet will be a function of the spring rate requirement up to a maximum of 20 feet. Pendants longer than 20 feet are hard to handle inside the aircraft and degrade the flight performance of the aircraft/slung load system. If the designer has difficulty designing a pendant with the proper spring rate

and under 20 feet in length, the following avenues should be explored:

1. Choose a different material, or combination of materials.

2. Put all or part of the required spring rate into a local unit in the pendant.

If no viable design solution can be found using these methods, ask the procuring agency for approval of a pendant longer than 20 feet, or for relief from the spring rate requirement.

Strength

In order to determine the required ultimate strength of the pendant, it is necessary to know the static load capacity of the sling system of which the pendant is a part and the highest design load factor for the helicopters with which the pendant will be used.

Using the helicopter design load factor, the pendant load factor is determined from Figure 22. The required ultimate strength of the pendant in pounds is 1.5 times the static load capacity of the pendant times the pendant load factor.

Ultimate Strength = 1.5 (Static Load Capacity of Pendant) x (Pendant Load Factor)

The value of K, which comes from Figure 22, depends upon the type of loads the pendant is to carry. If the heaviest type III loads $\geq$ .5 (capacity of pendant) then the pendant should be designed using Type III load factor (Figure 21). If the heaviest type III loads $<$ .5 (static capacity of pendant) then the pendant should be designed using Type I or II load factors (Figure 22). Refer to Appendix V for load classification.

The required ultimate strength for the pendant is compared to the <u>reduced ultimate strength</u> for the particular material chosen.

For example: Assume a pendant, with a static load capacity of 20,000 lb, is to be designed using Type XXVI nylon webbing in the sling legs. The pendant is to be used for Type III loads, with helicopters having a maximum of a 2.5G design load factor. From Figure 22, the pendant load factor is 4.8 and the

$$\text{Required Ultimate Strength} = 1.5\ (20{,}000)(4.8) = 144{,}000 \text{ lb}$$

From Tables I and IV the reduced ultimate strength for a single ply of Type XXVI nylon webbing is (assuming good pin design)

$$16{,}368\ (.540)(.932)(.903) = 7438.6 \text{ lb}$$

Twenty plies of Type XXVI nylon webbing are required in the pendant.

If Type VI Dacron is used, the reduced ultimate strength for a single ply, assuming good pin design, is

$$19092(.905)(.941) = 16258.8$$

Nine plies of Type VI Dacron are required in the pendant.

Pendant End Fittings

In order to be compatible with the aircraft and the sling with which the pendant will be used, the pendant end fittings must be designed to the criteria set forth below.

Upper Fitting

The upper fitting is used to connect the pendant to the aircraft hook. This fitting should be dimensionally stable under load so that it does not tighten itself on the aircraft hook and prevent the smooth release of the load when the aircraft hook is opened. Therefore, the upper fitting should be an oblong link, a pear-shaped link, or a ring, in that order of preference. Refer to Figure 21.

Note that commercially produced links or rings are of two types: welded and forged. The forged links are about 75 percent stronger than the welded links for a given size and therefore weigh less for a given strength requirement.

The ultimate strength requirement for the upper fitting is the same as for the pendant.

Lower Fitting

The lower fitting on the pendant engages the apex fitting of the sling. This engagement (hookup) is made by one man standing on the item to be lifted, holding the apex fitting of the sling in his hands. As the helicopter hovers overhead with the pendant dangling, the hookup man engages the sling apex fitting into the lower pendant fitting. Hookup is accomplished quickly, usually in a few seconds. To satisfy these requirements, the lower pendant fitting must meet the same dimensional requirements established for the aircraft cargo hook and shown in Figure 29.

The ultimate strength requirement for the lower pendant fitting is the same as for the pendant.

Release Requirement

When so specified by the procuring agency, the lower pendant fitting shall have a release device which can be actuated, usually manually, from within the aircraft. The release mechanism shall be capable of opening the lower fitting when the weight of the suspended load is on the ground and a maximum load of 300 pounds, usually due to sling

weight, is acting on the lower pendant fitting. This allows the crewman in the aircraft to release the sling and the slung load without jettisoning the pendant and without requiring assistance from the ground.

DESIGN GUIDE FOR AIRCRAFT HARD POINTS

SINGLE-POINT SYSTEMS

HARD-POINT LOCATION

The aircraft hard point shall be located such that the load line of action passes through or as closely as possible to the center of gravity of the helicopter. This requirement must be met both when the load hangs vertically and during normal load swing.

Several methods have been devised to move the effective load reactions point of an externally mounted cargo hook or aircraft hard point close to the helicopter's center of gravity:

1. The swing sling, described in Reference 5.

2. The low response sling, described in Reference 6.

3. The beam mounted cargo hook, described in Reference 7.

The location selected should permit quick and easy attachment of a sling with minimum hazard to ground personnel. Cargo hooks attached to the underside of the fuselage are not desirable because they require ground personnel to work in close proximity to the hovering aircraft while hookup is being made. If such a hook location offers the only reasonable solution, provisions must be made for the use of an auxiliary pendant to extend the sling attach point to at least 10 feet below the underside of the helicopter. The pendant must be deployable and retrievable while the helicopter is in hover.

The hard-point locations should permit the helicopter to land safely in the event of an emergency, without requiring the cargo hook to be retracted. Adequate ground clearance shall be provided under flat-tire conditions. A cargo hook installation may be made retractable and still meet the above requirements. An example of such an installation is the low response sling (Reference 6). Such an installation permits the helicopter to land safely even though the hook might suffer extensive damage.

Fixed cargo hook attached to the airframe, or to a sling which is in turn attached to the airframe, need not be free to rotate around a vertical axis (swivel), provided provisions have been made for the use of a pendant which would contain its own swivel. Materiel carried by a single-point suspension system will rotate or spin under the action of aerodynamic forces. A swivel must be provided to prevent the sling from twisting upon itself and breaking. Cargo hooks mounted on a single tension member some distance away from the aircraft, where a pendant is unnecessary, must swivel under full load conditions.

HARD-POINT STRENGTH REQUIREMENTS

The helicopter's maximum load-carrying capability, based on 30 minutes of fuel at sea level, standard day conditions, shall be used as the static design capacity of the hard point. The effect of rotor downwash may be ignored since it will only result in a decrease in the allowable weight of materiel to be carried and will not change the maximum load felt at the hard point.

Past experience has shown that the lifting capability of a basic helicopter model is likely to increase due to product improvement programs and growth versions which fly at increased gross weights. A gross weight increase of 25 percent is common. Since most of the increased gross weight capability is available for payload lifting purposes, significant increases in payload capability are achieved. It may be possible for the designer to design the helicopter hard point to this future load-carrying capacity with veıy little penalty in weight and thereby avoid costly redesign and procurement problems in the future.

The hard-point limit load factors for the vertical, longitudinal and lateral components of the static design load capacity are shown in Figure 28 as they relate to the helicopter design limit load factor. Having determined the hard point limit load factors, multiply each of these by the static design load capacity to obtain actual limit loads. Multiply the limit loads by 1.5 to obtain the ultimate strength requirements for the hard point.

For example: Assume a helicopter with a design limit load factor of 2.5 and a static lifting capacity (payload capability) of 30,000 pounds, From Figure 28 the hard point limit load factors are: vertical = 2.75, longitudinal 0.95, and lateral 1.28. The ultimate strength requirements for the hard point are:

Ultimate Strength, Vertical = 30,000 x 2.75 x 1.5 = 123,750 lb

Ultimate Strength, Longitudinal = 30,000 x 0.95 x 1.5 = 42,750 lb

Ultimate Strength, Lateral = 30,000 x 1.28 x 1.5 = 57,600 lb

In the case of a cargo hook on a cable, the hook itself would be subject to vertical forces only; the supporting structure would be subject to vertical, longitudinal and lateral forces.

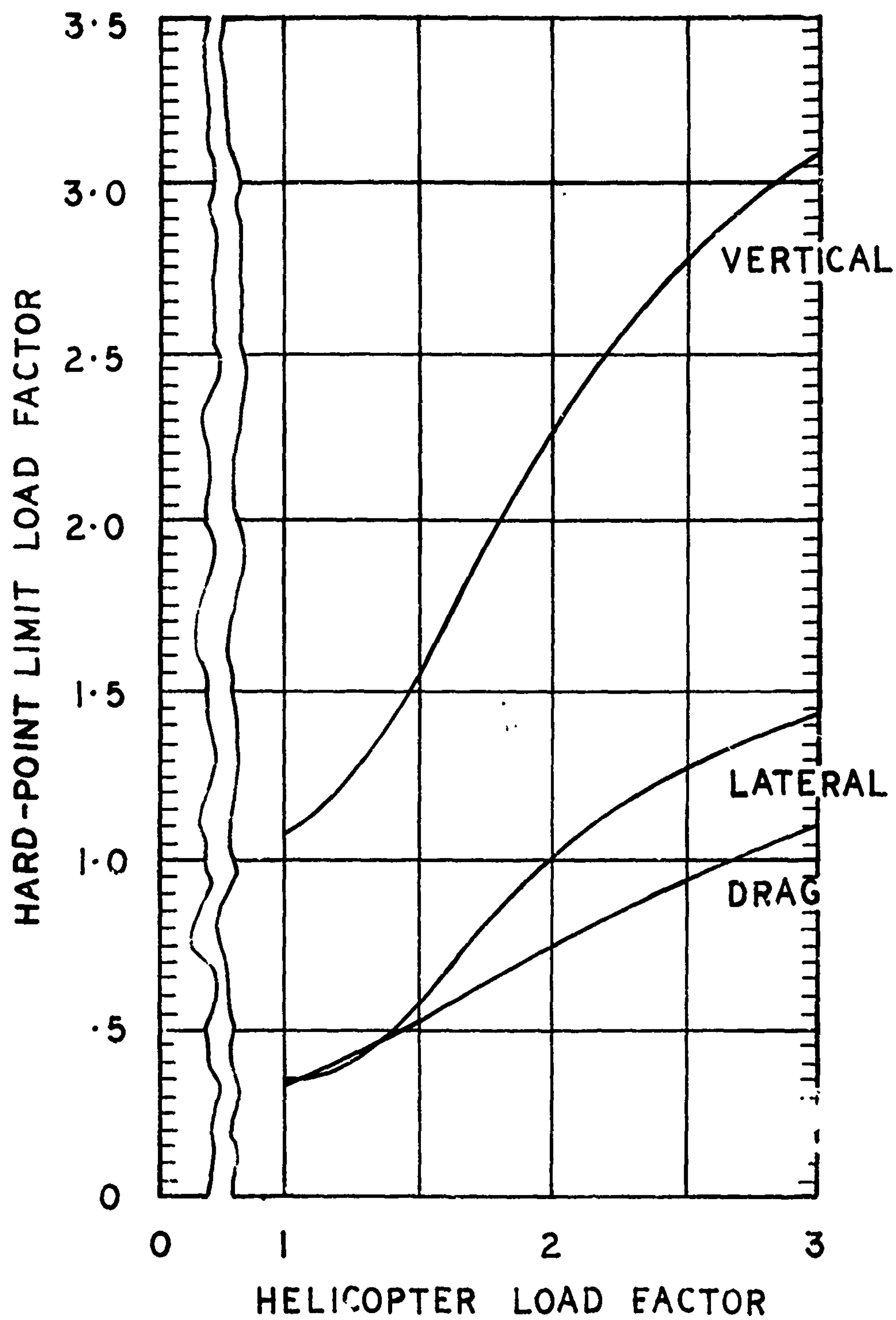


Figure 28. Aircraft Hard-Point Load Factors - Single-Point Suspension System.

VIBRATION ISOLATION

It is mandatory to either provide a positive means of preventing "vertical bounce" or to prove analytically that such a phenomenon will not be encountered. The practice of requiring the use of a specific sling configuration or type to eliminate vertical bounce is not acceptable. However, the use of a specific pendant for this purpose, provided it is supplied with the helicopter and meets the strength requirements, is acceptable.

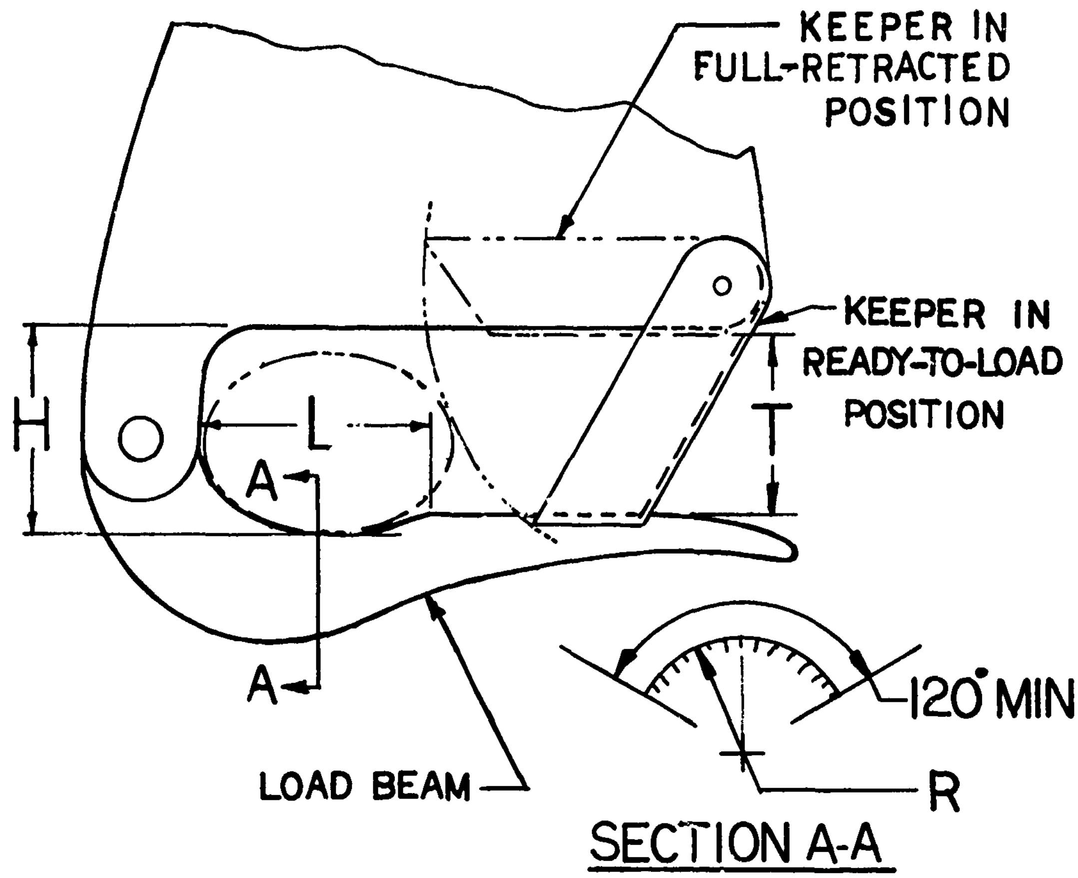
See Appendix IV for more detailed information on the vertical bounce phenomenon.

HARD-POINT CONFIGURATION

The aircraft hard point shall consist of a cargo hook (or other device) which will permit materiel ranging in weight up to the lifting capacity of the helicopter, and suspended by sling systems with capacities up to the lifting capacity of the helicopter, to be rapidly attached to, transported by, and released from the helicopter.

The cargo hook (or other device) shall permit rapid load release from the cockpit and from the crew station in the helicopter and by ground personnel. An independent secondary release system, operable from the cockpit, is required as a backup for the primary release mode. The primary and secondary release systems shall be entirely separate, such that a failure of one system will not interfere with the operation of the other.

The cargo hook or device shall meet the dimensional requirements of Figure 29 so that it will be compatible with the slings and/or pendants with which it will be used. It shall have a positive means for retaining the sling or pendant apex fitting in position on the load-carrying member. The load-carrying member, or load beam, shall be made from a tough resilient material which is capable of withstanding repeated loading and unloading of forged steel rings, links or shackles without appreciable degradation of strength.



Hook Capacity (lb)	H (in.)	L (in.)	T (in.)	R (in.)
5,000	2-3/8	2-1/4	2	5/8 ± 1/16
10,000	2-5/8	2-3/4	2-1/4	7/8 ± 1/16
25,000	3-3/8	4	3	1-1/2 ± 1/16
50,000	4-1/2	5	4	2-1/4 ± 1/8
75,000	5-5/8	5-7/8	5	3 ± 1/8
100,000	6-3/4	6-3/4	6	3-3/4 ± 1/8

Figure 29. Cargo Hook Dimensional Requirements.

FOUR-POINT SYSTEMS

HARD-POINT LOCATION

The four aircraft hard-point locations, when projected on a horizontal plane, shall form the four corners of a rectangle. The intersection of the two diagonals of this rectangle shall be located directly below the aircraft center of gravity. The size and shape of the rectangle will depend upon the spectrum of materiel to be carried by the helicopter, modified to conform to the physical size of the helicopter's fuselage. The hard points shall be located far enough above the ground to allow the aircraft to straddle the materiel to be lifted. The hard points shall be capable of supporting a pod, and meet FAA requirements for the helicopter transport of pods.

Tension member fleet angles, the angle between vertical and the load line of action, should not exceed 20°.

In special cases, very large loads may be attached to the helicopter while it is hovering. This type of pickup is considered the exception rather than the rule, since it is more hazardous than the ground straddle pickup wherein the load is snugged up to the helicopter, thus permitting landing without requiring the materiel to be detached.

HARD-POINT STRENGTH REQUIREMENTS

The helicopter's maximum load-carrying capability, based upon 30 minutes of fuel at sea level, standard day conditions, shall be used as the total static capacity of the hard-point system. The required vertical static capacity (V_s) of each hard point is obtained by multiplying the total static capacity by .382. This takes into account the permissible asymmetry in the location of the center of gravity of the materiel to be carried, and accounts for the indeterminate nature of the four-point suspension system, wherein two of the lift points comprising a diagonal may carry more load than the other two. The horizontal static capacity (H_s) of each hard point is found by multiplying V_s by .342, and this horizontal static force may act along any azimuth in the horizontal plane.

Figure 30 shows the factors that must be applied to H_s and V_s, the calculated static loads at the hard points for helicopters with design load factors from 1 to 3. The vertical factor multiplied by 1.5 V_s is the required ultimate strength of the hard point in the vertical direction. The lateral factor multiplied by 1.5 H_s is the required ultimate strength of the hard point in the horizontal direction, and the drag factor multiplied by 1.5 H_s is the required ultimate strength in the fore and aft direction. This shown in equation form is as follows:

Required Ultimate Strength Vertical Direction = (Vertical Factor) x 1.5 (V_s)

Required Ultimate Strength Horizontal Direction = (Lateral Factor) x 1.5 (H_s)

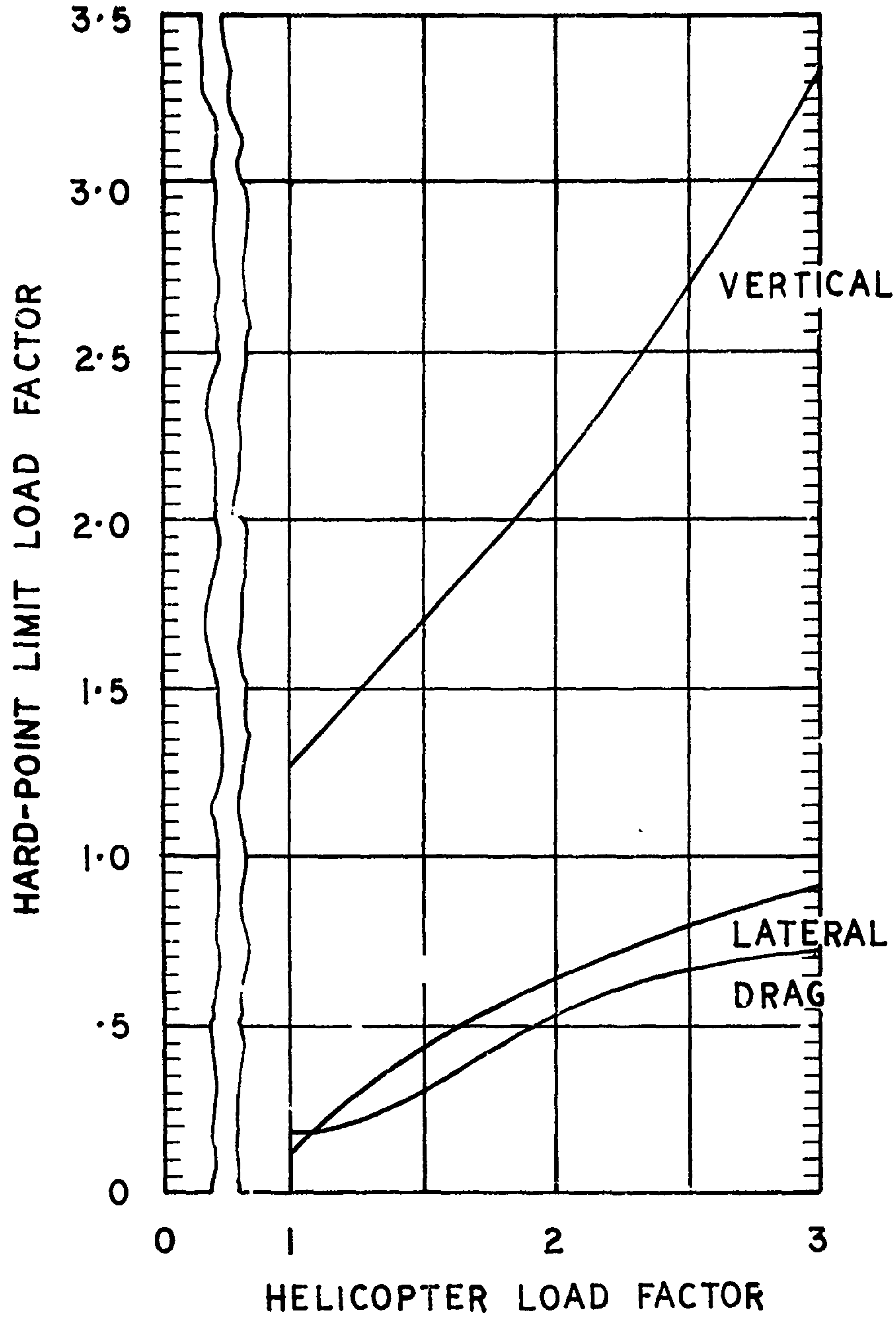


Figure 30. Aircraft Hard-Point Load Factors - Two-Point and Four-Point Suspension Systems.

Required Ultimate Strength = (Drag Factor) x 1.5 (H_s)
Fore and Aft Direction

The tension members, if there are any in the system, would run from a hard point all the way to, or part of the way to, the materiel lift point. The static load in each tension member is found by multiplying V_s by 1.064. Figure 24 shows the tension member load factors for helicopters with load factors from 1 to 3. The tension member load factor multiplied by 1.5 times the static load in the tension member is the required ultimate strength for each tension member.

This shown in equation form is as follows:

Static Load = 1.064 (V_s)

Required Ultimate Strength = (Load Factor) x 1.5 (Static Load)
Tension Member

VIBRATION ISOLATION

It is mandatory to either provide a positive means of preventing vertical bounce or to prove analytically that such a phenomenon will not be encountered. The practice of requiring the use of a specific load tension member to eliminate vertical bounce is not acceptable.

See Appendix IV for more detailed information on the vertical bounce phenomenon.

Hard-Point Configuration

Two basic four-point systems which may be used:

> The fixed type, wherein a hook, ring, shackle or similar device is attached directly to the hard point. During load acquisition, the materiel must be raised off the ground into position for attachment to the aircraft hard points by means external to the aircraft.
>
> The actuated type, wherein a hoist, jack screw, hydraulic or pneumatic cylinder or other mechanism is attached at the hard point to enable the materiel to be lifted off the ground prior to flight. The actuated type is generally preferred since it makes the helicopter operation independent of special support equipment; permits the use of load sharing devices; and reduces the time required to acquire, attach, and take off with a load.

THE ACTUATED FOUR-POINT SYSTEM

The stroke of the actuating mechanism shall be large enough so that when the materiel is lifted, adequate ground clearance is provided below the materiel, to allow routine takeoffs and landings. When determining the required length of stroke, the designer should take into account the wheel drop on most vehicles and the track sag on tracked type vehicles. Similarly, the amount by which the aircraft's landing gear struts will compress, together with tire compression as the aircraft acquires the load, will reduce the effective ground clearance.

A positive means shall be provided at each hard point to divide the total static load among the four hard points in as nearly equal a manner as possible. The ratio of the highest static load at any hard point to the lowest static load at any hard point shall not exceed 1.4.

Each hard point shall have a materiel attach/disconnect device compatible with the materiel lift point requirements given in the Multipoint Suspension Systems section on page 20.

The attach/disconnect device shall permit both the rapid attachment to and disconnecting from the materiel lift point. Safety hooks, with integral keepers, meet this requirement.

THE FIXED-TYPE FOUR-POINT SYSTEM

Fittings shall be permanently attached to the helicopter shackles which conform to or exceed the structural requirements of Federal Specification RR-C-271a, Type IV, Class 4. Refer to Figure 31. Shackles shall be mounted to permit manual orientation while unloaded for proper alignment with the attaching load tension member.

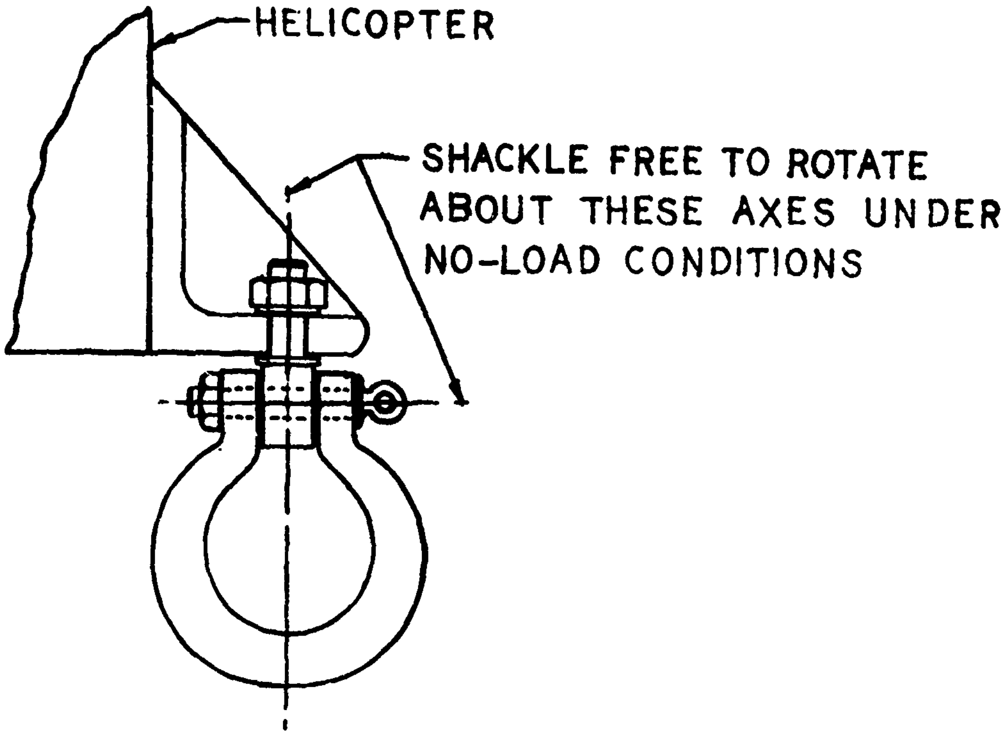


Figure 31. Shackle Installation - Four-Point Suspension System.

TWO-POINT SYSTEMS

HARD-POINT LOCATION

The two aircraft hard points, when projected on a horizontal plane, shall lie along a line parallel to the centerline of the aircraft; the midpoint of this line shall coincide as closely as possible with the aircraft center of gravity. The spacing between the two hard points will depend upon the spectrum of materiel to be carried by the heliocpter and the physical size of the helicopter's fuselage. The hard points shall be located far enough above the ground to allow the aircraft to straddle the materiel to be lifted. The hard points shall be capable of supporting a pod and meet FAA requirements for helicopter transport of pods.

Tension member fleet angles, the angle between a vertical and the load line of action as seen in a side view, should not exceed 20°.

HARD-POINT STRENGTH REQUIREMENTS

The helicopter's maximum load-carrying capability, based upon 30 minutes of fuel at sea level, standard day conditions, shall be used as the total static capacity of the hard-point system. The required vertical static capacity (V_s) of each hard point is obtained by multiplying the total static capacity by .545. This takes into account the permissible asymmetry in the location of the center of gravity of the materiel to be carried. The horizontal static capacity (H_s) of each hard point is found by multiplying V_s by .342, and this horizontal static force may act along any azimuth in the horizontal plane.

Figure 30 shows the factors that must be applied to H_s and V_s, the calculated static loads at the hard points for helicopters with design load factors from 1 to 3. The vertical factor multiplied by 1.5 V_s is the required ultimate strength of the hard point in the vertical direction. The lateral factor multiplied by 1.5 H_s is the required ultimate strength of the hard point in the lateral direction, and the drag factor multiplied by 1.5 H_s is the required ultimate strength in the fore and aft direction.

The tension members, if there are any in the system, would run from a hard point all the way to, or part of the way to, the materiel lift point. The static load in each tension member is found by multiplying V_s by 1.064. Figure 22 shows the tension member load factors for helicopters with load factors from 1 to 3. The tension member load factor multiplied by 1.5 times the static load in the tension member is the required ultimate strength for each tension member.

VIBRATION ISOLATION

It is mandatory to either provide a positive means of preventing vertical bounce or to prove analytically that such a phenomenon will not be encountered. The practice of requiring the use of a specific load tension member to eliminate vertical bounce is not acceptable. Load isolation should be provided somewhere in the load suspension system. See Appendix

IV for more detailed information on the vertical bounce phenomenon.

HOOK CONFIGURATION

For detailed hook configuration information, see Figure 29 and the Single-Point Systems section.

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APPENDIX I

PAYLOAD CAPABILITY AND DESIGN LOAD FACTORS OF ARMY AIRCRAFT

TABLE II. PAYLOAD CAPABILITY AND DESIGN LOAD FACTORS OF ARMY AIRCRAFT

Aircraft	Design Gross Weight		Maximum Gross Weight		Type of Suspension System
	Payload Capability at	Aircraft Load Factor	Payload Capability at	Aircraft Load Factor	
UH-1H	1750	3	4650	2.08	S
CH-47	10618	2.66	15068	2.3	S
CH-47B	13625	3	19175	2.56	S
CH-47C	12760	3	19760	2.48	S
CH-54A	15556	2.5	19556	2.26	S, M
CH-54B	27310	2	27310	2	S, M

S Indicates Single-Point Suspension System

M Indicated Multi-Point Suspension System

APPENDIX II

PROPERTIES OF SLING MATERIALS

This appendix identifies and describes the necessary mechanical and physical properties of some materials which could be used in the design of slings and pendants. The materials included are generally those for which sufficient test data have been generated to establish quantitative physical properties and quantitative effects of environment on these physical properties. The designer is not limited to the materials described in this text provided that quantitative data on the effects of environment are available for any sling material chosen.

Sling materials have been grouped into two categories: wire rope and textiles.

WIRE ROPE

Wire rope is made up of wire strands and a core (see Figure 32). The center wire of each strand is a round or a shaped wire, used as the body member. Around this, a group of wires are helically laid to form a strand. The strands are supported by a core, which also maintains the position of the strands during movement involving bending and load stresses.

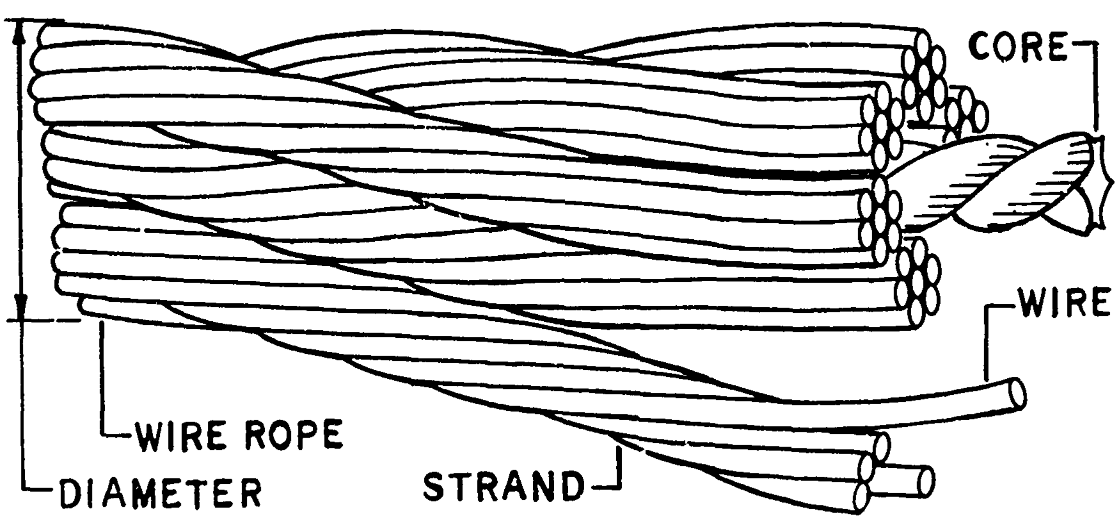


Figure 32. Components of a Wire Rope.

There are two basic wire rope cores. The fiber core (FC) is generally sisal or man-made synthetic fiber rope. It is treated with special lubrication and recommended for light duty service. The limitations of fiber core ropes are reached when pressure, such as crushing on a drum, collapses the core and distorts the rope strands. The independent wire rope core (IWRC) is composed of a separate 7 x 7 wire rope (see Figure 33). It is recommended for slings because of its ability to minimize crushing and distortion. An IWRC adds approximately 7.5 percent to the strength of a six-strand rope.

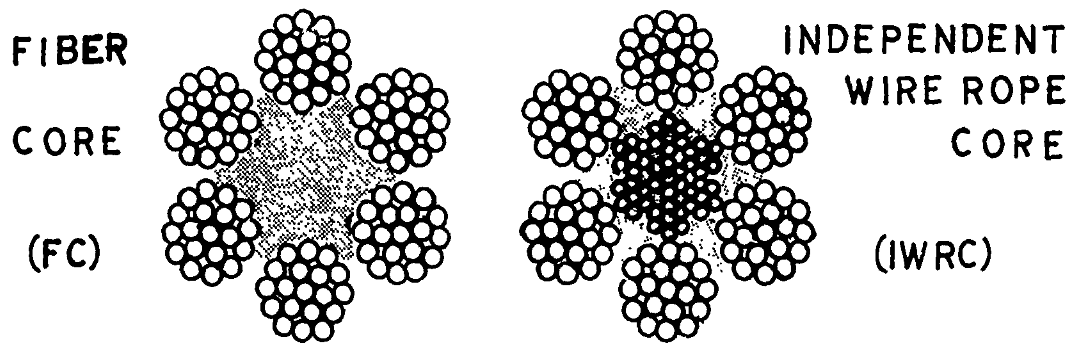


Figure 33. Wire Rope Cores.

Table III lists the weights and strengths of some common wire ropes suitable for sling system design. Additional sizes and constructions can be found in wire rope manufacturers' catalogs.

TABLE III. STRENGTH AND WEIGHT OF WIRE ROPE

Nominal Diameter (in.)	7 x 7, 7 x 19, 6 x 19 (IWRC) Cable			
	Carbon Steel, MIL-W-1511		Stainless Steel, MIL-C-5424	
	Weight (lb/100 ft)	Break Strength (lb)	Weight (lb/100 ft)	Break Strength (lb)
1/4	11.00	7,000	11.00	6,400
3/8	24.30	14,400	24.30	12,000
1/2	45.80	22,800	45.80	22,800
5/8	71.50	35,000	71.50	35,000
3/4	105.20	49,600	105.20	49,600
7/8	143.00	66,500	143.00	66,500
1	187.00	85,400	187.00	85,400
1-1/8	240.00	106,400	240.00	106,400
1-1/4	290.00	129,400	290.00	129,400
1-3/8	330.00	153,600	330.00	153,600
1-1/2	420.00	180,500	420.00	180,500
1-3/4	567.00	266,000	567.00	266,000
2	739.00	344,000	739.00	344,000

Spring Rate

Equations for determining the spring rate for various types of wire rope are listed below

where K = Spring rate in pounds per inch of elongation

D = Nominal rope diameter in inches

ℓ = Length of wire rope in inches

7 x 7 Carbon Steel	$K = D^2(10^7)/1.07\ell$
7 x 7 Stainless Steel	$K = D^2(10^7)/1.20\ell$
7 x 19 Carbon Steel	$K = D^2(10^7)/1.40\ell$
7 x 19 Stainless Steel	$K = D^2(10^7)/1.62\ell$
6 x 19 FC Carbon Steel	$K = D^2(10^7)/2.03\ell$
6 x 19 FC Stainless Steel	$K = D^2(10^7)/2.26\ell$
6 x 19 IWRC Carbon Steel	$K = D^2(10^7)/1.36\ell$
6 x 19 IWRC Stainless Steel	$K = D^2(10^7)/1.57\ell$
6 x 37 FC Carbon Steel	$K = D^2(10^7)/2.19\ell$
6 x 37 FC Stainless Steel	$K = D^2(10^7)/2.41\ell$
6 x 37 IWRC Carbon Steel	$K = D^2(10^7)/1.44\ell$
6 x 37 IWRC Stainless Steel	$K = D^2(10^7)/1.60\ell$
8 x 19 IWRC Carbon Steel	$K = D^2(10^7)/1.70\ell$
8 x 19 FC Carbon Steel	$K = D^2(10^7)/2.97\ell$

TEXTILE MATERIALS

Textile materials such as nylon and polyester (Dacron) may be used in the design of sling systems. These synthetic fibers are usually woven into webbing of different widths and thicknesses, or spun or braided into ropes. Textile materials may be coated to provide protection against environmental degradation. The effects of ultraviolet light, sand and hostile fluids may be reduced through the use of protective coatings.

Nylon webbings that conform to the requirements of MIL-W-4088 and Dacron webbings that conform to the requirements of MIL-W-25361 are described in Table IV.

TABLE IV. CONSTRUCTION AND PHYSICAL REQUIREMENTS FOR WEBBING

Material	Width (in.)	Thickness (in.)	Break Strength (lb)	Weight (lb/ft)
Nylon Type X	1-23/32 ± 3/32	.105 - .140	10,427	.0787
Nylon Type XIX	1-3/4 ± 3/32	.100 - .130	11,735	.0853
Nylon Type XXVI	1-3/4 ± 1/16	.150 - .180	16,368	.1020
Dacron Type V	1-3/4 ± 1/16	.110 - .130	11,976	.0812
Dacron Type VI	1-3/4 ± 1/16	.215 - .235	19,092	.1532

Commercial webbings with coatings to protect against ultraviolet light damage are available for use as sling materials. Some of these are:

1. Safe-T-core nylon webbing is a specially woven nylon webbing available in widths up to 12 inches and coated with HS-7 to provide high resistance to abrasion and sunlight. Breaking strength is 8000 lb per inch of width for the as-sewn product. Red core yarns are positioned at the edges of the webbing and evenly spaced across the width. Exposure of the red yarn automatically signals excessive wear. When two thicknesses are sewn together, the breaking strength is 13,500 pounds per inch of width up to 4 inches; for three plies the breaking strength is 19,200 pounds per inch of width up to 4 inches. For example, three plies of 2-inch webbing sewn together to act as a unit and then sewn to form an endless loop would form a sling leg with a breaking strength of 76,800 pounds.

2. Safe-T-Core polyester webbing is identical in size and strength to the nylon webbing described in 1 above. The primary differences are the higher spring rate and the higher resistance to ultraviolet light.

3. TRX-coated nylon webbing has a total thickness of approximately .135, including a synthetic polymer coating for abrasion resistance, fluid penetration resistance and a non-marring surface. The coating also offers considerable protection from ultraviolet light. It has a breaking strength of 6000 pounds per inch of width and is available in widths up to 6 inches.

Synthetic Ropes

Synthetic ropes, coated and uncoated, are available for use as sling materials. Some of these are:

1. A rope of 2 in 1 braided construction which has a braided core protected by a braided cover is available in diameters of .25 inch through 5.0 inches with breaking strengths up to 620,000 lb, depending upon the diameter and materials from which the core and cover are made. The rope can be coated with urethane or other polymers for increased protection against ultraviolet light and the effects of sand. Braided rope has nonrotating characteristics which make it suitable for pendant design.

2. Three strand nylon rope, which is available in diameters up to about 5 inches with strengths up to 700,000 lb, can also be coated for additional protection against the effects of ultraviolet light and sand.

Spring Rate

Spring rate for some textile materials are given in Figures 34 through 40. Consult the material manufacturer for spring rates of other textile materials.

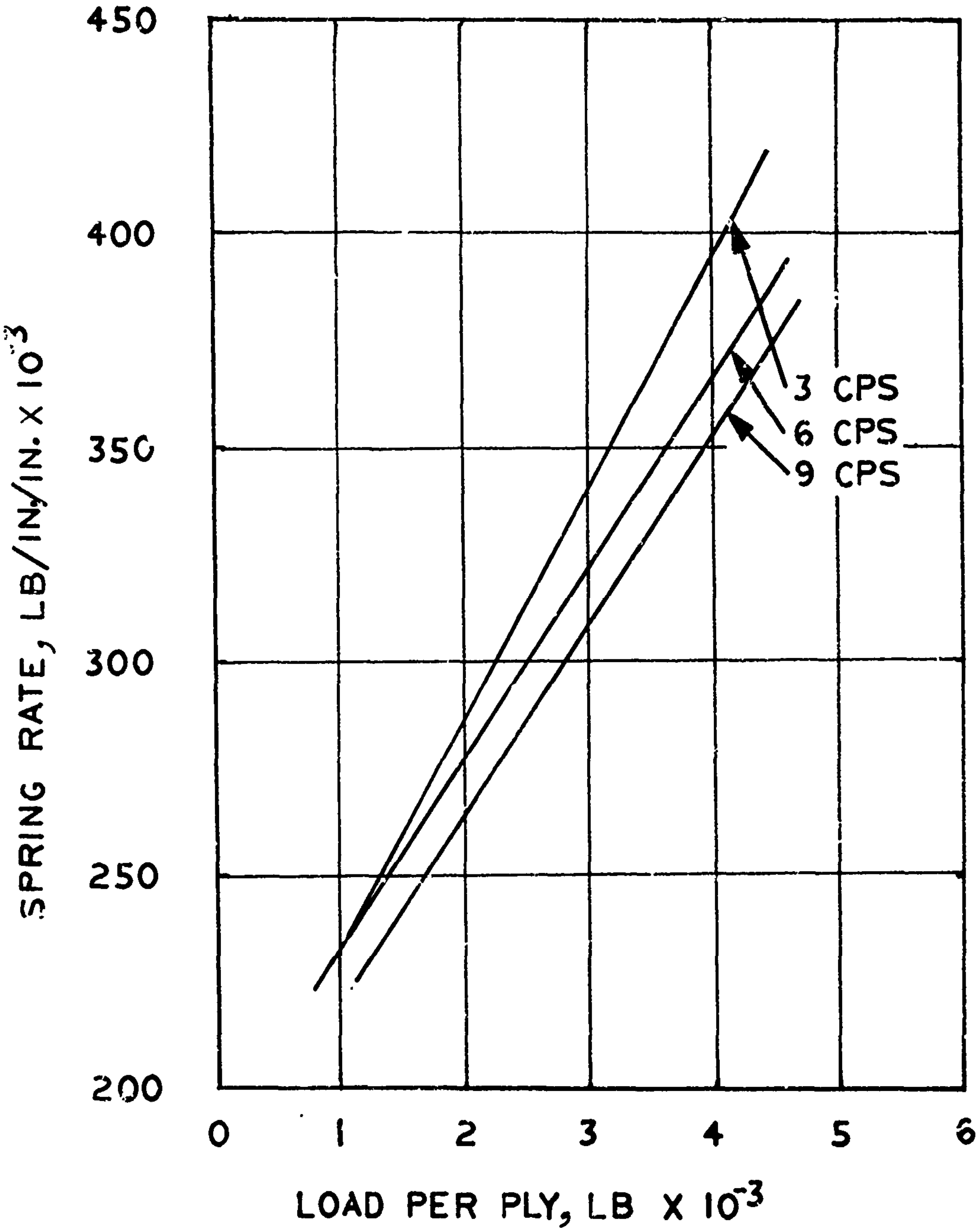


Figure 34. Spring Rate -
Type V Dacron.

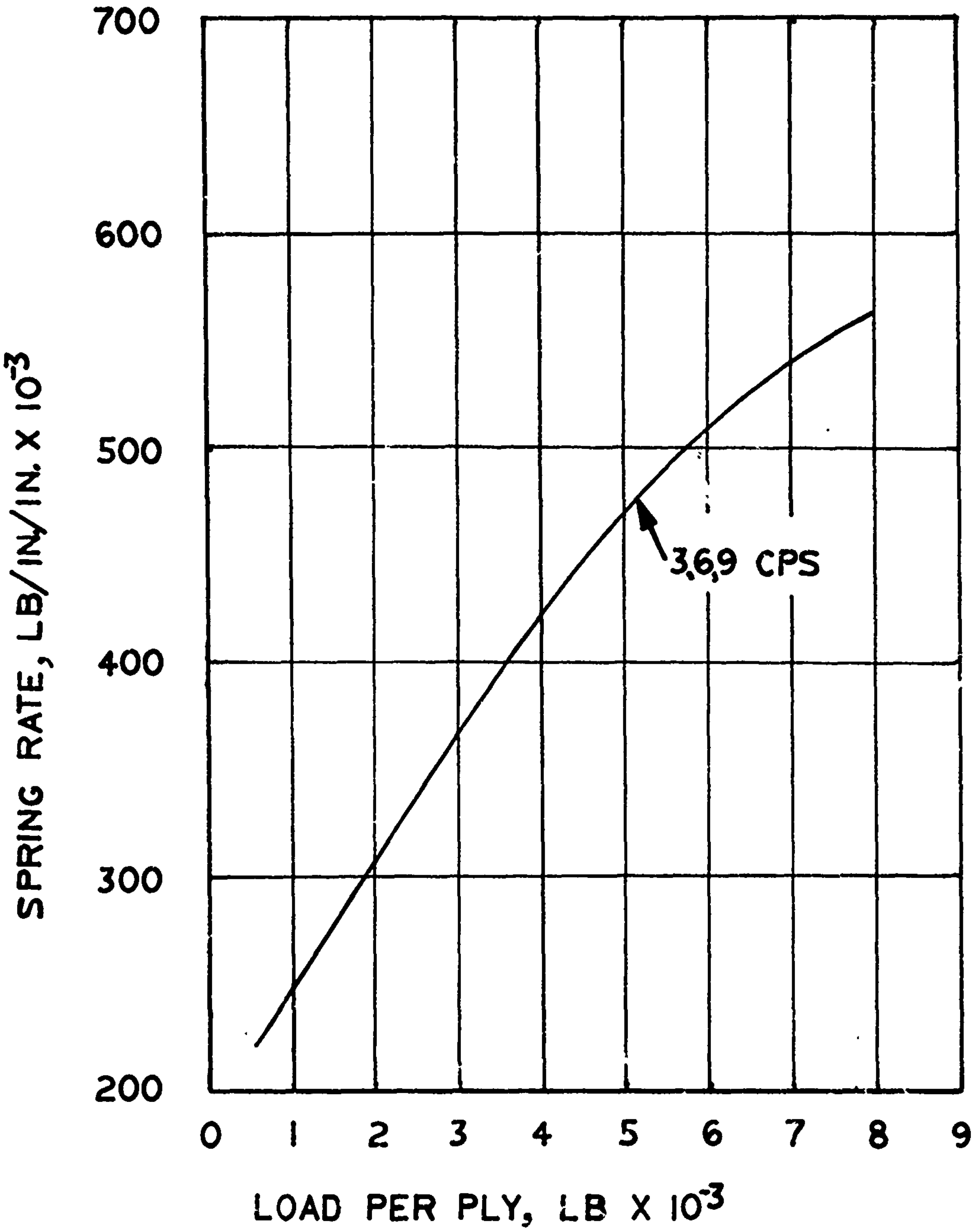


Figure 35. Spring Rate - Type VI Dacron.

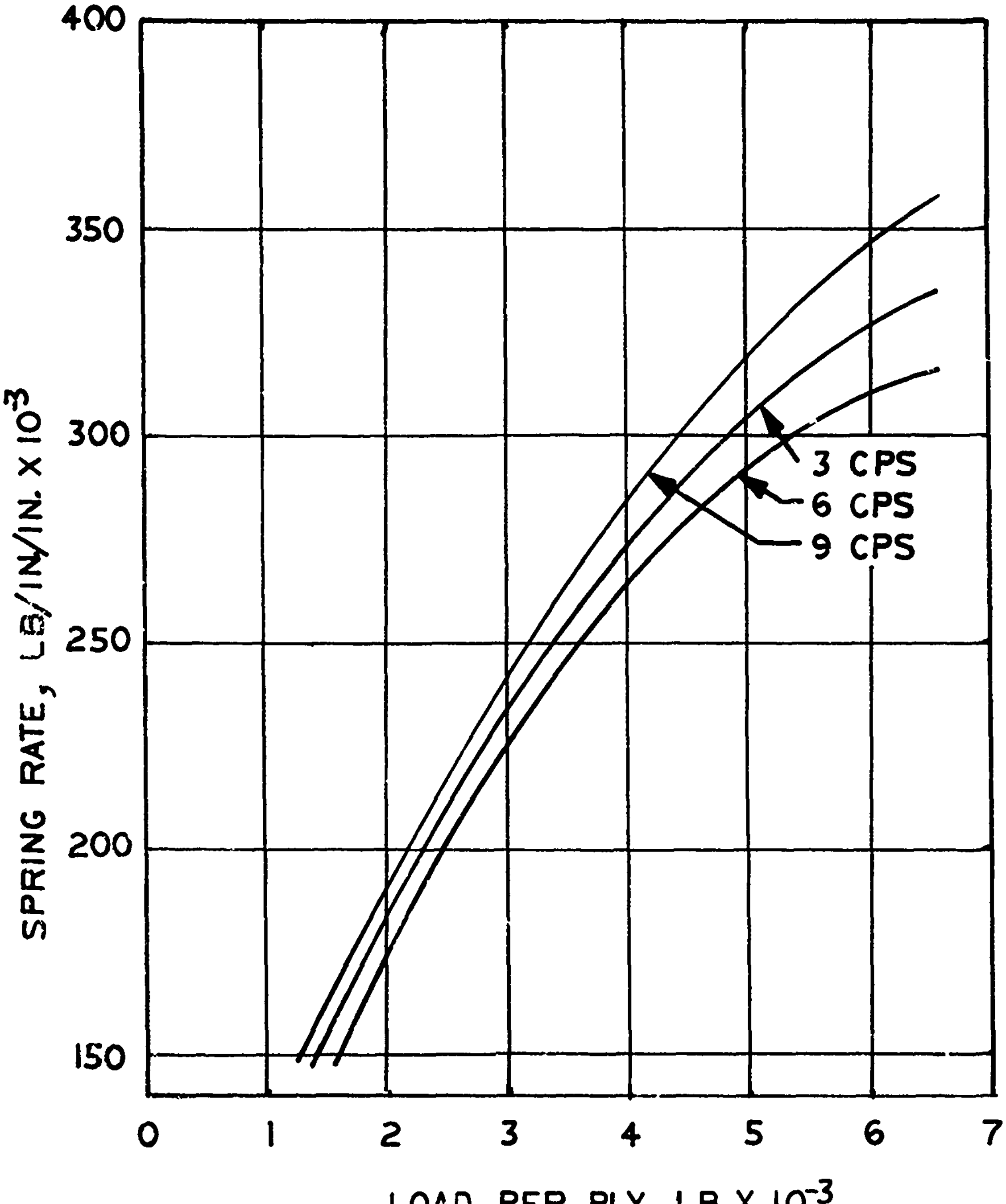


Figure 36. Spring Rate - Type X Nylon.

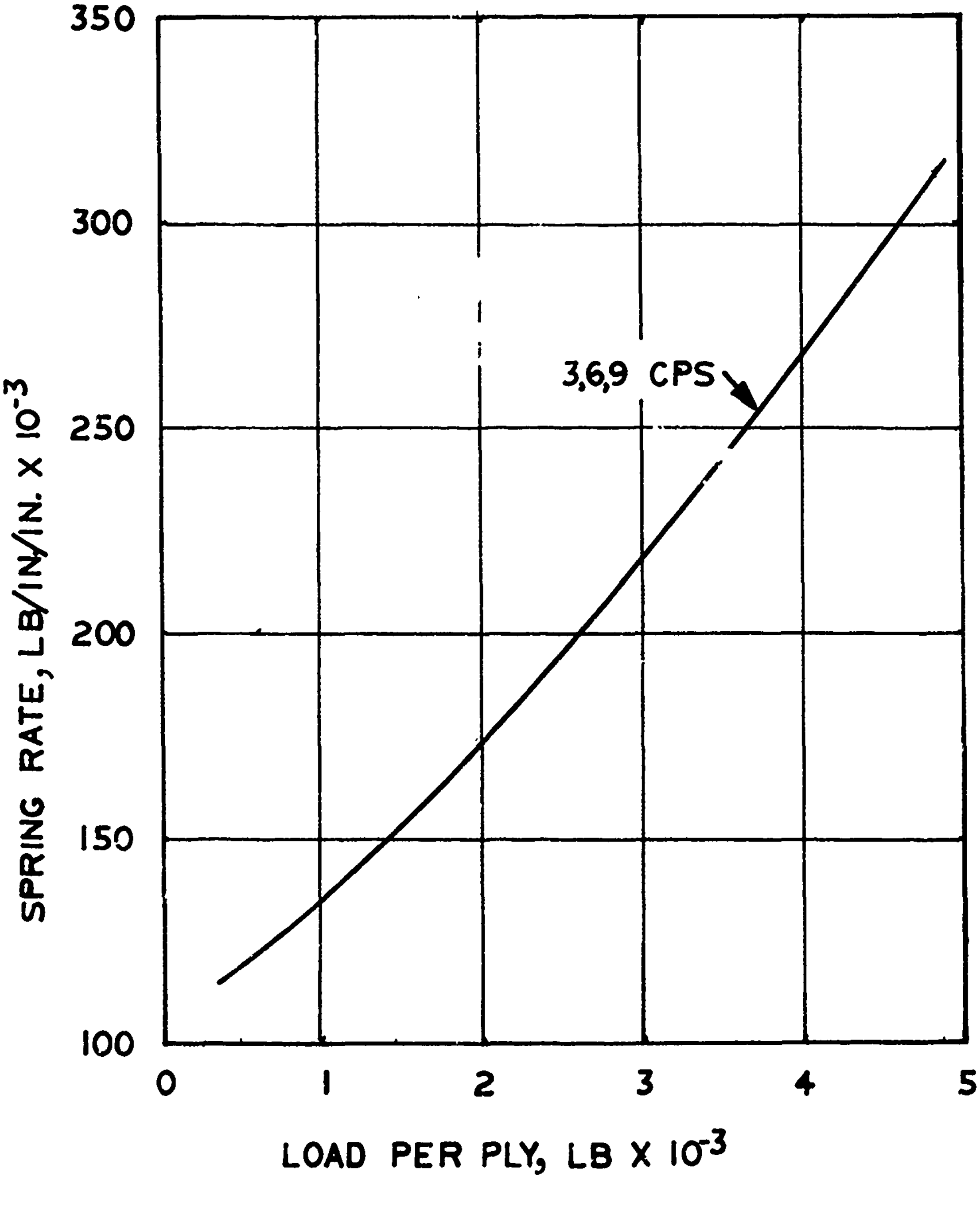


Figure 37. Spring Rate - Type XIX Nylon.

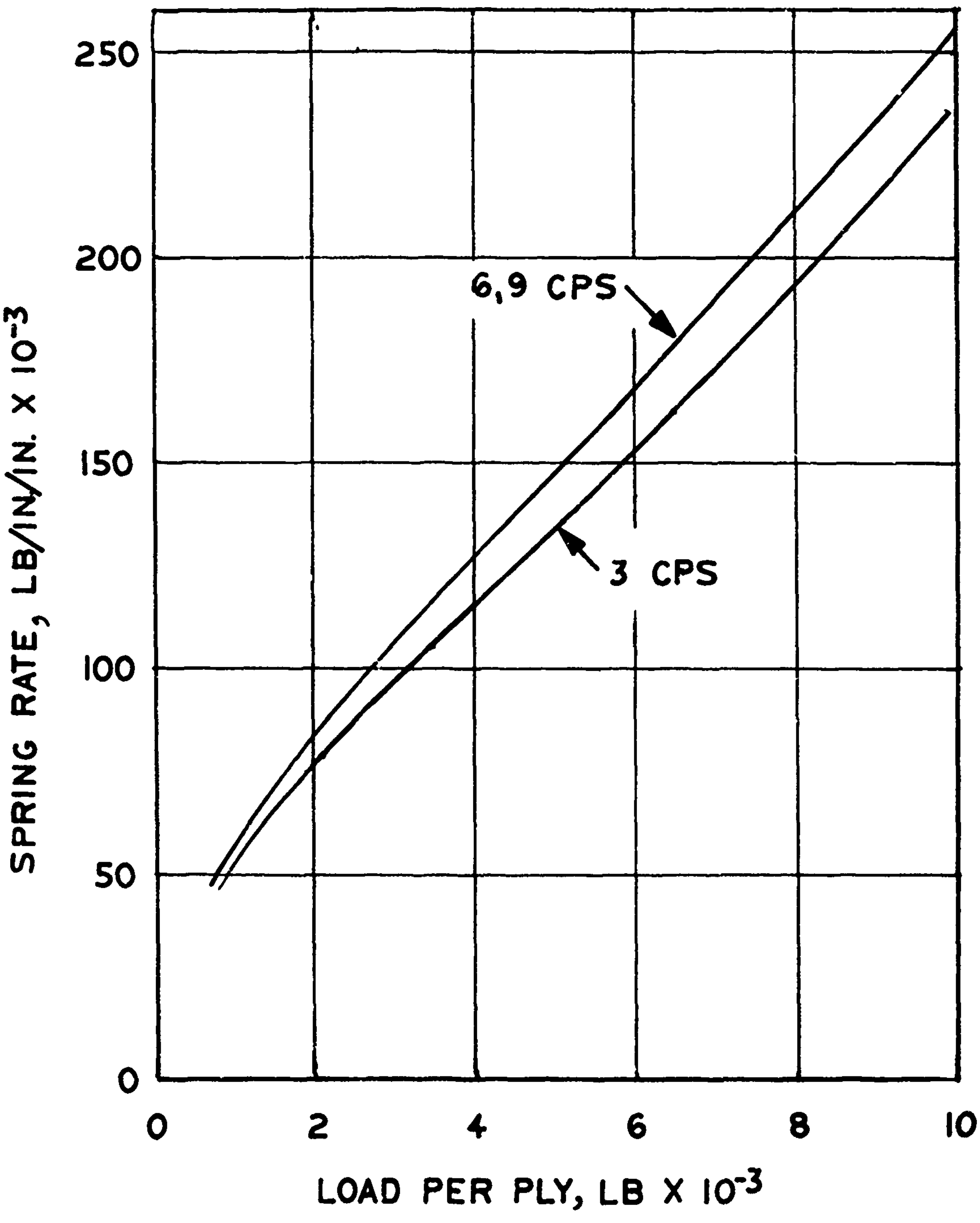


Figure 38. Spring Rate - Type XXVI-L Nylon.

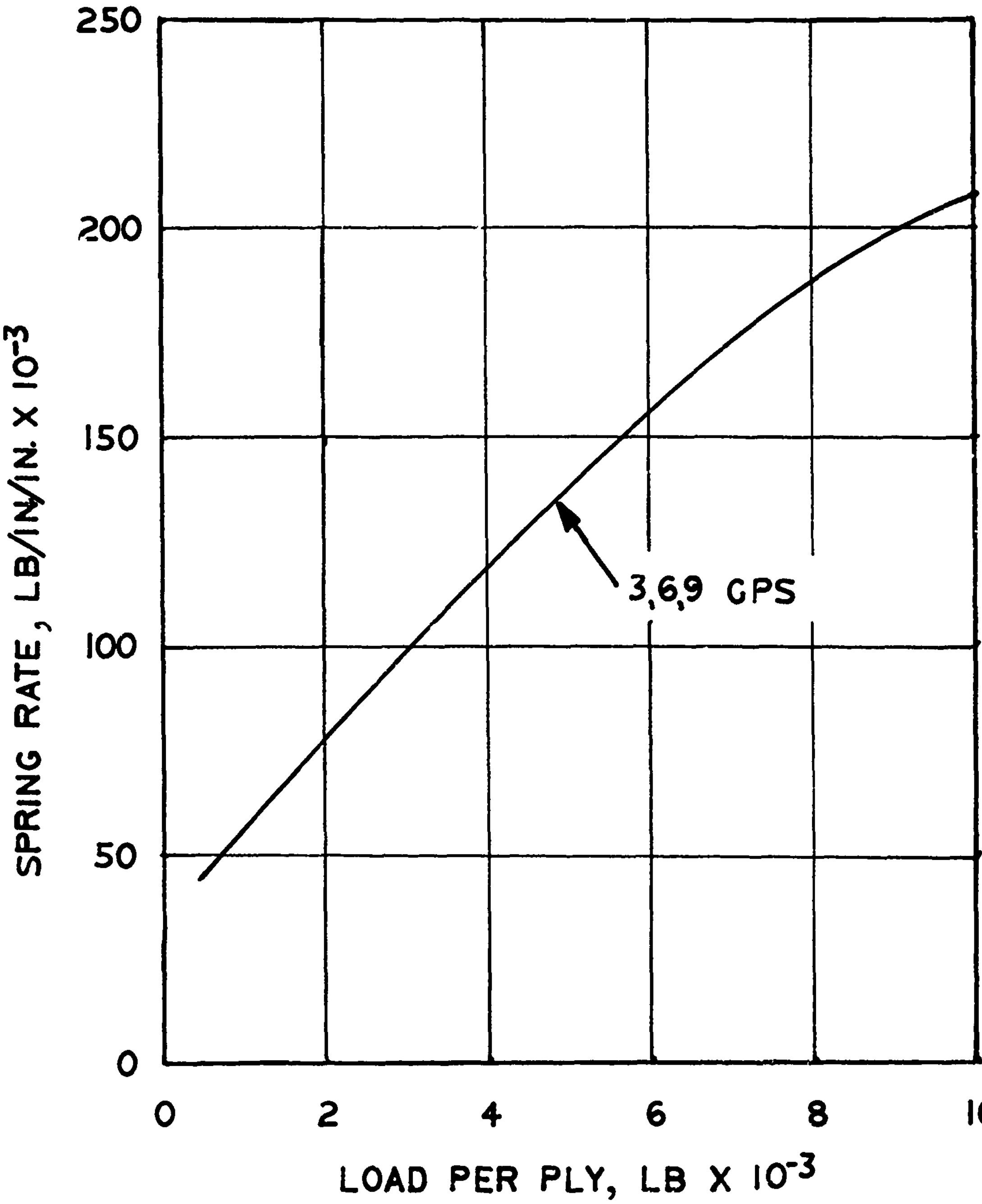


Figure 39. Spring Rate - Type XXVI-R Nylon.

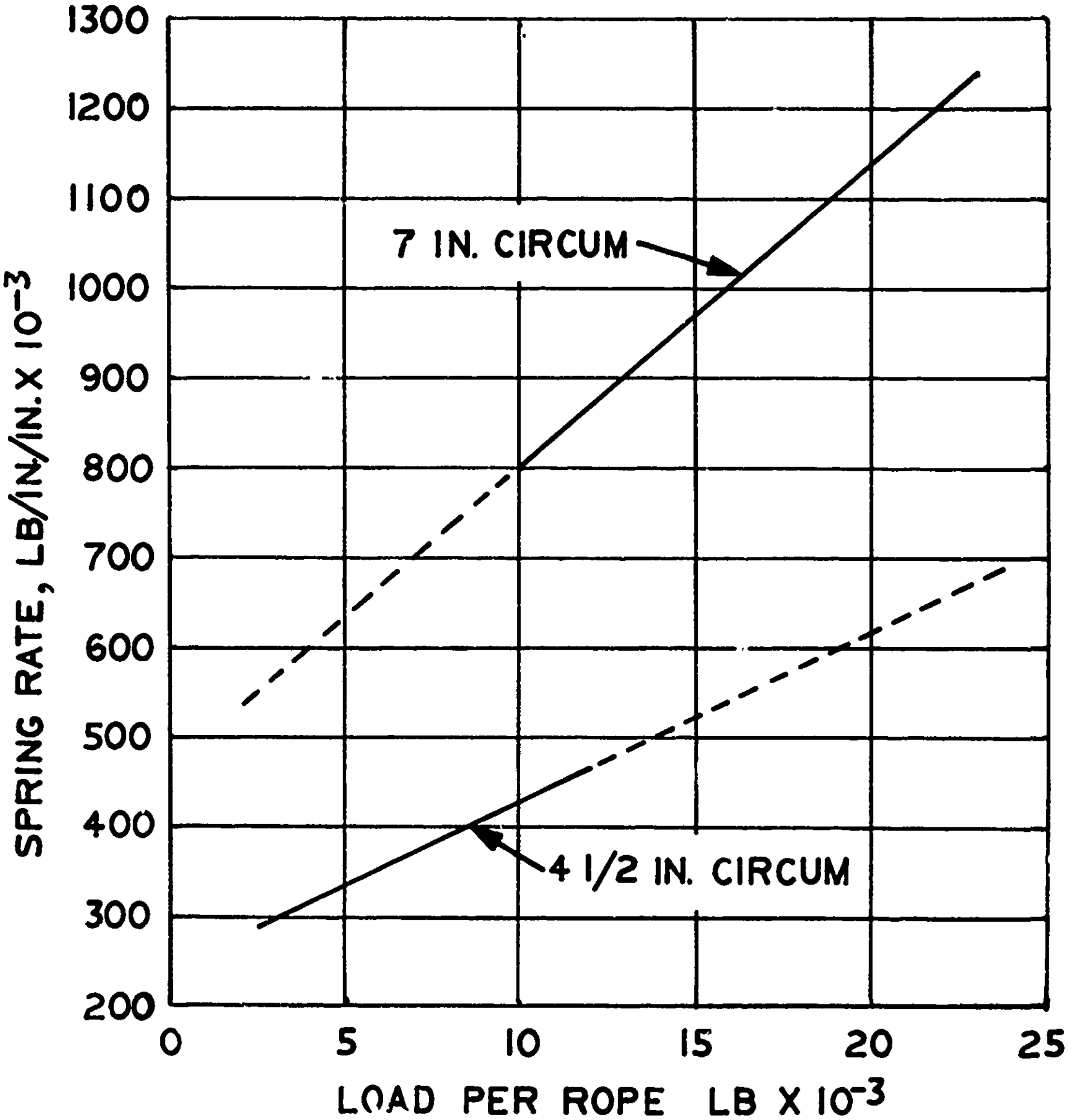
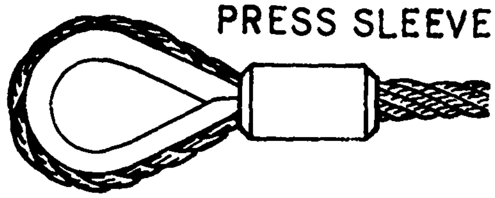


Figure 40. Spring Rate -
2 in 1 Braided Nylon/Nylon.

APPENDIX III

WIRE ROPE TERMINALS

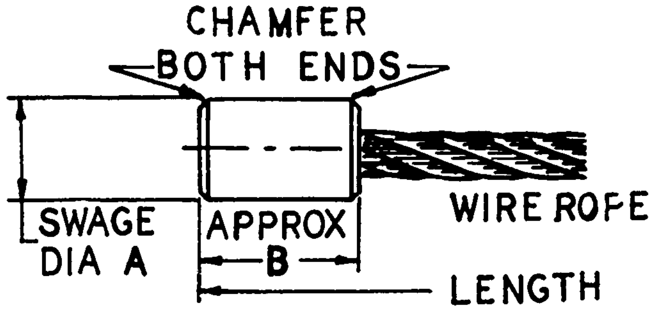
THIMBLE LOOP WITH PRESS SLEEVE



EXTRA HEAVY WIRE ROPE THIMBLES

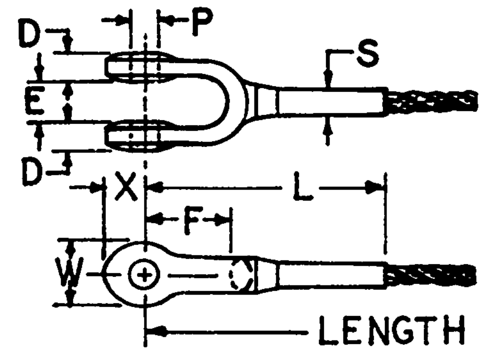
Wire Rope Dia.	Dimensions In Inches						Weight, Pounds Per 100
	Overall Length	Overall Width	Length Inside	Width Inside	Overall Thick.	Max. Pin Dia.	
1/4	[illegible]	1-1/2	[illegible]	7/8	13/32	13/16	7.5
3/8	[illegible]	2-1/8	[illegible]	1-1/8	21/32	1-1/16	[illegible]
1/2	[illegible]	2-3/4	[illegible]	1-1/2	27/32	1-7/16	51
5/8	[illegible]	3-1/8	3-1/4	1-3/4	1	1-5/8	75
3/4	5	3-13/16	[illegible]	2	[illegible]	1-7/8	147
7/8	[illegible]	4-1/4	4-1/4	2-1/4	1-3/8	2-1/8	185
1	[illegible]	4-15/16	4-1/2	[illegible]	1-9/16	[illegible]	300
1-1/8 - 1-1/4	7	5-7/8	5-1/8	2-7/8	1-7/8	2-3/4	410
1-1/4 - 1-3/8	9-1/16	6-13/16	6-1/2	3-1/2	2-1/4	3-1/4	834
1-3/8 - 1-1/2	9	7-1/8	6-1/4	3-1/2	2-5/8	3-3/8	1200

Figure 41. Wire Rope Terminal - Thimble Loop With Press Sleeve.



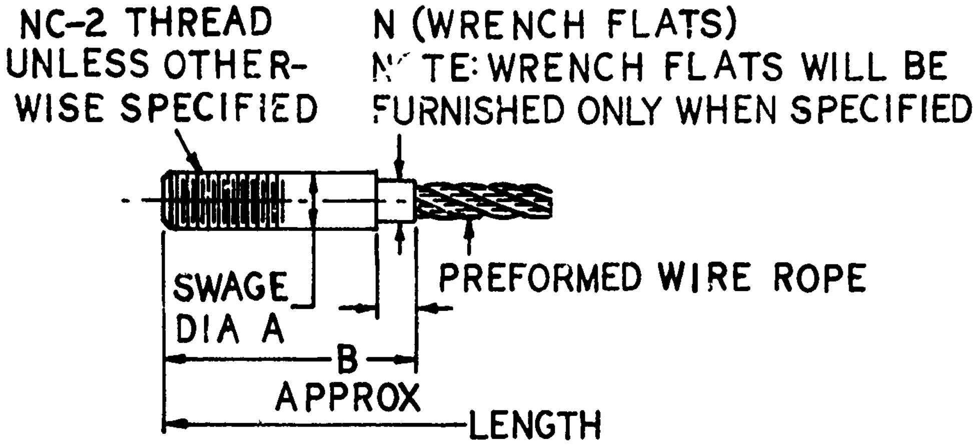
Wire Rope Dia. (in.)	A (in.)	B (in.)
1/4	5/8	1-1/8
3/8	7/8	1-3/4
1/2	1-1/8	2-1/4
5/8	1-3/8	3
3/4	1-9/16	3-1/2
7/8	1-3/4	4-1/4
1	2	4-3/4
1-1/8	2-1/4	5-3/8
1-1/4	2-1/2	6
1-3/8	2-3/4	6-3/4
1-1/2	3	7-1/2

Figure 42. Wire Rope Terminal - Ferrule.



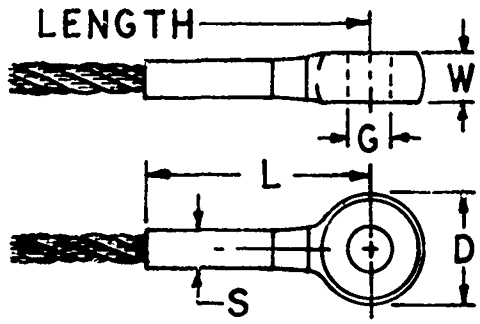
Wire Rope Dia. (in.)	D (in.)	E (in.)	F (in.)	L (in.)	P (in.)	W (in.)	X (in)
1/4	3/8	11/16	1-1/2	4	11/16	1-1/4	23/32
3/8	15/32	13/16	1-3/4	5-5/16	13/16	1-1/2	7/8
1/2	9/16	1	2	6-11/16	1	1-7/8	1-1/16
5/8	21/32	1-1/4	2-1/4	8-1/8	1-3/16	2-3/8	1-11/32
3/4	25/32	1-1/2	2-3/4	10	1-3/8	2-7/8	1-5/8
7/8	3/4	1-3/4	3-1/4	11-5/8	1-5/8	3-1/8	2-13/32
1	7/8	2	3-3/4	13-3/8	2	3-11/16	2-3/32
1-1/8	1	2-1/4	4-1/4	15	2-1/4	4-1/16	2-5/16
1-1/4	1-1/8	2-1/2	4-3/4	16-1/2	2-1/2	4-1/2	2-9/16

Figure 43. Wire Rope Terminal - Open Swage Socket.



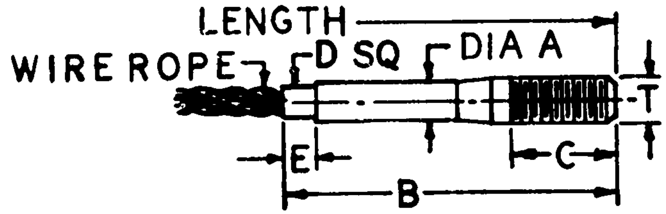
Wire Rope Data (in.)	A_s (in.)	B(in.)	T(in.)	L(in.)	N(in.)
1/4	1/2	2-1/4	1-1/2	1/2	3/8
3/8	3/4	3-1/2	2	3/4	1/2
1/2	1	4-1/2	2-1/2	1	5/8
5/8	1-1/4	5-1/2	3	1-1/4	7/8
3/4	1-1/2	7	4	1-1/4	1
7/8	1-3/4	8	5	1-3/8	1-1/4
1	2	9	6	1-1/2	1-3/8
1-1/8	2-1/4	10-1/2	7-1/2	1-1/2	1-5/8
1-1/4	2-1/2	12	9	1-1/2	1-7/8
1-3/8	2-3/4	13-1/2	10-1/2	2	2
1-1/2	3	15	12	2	2-1/4

Figure 44. Wire Rope Terminal - Threaded Sleeve.



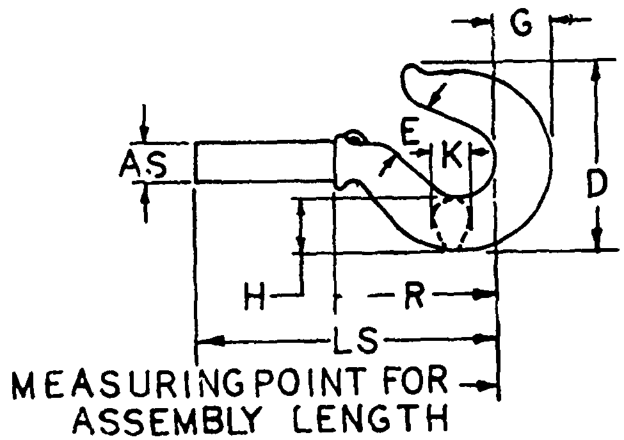
Wire Rope Dia. (in.)	D(in.)	G(in.)	L (in.)	W (in.)
1/4	1-7/16	.750	3-1/2	1/2
3/8	1-11/16	.875	4-1/2	11/16
1/2	2	1.063	5-3/4	7/8
5/8	2-1/2	1.250	7-1/4	1-1/8
3/4	3	1.469	8-5/8	1-5/16
7/8	3-1/2	1.719	10-1/8	1-1/2
1	3-5/8	2.094	11-1/2	1-3/4
1-1/8	4	2.344	12-3/4	2
1-1/4	4-1/2	2.594	14-3/8	2-1/4

Figure 45. Wire Rope Terminal - Closed Swage Socket.



Wire Rope Dia. (in.)	T Thread Size NC (dia.in. - thds/in.)	A (in.)	B(in.)	C(in.)	D(in.)	E(in.)
1/4	1/2-13	7/16	3-1/2	1-1/8	3/8	7/16
3/8	3/4-10	5/8	5-1/8	1-5/8	9/16	1/2
1/2	7/8-9	3/4	6-5/8	2-1/4	11/16	9/16
5/8	1-1/8-7	1	8-1/4	3	3/4	5/8
3/4	1-3/8-6	1-1/4	9-3/8	3-1/2	7/8	3/4
7/8	1-1/2-6	1-3/8	11	3-1/2	1-1/16	7/8
1	1-3/4-5	1-9/16	12-3/4	4-3/8	1-3/16	1

Figure 46. Wire Rope Terminal - Threaded Stud.



Wire Rope Dia. (in.)	Hook Size (No.)	A_s (in.)	[illegible] (in.)	E(in.)	G(in.)	H(in.)	K(in.)	R(in.)	L_s (in.)
1/4	4	1/2	3-9/16	1-1/8	1	1-1/8	11/16	2-5/8	5-1/8
3/8	6	3/4	4-9/16	1-3/8	1-11/16	1-9/16	31/32	3-1/4	5-15/16
1/2	[illegible]	1	[illegible]-7/8	1-3/4	1-11/16	2	1-1/4	4-1/8	7-5/8
5/8	10	1-3/16	7-3/16	2-1/16	2-1/32	2-13/32	1-17/32	5-1/8	9-1/8
3/4	11	1-3/8	[illegible]-9/16	2-1/2	2-17/32	2-31/32	1-13/16	6-1/8	10-5/8
7/8	13	1-1/2	[illegible]-9/16	3	2-25/32	3-9/32	1-15/16	6-3/4	11-3/4
1	14	1-3/4	11-7/16	3-3/8	3-7/32	3-3/16	2-7/32	7-9/16	13-1/16

Figure 47. Wire Rope Terminal - Shank Hook.

APPENDIX IV

VERTICAL BOUNCE CRITERIA

The following is a reprint of Appendix 4 from Technical Report 68-2 entitled, Aerial Recovery Kit, Concept Formulation Study; U. S. Army Aviation Materiel Command, St. Louis, Missouri, June 1968, AD 673102.

2.1.4.1 APPENDIX 4

TITLE: Design Criteria and Analysis for the Prevention of Vertical Bounce

4.1 Summary

A dynamic analysis was performed to generate Universal Sling Kit Design criteria for the prevention of "vertical bounce", which is a condition of excessive helicopter vibration at a frequency of 1 x main rotc. .peed resulting from normal, inherent, main rotor forces amplified by the tuned response of an aircraft and its suspended load. Further, the system's tuning characteristics are primarily controlled by the spring rate of the suspension system between the two masses.

Design criteria, or limitations on the spring rate of the Universal Sling, were established for the UH-1D and CH-47 aircraft. These criteria were based on Sikorsky Aircraft's experience and data obtained during the development of the CH-54A aircraft. No limitations were imposed on the sling for use on the CH-54A aircraft since a dynamic decoupler has already been incorporated into this aircraft's cargo handling system.

An analysis of the actual Universal Sling design is presented to justify that it meets the design criteria requirements. It was shown that the Universal Sling Kit, for use with either prime mover aircraft, or for any suspended load configuration, meets and exceeds the design criteria requirements.

4.2 Symbols

1p	1 x main rotor
f1p	frequency of 1p or system excitation frequency (cpm)
f_{RBM}	coupled aircraft - load rigid body mode natural frequency (cpm)
$f1p/f_{RBM}$	proximity ratio (cpm/cpm)
Wsl	weight of slung load (lb)
$W_{A/C}$	weight of aircraft (lb)
μ	$Wsl/W_{A/C}$ = mass ratio (lb/lb)
Ks	spring rate of suspension system (lb/in.)

g gravitational constant (in./sec.^{2})

f_{VBM} aircraft uncoupled first vertical bending mode natural frequency (cpm)

f_{lp}/f_{VBM} proximity ratio (cpm/cpm)

4.3 Background

During the early stages of the CH-54A development program, a vibration phenomenon was sometimes encountered when heavy loads were lifted by a cable suspension system. The incidence of these events was infrequent. However, when encountered, it was evident that the response could build up and become serious enough to cause the pilot to jettison the load. It was also noted that the frequency of the response was at or near lp.

This phenomenon was explained as a resonance of the aircraft and suspended load system, excited by the main rotor head lp forces. The aircraft behaved basically as a rigid body mass, the suspension system constituted the spring, and the suspended load was the second mass in the total dynamic system.

High response could most easily be achieved by slowly varying the cable length while in-flight. Since this varied the cable spring rate, this was a convenient means of experimentally tuning the system. Significantly, the response curve exhibited a narrow "Q" characteristic, meaning that significant response only occurred within a narrow proximity margin. This is defined as the proximity ratio f_{lp}/f_{RBM}.

High response was also most evident to the pilot when heavy loads were carried. As the suspended load to prime mover aircraft mass ratio increased, the system's mode shape was altered resulting in increased aircraft or cockpit participation. This mass ratio is defined as

$$\mu = W_{sl}/W_{A/C}$$

For design purposes, vibration acceptablility levels are based on pilot comfort criteria rather than structural integrity criteria. These oscillations are characterized by large displacement excursions and low acceleration amplitudes. In this region, inertial forces are low, but human susceptibility is high.

As part of the CH-54A development program, a dynamic decoupler was incorporated into the single point cargo handling system. This provision is basically a soft spring which is compatible with any impedance, or suspended load characteristic, keeping the system always well within acceptable limits of vibration. It only functions for suspended loads having mass ratios of approximately 0.5 or higher. This parameter, and its proximity ratio parameter, have been fully evaluated and substantiated by flight test measurements.

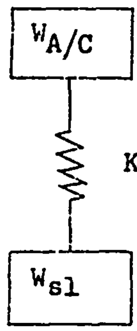
4.4 Parametric Considerations

The "background" introduced each of the pertinent parameters necessary to consider in establishing design criteria. Each is discussed below:

Proximity Ratio of Fuselage First Vertical Bending Mode (f_{1p}/f_{VBM})

Investigation of the vertical bounce phenomenon at Sikorsky Aircraft has shown that cockpit response is the summation of the rigid body response and some first fuselage bending mode response. However, the model below is a close analog representation of the phenomenon capable of extrapolating the CH-54A experience to other aircraft, if the following proximity margin relationship is observed.

$$f_{1p}/f_{VBM} \leq \frac{185 \text{ cpm}}{235 \text{ cpm}} = 0.79 \qquad (54)$$



Proximity Ratio (f_{1p}/f_{RBM})

Experience with the CH-54A aircraft has substantiated the following proximity ratio with the heaviest suspended load:

$$f_{1p}/f_{RBM} \geq \left.\frac{185 \text{ cpm}}{105 \text{ cpm}}\right|_{CH\text{-}54A} = 1.76 \qquad (55)$$

Mass Ratio $\mu = W_{sl}/W_{A/C}$

Experience with the CH-53A aircraft has shown that the suspended load is significant only for mass ratios:

$$\mu = W_{sl}/W_{A/C} \geq \left.\frac{10{,}000 \text{ lb}}{22{,}000 \text{ lb}}\right|_{CH\text{-}54A} = 0.45 \qquad (56)$$

Spring Rate (K_s)

The non-trivial natural frequency of the rigid body system shown above is:

$$f = \frac{60}{2}\left[\frac{K_s\,(W_{A/C} + W_{sl})\,g}{(W_{A/C})\,(W_{sl})}\right]^{1/2} \qquad (57)$$

We now have the significant parameters defined and are prepared to determine the dynamic design criteria for the prevention of vertical bounce.

4.5 Design Criteria

Dynamic criteria for the Universal Sling Kit will be generated by defining limitations and latitude of the stiffness of the sling. By controlling the sling stiffness the frequency of the rigid body mode is controlled thereby providing suitable isolation from the lp forces. Using the parameters developed above, stiffness criteria for the sling were developed for use of the kit with the UH-1D and CH-47. Characteristics of slings used on the CH-54A are not restricted because load isolation is incorporated in its cargo handling system.

The lp frequencies and fuselage first vertical bending mode frequencies are tabulated below.

MODEL	f_{1p}	f_{VBM}	f_{1p}/f_{VBM}
CH-54A	185 cpm	235 cpm	0.79
UH-1D	310 cpm	395 cpm	0.79
CH-47	230 cpm	470 cpm	0.49

As shown in the table the UH-1D and CH-47 meet or exceed the requirements of equation (54).

The required rigid body mode frequency is found by rearranging equation (55).

$$f_{RBM} \leq 0.57\ f_{1p} \tag{58}$$

and substituting the appropriate lp frequency for the UH-1D and CH-47. With the maximum rigid body mode frequency defined, the sling stiffness may be evaluated. Algebraic manipulation of equation (57) to solve for sling stiffness gives

$$Ks = \left(\frac{2\ f\pi}{60}\right)^2 \frac{(W_{A/C})(W_{s1})}{(W_{A/C} + W_{s1})\ g} \tag{59}$$

By solving equation (59) using the rigid body mode frequency determined from equation (58) and the maximum slung load weight, the sling stiffness for the UH-1D and CH-47 is determined. This spring rate represents the upper limit.

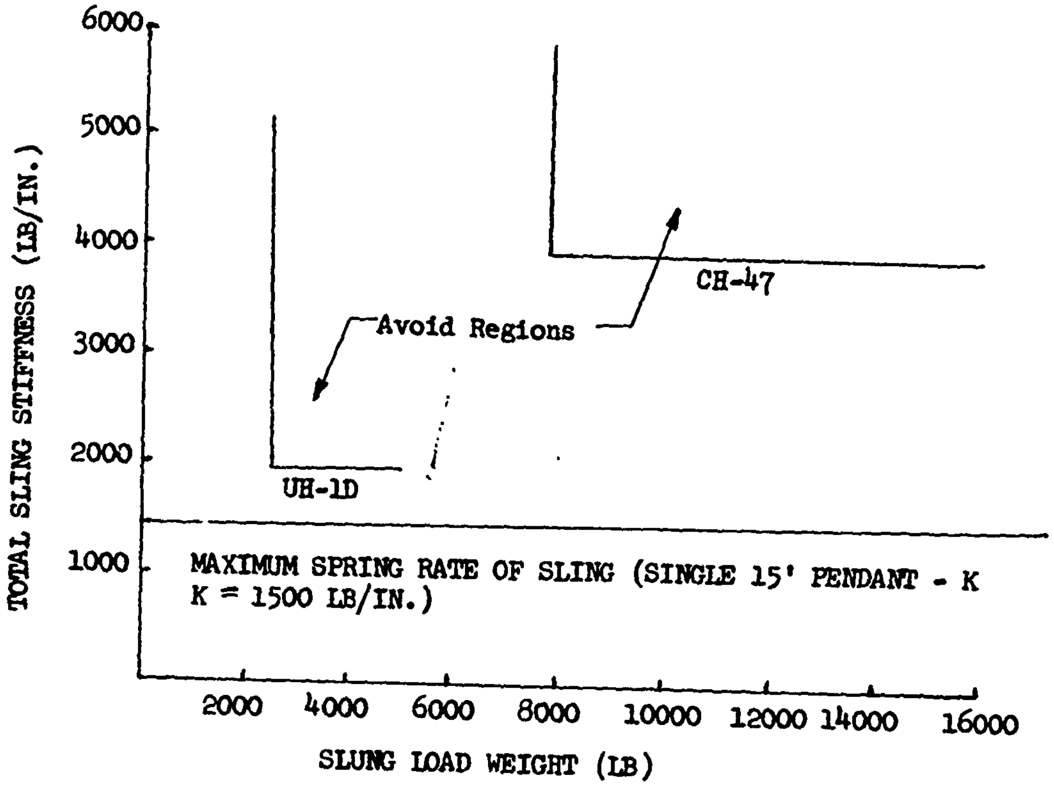
For the purpose of this analysis the slung load weight was defined as the maximum payload, and aircraft weight was defined as the difference between the maximum gross weight and the maximum payload. These values are tabulated below.

MODEL	G.W. (MAX.)	W_{sl}	$W_{A/C}$
CH-54A	42,000 lb	20,000 lb	22,000 lb
UH-1D	9,500 lb	4,000 lb	5,000 lb
CH-47	33,000 lb	17,000 lb	16,000 lb

Rearrangement of equation (55) gives

$$W_{sl}\ (\text{Min.}) = 0.45\ W_{A/C} \qquad (60)$$

Substituting the respective aircraft weights as defined above permits evaluation of the minimum sling load weight for which isolation is required. Results of the dynamic design criteria determinations are shown graphically in Figure (84).



NOTES: Upper weight boundaries defined by maximum sling load capacity Lower weight boundaries defined by the ratio of mass of slung load to mass of prime mover.

Figure 84. Universal Sling Kit
Total Sling Stiffness Vs. Slung Load Weight
Restrictions Applicable To UH-1D And CH-47 A/C.

DESIGN JUSTIFICATION

Upon determination of the general design configuration of the Universal Sling Kit it is necessary to evaluate the equivalent stiffness of specific sling configurations. The stiffness criteria developed represents the total sling stiffness whereas the kit may logically be thought of as consisting of three separate and distinct sections, the pendant, bridle, and belly bands, which contribute to the kit's total stiffness. Techniques for evaluating the stiffness of the individual sections, and then the total stiffness of configuration are shown in Figure (85).

Review of all the sling arrangements showed that the stiffest sling configuration was the single 15' pendant used to carry a downed UH-1D by attachment to the rotor head. Analysis of this configuration indicated that its spring rate is 1,500 lb/in. Referring to the criteria, shown in Figure (84) shows that this stiffness, for the stiffest possible sling configuration, is well below that required. Consequently the universal sling kit design will provide greater isolation than that required for the prevention of vertical bounce.

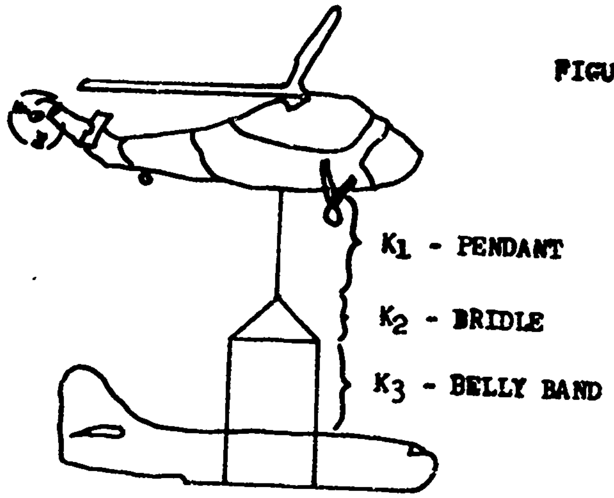
The kit will also provide isolation from the Np forces. This is shown by recalling that $f_{np} = N f_{1p}$

and therefore $f_{np} > f_{1p}$

substituting in equation (58) shows $f_{RBM} \ll f_{np}$

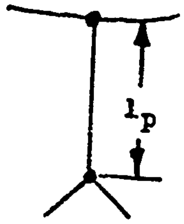
indicating an even greater isolation from Np forces.

FIGURE 85



$$K_T = \frac{K_1 K_2 K_3}{K_1 K_2 + K_1 K_3 + K_2 K_3}$$

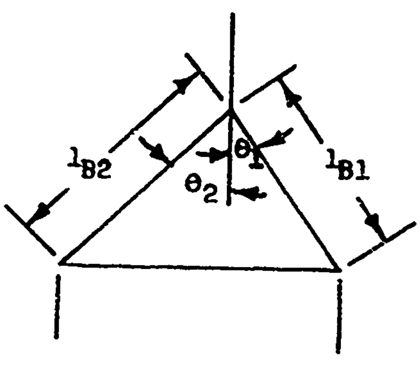
PENDANT



$$K_1 = \frac{k_p}{l_p}$$

k_p = Spring Rate of Pendant Material per Unit Length

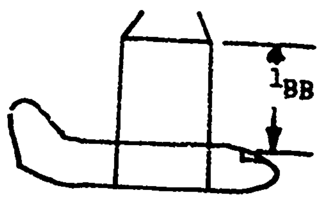
BRIDLE



$$K_2 = K_B \left[\frac{1}{l_{B1}} \cos^2 \theta_1 + \frac{1}{l_{B2}} \cos^2 \theta_2 \right]$$

k_B = Spring Rate of Bridle Material per Unit Length

BELLY BAND



$$K_3 = N \frac{k_{BB}}{l_{BB}}$$

k_{BB} = Spring Rate of Belly Band per Unit Length

APPENDIX V

MATERIEL CLASSIFICATION

Types of Materiel

The type of materiel to be carried is a major factor in determining lift point structural requirements. All types of materiel do not behave identically in flight when suspended from a helicopter. However, when separated into classes with the ratio of projected vertical area to weight as the parameter, materiel with like flying qualities can be found. Determination of the class into which a given type of materiel will fall requires that the weight and the maximum projected vertical area be determined. Maximum projected vertical area is defined as the maximum area projected on a vertical plane when the materiel is suspended from the sling. This automatically excludes all horizontal surfaces. It includes all vertical surfaces since the sling is normally suspended from a free swiveling hook. Figure 48 shows the materiel classifications with respect to the frontal area to weight ratio. Since the distinction between load types is not precise, Figure 48 shows a shaded area at the interfaces. Any materiel falling within the shaded areas requires that both materiel types be analyzed. When a helicopter is carried as an external load, materiel classification is not made. There is a special curve on Figure 8 to cover these cases.

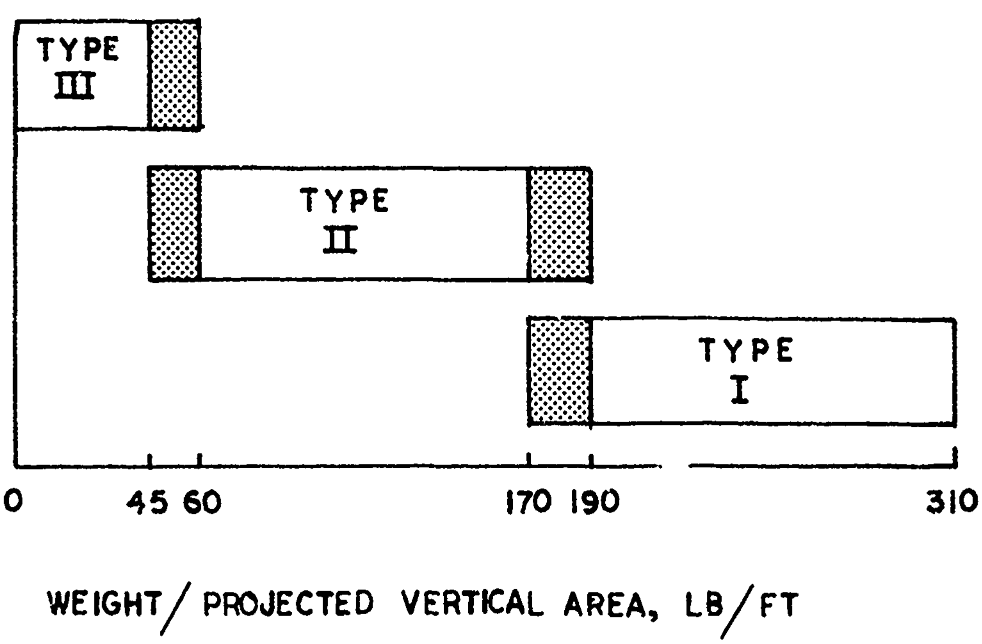


Figure 48. Materiel Classification Chart.