DESIGN DATA SHEET

EQUIPMENT SWAY BRACE DESIGN

DEPARTMENT OF THE NAVY
NAVAL SEA SYSTEMS COMMAND
WASHINGTON, DC 20362-5101

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072-5-a INTRODUCTION

072-5-a(1) Purpose. The purpose of this document is to provide guidance for the selection and design of sway braces for shipboard equipment (usually electronic equipment cabinets). Sway braces provide limited, horizontal support at the upper end of base-mounted equipment in order to resist lateral operational loads, as well as loads caused by vibration excitation or ship motion.

072-5-a(2) Scope. This Design Data Sheet will address the criteria governing the use of sway braces for surface ships and submarine equipment and discuss the configurations and design of sway braces commonly used. Sample problems illustrating the methods and techniques will be presented.

A brief discussion of the design and analysis of foundation upper supports is presented herein in order to emphasize the differences between sway braces and upper supports. For methods and techniques of shock design of foundation upper supports reference (1), the "Shock Design Criteria for Surface Ships", should be consulted.

072-5-b REFERENCES

(1) NAVSEA Document No. 0908-LP-000-3010, "Shock Design Criteria for Surface Ships," May 1976

(2) MIL-STD-167 (SHIPS), "Mechanical Vibrations of Shipboard Equipment"

(3) MIL-S-901 (NAVY), "Shock Tests, H.I. (High Impact); Shipboard Machinery, Equipment and Systems, Requirements For."

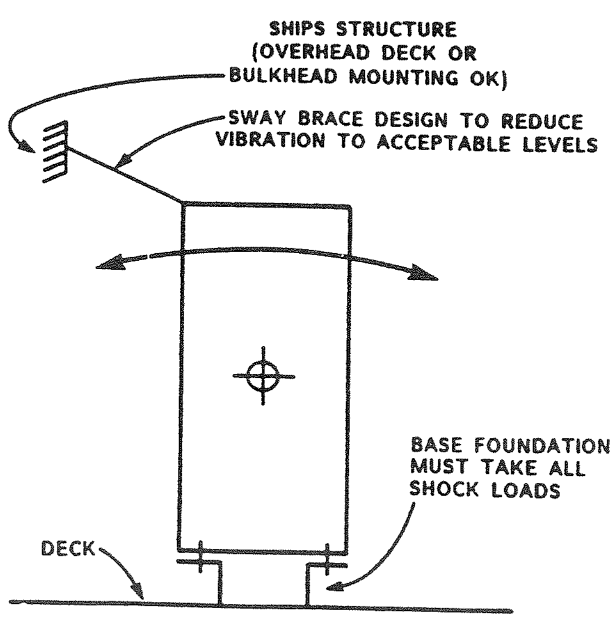
072-5-c DEFINITIONS

072-5-c(1) Sway Braces. A support structure added to the upper portion of a piece of equipment for the specific purpose of preventing excessive vibration levels.

Sway braces must not be confused with "upper support" portions of shock designed foundations. The distinction between foundation "upper supports" and sway braces is very important. "Upper supports" must be designed to resist their full share of horizontal shock load, which will be transmitted to the equipment itself. Sway braces must be designed to either yield (fail) or be sufficiently flexible when a specified, limiting load (between 2 and 5 g's) is applied at the equipment's center-of-gravity, so that no additional force is transmitted to the equipment.

NOTE: Unless otherwise specified, "g" in this document refers to a nondimensional force multiplier.

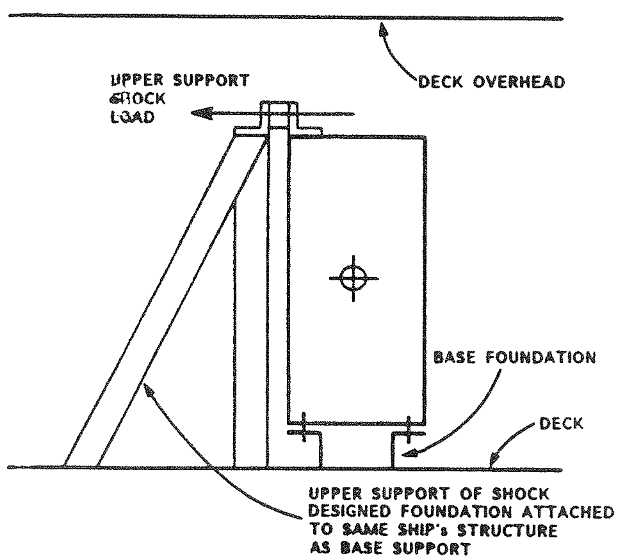
Sway braces are not intended to withstand shock loading. Accordingly, they are to be embodied with a failure mechanism or must possess sufficient flexibility to ensure that shock loads are transmitted only to the structural foundation at the base of the equipment. Since the sway brace is designed to provide



horizontal support only, vertical restraint must not be designed into the brace.

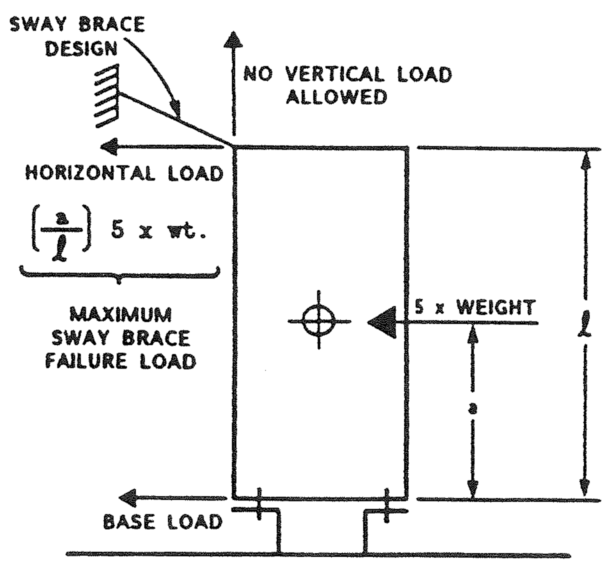
072-5-c(2) Foundation Upper Support. A support structure added to the upper portion of a piece of equipment for the purpose of preventing damage to the equipment during shock.

Consequently, an upper support will also raise the lateral natural frequencies of the system, thus avoiding objectionable resonances, and will provide added support for the equipment while it is exposed to operational and heavy sea state loads. An upper support is an integral element of the equipment foundation and, as such, must meet the shock requirement of the equipment foundation design.



072-5-c(3) Sway Brace Failure Load. The load at which a sway brace is to become ineffective, either by plastic (yielding) action of the sway brace mechanism, by elastic instability, or by bolt shear failure.

Sway braces are to be designed using a failure load which marginally exceeds the most severe combination of operational and ship motion loads. Furthermore, the failure load cannot be greater than five times the weight of the unit.



072-5-c(4) Stability Under Vibration. The state of being relatively vibration free while exposed to the spectrum of shipboard vibratory driving forces. Lack of stability will result in excessive vibration levels which could lead to failure or improper operation of the equipment.

072-5-c(5) Flexibility. The characteristic of structural members which have little rigidity. Flexible structures are those which accommodate large degrees of movement without yielding or rupturing. Sway braces which do not utilize failure mechanisms are to possess this property in order to permit relative motions under shock without damaging supported equipment.

072-5-c(6) Spring Plate. Structural members consisting of unstiffened plates or flat bars positioned such that vertical loading will produce bending of the members about their weak axis. They are used to provide sway braces with flexibility in the vertical direction.

072-5-c(7) Hinged Braces. Sway braces which employ hinged connections at their attachment to equipment and also at their connection to support structure are referred to as "Hinged Braces". An example of such a brace is shown in Figure 6.

072-5-d CRITERIA FOR APPLICATION OF SWAY BRACES

Established sway brace design criteria, as delineated in ship specifications, can be identified by the following five major requirements.

072-5-d(1) Height to Base Width Ratio Must be Three or Less.

Sway bracing for electronic equipment or other enclosures should be installed if the ratio of the height to the smaller base dimension is three or greater. The sway brace should be designed so as to prevent motion in the plane of the dimension under consideration. If the ratio of height to larger base dimension is also three or greater, a sway brace would also be required in that direction.

In some cases, however, individual ship specifications may stipulate that sway braces need not be used if cabinets are vibration tested, as outlined in 3 below, for shipboard use in the stand alone configuration. In such cases, the specifications also require that the natural frequency of vibration of the mounted cabinet in its rocking modes be greater than 1.25 times the maximum propeller blade rate frequency. The equipment is normally qualified by means of vibration tests in compliance with reference (2).

Bottom mounted units which are tall in comparison to their base dimensions tend to have inherent lateral flexibility. For this reason, in the overturning modes, they are prone to result in low equipment/foundation natural frequencies which cause resonance conditions with the ship's propeller, or other sources of shipboard excitation, thus producing excessive vibration levels. Such a harmful condition can be avoided by raising the lateral natural frequencies of the system. This can be accomplished by either adding sway braces to the upper portion of the equipment unit or by stiffening its foundation, under-deck structure and equipment enclosure. Sway braces can have inherent weight and cost advantages when used appropriately. Accordingly, their use is preferred over equipment or foundation modification. Stiffening of the equipment framework and foundation is usually an inefficient and costly solution and, therefore, should be avoided.

072-5-d(2) Limited Restraint in Both Magnitude and Direction.

The sway brace is not designed to resist shock loads. The maximum load transmitted laterally (horizontally) via the sway brace design must not exceed five times the weight of the equipment applied at its center-of-gravity. Horizontal braces are preferred, but in no case shall the load path angle of inclination of the brace exceed 45 degrees from the horizontal, keeping vertical loads transmitted to a minimum. In any event, sway braces shall have sufficient flexibility in the vertical direction to accommodate motions without overloading the equipment or ship's structure.

The sway brace design and its support structure must be sufficiently rigid to provide proper lateral restraint to the unit, but also sufficiently flexible to fail at loads marginally exceeding the combined operational and ship motions loads. This load should be between 2 and 5 g's applied at the equipment's center-of-gravity. Specifically, the sway brace shall fail before the component fails under these conditions.

072-5-d(3) Excessive Vibration in Equipment Must Not Occur

Ship specifications stipulate that shipboard equipment is to be free from excessive vibration, excessive vibration being defined as vibratory levels which result in damage to ship's structure, equipment or systems, or which interfere with the proper operation of any ship component. The existence of resonance conditions between the natural frequencies of an equipment unit and the excitation forces produced by the ship's propeller, or by rotating machinery in the vicinity of the unit, is undesirable. Such a condition could produce vibration levels sufficiently severe to lead to malfunction or damage of the equipment or to catastrophic failure of its structural framework. The use of sway bracing will serve to raise the lateral natural frequencies of an equipment/foundation system to levels at which resonance will be avoided.

Sway braces should only be used when they are necessary to ensure that an equipment unit satisfies the vibration criteria. Their need is usually established by vibration testing as specified in reference (2). Failure to satisfy the specified Type I testing requirements of reference (2) will necessitate either modification of the equipment or the addition of sway braces. Regardless of the corrective action chosen, the modified configuration must be proven satisfactory. Consequently, if sway braces are added, the equipment must be vibration tested in accordance with reference (2), with the sway braces installed.

072-5-d(4) <u>Noise Shorts Must Not be Introduced</u>

Base-mounted equipment which require sound isolation (resilient) mounts may also require support at its top as a result of requirements 1 or 3 above. Often, this support must also satisfy shock requirements and thus must be designed as upper foundation support in accordance with criteria specified in reference (1).

However, if the sway brace concept is used, it must also have a sound isolation element within the load path to ensure no noise is transmitted from the equipment to ship's structure.

072-5-d(5) <u>Installations Must be Consistent With Shock Qualification Tests</u>

If an item is intended to be installed aboard ship with an upper support foundation, the shock qualification tests must duplicate that installation configuration. If an item has been shock tested with an upper foundation an equivalent foundation must be used in the ship installation. A sway brace design cannot be used to represent an upper support required by a qualification test since the sway brace is designed to fail when the specified failure loads (between 2 and 5 g's) are applied at the center-of-gravity of the equipment.

Sway braces shall not be included in shock qualification testing of an item. Calculations, however, must be provided to show compliance with the failure criteria.

Obviously, if a unit is vibration tested with a sway brace, a sway brace must be used in the ship installation.

072-5-e SWAY BRACE FAILURE MECHANISMS

The failure mechanism of a sway brace is that design characteristic that will cause the brace to become ineffective when the failure load, based on the 2 to 5-g criterion, is applied. The failure mechanism usually involves yielding of the sway brace, elastic instability (buckling), or bolt shear failure.

The first step in selecting the mode(s) of failure to be used in the sway brace design is to determine the magnitude of the failure-inducing load. The accepted procedure for determine of the sway brace failure load is as follows:

(1) A 5-g horizontal load is applied at the equipment unit's center of gravity.

(2) The load is distributed as a function of geometry between the sway brace and foundation at the lower end of the equipment unit.

(3) The resulting horizontal reaction at the sway brace is the failure load and governs the design of the sway brace and its failure mechanism.

(4) Confirm that the failure load is greater than 2 g's.

The next step is the selection of the particular failure mode(s) to be used in the sway brace design. The four major failure mechanisms listed in their order of preference are:

(1) Yielding (bending)
(2) Buckling
(3) Shear bolt
(4) Flexibility

072-5-e(1) Yielding. Loading a structural member past its yield point will result in the formation of plastic hinges and the redistribution of load to other members of the structural system. The yielding of sway brace members is a valid failure mechanism used in sway brace design. Members must be rigid enough to properly support the equipment but must yield at the prescribed failure loading and redistribute the load to the foundation at the lower end of the equipment.

The yielding of structural members in bending is also an accepted technique to prevent a sway brace from resisting vertical loads. Plastic actions of unstiffened plate, light angles, and unstiffened connections are examples of techniques often employed to ensure that sway brace designs do not resist vertical loadings.

The yielding-type sway brace will become distorted when exposed to shock loadings, but will not create a missile hazard or require replacement of bolts and nuts. Consequently, the yielding-type sway brace is a preferable installation.

072-5-e(2) Buckling. Buckling of unstiffened plates can also be employed as a failure mechanism in sway brace design. As buckling occurs in compression loading only, an alternative failure mechanism must be employed for tensile loading in sway brace members. Because two failure mechanisms must be utilized, sway braces of this type are not often used.

072-5-e(3) Shear Bolt. Utilization of this mechanism requires that each brace contain a mounting bolt or shear pin, hereafter designated as shear bolt, and sized accordingly. Shear bolts are to reach their ultimate shear stress at the sway brace failure load. In many cases this will entail the use of very small diameter bolts made of relatively low strength material. Whenever possible, the design of the sway braces should be such that the shear bolts will fail when the failure load is applied in either opposing horizontal direction. In employing this type of failure mechanism consideration must be given to the possibility of bolt fragments becoming missile hazards and striking personnel or vital equipment.

To prevent bolt fragments from becoming missile hazards to personnel or vital equipment, it is required that when employing this type of failure mechanism, captive features be used. Sway brace shear bolt captive features could include wiring of the bolt head and nut, tack welding of the bolt head and nut, or utilizing specifically designed washers or clips which wrap around the corresponding bolt portions.

Where obviously small bolts are used in the sway brace, there is the tendency for the ship's force to inadvertently upgrade (increase in size) the bolt on aesthetic evaluations. This may convert a shear bolt type sway brace design into a potential source of shock damage to the equipment. While the shear bolt design is not the preferred method, shipbuilding specifications generally do not prohibit this approach.

072-5-e(4) Flexibility Type. Although not a true failure type sway brace, an alternate approach to the design of a sway brace is to provide a sway brace structure which does not utilize a failure mechanism, but which is flexible enough to become ineffective under shock by virtue of accommodating large degrees of movement without yielding or rupturing. In this type of design the sway brace is to be flexible enough to allow motions under shock so that no damage to the equipment will result. In addition, it is to be sufficiently rigid to prevent excessive vibration levels, and sufficiently sturdy to resist the most severe combination of operating and storm condition loadings. Care must be taken with this method to ensure that large displacements do not compromise clearance requirements. This flexibility type design is difficult to achieve and the failure type design, specifically the yielding type, is preferred.

It is emphasized that, in all cases, the sway brace must not be able to resist significant vertical loads, that its failure load must be no greater than the load resulting from the application of 5 g's horizontally at the center-of-gravity of the equipment, and that its failure load be greater than the load resulting from the application of 2 g's horizontally at the center-of-gravity of the equipment.

In some cases, relatively stiff sway braces may be required to provide proper sway brace rigidity in order to meet criteria other then shock (e.g. limiting vibration levels of displacement). If this is the case, the designer should ensure that the failure mechanism is still effective for shock.

072-5-f TYPICAL SWAY BRACE AND UPPER SUPPORT DESIGNS

When it is determined by the criteria previously specified that a sway brace is required, proper selection of a sway brace design is essential, and as in any engineering problem there is a preferred design solution. However, there are many different sway bracing methods available to overcome problems encountered, and many designs which satisfy these criteria are acceptable. Some examples of commonly used sway brace designs are presented in the following paragraphs; also presented are some typical upper support designs to show contrast.

072-5-f(1) Yielding. An example of a yielding type sway brace failure mechanism is shown in Figure 1. This configuration utilizes the formation of a plastic hinge as a means of limiting the load carried by the sway brace and, consequently, yielding serves as the sway brace's failure mechanism. Application of the failure load will result in bending stresses, in the cantilevered angle shown, in excess of the material yield point. This type of sway brace will become distorted when exposed to shock loading, but, unlike the type in which a shear bolt failure mechanism is used, will not create a missile hazard or require replacement of bolts and nuts. Consequently, the yielding type sway brace is a preferable installation.

The sway brace of Figure 1 employs a bolted connection with a 3" long slotted hole. This mechanism is used to permit relative vertical displacements between the two supporting surfaces of the equipment and will therefore prevent vertical loads from being transmitted to the sway brace members. Overhead structure is used to support the sway brace and an angle header is provided to bridge the deck longitudinales.

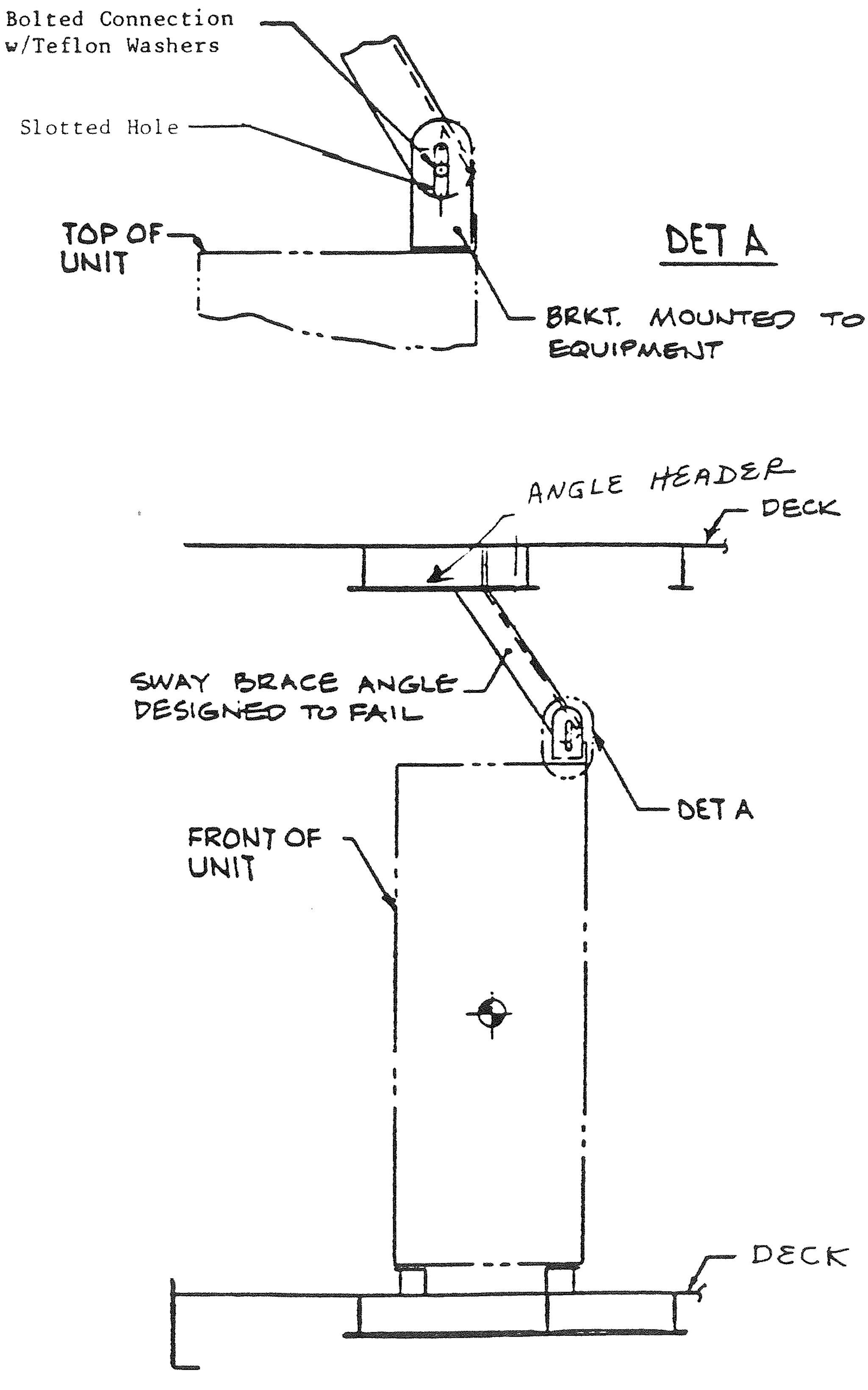


Figure 1. Typical Yielding-Type Sway Brace

072-5-f(2) 45° Braces. An example of a "45° Brace" type of sway brace is illustrated in Figure 2. The configuration shown uses two angle braces, welded to an unchocked bulkhead header, which are attached to the top of the unit by bolted connections. The braces are designed to resist horizontal loads up to the sway brace failure load. When this magnitude of loading is applied, yielding will occur at both ends of the sway brace thus creating a failure mechanism. The sway brace will not resist vertical shock loads or restrain vertical motions due to the flexibility of the linkage that will be formed. Consequently, the vertical stiffness of the foundation at the bottom of the unit is much higher than that of the sway braces. In addition, a sufficient amount of unsupported plate has been provided at the equipment end of each sway brace to prevent damage to, or puncturing of, the top of the unit due to vertical shock excursions.

072-5-f(3) Buckling. An example of a combination buckling/shear bolt type sway brace is illustrated in Figure 3. The configuration utilizes a flat or angle brace attached to the top of the equipment by non-shear bolts and attached to the bulkhead by shear bolts.

A buckling type sway brace failure mechanism will require that the sway brace members have large ratios of length to radius of gyration; that is, that they be slender members. The radii of gyration shall be measured about the principal axes of the member cross-section. To accomplish this, it is necessary that the equipment be located at an appreciable distance from rigid structure (a large "L") and that a thin unstiffened plate or flatbar (a small "r") be used. Each compression member should be oriented such that its weak bending axis is horizontal. This will provide flexibility in the vertical direction and thus prevent sway brace members from carrying vertical load. The failure mechanism must be designed such that it will buckle at the sway brace failure load.

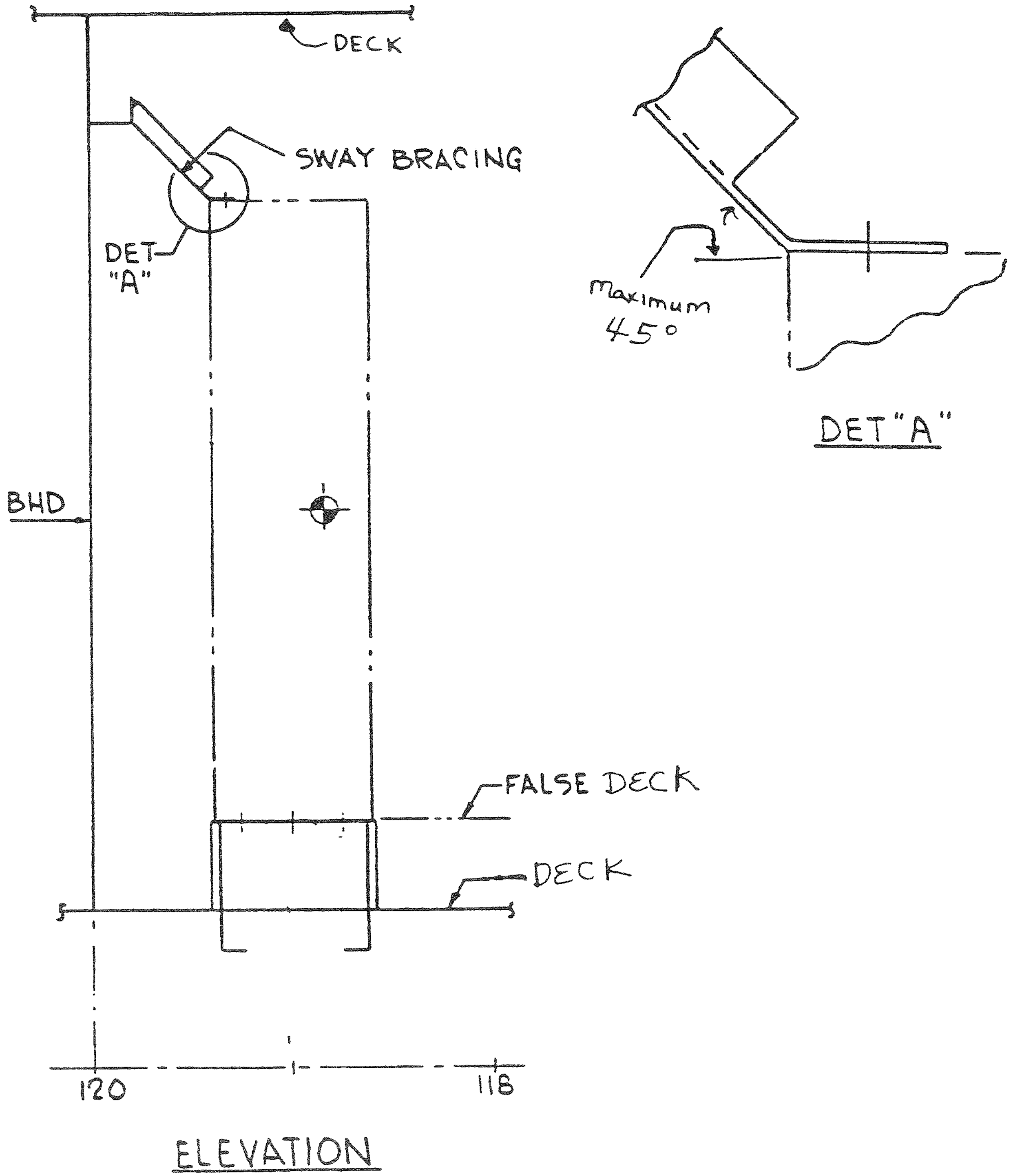


Figure 2. Typical 45° Brace

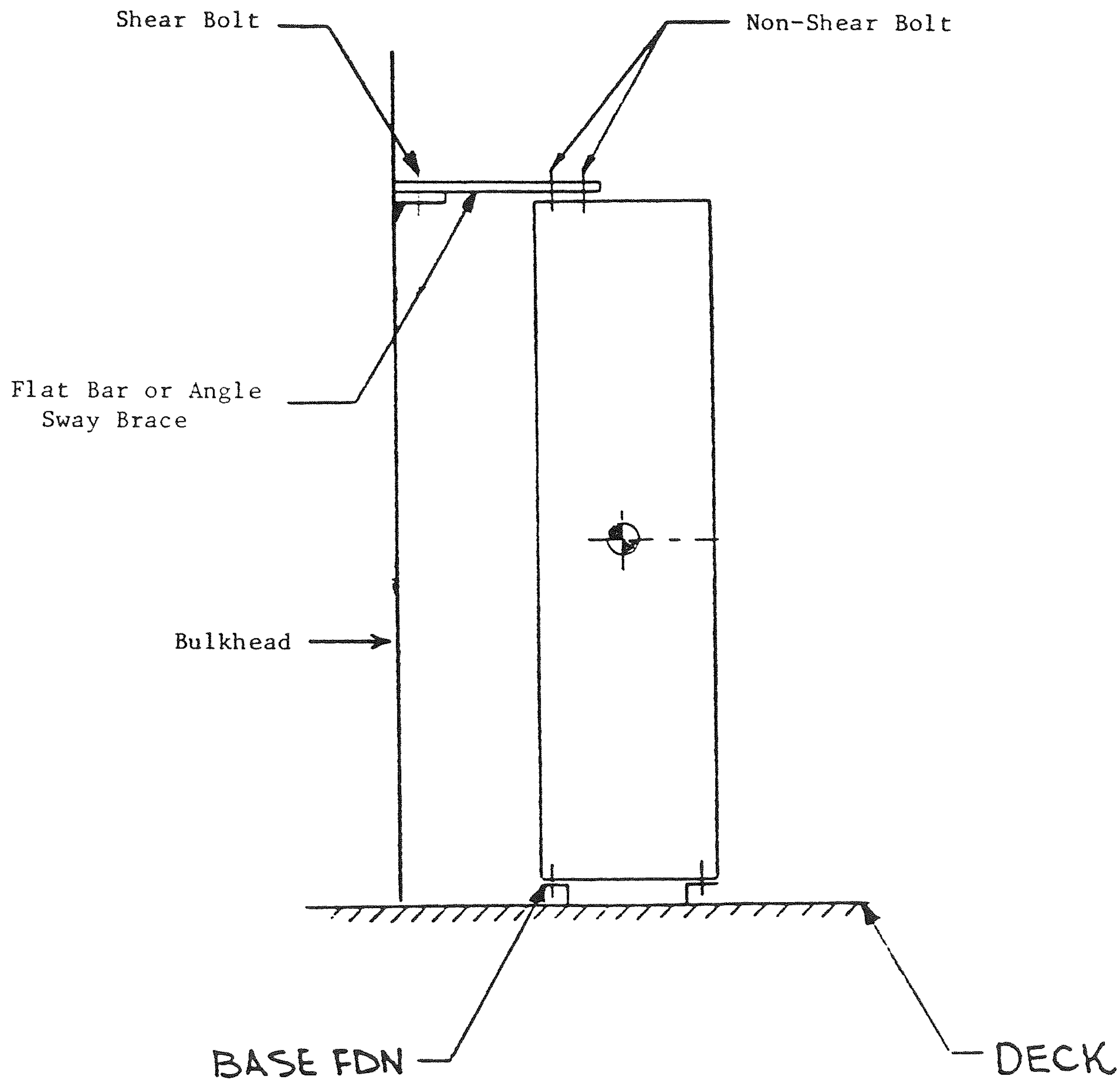


Figure 3. Typical Buckling Failure Mechanism

072-5-f(4) Shear Bolt. Typical shear bolt type sway braces are shown in Figure 4 and 5. Each of the configurations illustrated contains a shear bolt failure mechanism and each is supported by a structural bulkhead. In addition, all use angle sway brace members and all have shear bolt connections at the structural bulkhead. Vertical loads cannot be resisted by any of the configurations because of the linkage action incorporated in the design.

Figure 4 employs two braces to resist loads in the transverse direction and utilizes a truss in the longitudinal loading direction. Two No. 10 machine screws and a 1/4" diameter bolt are used as shear failure mechanisms and all bulkhead padeyes are positioned to align with bulkhead stiffeners.

In Figure 5 the sway brace members are attached to the sides of the equipment unit as opposed to its top. It is also configured such that horizontal loads in the two principal ship directions are resisted by the sway braces in truss action. Typical back-up structure has been added to the bulkhead to demonstrate proper support sway brace padeyes.

072-5-f(5) Hinged Braces. Sway braces which employ hinged connections at their attachment to equipment and also at their connection to support structure are referred to as "Hinged Braces". An example of such a brace is shown in Figure 6. Hinged braces are positioned such that they will work as linkages in the vertical direction and thus will not resist vertical loading. The example shown uses shear bolt failure mechanism which is located at the brace's connection to the support structure.

The configuration shown in Figure 6 uses angle members to form the sway brace and is mounted to a structural bulkhead.

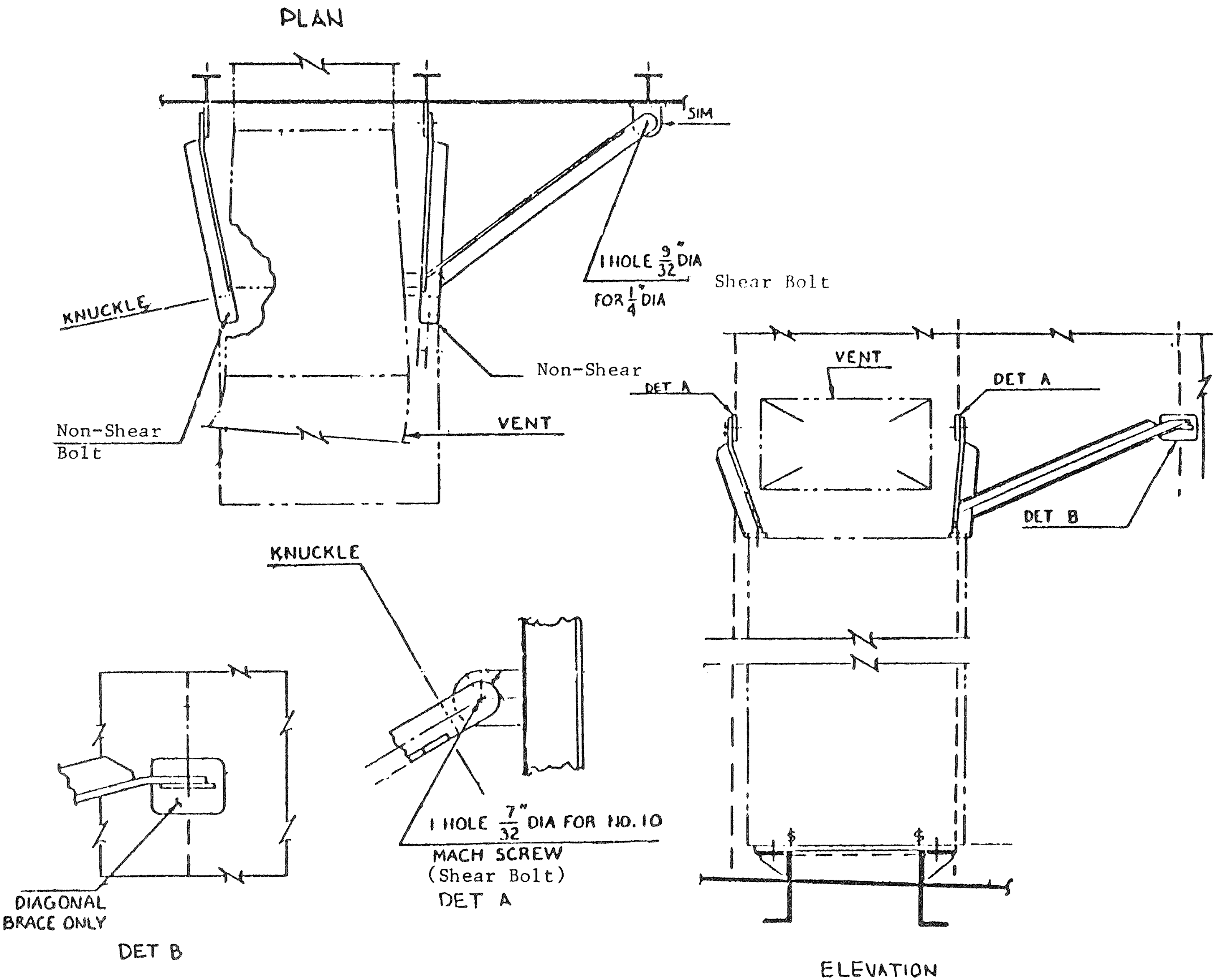


Figure 4. Typical Shear Bolt

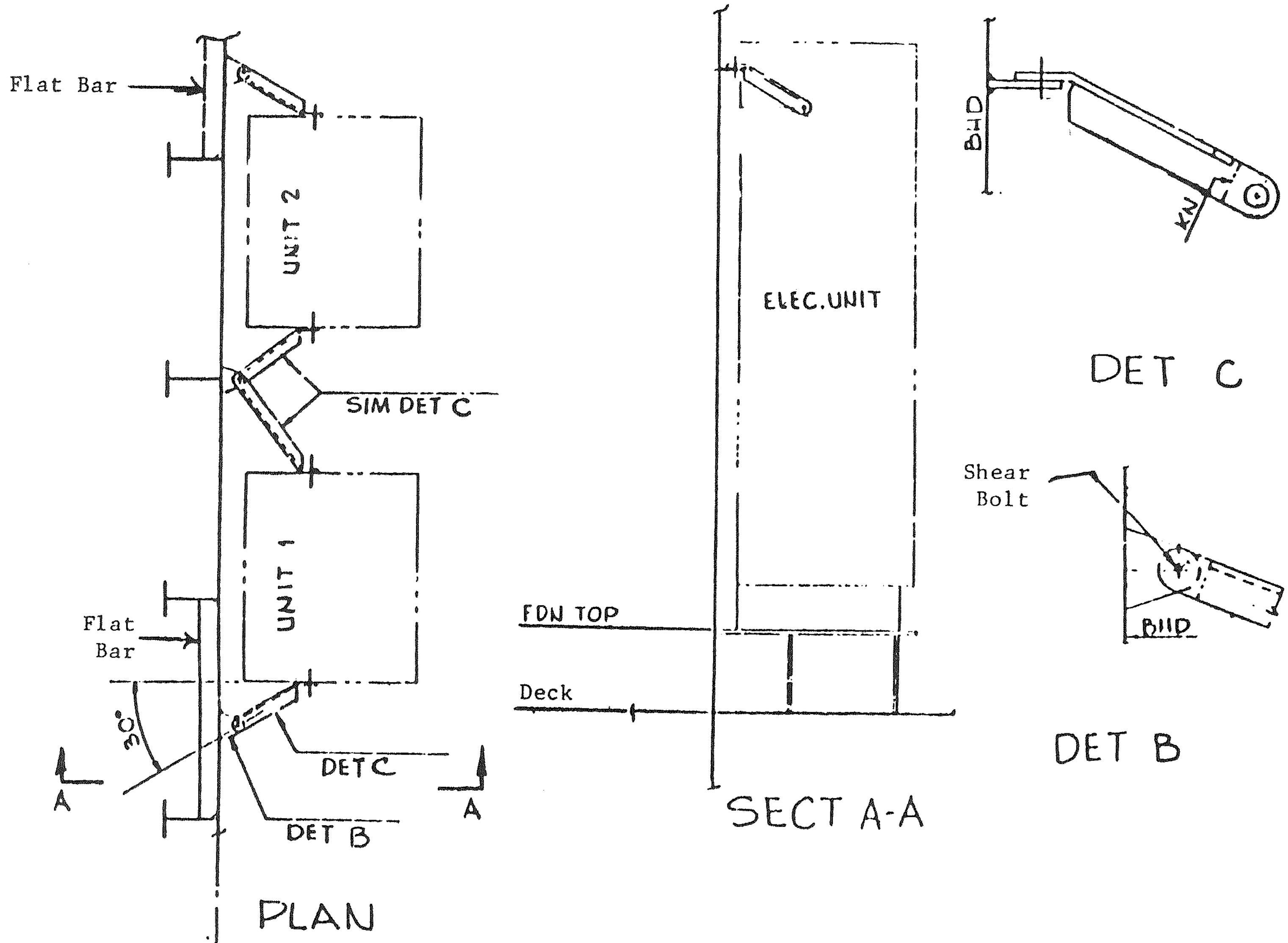


Figure 5. Typical Shear Bolt

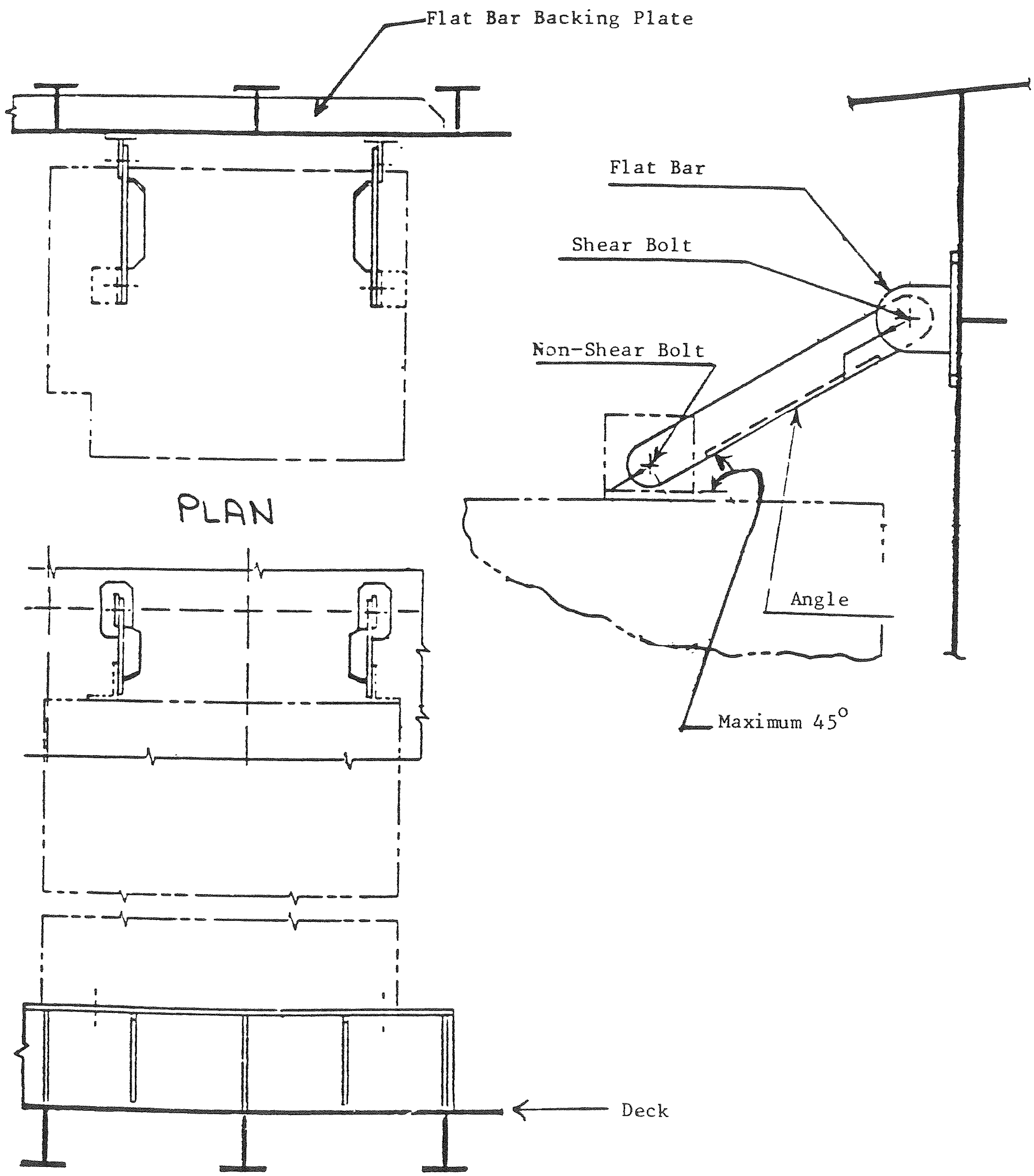


Figure 6. Typical Hinged Brace

This configuration is effective in preventing overturning of the unit about its narrow dimension, but provides little support in preventing overturning about the wider dimension.

072-5-f(6) Spring Plate. Spring Plates are structural members consisting of unstiffened plates or flat bars positioned such that vertical loading will produce bending of the members about their weak axis. They are used to provide sway braces with flexibility in the vertical direction. Consequently, spring plates will prevent the sway braces from resisting significant vertical loads and, under shock, will allow relative vertical displacements.

Figure 7 illustrates the use of spring plates and depicts a sway brace which uses bolt shear as a failure mechanism and utilizes a spring plate to prevent the plate from resisting appreciable vertical loads.

072-5-f(7) Flexibility. U.S. Navy Ship Specifications generally permit the substitution of sway braces which possess sufficient flexibility for those which contain failure mechanisms designed for 5 g's or less. Sufficient flexibility is defined as that condition where a sway brace will accommodate relative motions under shock without damaging the supported equipment. Sway braces designed to flexibility criteria can be expected to distort (buckle or yield) when exposed to shock, but should be sufficiently rigid to properly support the equipment under normal conditions.

A typical flexibility type sway brace is shown in Figure 8. There is no failure load associated with these sway braces. Instead, they use their inherent flexibility to limit the load they withstand. Sway braces of this configuration are normally designed by equipment vendors or the government and are provided

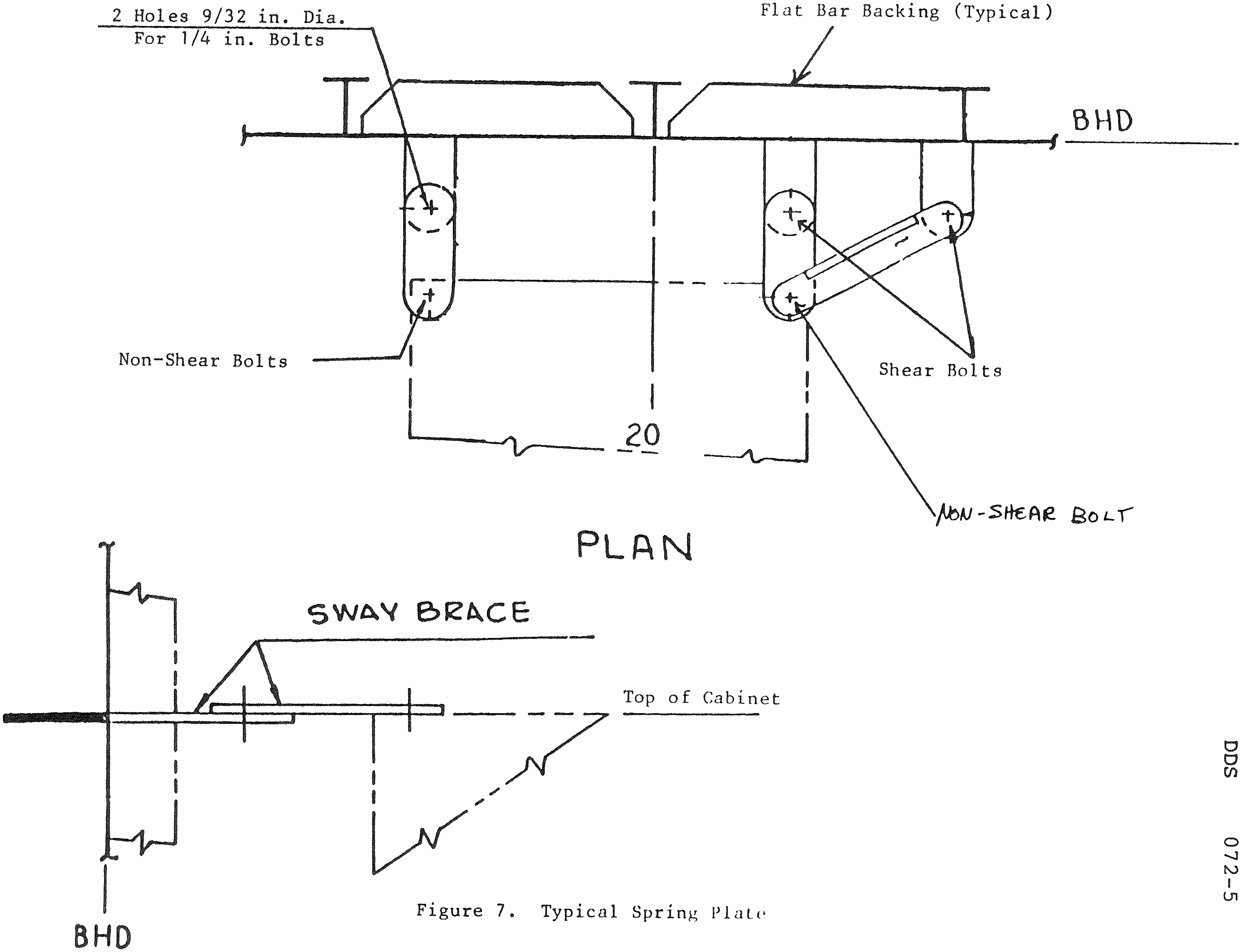


Figure 7. Typical Spring Plate

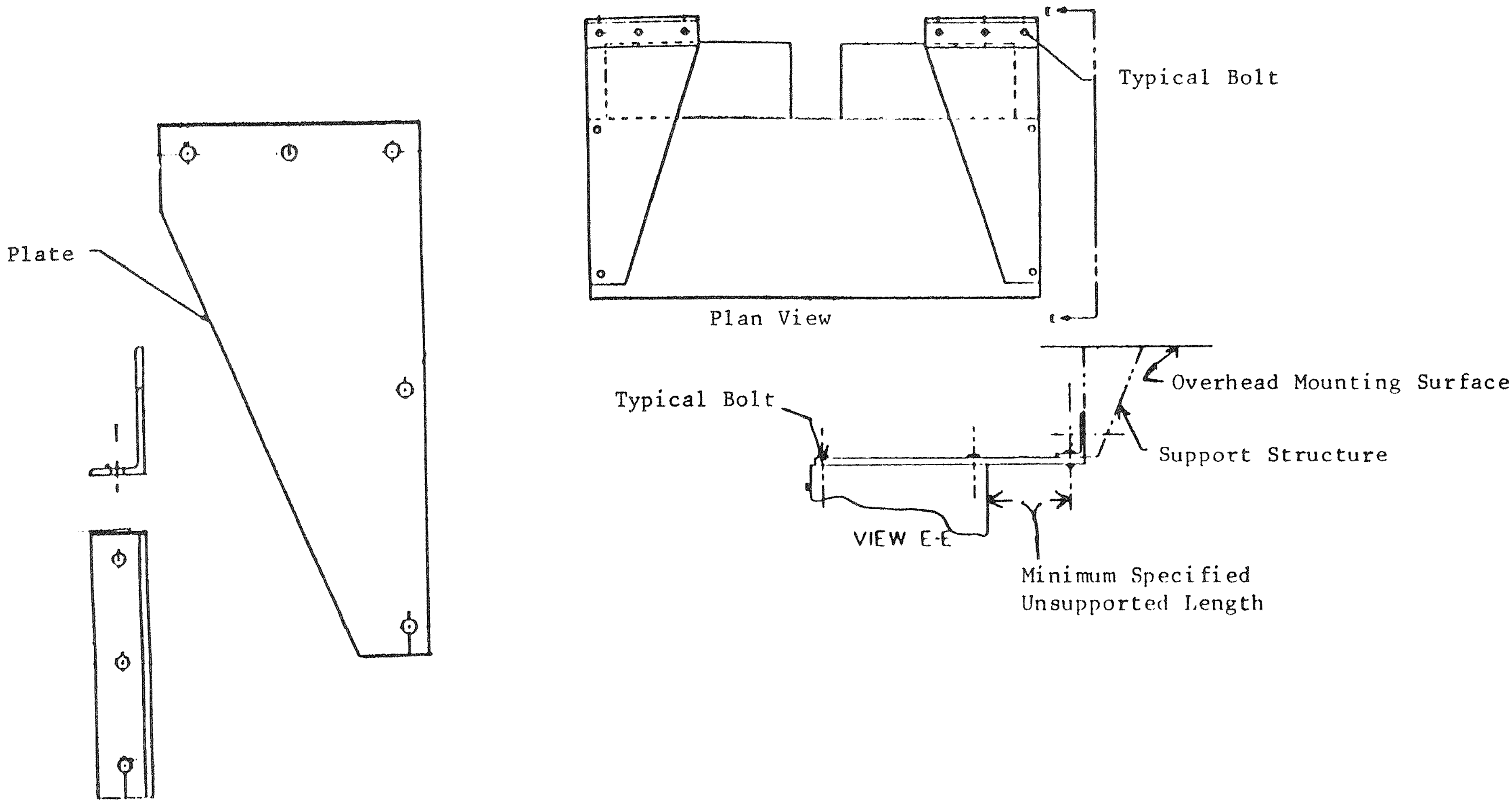


Figure 8. Typical Flexibility Sway Brace

by the shipyard. Consequently, the shipyard or ship design activity is not responsible for their design and adequacy. However, they are responsible to insure that adequate structure is provided to properly support each of the sway braces.

The sway brace detailed in Figure 8 consists of two unstiffened plates which are mounted with their weak bending axes horizontal. In addition, the unsupported length for each plate is as specified (sufficient to allow the necessary flexibility). These characteristics combine to provide sufficient flexibility in the vertical direction to allow for relative displacement of the two surfaces supporting the equipment, thus excluding vertical loading from sway brace members. In the horizontal direction, however, the sway brace has sufficient strength and rigidity to result in appreciable load carrying ability.

Since there is no failure load associated with this type of sway brace, alternate design criteria must be used to design their supporting structure. An effort must be made to determine the maximum load carrying capability of the sway brace in each of the two horizontal directions. The weakest failure condition, whether it be bolt shearing, sway brace bending, or tear-out in way of bolting, is to be used.

In the interest of minimizing weight, the design load should not exceed the expected shock loading. That is, the sway brace supporting structure should not be designed to withstand loading greater than the shock reaction acting at the upper connection of the equipment assuming that the sway brace will behave as a full upper support. This procedure is somewhat conservative because the flexibility of the sway braces will result in a portion of the shock reaction being transmitted through the equipment to the lower foundation structure.

072-5-f(8) Upper Support. Examples of upper supports for hard mounted equipment (with no resilient mounts) are shown in Figures 9 and 10. As defined, upper supports are designed to withstand shock loads and do not include any type of failure mechanism. From the examples it can be seen that upper supports entail heavier and sturdier structures than those used for sway braces. This is a direct result of their intended function.

Figure 9 shows an upper support which is attached to the overhead. It consists of a series of truss-like members mounted to deck longitudinales or deck headers. In addition, the equipment is fitted with a spring plate to allow for relative displacement between the deck and the overhead.

Figure 10 illustrates an upper support which is attached to the same deck surface as the unit's foundation. Thus, the equipment is supported by a common foundation/upper support structure. This type of upper support requires a very heavy structure and should only be employed when other means of support are not practical. Heavy scantlings are required to provide proper stiffness so that the equipment's upper connections are effective in carrying load. No means to allow for relative vertical displacement are required because the equipment is supported solely from one deck.

072-5-f(9) Resilient Mounts. The basic function of resilient mounts is to provide noise isolation for equipment. Sensitive items, such as electronic cabinets, which are prone to malfunction or damage as a result of shipboard vibrations, are normally resiliently mounted. Furthermore, units of this type usually employ resilient mounts both at the top and base of the unit. These installations are almost always associated with upper supports as opposed to sway braces. Specific types of resilient mounts may be used specifically for shock isolation.

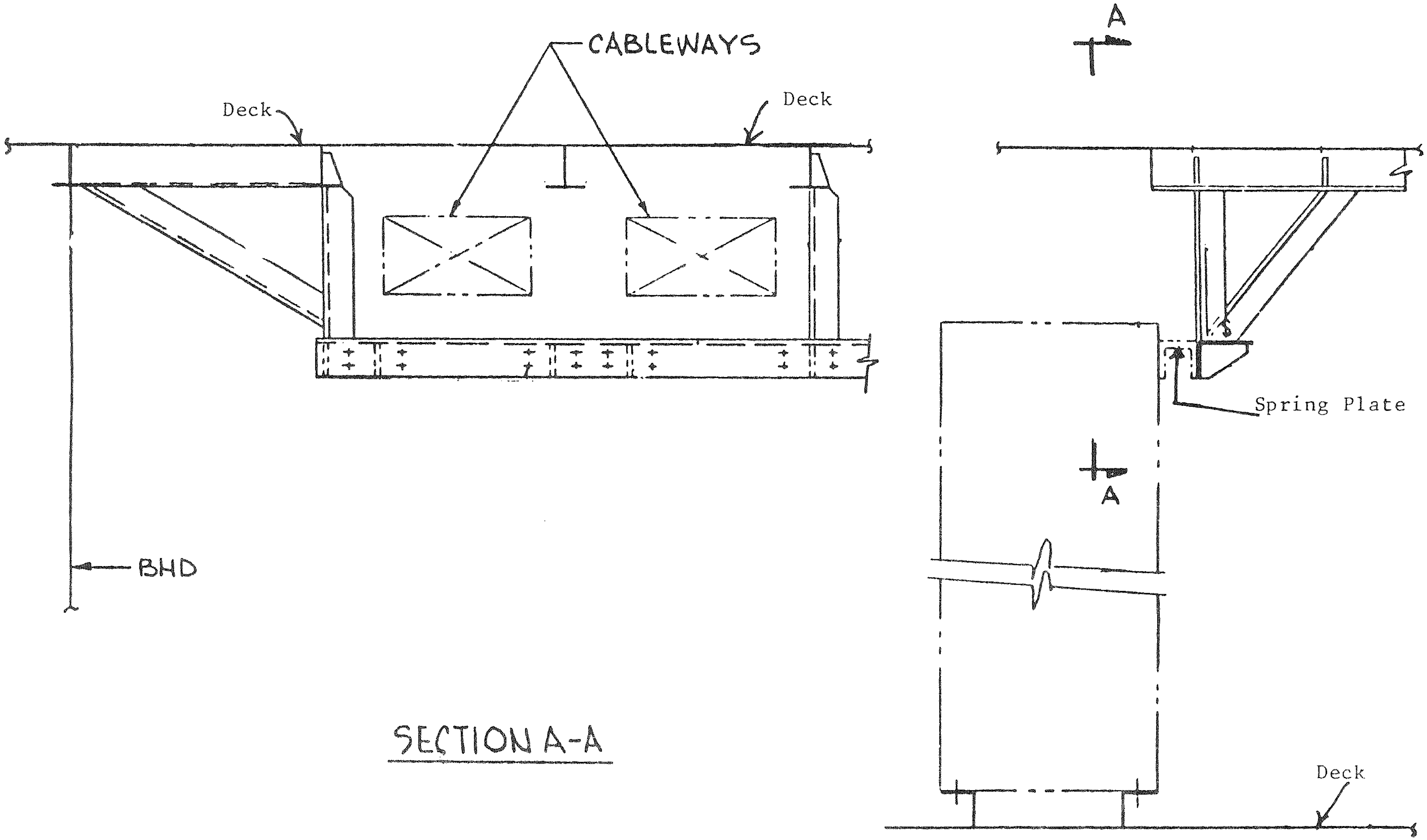


Figure 9. Typical Upper Support - Overhead Mounting

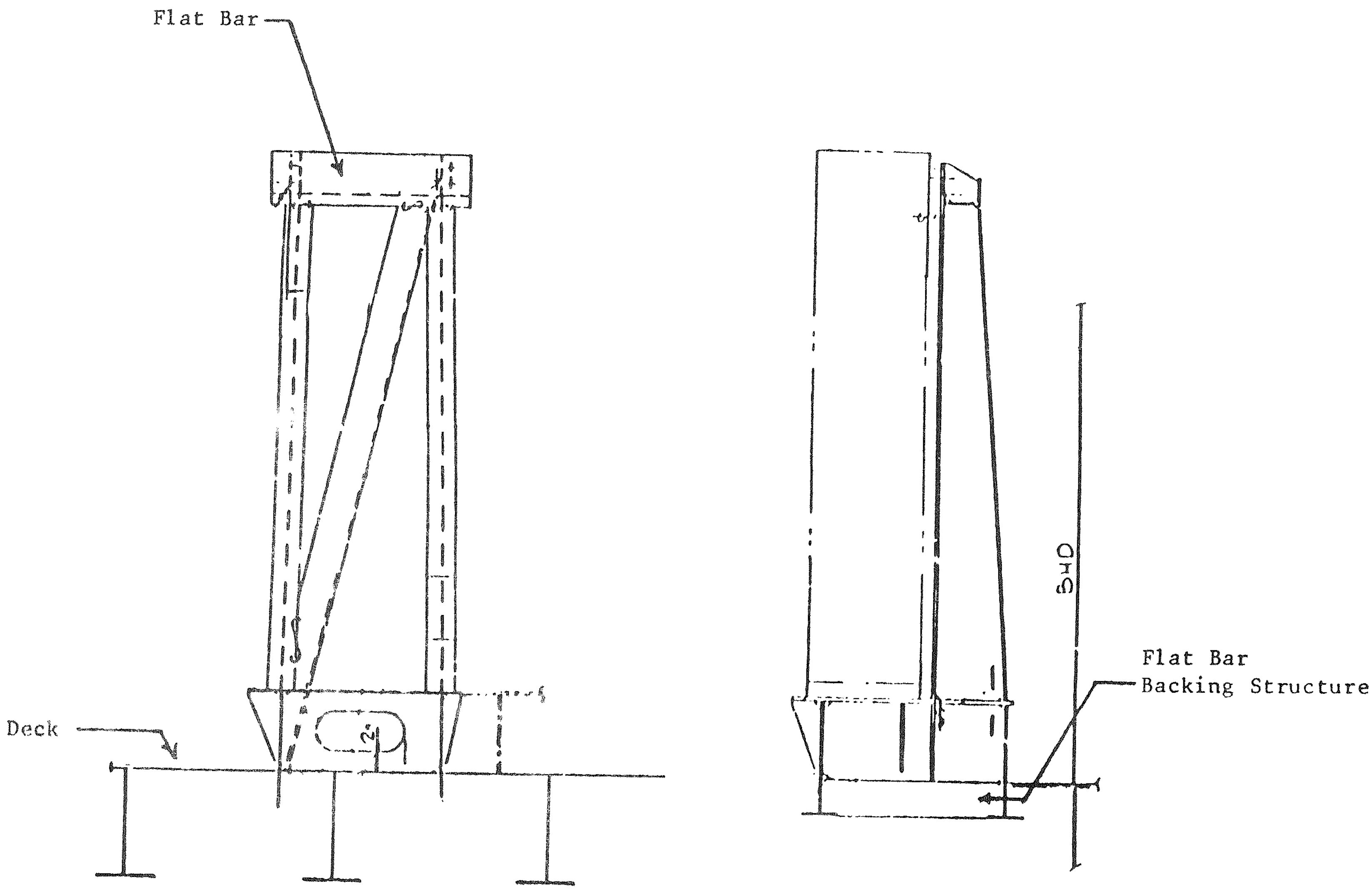


Figure 10. Typical Upper Support - Deck Mounting

Figures 11 and 12 depict upper support designs for units which are resiliently mounted. Both configurations are capable of withstanding shock loading in the horizontal direction but are specifically designed such that vertical shock loads will not be reacted. The resilient mounts will insure that vertical loading is not transmitted to the upper support. Both designs utilize upper support structure which is attached to the overhead and integrated with the structural components of the deck. Figure 11 presents a noise isolation mounting configuration. The method shown by Figure 12 does not provide noise isolation and is used for vibration and shock mitigation.

072-5-g SHOCK TEST CONSIDERATIONS

072-5-g(1) Sway Braces. In Navy ships, vital equipment and associated support structure must be qualified for shock. Qualification of equipment is normally done my means of machine or barge testing, as described in Reference (3). To insure that the shock test properly duplicates the shipboard installation, it is of extreme importance that the fixture supporting the test specimen simulates the unit's shipboard foundation structure. Failure to do so can result in invalid test conclusions and possible equipment damage when exposed to an actual shock environment.

Sway braces which contain failure mechanisms are designed to become ineffective at loads of much lower magnitude than those expected to be experienced under shock. Consequently, when exposed to a shock environment, the sway braces will do little to resist shock loading and can be disregarded. Shock testing of equipment, which in its shipboard installation will be supported by sway braces, should therefore be undertaken without

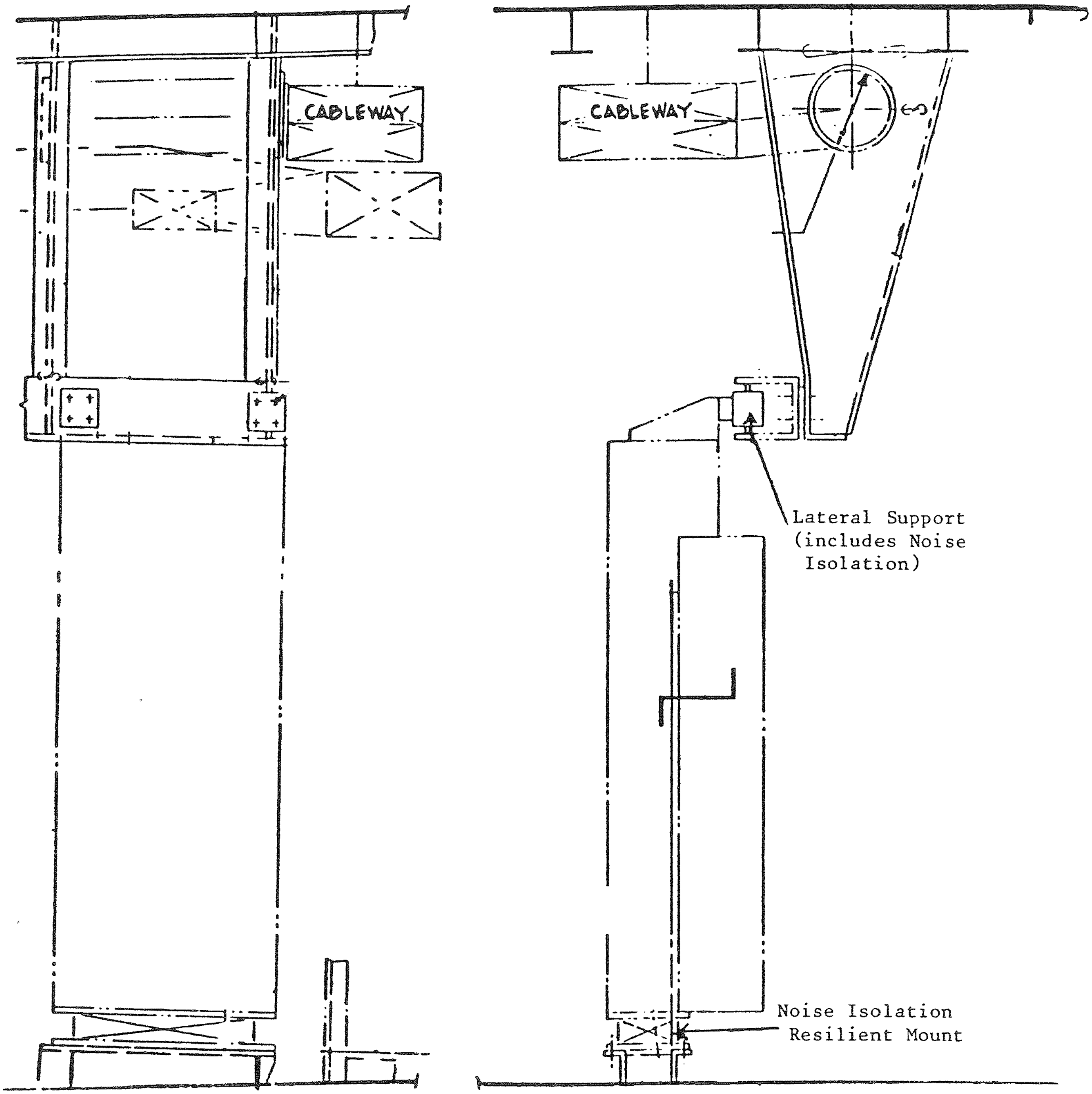


Figure 11. Typical Resilent Mounts Upper Support - Noise Isolation

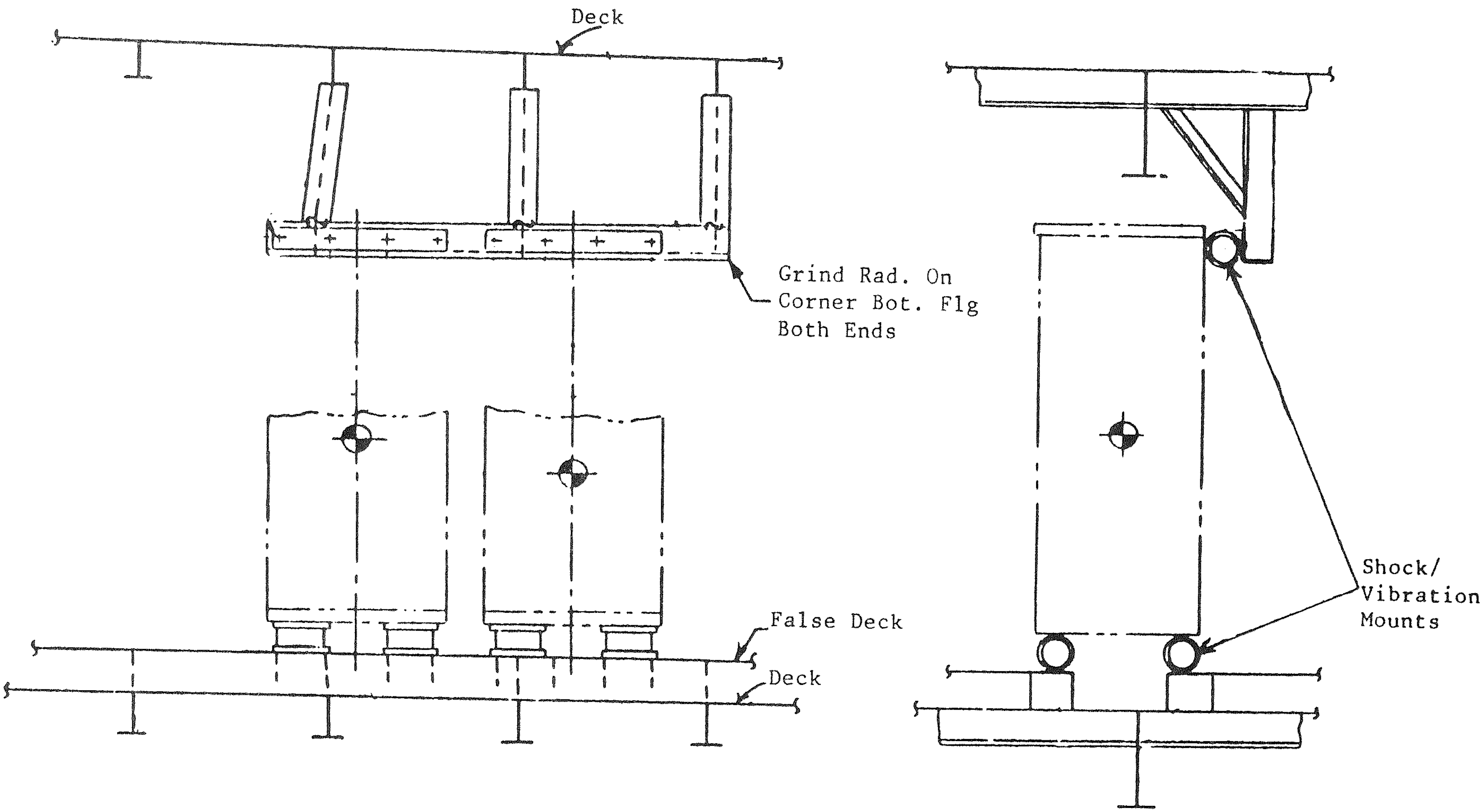


Figure 12. Typical Resilient Mounts Upper Support - Vibration and Shock Mitigation

the associated sway braces. The exception to this rule is equipment which utilizes flexibility type sway braces.

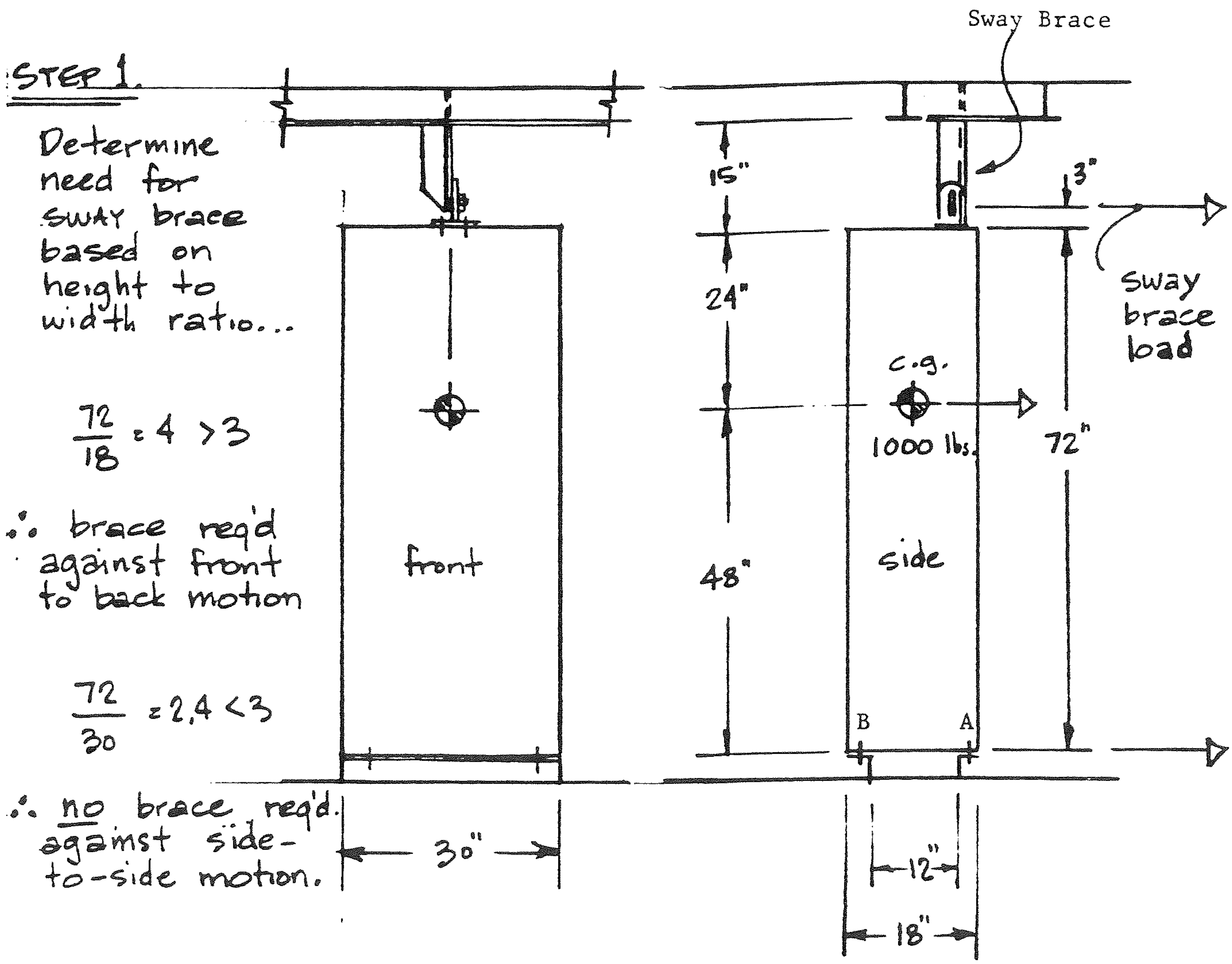
Due to the very nature of their design, flexibility type sway braces will resist some degree of shock loading. The amount of load resisted is a direct function of the rigidity of the sway braces. Consequently, to properly shock test equipment which employs such sway braces it is essential that flexibility type sway braces be included in the test set up. In addition, it is necessary that the sway braces be properly supported by the test fixtures.

072-5-g(2) Upper Supports. Equipment which is designated as grade "A" or "B" shock item and which is found to be deficient in withstanding lateral shock loads requires design modifications. The modifications can involve either the reinforcement of the unit proper or the addition of upper supports. If upper supports are added, they will in all cases be required to satisfy the same shock criteria as the equipment to which they are attached.

Upper supports are normally added at the request of equipment manufacturers and should only be used when they are required to insure that equipment satisfies the applicable shock criteria. Shock qualification is usually achieved by means of testing as specified in Reference (3). Once the need for upper supports has been established, it is paramount that the equipment be retested with the proposed upper supports installed. The test fixture used should attempt to simulate the shipboard installation as closely as possible. This applies to both the equipment foundation and the upper support structure.

072-5-h <u>EXAMPLES.</u> The following examples provide typical design considerations to be utilized in the design and selection of sway braces. An upper support design example is also provided for comparison.

072-5-h(1) <u>Yielding Type Sway Brace</u>. Example 1 is a yielding type sway brace utilizing a cantilever beam with slotted hole to accommodate vertical motion.



STEP 2.

Determine the maximum load necessary to induce failure in the sway brace design

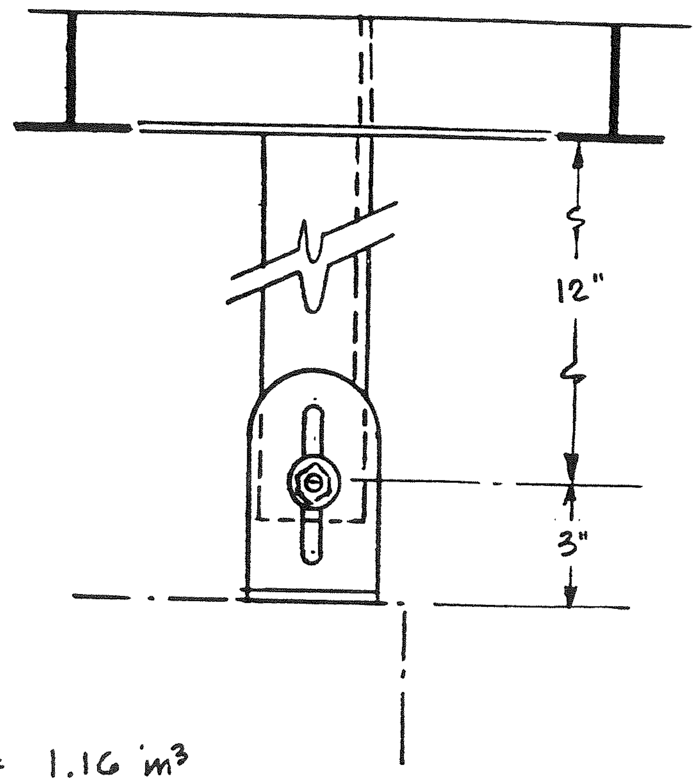
$$\text{Load} = \left[\begin{array}{c}\text{weight}\\ \text{of}\\ \text{equipment}\end{array}\right]\left[\begin{array}{c}\text{5g's}\\ \text{applied}\\ \text{horizontally}\end{array}\right]\left[\begin{array}{c}\text{horizontal}\\ \text{portion distributed}\\ \text{to the sway brace}\end{array}\right]$$

$$= 1000 \text{ lbs.} \left[5\right]\left[\frac{48}{72'' + 3''}\right]$$

$$= 3200 \text{ lbs}$$

STEP 3.

Select the size for one cantilever beam with a max. momt. of...



$$M_{@\,LOAD} = F \cdot l$$

$$= 3200 \text{ lbs } (12 \text{ in})$$

$$= 38{,}400 \text{ in} \cdot \text{lbs}$$

Then the max. allowable section modulus, using mild steel, will be...

$$S.M. = \frac{M_{@\,LOAD}}{\sigma_Y}$$

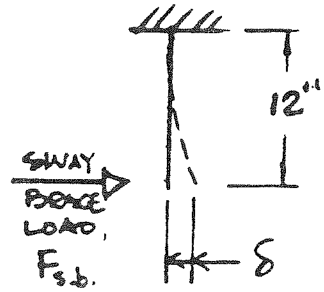
$$= \frac{38{,}400 \text{ in} \cdot \text{lbs}}{33{,}000 \text{ psi}} = 1.16 \text{ in}^3$$

Since this is a max. design section modulus, a smaller section can be chosen so long as it provides enough stiffness for the cantilevered beam to accept sufficient horizontal load to induce failure in the beam.

∴ Try a 3 x 3 x 3/16 L with S.M. = 0.44 in.^3 and a moment of inertia of 0.96 in.^4.

STEP 4.

Check the actual load taken by the sway brace based on the stiffness of sway brace design relative to the stiffness of the base foundation.

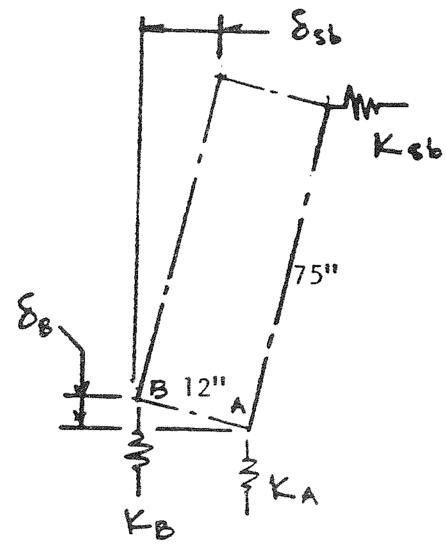


$$k_{s.b.} = \frac{F_{sb}}{\delta} = \frac{3EI}{l^3} = \frac{3(30\times10^6)(0.96\ in^4)}{(12\ in)^3}$$

$K_{s.b.}$ = 50,000 lb/in

Assuming the equipment is rigid and the stiffnesses at the base have been calculated to be...

$$k_A = k_B = 500{,}000\ lb/in$$



Then, by geometry, assuming rotation about the base foundation, the ratio of displacements will be nearly (and in the case of zero rotation, exactly)...

$$\delta_{sb} = \delta_B\left(\frac{75\ in}{12\ in}\right)$$

$$\frac{F_{sb}}{K_{sb}} = \frac{F_B}{K_B}\left(\frac{75}{12}\right)$$

OR $$F_B = \frac{K_B}{K_{sb}}\left(\frac{12}{75}\right)F_{sb}$$

Assuming static equilibrium, the summation of moments about point A will be...

$$\Sigma M_A = F_{sb}(75) + F_B(12) - F_{\substack{TOTAL\\LOAD}}(48) = 0$$

$$= F_{sb}(75) + \frac{K_B}{K_{sb}}\left(\frac{12}{75}\right)F_{sb}(12) - F_{TL}(48) = 0$$

$$F_{sb}(75) + \left(\frac{500{,}000}{50{,}000}\right)\left(\frac{12}{75}\right)F_{sb}(12) = 1000(5)(48)$$

$$75\,F_{sb} + 19.23\,F_{sb} = 240{,}000$$

$$F_{sb} = 2547 \text{ lbs.}$$

NOTE: The actual load taken by the sway brace, F_{sb} = 2547 lbs, which is based on the relative stiffness of the base foundation to that of the sway brace (K_B/K_{sb}), is significantly less than the maximum load necessary to induce failure (calculated in step 2).

Had a larger section, and thus more stiffness, been chosen for the cantilevered beam, more load would have been accepted by the sway brace design.

Checking the stress in the sway brace due to the actual load,

$$\sigma = \frac{\text{Momt.}}{\text{Section Modulus}} = \frac{2547 \text{ lbs } (12 \text{ in})}{0.44 \text{ in}^3}$$

$$= 69{,}464 \text{ psi} > 33{,}000 \text{ psi}$$

∴ Yielding will be induced. The elastic design stress will be reached at:

$$75\ F_{sb} + 19.23\ F_{sb} = 1000\ (g)\ (48)$$

$$F_{sb} = \frac{g\ (48)\ (1000)}{94.23}$$

$$\sigma = \frac{\text{Momt}}{\text{Sect Mod}} = \frac{F_{sb}\ (12)}{.44\ in^3}$$

$$\sigma = \frac{g(48)(1000)(12)}{(94.23)\ (0.44)}$$

$$\sigma = 33{,}000$$

$$\therefore\ g = \frac{94.23)(0.44)(33{,}000)}{(48)\ (1000)\ (12)}$$

$$g = 2.4g's$$

The limit moment for an angle, assuming a shape factor of 1.7, is:

$$M_{limit} = 1.7\ M_{elastic}$$

And failure of the beam would occur around 4.1 g's (i.e. 2.4 g's x 1.7).

The sway brace design will definitely fail between 2 and 4 g's.

If a greater section modulus had been selected, the g's to failure would of course increase, but for this example it is assumed that the 2-g lower limit is above the operation load requirement and the section chosen in step 3 can still be used.

STEP 5

Check the system frequency to ensure excessive vibration does not occur.

The actual static force at the sway brace due to the weight of the equipment applied horizontally is...

$$F_{sb} = \frac{2547 \text{ lbs}}{5 \text{ g's}} = 509 \text{ lbs.}$$

which is based on the actual relative stiffness of...

$$K_B / K_{sb} = 500/50$$

For a single-degree-of-freedom system the static displacement of the center-of-gravity will be...

$$\delta_{c.g.} = \delta_{sb}\left(\frac{48 \text{ in}}{75 \text{ in}}\right) = \frac{F_{sb}}{K_{sb}}\left(\frac{48 \text{ in}}{75 \text{ in}}\right) = \frac{509 \text{ lbs}}{50 \times 10^3 \text{ lbs/in}}\left(\frac{48}{75}\right)$$

$$= 0.0065 \text{ in.}$$

And the frequency of the system will be...

$$f = \frac{3.127}{[\delta_{cg}]^{1/2}} = 39 \text{ Hz}$$

As long as 39 Hz is greater than the propeller blade rate frequency or another exciting frequency in the immediate area, the section chosen for the cantilever beam is adequate, and the sway brace design is complete.

072-5-h(2) Shear Bolt Failure Mechanism, Example 2.

Use a hinged brace configuration as shown in Figure 13. It consists of two hinged angles, located on each side of the equipment. The braces are mounted using bolted connections atop of equipment and shear bolts at the connection to the overhead deck structure. The equipment weighs 1000 pounds and its center of gravity is located 48" above the base.

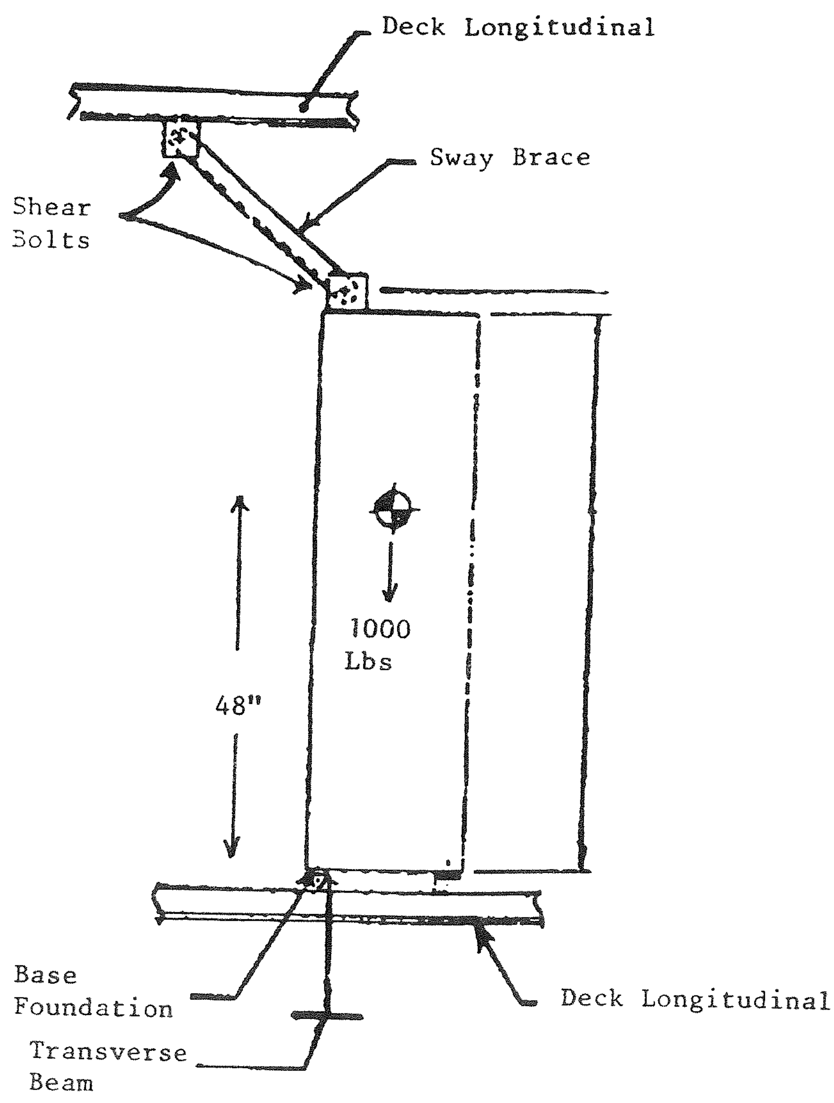


Figure 13. Hinged Brace Configuration

STEP 1.

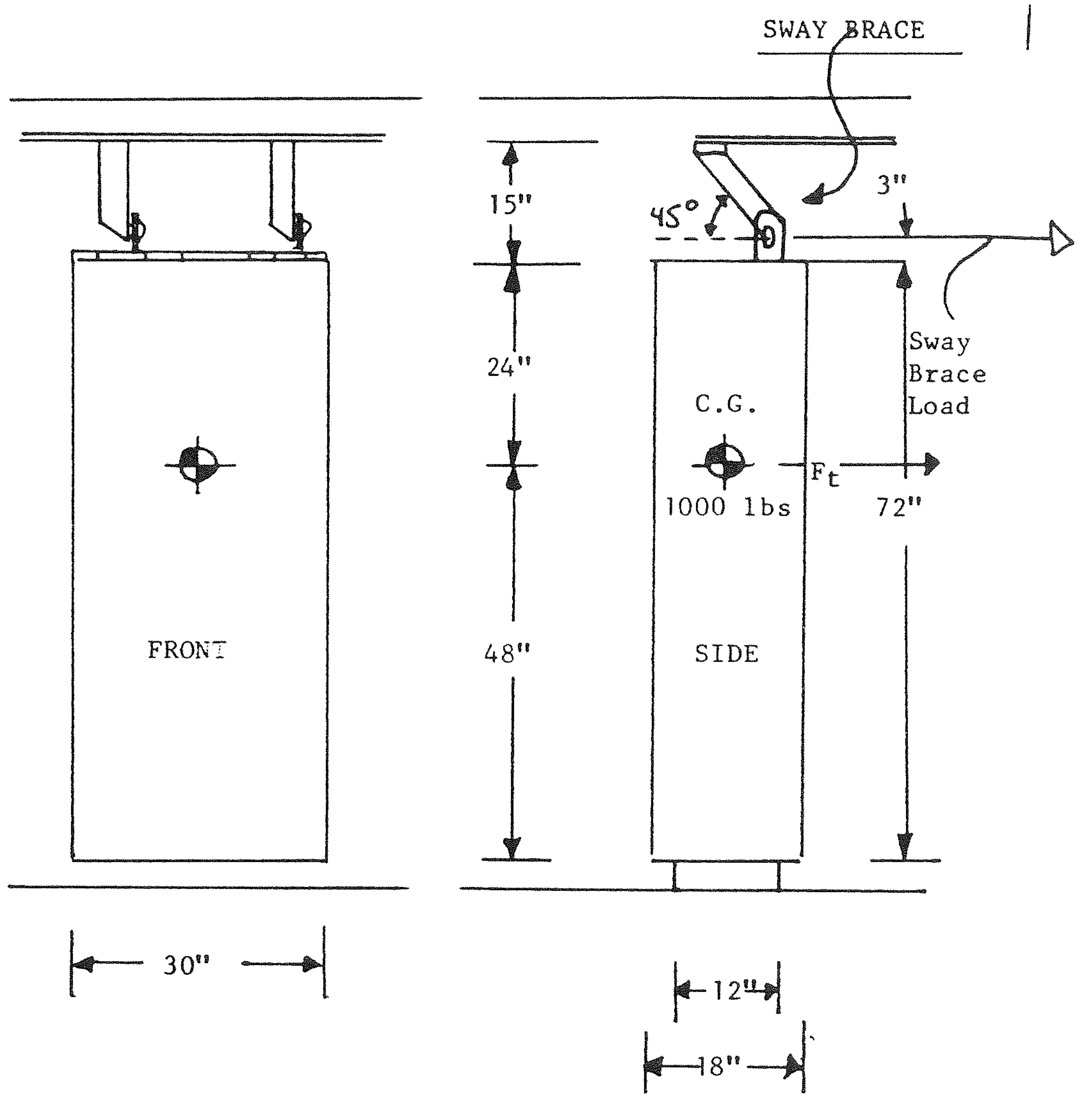
Determine the need for sway brace based on height to width ratio...

$$\frac{72}{18} = 4 > 3$$

∴ brace required against front to back motion

$$\frac{72}{30} = 2.4 < 3$$

∴ no brace required against side-to-side motion.



STEP 2.

Determine the maximum load, F_t, necessary to induce failure in the sway brace design

$$F_t = \left[\text{weight of equipment}\right] \left[\text{5 g's applied horizontally}\right] \left[\text{horizontal portion distributed to the sway brace}\right]$$

$$= 1000 \text{ LBS} \times 5 \times \frac{48''}{72'' + 3''}$$

$$= 3200 \text{ LBS} = 3.2 \text{ KIPS}$$

Since the braces are hinged at both ends the axial load along the braces is:

$R_t = F_t / \cos 45$ where 45 represents the angle between the brace and the horizontal axis

$R_t = F_t / .707$

$R_t = 3200/.707 = 4.53$ kips

$R_t/\text{brace} = R_t/2 = 2.26$ kips

Step 3. Now it is necessary to choose a bolt that will fail under this load. Steel bolts are desirable if they can be made to fail at the required load. In addition, steel bolts which satisfy the requirement of MIL-S-1222 (Grade 2 equivalent) should be used and a minimum diameter of 1/4" is recommended. The ultimate shear strength of such a bolt is 60 ksi. Consequently, using 1/4" diameter (Grade 2) steel bolts with a shear area of .049 in :

Shear Stress = 2.26/.049 = 46.1 ksi

This is less than required 60 ksi and the 1/4" bolt will obviously not shear at the required load.

Since the steel bolt having the minimum recommended size will not fail at the required design load, an aluminum bolt should be used. Federal Specification QQ-A-225/6 bolts (Aluminum Alloy 2024-0) are recommended, and a minimum bolt diameter of 3/16" should be used. The ultimate shear stress for such aluminum bolts is 21 ksi.

$$\text{Shear Stress} = \frac{2.26 \text{ kips}}{.028 \text{ in}^2} = 80.7 \text{ ksi} > 21.0 \text{ ksi}$$

This is unacceptable, as the bolt will actually shear at 1.3 g's, which is less than 2 g minimum. Increasing the bolt diameter to 1/4";

$$\text{Shear Stress} = \frac{2.26 \text{ kips}}{.049 \text{ in}^2} = 46.2 \text{ ksi} > 21 \text{ ksi}$$

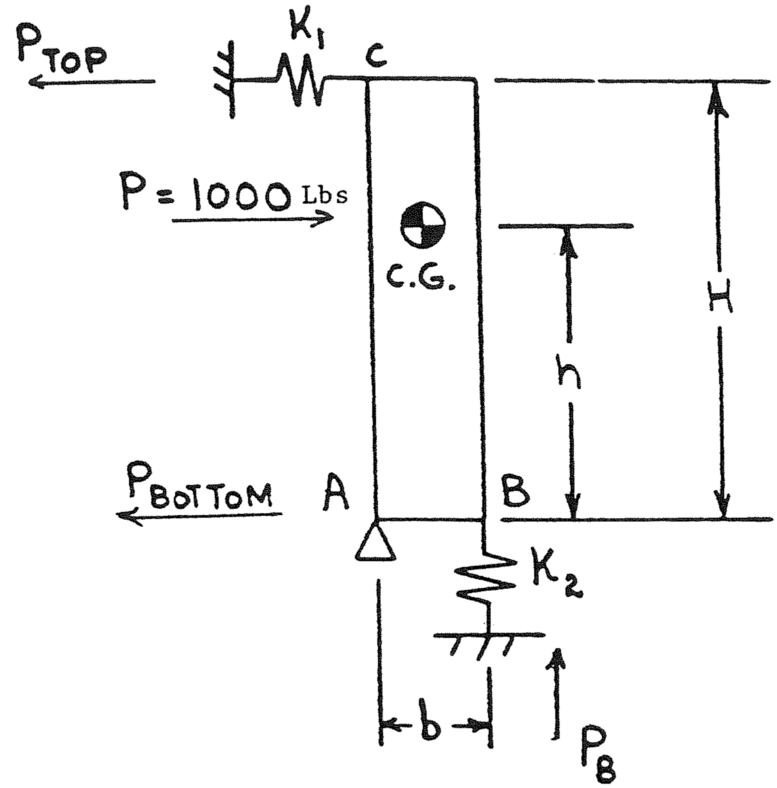
This is considered acceptable as the bolt will actually shear at 2.2 g's.

The sway brace should be designed such that the bolts will fail at approximately the same load longitudinally and transversely. If this is not possible, the bolts should be designed to fail using the lower of the two loadings. However, to prevent possible failure due to ship's motions, in no case should the minimum failure load in any direction be less than 2 g's. The angles which form the sway braces proper should be of sufficient size to resist an axial load in excess of the 2.26 kips failure load.

Steps 4 and 5. The sway brace configuration to be considered is depicted in Figure 13 (at beginning of example 2). It consists of a hinged angle which is mounted to the top of the unit and is supported by the deck structure above. The equipment unit in question weighs 1000 pounds and its center of gravity is located 48" above the base of the unit.

The sway brace members will be designed to provide adequate stiffness to properly support the unit and to insure that a resonance condition with the ship's propeller will not occur. A frequency of 18 Hz will be used as the maximum driving frequency of the ship's propeller increased by an appropriate factor (usually multiplied by 1.25). Consequently, the natural frequency of the equipment/foundation system must be above 18 Hz.

A representation of the spring system for this configuration and pertinent data is provided below:



K1 = 50,000 LBS/IN

K2 = 250,000 LBS/IN

h = 48"

H = 72"

b = 12"

Point "A" has been assumed a rigid support due to the relatively high stiffness of the transverse beam. In addition, K_1 has been calculated assuming two 2 X 2 X 1/4"L sway brace members and utilizing the stiffness of the overhead deck structure, while K_2 has been developed considering the stiffness of the deck longitudinals.

Applying a 1-g load at the equipment units center of gravity,

$$P_{TOP} + P_{BOTTOM} = 1000 \text{ Lbs}$$

and, by geometry.

$$\frac{P_{TOP}}{K_1} = \frac{P_B H}{K_2 b}$$

Taking sum of the moments about Point "A",

$$\Sigma MA = 0$$

$$Ph = P_{TOP}H + P_B b$$

$$Ph = \frac{P_B K_1 H^2}{bK_2} + P_B b$$

$$1000\ (48) = P_B\left(\frac{50{,}000 \times 72^2}{12 \times 250{,}000} + 12\right)$$

$$P_B = 488 \text{ Lbs}$$

$$P_{TOP} = 586 \text{ Lbs}$$

If the horizontal load had been divided as a function of geometry,

$$P_{TOP} = \frac{Ph}{H} = \frac{1000\ (48)}{72} = 667 \text{ Lbs}$$

$$\%\ \text{EFFICIENCY} = \frac{586}{667} \times 100 = 87.9\%$$

Therefore the sway brace is adequately stiff to provide proper support for the unit.

Solving for the deflection at the center of gravity,

$$\delta_c = \frac{P_{TOP}}{K_1} = \frac{586}{50{,}000} = 0.0117''$$

$$\delta_{C.G.} = \delta_c \frac{h}{H} = .0117\ \frac{48}{72} = .0078''$$

$$K = \frac{P}{\delta_{C.G.}} = \frac{1000}{.0078} = 128{,}205 \text{ Lbs/In}$$

Calculating the natural frequency of the system,

$$\omega = \sqrt{\frac{Kg}{W}} = \sqrt{\frac{128,205(386)}{1,000}} = 222 \text{ RAD/SEC}$$

$$f = \frac{\omega}{2\pi} = \frac{222}{2(3.14)} = 35.33 \text{ hz} > 18 \text{ hz} \quad \text{O.K.}$$

WHERE g = acceleration of gravity.

Consequently, the sway brace is considered adequate.

072-XXX5-h(3) Upper Support. In order to emphasize the differences in design procedures used for sway braces as opposed to those used for upper supports, the following example problem illustrating the design of an upper support is provided. A unit which is hard mounted to its base foundation and utilizes sliding mounts at its upper connection has been chosen as a representative example.

Upper Support Example Problem. The upper support configuration to be considered is depicted in Figure 14. It consists basically of a cantilevered structure supported from the overhead. The equipment unit weight is 1000 pounds and its center of gravity is located at 48" above the base of the unit. The following shock "g" factors will be employed in the example problem:

Vertical Shock	=	70 g's
Transverse Shock	=	28 g's
Longitudinal Shock	=	14 g's

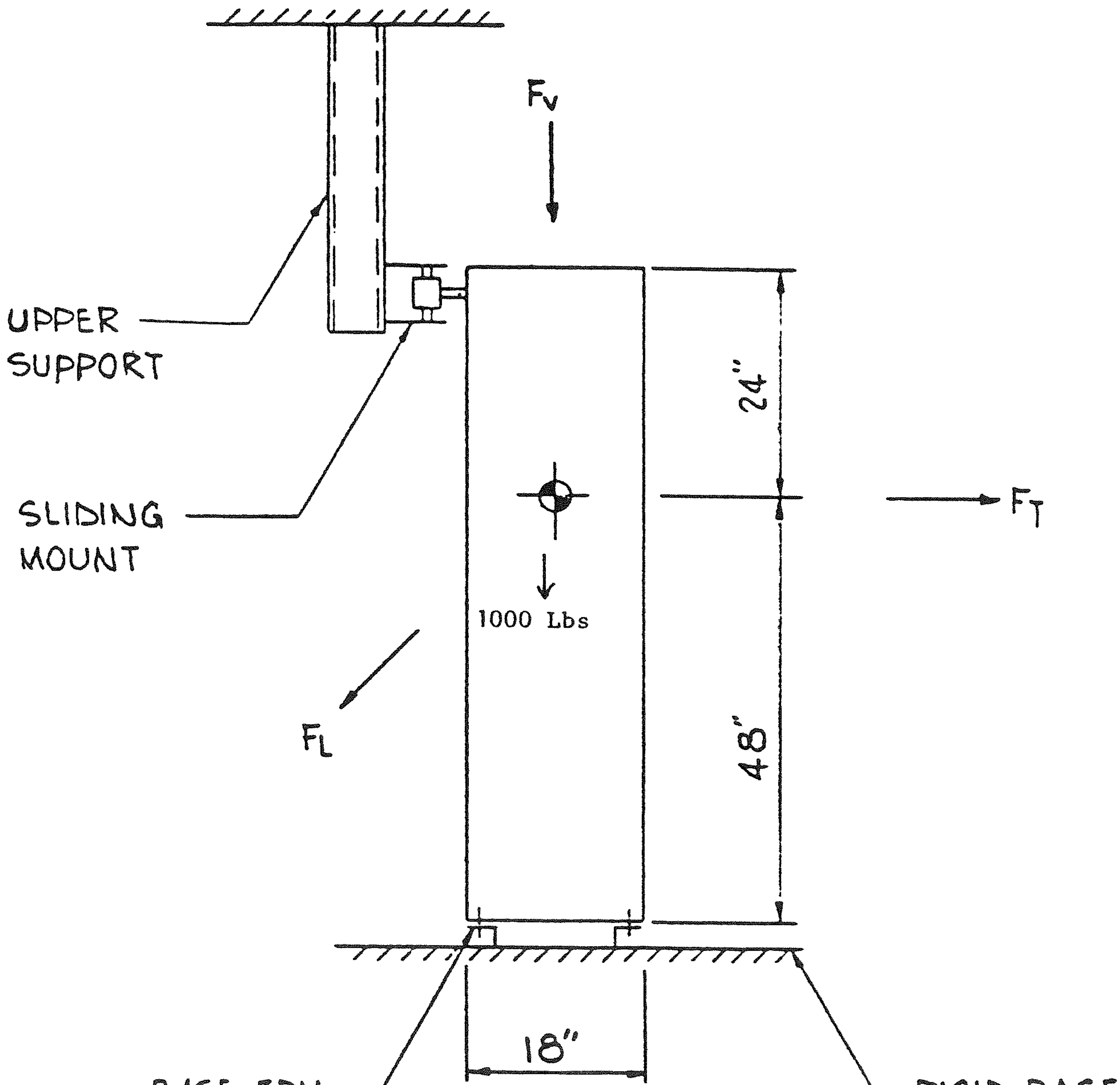


Figure 14. Upper Support Example Problem

Vertical Shock. With respect to vertical shock, the sliding mount attached to the upper connection of the unit will insure that no load is transmitted to the upper support. The base foundation will resist the entire vertical shock load. In addition, the sliding mount will compensate for relative displacements between the two surfaces (deck and overhead) supporting the equipment. Consequently, the upper support need not be designed for this direction of shock.

Transverse Shock. The upper support must however carry its share of the transverse shock load.

F_t = 1000 lbs x 28 g's = 28 KIPS

R_{top} = Reaction at Upper Support

R_{bottom} = Reaction at Base Foundation

Distributing the load on the basis of geometry:

a = 24"

b = 48"

$$R_{top} = F_t \times \frac{b}{a+b} = 28.0 \text{ KIPS} \times \frac{48"}{72"} = 18.67 \text{ KIPS}$$

$$R_{bottom} = F_t \times \frac{a}{a+b} = 28.0 \text{ KIPS} \times \frac{24"}{72"} = 9.33 \text{ KIPS}$$

The reaction at the upper connection of the unit, R_{top}, is to be used to design the upper support structure. To accomplish this task, the design methods and criteria described in Reference (1) are to be utilized.

<u>Longitudinal Shock.</u> The upper support must also be designed to carry its portion of the longitudinal shock loading. This must be done in the same manner as described in the analysis for transverse shock. When the shock force acts in the longitudinal direction there is a tendency for the upper support to twist, since the reaction at the sliding mount is eccentric with respect to the shear center of the upper support cross section. The twisting induces additional shear loads in the upper support, and should be considered in the design.