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Cargo Shoring Guidelines

FOREWORD

This SAE Aerospace Recommended Practice (ARP) specifies guidelines to be used when performing heavy cargo load spreading (shoring) on board civil transport aircraft. It identifies the various concerns to be taken into consideration to ensure protection of aircraft structure, and provides recognized industry standard methods to achieve it. It is intended as a guide toward standard practice, representing the state of the art at the date of publication. Since cargo shoring is a complex specialty largely based on accumulated experience, it is subject to change in order to keep pace with experience and technical advances.

Throughout this document, the minimum essential criteria are identified by use of the key word "shall". Recommended criteria are identified by use of the key word "should" and, while not mandatory, are considered to be of primary importance in providing safe cargo shoring arrangements. Deviation from recommended criteria should only occur after careful consideration and thorough service evaluation have shown alternate methods to provide an equivalent level of safety.

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1. SCOPE:

1.1 Purpose:

1.1.1 This SAE Aerospace Recommended Practice (ARP) specifies guidelines for calculating and performing shoring (load spreading) required on board civil transport aircraft whenever a piece of cargo to be carried exceeds the aircraft's maximum allowable limits in area load, running load, or both. It provides both the engineering methods needed to properly design a shoring arrangement, and the main practical dos and donts known from experience to ensure its effectiveness in protecting the aircraft's structure against overload.

1.1.2 This document aims at providing recognized industry standard methods to achieve the best attainable level of aircraft structural protection when designing and performing a shoring arrangement, taking into account the general requirements expressed in the aircraft manufacturers Weight and Balance Manuals, the requirements to be met as a result of the air cargo pallets airworthiness certification requisites, as well as the various potential areas of concern identified based on experience.

1.1.3 This document, therefore, provides recommended practical means of compliance with flight safety objectives, intended to be available as a common base for carriers as well as their airport handling agents when establishing their own in-house procedures, publications and staff training programs.

1.1.4 This document, however, is primarily intended for use by qualified structural engineers to be responsible for calculating and implementing cargo shoring arrangements where the size and weight of the piece of cargo require. It is not intended as a guide for more common simpler shoring requirements, identified thereafter: ARP5486, Air Cargo Pallets - Utilization Guidelines, Section 5 addresses such relatively simple cases.

1.1.5 This document shall not, under any circumstance, supersede the requirements of applicable airworthiness regulations (see FAR Part 25) or the aircraft manufacturer’s Weight and Balance Manual.

1.1.6 In addition, any aircraft manufacturers specific cargo shoring instructions shall be strictly complied with. Since in several instances they contain proprietary data, such data should be used only by authorized companies and persons with proper understanding thereof.

1.2 Field of Application:

1.2.1 This Aerospace Recommended Practice applies to shoring (load spreading) of individual pieces of cargo to be carried on board civil transport aircraft:

a. onto one or several airworthiness certified air cargo pallets meeting the requirements of TSO C90, themselves restrained into aircraft lower, main or upper deck cargo systems, or

b. nonunitized pieces of cargo, or pieces of cargo placed onto one or several unrestrained (“floating”) pallet(s) into lower, main or upper deck containerized cargo compartments of an aircraft, or

c. individual pieces of cargo loaded in noncontainerized (bulk loaded) baggage or cargo compartments.

1.2.2 Its field of application includes the pallets and shoring stands prepared within ground premises, whether at a shipper’s facilities or an airport cargo warehouse, including those intended to be loaded into the aircraft in a “floating” (not fully system restrained) position requiring tie-down onto the aircraft’s structure instead of the pallet’s tracks.

1.2.3 Its provisions also entirely apply in the event of “pre-embarked” pallets, i.e., pallets loaded empty into the aircraft to be used as a floor on which cargo is later brought and palletized inside the cargo compartment. In such a case, it pertains to the operator to implement the shoring scheme at aircraft loading.

1.2.4 Cargo shoring instructions shall be established by the aircraft operator, under control of his reporting Authority. The shoring instructions shall ensure compliance with the general airworthiness requirements and the applicable aircraft Weight and Balance Manual, and should incorporate the requirements of the present document, or equivalent industry standard (see 2.2). They should further define load or load concentration limits over which design and/or approval of the shoring scheme by designated load engineering structural engineers (see 7.2) is mandatory prior to implementation.

1.2.5 Actual cargo shoring in accordance with these instructions shall be performed and checked exclusively by an operator approved loadmaster constituting a competent, suitably trained (see 7.3), personnel as defined in ISO 9002, clause 4.18, or equivalent pertinent industry training and proficiency standards.

1.2.6 This document is not intended to be used for cargo shoring aboard military transport aircraft, and does not take into account any specific criteria for military aircraft. Nothing, however, precludes it being used for guidelines in this case, it pertaining to the military operator to identify and implement any additional applicable criteria.

2. REFERENCES:

2.1 Applicable Documents:

The following publications form a part of this document to the extent specified herein. The latest issue of SAE publications shall apply. The applicable issue of other publications shall be the issue in effect on the date of the purchase order. In the event of conflict between the text of this document and references cited herein, the text of this document takes precedence. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

2.1.1 SAE Publications: Available from SAE, 400 Commonwealth Drive, Warrendale PA 15096-0001.

AS1130	Air and Air/Surface (Platform) Cargo Pallets
AS1491	Interline Air Cargo Pallets
ARP5486	Air Cargo Pallets - Utilization Guidelines
ARP5595	Cargo Restraint Straps - Utilization Guidelines
AS36100	Air Cargo ULDs - Performance Requirements and Test Parameters

2.1.2 Government Publications: Available from U.S. Government Printing Office, M/S SSOP, Washington, DC 20402.

14CFR Part 21	Technical Standard Orders (TSO C90c, Cargo Pallets, Nets and Containers)
14CFR Part 25	Airworthiness Standards: Transport category airplanes (FAR Part 25)
14CFR Part 121	Air carriers certification and operation (FAR Part 121)
FAA AC 120-59	Air carriers internal evaluation program

2.1.3 AIA Publications: Available from AIA, 1725 De Sales Street NW, Washington DC 20036.

NAS 3610	Cargo Unit Load Devices, Specification for

2.1.4 Airplane Manuals: Available from the relevant aircraft manufacturer(s).

Weight and Balance Manual(s) for the aircraft type(s)/sub-type(s) concerned

Shoring Guidelines Manual(s) for the aircraft type(s)/sub-type(s) concerned [when available], e.g.: BOEING D6-35527, Shoring Guidelines for Outsized Cargo [applies to model 747 aircraft]

2.2 Reference Documents:

2.2.1 ISO Publications: Available from ANSI, 25 West 43rd Street, New York, NY 10036-8002.

ISO 4117	Air and air/land cargo pallets - Specification and testing
ISO 4171	Air cargo equipment - Interline pallets
ISO 8097	Aircraft - Minimum airworthiness requirements and test conditions for certified air cargo unit load devices [endorsement of NAS 3610]
ISO 9002	Quality systems - Model for quality assurance in production, installation and servicing

2.2.2 ATA Publications: Available from International Air Transport Association, 800 place Victoria, P.O. Box 113, Montréal Québec H4Z 1M1, Canada.

ULD Technical Manual:

UTM 50/1	Pallet for NAS 3610 Class II restraint systems
UTM 50/9	16ft or 20ft pallet for NAS 3610 Class II restraint systems

Airport Handling Manual:

AHM 673	Bulk compartment load limitations
AHM 676	Handling/bulk loading of heavy items
AHM 677	Handling and loading of BIG or overhang items
AHM 692	Ramp handling and loading procedures, training and qualifications

Other Publications:

Principles of Aircraft Handling [incorporating: ULD Handling guide]

2.3 Definitions:

FLOATING (- PALLET): an air cargo pallet, or several coupled pallets supporting a single piece of cargo, or equivalent flat support device, located onto an aircraft's cargo compartment rollerized conveyor but not restrained by the NAS 3610 compatible cargo system, the pallet(s) and its load constituting "nonunitized" cargo and being restrained to aircraft structural points.

FORE AND AFT: the directions, relative to the aircraft structure, determined parallel to the aircraft centerline towards the direction of flight, or opposed to it.

FREE SPAN: the part(s) of a shoring arrangement or shoring stand that extend out of the base area of the piece of cargo, in order to expand its effective bearing length or width.

2.3 (Continued):

HEAVY DUTY (- PALLET): any type or size of NAS 3610 Class II certified aircraft pallet with a base core stiffness (EI value) of 2 x 10^6 lb x in^2/in width of core (24 x 10^6 N x cm^2/cm width of core) or more.

LATERAL: the directions, relative to the aircraft structure, determined perpendicular to the aircraft centerline and parallel to its floor, left hand or right hand.

LOAD SPREADING (- ER): equivalent to SHORING (- MATERIAL).

LONGITUDINAL: equivalent to FORE AND AFT.

PALLET (AIR CARGO -): any type and size of NAS 3610 Class II certified aircraft pallet meeting the requirements of either AS1491B (ISO 4171, IATA 50/1: most consist of an aluminum plate base) or AS1130F (ISO 4117, IATA 50/9: heavy duty, stiffer, typically 2 to 2.5 in/50 to 63 mm thick, units).

PALLET (WOODEN -): any type and size of industrial forkliftable pallet for general use, made of wood or similar materials, used to facilitate handling and stacking pieces of cargo.

SHORING: the methods or equipment used to evenly distribute a concentrated cargo load over an aircraft floor or a pallet's surface in order to meet the applicable aircraft floor load limitations.

SHORING ARRANGEMENT: assembly of individual shoring materials located under a piece of cargo to ensure its shoring. The geometric layout of such an assembly.

SHORING STAND: a purpose built high rigidity device designed for shoring a piece of cargo critical by its weight, dimensions, or load concentration. Stands may be built either by shippers or aircraft operators or subcontractors, but their design must be approved by the operator's load engineering specialists.

SIDE(S): equivalent to LATERAL.

SPREADER FLOOR: local shoring intended to meet contact load limitations in a bulk compartment.

TIE-DOWN: The methods or equipment used to ensure proper restraint of cargo onto a pallet's edge track or the aircraft's structure to replace or complement net restraint when necessary. Tie-down guidelines are provided in ARP5595 (ISO 16049-2, IATA AHM 671).

UPWARD: the upward direction relative to the aircraft structure.

3. GENERAL REQUIREMENTS:

Shoring is required, under any piece of cargo that exceeds them, in order to ensure both the area load and the running load limitations of the relevant airplane section or position are effectively met.

3.1 Area Load:

3.1.1 The load on any given area of significant size (typically more than 5 ft^2/0.5 m^2 for bulk compartments, 10 ft^2/1 m^2 for palletized loads) should meet the maximum area load limitation specified in the Weight and Balance Manual for the lower, main or upper deck position it is to be loaded on in the aircraft.

3.1.2 Whenever the aircraft type is unknown at the time of load planning or pallet build-up, a maximum area load limitation of 150 lb/ft^2 (732 kg/m^2) for bulk cargo compartments, 200 lb/ft^2 (975 kg/m^2) for AS1491B (ISO 4171, IATA 50/1) pallets or 400 lb/ft^2 (1950 kg/m^2) for AS1130F (ISO 4117, IATA 50/9) or heavy duty pallets may be assumed for usual civil transport aircraft types.

3.1.3 Any deviations in specific circumstances should be allowed only to the extent determined by an operator performed specific engineering study, taking into account the characteristics of the load, the pallet's stiffness, the overall pallet CG location, and structural allowances of the aircraft's manufacturer.

3.1.4 The area load limitation is determined by the capability of the underlying aircraft structure (floor beams, stringers, rollers pattern in the case of a pallet). Accordingly, for relatively small loads (up to typically 5 ft/1.5 m maximum unsupported dimension, or all loads in bulk compartments), what shall be taken into account to verify the area load limitation is the total bearing area, i.e., that of the outer perimeter defined by all contact points of the load onto the pallet (see Figure 1 example in 4.1 hereafter). For larger size loads carried over a pallet (whether or not restrained into the aircraft's cargo loading system), the unsupported span between the load's contact points may require underneath shoring. See 4.2 hereafter.

3.1.5 Area load is not to be mistaken for "local" or "contact" or "footprint" load (the load divided by the actual contact area): local load limitations may or may not be defined in the aircraft's Weight and Balance Manual, but they seldom are critical for aircraft structural safety on typical air cargo pallets. They may raise concern only:

a. over bulk cargo compartments floor panels where a risk of panel puncture exists, or

b. when they result in significant local deformation of a pallet, which may result in difficulties to move over roller conveyors (a reliable factual indication of excessive deformation overloading rollers) or affect pallet restraint hardware functionality by excessive upward bending of the edges.

3.1.5 (Continued):

In either case, this should be taken care of by locally increasing the actual contact bearing area through intermediate elements constituting a local spreader floor, such as wood, plywood, or a wooden pallet, between load supports and floor panel or pallet sheet.

3.1.6 Elementary shoring procedures such as using wooden pallets to enlarge cargo’s footprint on the pallet should be considered first and are in many circumstances sufficient to ensure compliance with the maximum area load restriction. In very heavy or concentrated load cases, however, the study and implementation of a proper shoring arrangement may be required to meet it: see Section 4 hereafter.

3.2 Running Load:

3.2.1 The load on any given significant (typically more than 2 frame spacings, i.e., 3 to 4 ft/1.0 to 1.2 m) fuselage length measured parallel to the aircraft's centerline should meet the maximum running load limitation specified in the Weight and Balance Manual for the lower, main or upper deck position it is to be loaded on in the aircraft.

3.2.2 The maximum allowable running load in lb/in (kg/m) considerably varies according to aircraft type and, for a given type, between the various sections of bulk and containerized cargo compartments. It may also be affected by other structural limitations (e.g., combined between several decks, or even overall aircraft balance condition during flight) which require planning the airplane's total load and not only one single position. Accordingly, no general assumptions can be used in its absence, as in the case of the area load.

NOTE: The maximum area load in a certain aircraft floor area, divided by the maximum running load in that area, provides the maximum transverse (lateral) linear load, which it is in some instances also necessary to use in shoring calculations. See example in 5.2.3.4 hereafter.

3.2.3 Any deviations in specific circumstances should be allowed only to the extent determined by an operator performed specific engineering study, taking into account the characteristics of the individual load and the whole planned aircraft load, the pallet's stiffness, the pallet's CG location, and structural allowances of the aircraft’s manufacturer.

3.2.4 Such studies should determine the actual running load at the aircraft interface, that is at the underside of a pallet: as a result, an example of a deviation which may sometimes be justified and authorized by an engineering study, when using a high stiffness (AS1130F, ISO 4117, IATA 50/9 or heavy duty) pallet, is taking into account in the calculation the known pallet stiffness as an already provided free span shoring, allowing to somewhat increase fore and aft the effective bearing length of the load, thus to reduce its effective running load.

3.2.5 When a piece of cargo overhangs out of a pallet parallel to the aircraft's centerline and prevents the adjacent pallet position(s) in the aircraft from being occupied, the total running load for the pallet may sometimes be determined based on the total floor length occupied in the aircraft, subject to compliance with the area load limitation and all other requirements of the Weight and Balance Manual and, should this result in exceeding the pallet position's own certified maximum gross weight or other limits, restraint or additional restraint being performed directly onto the aircraft structure.

3.2.6 Whenever the calculation, including the effect of any acceptable and engineering justified deviations, results in a running load exceeding the maximum allowable value determined according to the Weight and Balance Manual, free span longitudinal shoring is required: see 4.3 hereafter for shoring calculation.

3.3 General Precautions:

Regardless of the relative shoring complexity (see Section 4 hereafter), general precautions shall systematically be applied in order to guarantee shoring effectiveness:

3.3.1 Whenever either the area load or the running load limitation is reached by a given piece of cargo with or without shoring, it becomes prohibited to locate any other load over it and its shoring (in both instances) or besides them (in the case of running load limitation).

3.3.2 Whenever loading heavy cargo onto a pallet, the load's center of gravity position is essential and shall be systematically checked:

a. if the pallet is restrained into the aircraft cargo system, it shall meet the applicable NAS 3610 maximum CG deviation limits (see ARP5486), and

b. whether it is so restrained or unrestrained (floating pallet), a significantly offset CG (for instance due to a strongly asymmetrical piece of cargo, or an overhang at one end of an otherwise symmetrical piece) in the horizontal plane increases the load bearing on the heaviest end so that the average load over the whole bearing area or the whole bearing length may not be used, and these limitations should be checked on the heaviest end of the piece or the pallet.

c. a load CG higher than the applicable NAS 3610 maximum limit (which may occur as a result of high shoring materials being used) is out of the certification criteria of the pallet's restraint system, hence the load in this case should be restrained by tie-down directly to the aircraft structure, taking into account the higher CG to determine the locations and angles of the tie-down elements.

3.3.3 In any event, an even well designed and properly calculated shoring arrangement will be effective only insofar as it is appropriately and professionally performed: many performance details can jeopardize its actual effectiveness (see 6.1 hereafter). Accordingly, any shoring arrangement shall, prior to aircraft release, be checked and approved by a suitably trained, operator approved, loadmaster per 1.2.5.

4. SHORING COMPLEXITY LEVELS:

Situations where some degree of shoring is required are very various, and correspond to very different degrees of complexity. In the simplest instances which are the majority, very simple methods can be used. On the contrary, some very heavy or concentrated loads require complex engineering calculations and precautions that exceed the know-how of most, even experienced, loadmasters alone. Accordingly, the following classification is recommended as a general guide for selecting appropriate procedures and techniques.

4.1 Elementary Shoring:

4.1.1 Elementary shoring includes all cases of shoring heavy cargo in bulk cargo compartments, and, within the limits stated hereafter, many cases of shoring on air cargo pallets.

4.1.2 The necessity of cargo shoring in a bulk cargo compartment should be systematically evaluated for any piece of cargo weighing 330 lb (150 kg) or more, designated by the IATA handling code "HEA". In practice, the running load limitation in a bulk compartment essentially applies to the whole load of a compartment's net section, so that most shoring requirements address the area load limitation.

4.1.3 Example of elementary shoring calculation in a bulk cargo compartment:

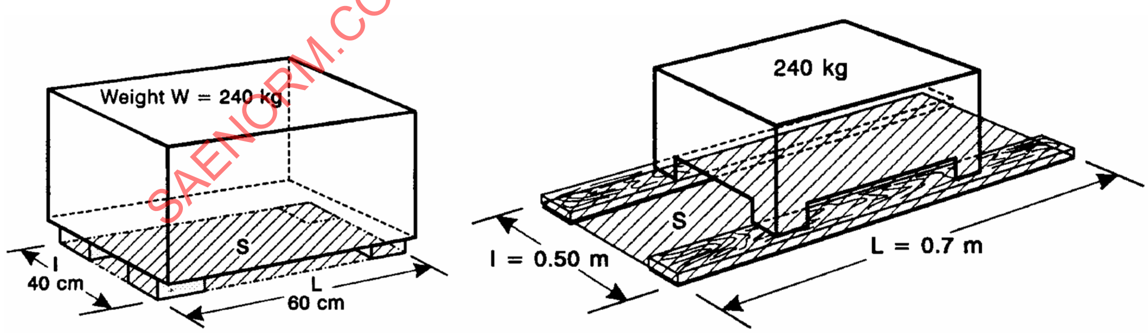


FIGURE 1

Assuming a 240 kg (530 lb) load with a 0.4 m x 0.6 m (16 in x 24 in) bearing base, taking into account the outer perimeter defined by all contact points of the load, the area load is:

4.1.3 (Continued):

$$\frac{240}{0.4 \times 0.6} = 1000 \text{ kg/m}^2 \text{ (210 lb/ft}^2\text{)}$$, exceeding the typical 732 kg/m^2 (150 lb/ft^2) area load limit for a bulk compartment floor. Shoring is definitely required.

Two 0.7 m (27 in) planks located to ensure an overall width of 0.5 m (20 in) will reduce the area load to:

$$\frac{240}{0.5 \times 0.7} = 686 \text{ kg/m}^2 \text{ (141 lb/ft}^2\text{)}$$, and constitute a simple but satisfactory shoring arrangement.

Unless a wooden pallet is used instead, the shoring planks require sufficient stiffness. Up to free spans of about 0.3 m (1 ft), which are hardly ever exceeded, 20 to 25 mm (3/4 to 1 in) thick planks will provide sufficient stiffness for all shoring cases encountered in bulk cargo compartments. See IATA AHM 673 for additional, more detailed, recommendations for shoring in bulk compartments.

4.1.4 Such elementary shoring may also be required on AS1491B (ISO 4171, IATA 50/1) aluminum pallets:

a. for concentrated loads likely to cause local bending of the aluminum sheet and result in difficulties to freely move over rollers, or to engage the aircraft's latches due to edge bending. A typical common case is automobiles, where some elementary shoring is required between the wheels and the pallet. Or

b. more seldom, for high density pieces of cargo (e.g., crated castings or similar mechanical parts).

c. It is normally never required or even useful on AS1130F (ISO 4117, IATA 50/9) or heavy duty, stiffer, typically 2 in/50 mm thick, units because their own stiffness (EI value) is considerably higher than any elementary shoring material's.

4.1.5 One of the commonest and most easily available elementary shoring techniques, either in a bulk compartment or on an aluminum plate pallet, is using a wooden pallet to enlarge the piece of cargo’s footprint. Due to its height (usually 10 to 15 cm, 4 to 6 in), hence stiffness, and its crushability (useful to spread locally concentrated loads), it constitutes a very effective means of equally spreading the load within the limits resulting from its dimensions: for the area load purpose, a typical 1.0 m x 1.2 m (40 in x 48 in) industrial pallet offers an area of 1.2 m^2 (13 ft^2), hence allows effective shoring of loads up to about 900 kg (2000 lb) in a bulk cargo compartment or 1200 kg (2500 lb) on a plate aluminum pallet, or twice as much if two wooden pallets are used for the same load. For enlarging the piece of cargo's bearing length in order to address the running load limitation, however, it remains limited by its largest dimension.

4.1.6 The systematic use of one or several wooden pallets whenever possible is therefore recommended. They can be used, within weight limits set by the operator, by normally trained cargo warehouse staff. However, when this is insufficient to meet the limitations, a more complex shoring study and more qualified supervision personnel are required.

4.2 Shoring Underneath the Load:

4.2.1 Elementary shoring as per the example in 4.1.3 (i.e., taking into account the outer perimeter of all contact points of the load onto the pallet to determine the effective bearing area) implies that the pallet, or shoring arrangement used under the load, is considered stiff enough to distribute the load between the contact points. This is an acceptable assumption for usual bulk cargo compartment loading using at least typical 20 to 25 mm (3/4 to 1 in) thick planks for shoring, or on (a) wooden pallet(s), or on an air cargo pallet up to common load ranges and unsupported lengths. However, when either the load is quite high or the unsupported length between contact points is significant, this assumption may not be true anymore. Accordingly, in such a case a calculation is required to determine the minimum shoring requirements.

4.2.2 A typical and common case is that of a heavy load sitting on only two parallel skids near its ends (if there are more than two skids, the problem remains the same as regards the unsupported length between skids). This results in severe load concentration under each skid, pallet deformation and aircraft systems and floor structure overloading. There are two ways in which an acceptable load distribution can be reestablished:

a. by adding additional intermediate support under the load's base between the existing skids, in order to reduce the unsupported length, and/or:

b. by keeping the two skids only, but setting them onto sufficiently stiff shoring materials/beams in the 90° direction to reduce the pallet deflection underneath the unsupported length.

Both methods are in fact equivalent from the stiffness computation standpoint (see 4.2.3 hereafter) and the choice will largely depend on the other characteristics of the load and the shoring materials available.

4.2.3 Minimum shoring stiffness and/or maximum supports spacing requirements underneath the load can be determined or at least sufficiently well approximated by simple standard engineering computations. A commonly used method is calculating the estimated pallet deflection and reducing it to a value deemed acceptable. Assuming the situation in Figure 2:

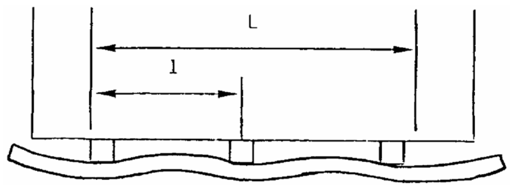


FIGURE 2 - Example

4.2.3 (Continued):

if "W" is the weight of the load, "L" its total bearing length, and "l" the spacing between any intermediate supports, the uniform average linear load "w" is $\frac{W}{L}$, and the maximum pallet deflection "d" may be approximated as:

[metric units] [imperial units]

$$(cm)\ d = \frac{5 \cdot w\ (kg/cm^2) \cdot l^4}{384 \cdot EI} \qquad (in)\ d = \frac{w\ (lb/in) \cdot l^4\ (in^4)}{192 \cdot EI\ \ (lb.in^2)}$$

If the EI value used is that of the pallet (value per unit width of core x pallet dimension to be considered), then stating a maximum objective for pallet deflection "d" will determine the maximum allowable spacing "l" between supports. If additional shoring materials are used below the load, their EI value must be added to the pallet's own to determine the maximum allowable spacing between supports. A key is keeping in mind maximum allowable spacing "l" varies as the (1/4th) power of the minimum EI value.

"d" maximum pallet deflection values between 0.25 and 0.50 mm (0.01 and 0.02 in) were experimentally found to be consistent with an effective measured load distribution on the underneath surface of the pallet.

NOTE: The above formula is applicable for two supports only: for more than two, it evaluates deflection per excess, so that using it remains on the safe side. For more accurate evaluation with more than two supports, when required, see 4.2.7 hereafter.

4.2.4 Such a simplified/approximate method (which does not require advance knowledge of the aircraft type or pallet position to be flown) is suitable only up to a certain amount of load "W" or average linear load "w". Over this amount, it may become preferable to perform a more precise computation reflecting the actual situation, i.e., taking into account the actual spacing of the rollers in the aircraft vs the load supports spacing, though general engineering calculation methods may still be used for that purpose (see 4.2.7 hereafter).

4.2.5 Such computations, even simplified/approximate, shall take into account any significant CG offset of the load in relation with its outer bearing supports. If it has one end significantly heavier than the other one, then the average linear load "w" taken into account in the calculation shall be accordingly adjusted.

4.2.6 Whenever more than two bearing supports are used, the main practical difficulty is determining how effectively they distribute the load under the previously unsupported length. This should be evaluated, taking into account complementary approaches, the engineer's (4.2.7) and the loadmaster's (4.2.8):

4.2.7 General Structural Engineering Laws Regarding Load Distribution Over a Series of Supports: Assuming the supports are identical and equally spaced, the loads on each support and pallet deflections between them are not proportional, but they theoretically are:

3 supports	4 supports	5 supports	6 supports	7 supports
Load on each support as percentage of total load "W" :				
19% 62% 19%	13% 37% 37% 13%	10% 28% 23% 28% 10%	8% 23% 19% 19% 23% 8%	7% 19% 16% 17% 16% 19% 7%
Deflection between two adjacent supports spaced "l" as percentage of the deflection for two, calculated under 4.2.3 :				
40% 40%	52% 4% 52%	48% 14% 14% 48%	52% 12% 25% 12% 52%	49% 12% 21% 21% 12% 49%

NOTES: This unfavorable "natural" load distribution is somewhat theoretical in practical cases, where all elements, including the underlying aircraft structure, have some flexibility. However, it indicates a significant trend which must be taken into account when designing high performance shoring.

One common way of somewhat alleviating the unequal load distribution is using for intermediate load support elements of a crushable (hard cushioning) nature, such as wooden pallets, fiberboard honeycomb plates (see …. hereafter), hard foam or rubber blocks, etc.: such materials tend to crush up to the precise point where they all support the same load, which tends to more evenly distribute it.

Also, the deflections distribution indicates a useful practical action: with more than three supports, those supports located at the ends always produce at least twice as much deflection as the intermediate ones. More even deflection can be obtained using smaller spacing between the two supports located at each end of the load, vs intermediate ones.

4.2.8 The actual physical situation, which closely depends on very small differences in height or flexibility of the supports and the load, hence should best be physically checked once the shoring arrangement was performed: it is important, for instance, to detect any element seemingly in place that would not effectively bear any load, which can be done, e.g., by attempting to slide a knife's blade or other thin tool between support and load, or support and pallet, or pallet and GSE rollers (noting that typical GSE roller beds are quite rigid, more than an aircraft's floor). If such a noneffectively bearing element is detected, then the shoring arrangement is unsatisfactory and requires improvement. Unequal deflection situations can usually also be visually detected by a trained eye from the end along a supposedly straight line such as a beam edge, etc. See 6.1 hereafter.

4.2.9 General structural engineering methods applicable to deformations of loaded beams and plates, however, can be used at appropriate levels of approximation or sophistication for computing shoring underneath the load, but are inadequate to compute any free span shoring arrangements, enlarging the actual total bearing length and/or area of the load onto the pallet and the aircraft floor. In such instances, more sophisticated methods must be used: see 4.3 hereafter.

4.3 Free Span Shoring:

4.3.1 Free span shoring, extending out of the load's own footprint, may be necessary either laterally in relation with the aircraft centerline (area load limitation), or longitudinally (running load limitation), or both simultaneously (see Figure 3):

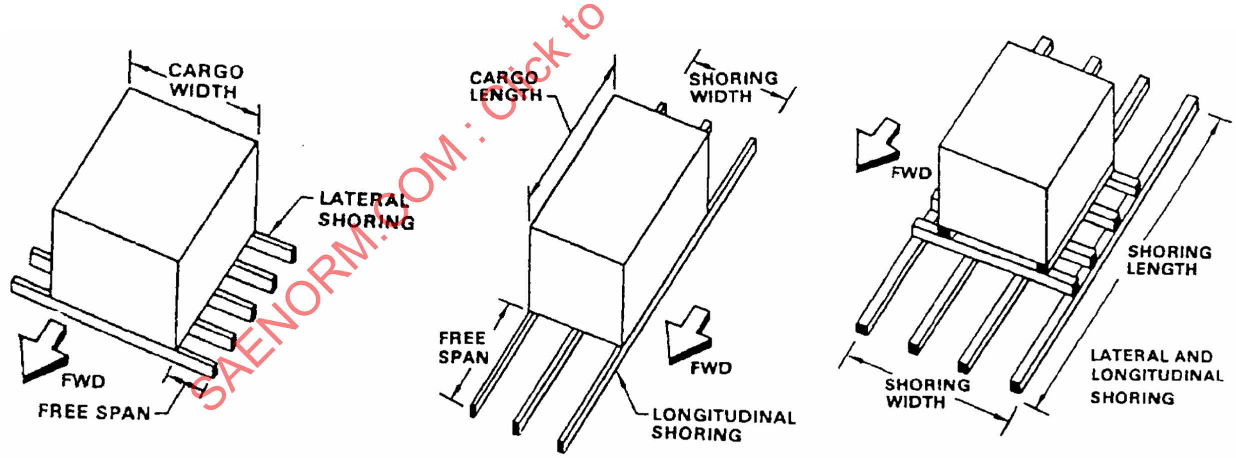


FIGURE 3

4.3.2 Whenever a planned change of aircraft may result in changing the pallet orientation within the aircraft, longitudinal shoring shall be performed in both directions to ensure the running load limitation will be met on both successive positions.

4.3.3 Free span shoring methods basically consist in locating the concentrated load on an arrangement of adequate stiffness materials providing a larger base in order to better distribute the total load over a larger area. The critical parameter in achieving this result is the total stiffness of the materials used, expressed as an EI value in lb x in^2 (N x cm^2), where:

- E is the Young modulus of the material, in lb/in^2 (N/cm^2 = 10 kPa),
- I is the vertical moment of inertia of the individual piece of material, in $inch^4$ (cm^4).

4.3.4 The pallet's own EI value may be taken into account for computing total shoring stiffness, in addition to that of the shoring materials used. For general information only (refer to actual data from the pallet type's manufacturer), typical EI value ranges for state of the art aluminum pallets on the market are as follow, in lb x in^2 (N x cm^2) (1):

Pallet specification	AS 1491 B / ISO 4171 / IATA 50/1		AS 1130 F / ISO 4117 / IATA 50/9	
Pallet size	88 x 125 "	96 x 125 "	96 x 196 "	96 x 238.5 "
E.I value lengthwise	0.35 - 0.55 x 10^6 (10 - 16 x 10^6)	0.4 - 0.6 x 10^6 (11 - 18 x 10^6)	200 - 600 x 10^6 (6 - 17 x10^9)	200 - 600 x 10^6 (6 - 17 x 10^9)
E.I value crosswise	0.5 - 0.8 x 10^6 (14 - 23 x 10^6)	0.5 - 0.8 x 10^6 (14 - 23 x 10^6)	400 - 1200 x10^6 (11 - 34 x 10^9)	500 - 1500 x 10^6 (15 - 42 x 10^9)

(1) Conversion factor : 1 lb x in^2 = 28.7 N x cm^2

4.3.5 The materials used over the pallet to constitute the shoring arrangement can have extremely different stiffness/EI values, due to both the difference in E value and even much more in moment of inertia. Typical Young modulus (E) values for commonly used materials in lb/in^2 (N/cm^2) are (1):

Material	Fir / spruce wood	Oak wood	Aluminum beam	Steel beam
Young modulus **E**	1.1 - 1.7 x 10^6 (0.8 - 1.2 x 10^6)	1.4 - 2.1 x 10^6 (1 - 1.5 x 10^6)	10 x 10^6 (7 x 10^6)	28 x 10^6 (20 x 10^6)

(1) Conversion factor : 1 lb / in^2 = 0.7 N / cm^2 = 7 kPa

4.3.6 The vertical moment of inertia (I) is given for a full rectangular cross section of width "w" and height "h" by the formula: $I = w \cdot h^3/12$. Hence, it increases to the third power of the material's height (refer to actual data from the beams manufacturer in the event of shaped beams being used).

4.3.7 Therefore, any shoring arrangement will be considerably stiffer, hence more effective for load spreading, if the materials used are located in order to maximize their height: rectangular cross section items such as lumber shall always be used on their edge, with their largest dimension vertical.

NOTE: When rectangular cross section items (e.g., 2x4 lumber) present an overturning risk, they should be located by pairs adjacent to each other in order to avoid their tilting/overturning, while keeping each of them on edge to retain maximum vertical EI: two of them, so located, are eight times stiffer than the same set flat onto each other.

4.3.8 When the length of available shoring materials is less than the total length of the load plus free spans required at both ends, i.e., total shoring length, shorter elements may be used providing at least half their length is effectively engaged under the load, and a longitudinal overlap is maintained between elements under the load in order to avoid a potential shear point.

4.3.9 The methods to calculate the minimum required free span shoring stiffness are indicated in Section 5 hereafter.

5. CALCULATION METHODS:

Under heavy loads and throughout acceleration loads incurred during flight, an aircraft's floor structure is elastic and the fundamental parameter for computing any free span shoring arrangement is the floor's elasticity factor, which can be obtained only from the aircraft's manufacturer. The fundamental equations to be used for such computation are those for finite length beams on elastic foundations, reproduced hereafter.

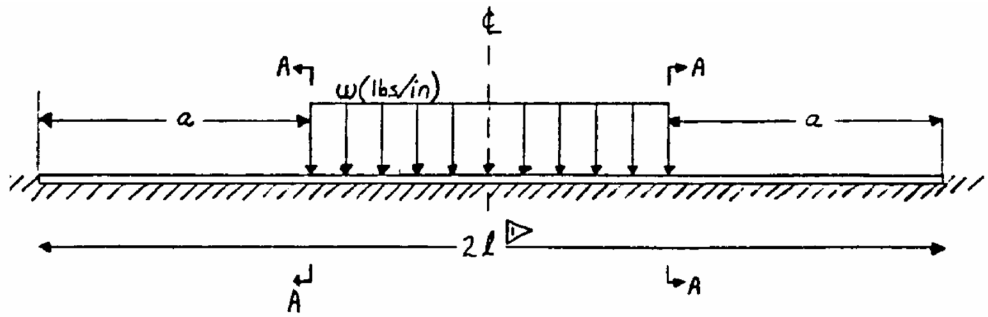
NOTE: Shoring calculation underneath the load, when required, may be approximated through simpler general structural engineering formulas (see 4.2), and do not necessitate using the more complex set of equations for beams on elastic foundations.

5.1 General Equations:

5.1.1 Parameters [imperial units]:

K = aircraft floor elasticity factor (lb/in^2). Depends on floor section considered. See manufacturer's data.
w = uniform (average) linear load over the load's length (lb/in). See 4.2.
l, a = dimensional parameters: see Figure 4

All forces are in (lb). All moments are in (lb x in). All deflections and beam dimensions are in inches. All slopes are in radians.



① Formulas model load and shoring as uniformly distributed load over one half length ℓ with the left end free and right end guided. See 4.2 above for means to ensure uniform load distribution underneath load.

FIGURE 4 - (x = ⟶)

All forces are in (lb). All moments are in (lb.in). All deflections and beam dimensions are in inches. All slopes are in radians.

5.1.2 Functions:

$$\beta = \left(\frac{K}{4\,EI} \right)^{1/4}$$

$F_1 = \text{Cosh}\ \beta x \ .\ \cos \beta x$

$F_2 = [\text{Cosh}\ \beta x \ .\ \sin \beta x] + [\text{Sinh}\ \beta x \ .\ \cos \beta x]$

$F_3 = \text{Sinh}\ \beta x \ .\ \sin \beta x$

$F_4 = [\text{Cosh}\ \beta x \ .\ \sin \beta x] - [\text{Sinh}\ \beta x \ .\ \cos \beta x]$

$Fa_1 = \langle x - a \rangle^{\circ} \ .\ \text{Cosh}\ \beta \langle x - a \rangle \ .\ \cos \beta \langle x - a \rangle$

$Fa_2 = [\text{Cosh}\ \beta \langle x - a \rangle \ .\ \sin \beta \langle x - a \rangle] + [\text{Sinh}\ \beta \langle x - a \rangle \ .\ \cos \beta \langle x - a \rangle]$

$Fa_3 = \text{Sinh}\ \beta \langle x - a \rangle \ .\ \sin \beta \langle x - a \rangle$

$Fa_4 = [\text{Cosh}\ \beta \langle x - a \rangle \ .\ \sin \beta \langle x - a \rangle] - [\text{Sinh}\ \beta \langle x - a \rangle \ .\ \cos \beta \langle x - a \rangle]$

$Fa_5 = \langle x - a \rangle^{\circ} - Fa_1$

$C_1 = \text{Cosh}\ \beta\ell \ .\ \cos \beta\ell$

$C_2 = [\text{Cosh}\ \beta\ell \ .\ \sin \beta\ell] + [\text{Sinh}\ \beta\ell \ .\ \cos \beta\ell]$

$C_3 = \text{Sinh}\ \beta\ell \ .\ \sin \beta\ell$

$C_4 = [\text{Cosh}\ \beta\ell \ .\ \sin \beta\ell] - [\text{Sinh}\ \beta\ell \ .\ \cos \beta\ell]$

$Ca_2 = [\text{Cosh}\ \beta(\ell - a) \ .\ \sin \beta(\ell - a)] + [\text{Sinh}\ \beta(\ell - a) \ .\ \cos \beta(\ell - a)]$

$Ca_4 = [\text{Cosh}\ \beta(\ell - a) \ .\ \sin \beta(\ell - a)] - [\text{Sinh}\ \beta(\ell - a) \ .\ \cos \beta(\ell - a)]$

$Ci_2 = [\text{Cosh}\ \beta\ell \ .\ \text{Sinh}\ \beta\ell] + [\cos \beta\ell \ .\ \sin \beta\ell]$

In the above functions, the unit step function is denoted by the symbol $\langle x - a \rangle^{\circ}$, where the use of the angle brackets $\langle\ \rangle$ is defined as follows:

If $x < a$, then $\langle x - a \rangle^{\circ} = 0$
If $x > a$, then $\langle x - a \rangle^{\circ} = 1$
If $x = a$, then $\langle x - a \rangle^{\circ}$ is undefined.

5.1.2 (Continued):

The functions Cosh β< x - a >, Sinh β< x - a >, cos β< x - a >, and sin β< x - a > are also defined as having a value of zero if x < a.

The use of the angle brackets < > is extended to other cases involving powers of the unit step function and the ordinary function $(x - a)^n$. Accordingly, the function $(x - a)^n$. < x - a >° is denoted by $< x - a >^n$ and is also given a value of zero if x < a, or its normal value if x > a.

5.1.3 Intermediate Calculation Elements:

$$\theta_A = \frac{w}{4\,EI\,.\,\beta^3} \cdot \frac{C_2.Ca_4 - C_4.Ca_2}{Ci_2} \qquad Y_A = \frac{-w}{4\,EI\,.\,\beta^4} \cdot \frac{C_1.Ca_2 + C_3.Ca_4}{Ci_2}$$

5.1.4 Formulas:

$$\text{Transverse shear} = V = -Y_A\,.\,2\,EI\,.\,\beta^3\,.\,F_2 - \theta_A\,.\,2\,EI\,.\,\beta^2\,.\,F_3 - \frac{w}{2\beta}\,.\,Fa_2$$

$$\text{Bending moment} = M = -Y_A\,.\,2\,EI\,.\,\beta^2\,.\,F_3 - \theta_A\,.\,EI\,.\,\beta\,.\,F_4 - \frac{w}{2\beta^2}\,.\,Fa_3$$

$$\text{Slope} = \theta = \theta_A\,.\,F_1 - Y_A\,.\,\beta\,.\,F_4 - \frac{w}{4\,EI\,.\,\beta^3}\,.\,Fa_4$$

$$\text{Deflection} = Y = Y_A\,.\,F_1 + \frac{\theta_A}{2\beta}\,.\,F_2 - \frac{w}{4\,EI\,.\,\beta^4}\,.\,Fa_5$$

5.1.5 Boundary Conditions:

1. Shear V at section A-A (for x = a) = 1/2 (cargo length) . (w - maximum allowable running load)
2. Shoring deflections must be negative: the interface between shoring and pallet is one way only, and does not withstand tension loads.

5.1.6 Equations Solution: The necessary shoring stiffness (EI) is the one that ensures all boundary conditions are met.

SOURCE: The equations for finite length beams on elastic foundations can be found in a variety of engineering publications. The source used for the above is “Formulas for stress and strain”, Roark & Young, 1985, © McGraw Hill Inc. Publishers (section 7.5, Beams on elastic foundations).

5.2 Shoring Design:

5.2.1 General:

5.2.1.1 The calculations are too complex to be reliably performed by hand in a reasonable time frame. Accordingly, they should be performed with a computer programmed using the above general equations. A standard PC is sufficient. See 5.4.2 hereafter for possible simplified operational methods.

5.2.1.2 Any computer program developed for this purpose should be formally checked and validated by the concerned aircraft manufacturer(s) stress engineering department(s) prior to being used to design shoring for overweight cargo.

5.2.1.3 The computer program once validated should be used exclusively by qualified engineers (see 7.2 hereafter for minimum training requirements) or under their direct supervision. Operators may elect either to entertain the appropriate engineering capability in-house under their own responsibility, or subcontract it to an approved organization, or refer all or certain items to the aircraft manufacturer for guidance.

5.2.1.4 It should at all times be remembered proper calculation of the required EI value is necessary but not sufficient to perform an appropriate shoring arrangement or build an appropriate shoring stand. All other rules in the present document, particularly those in 5.2.2 through 6.2 hereafter, should also be complied with at shoring scheme implementation, and the resulting arrangement once performed should be systematically checked by a qualified loadmaster (see 7.3 hereafter for minimum training requirements) prior to the pallet, or piece of cargo, being released for loading aboard an aircraft.

5.2.2 Calculation Steps:

5.2.2.1 The first step in calculation is assessing the nature of the shoring arrangement required, based on the limitations for the intended loading location in the aircraft: either lateral in relation with the aircraft centerline (area load limitation), or longitudinal (running load limitation), or both simultaneously. In the latter case, two separate calculations, one in each direction, will be required.

5.2.2.2 The second step is selecting the desired shoring length $2l$: it may be based on the available materials, or the length of the pallet (or pallets, if two or several ones are to support the piece of cargo), or a length estimated to meet the aircraft limitation. It should, however, be kept in mind that:

- unnecessarily long shoring usually is heavier, which may in turn result in increasing the required stiffness,

- with very heavy and/or short/concentrated loads, too long shoring may result in positive deflection at the ends (see 5.2.2.5), hence a lesser actual bearing length, and the shoring arrangement being ineffective.

5.2.2.3 The third step is calculating the minimum required shoring stiffness (EI) for the parameters, according to the program reflecting the applicable general equations, thus, after deducting the pallet's own EI value, the total EI required to be provided by shoring, then selecting among the available materials the number and size of primary shoring beams required to obtain it. There are generally several solutions, between a small number of high stiffness items or a larger number of lower stiffness ones:

- the first case usually is lightest (using similar materials, e.g., steel beams), but may result in either an overall height exceeding that available within the maximum pallet contour, and/or insufficient transverse load distribution inducing aircraft roller track overloading (see 5.2.3.6 hereafter),

- the latter case usually is heavier (see 5.2.2.4), but performs better on both other accounts. It should be remembered, however, that a number of parallel shoring beams exceeding that of the roller tracks below the pallet does not effectively contribute to improving transverse load distribution (see 5.2.3.5 hereafter).

5.2.2.4 The required shoring stiffness is determined by the total weight, i.e., cargo weight plus shoring weight. This results in an iterative calculation, which may be limited by systematically adding e.g. 3 to 5% to the cargo weight into the first calculation, to take into account an estimated shoring weight. Once the shoring materials were selected, their weight and that of any additional accessories shall be added to the cargo weight, and this actual total weight reentered into the calculation to check the required EI has not changed.

5.2.2.5 It may occur that calculation results in positive deflection at the ends of the shoring beams, that is their bending upward without contact with the pallet. This is not allowable (see boundary condition 2 in 5.1.5), and other solutions must be identified. They can often be found by using shorter free spans (shorter shoring length) with higher stiffness materials. If not, the only solution may be enlarging the length of the piece of cargo itself through pyramid shoring (see 5.3) as a next step of calculation.

5.2.2.6 For very heavy loads, it may also occur (because the equations involve exponential trends) that calculation results in a considerable required EI value, so high that materials cannot be procured, or building such a shoring arrangement appears impractical (e.g., due to the overall height limit within the pallet's maximum contour, etc.), or the weight of shoring brings the total pallet gross weight over its maximum allowable limit in the aircraft. In such a case as well, a solution may be enlarging the length of the piece of cargo itself through pyramid shoring (see 5.3). Another solution, which potentially allows to save a lot of shoring's weight, is designing and building a shoring stand with diagonal bracing (see 6.2.4).

5.2.3 Shoring Geometry:

5.2.3.1 Calculation as per 5.2.2 will only provide the required shoring stiffness. It is necessary to also determine the overall shoring arrangement geometry, and any additional components needed, in order to ensure shoring effectiveness and feed back the weight of the additional elements as required per 5.2.2.4. In addition to providing the calculated minimum stiffness, the shoring arrangement's geometry should also ensure:

a. as even as possible distribution of the loads onto the length of the shoring beams, and

b. the transverse loads distribution between the beams and onto the pallet be such as to avoid excessive uneven loads on certain pallet areas and subsequent aircraft roller tracks overloading.

5.2.3.2 Planned location of beams on the pallet(s). If the overall bearing width of shoring is less than the load's, it shall be checked the maximum area load (for longitudinal shoring) or the maximum running load (for lateral shoring) limitations are still met. In addition, the selected beam locations should take into account the underlying aircraft structure (see 5.2.3.5).

5.2.3.3 Defining the interface between the load itself and the selected shoring beams, e.g., if the shoring beams occupy a width larger than the load's, a layer of cross members will be required between beams and cargo to distribute the loads to the outer beams, or the shape of the cargo may dictate additional intermediate material at certain locations, etc.

5.2.3.4 When shoring is wider than the load and cross members are required, the general engineering law in 4.2.7 should be used: even though, under very heavy loads, the shoring arrangement's components and even the aircraft floor cannot be considered totally rigid, the trend still exists of the major part of the load bearing onto the center supports, with the outer ones relatively underloaded. This can be obviated by using the technique illustrated in Figure 5:

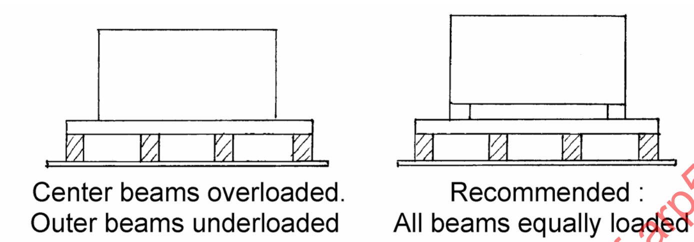


FIGURE 5

NOTE: In such a case, the minimum required stiffness of the free span cross members vs the maximum transverse linear load (see 3.2.2 NOTE) can be calculated using the same general equations and calculation steps.

5.2.3.5 Once the transverse load distribution is controlled, the same potential problem arises as to effective load distribution between the aircraft roller tracks transmitting the load to the main aircraft structure: hence the transverse location of the beams onto the pallet should be selected preferably between, rather than immediately over, the actual roller track locations, adjusting the spacing between shoring beams so that each roller track incurs approximately the same load, as illustrated in Figure 6:

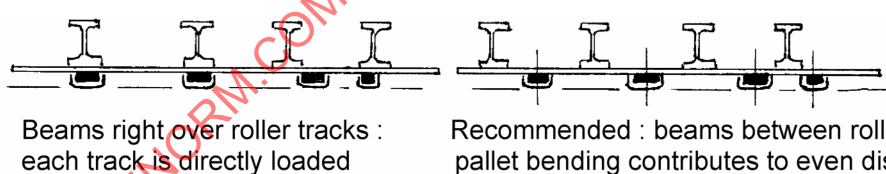


FIGURE 6

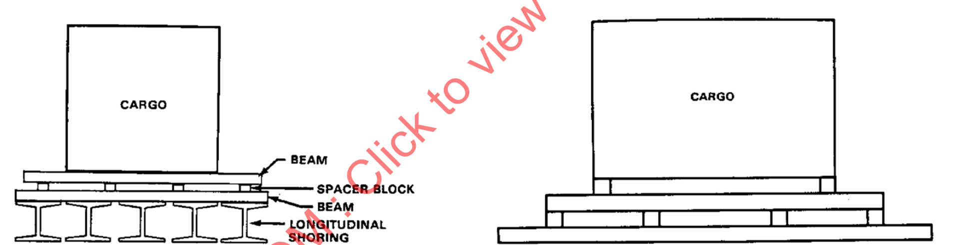
NOTE: This indicates that the optimum spacing of the beams in the transverse direction is a direct function of roller tracks spacing in the aircraft, and equal spacing is not necessarily optimum.

5.2.3.6 Accordingly, when selecting among the available materials the number and size of primary shoring beams required (see 5.2.2.3), not all solutions possible in terms of total EI provided are as good as each other: optimum results will usually be obtained by a number of primary beams equal to the number of roller tracks plus or minus one, appropriately located. Higher numbers, though heavier, can still be appropriately located, but smaller numbers (e.g., shoring with 2 beams only) may not be optimum, depending on the load. Where the shape of the load (e.g., heavy large size cylinder) makes it difficult to use more than two primary beams, additional transverse shoring may have to be considered below them.

5.3 Pyramid Shoring:

5.3.1 When the load is heavy and concentrated enough to require an impractical shoring arrangement, or the beams exhibit (or calculation indicates) positive deflections at the ends (see 5.2.2.5 and 5.2.2.6), pyramid shoring is a technique which allows enlarging the bearing length of the load, making it in fact equivalent to a longer one, in order to reduce primary shoring requirements.

5.3.2 Pyramid shoring may be used when needed either in the lateral or the longitudinal direction (see Figure 7):



Lateral pyramid shoring　　Longitudinal pyramid shoring

FIGURE 7

The bearing dimension of the load is effectively enlarged up to the outer spacer blocks or cross members. Insofar as the upper tier's supporting points are located between the lower tier's, the load is effectively evenly distributed to the lower level. The required EI value for primary shoring may be calculated based on this larger load dimension.

5.3.3 Pyramid shoring allows significant reduction of the primary shoring's EI value, and in many instances allows performing shoring arrangements which would be impossible or impractical otherwise. However, apart from the added difficulty and additional precautions required for stability, its main inconvenient is it increases the overall height of the palletized load, which may run into the pallet CG or contour height limit.

NOTE: It should be noted, however, that the upper tier cross members do not require high stiffness, hence do not need to be of an important height: they only need to be strong enough to withstand the load without breaking under the limit load factors incurred during flight, but any flexibility will in fact help in evenly distributing the load to the lower tier, providing the upper tier's supporting points are located between the lower tier's, as is the principle.

5.4 Field Methods:

5.4.1 The complexity of calculation and the various problems to be taken into account may render it difficult to adequately design a shoring scheme in the absence of the piece of cargo concerned. Visualization of the piece by the responsible engineer is recommended whenever possible. Yet, when shoring is performed based on engineering instructions, unforeseen problems may arise that change the parameters assumed during shoring design, and require being identified and properly handled.

5.4.2 Such unexpected problems occur on the field, where the necessary all encompassing expertise is not necessarily on hand. Though a portable computer may be programmed with the EI calculation formulas, it does not replace the qualified engineer supposed to use it to design the shoring scheme. Accordingly, the aircraft manufacturers, or operators subject to their approval, may elect to develop simplified methods more readily usable in field practice. Such methods may include:

a. graphs, established from the computer program, allowing to determine the required shoring stiffness and geometry parameters (e.g., Boeing D6-35527 shoring guidelines document),

b. equivalent numeric charts and shoring instructions,

c. pre-computed standard shoring arrangements valid within stated load weight and size limits.

5.4.3 One key in developing such simplified methods is precisely determining and identifying which level of expertise they are designed for. The field use of such documents should be restricted to authorized personnel who completed a defined and appropriate theoretical and practical training program.

5.4.4 Another key is, such instructions should explicitly state (using language understood by the personnel category concerned) any underlying assumptions that need to be confirmed to ensure their validity, and identify possible biases to be checked.

5.4.5 The last key is, the authority of each document and each category of personnel/training level for evaluating and implementing a shoring scheme should be explicitly limited to stated load weight, size and concentration levels (see 1.2.4). Proper operational management primarily consists in establishing these levels and the contents of the corresponding documents, based on experience and direct knowledge of the capabilities of personnel in charge, so that no unforeseen problem will go unnoticed or improperly handled to an extent it may result in damage to the aircraft.

6. IMPLEMENTATION:

6.1 Shoring Effectiveness:

6.1.1 As underlined in 1.2.5 and 3.3.3, proper shoring calculation and design are not sufficient to ensure an effective protection of the aircraft structure: the effectiveness of the actual shoring arrangement performed must be checked by a qualified loadmaster prior to pallet or load release. The following outlines some of the practical points to be systematically checked in order to verify this actual effectiveness.

6.1.2 It shall be checked that all contact points where part of the load is transmitted are actually bearing/ load transmitting.

An easy common way it to try sliding a thin tool such as a knife's blade or equivalent under each bearing element (e.g., between load ends and primary shoring, between primary shoring, particularly at its ends, and pallet; and, wherever permitted by the GSE used, between pallet and GSE roller bed, again particularly at the pallet's ends). If a thin object can be inserted, then there is no effective bearing at all at this location, and the shoring arrangement's design or implementation must be reviewed to eliminate the resulting uneven loading.

The general bending situation on the shoring beams or the pallet edges can also, with some training, be visualized locating one's eye close to one end and looking along a straight line: load unevenness may appear as uneven slopes or bending in the element concerned.

6.1.3 Measurable pallet edge upward deformation is acceptable to an extent, if there is certainty that both the length effectively bearing on the rollers is at least the minimum calculated shoring length, and the upward bending is not such that it will prevent the pallet from properly engaging aircraft restraints.

6.1.4 Measurable pallet core deformation in the loaded area may not be contrary to shoring effectiveness, because it will normally contribute to more evenly distribute the load between roller tracks (see example in Figure 6). However:

a. if the deformation occurs across the direction of pallet movement, even relatively low deformations will render the pallet extremely difficult to move in the aircraft. See Figure 8 (exaggerated for clarity):

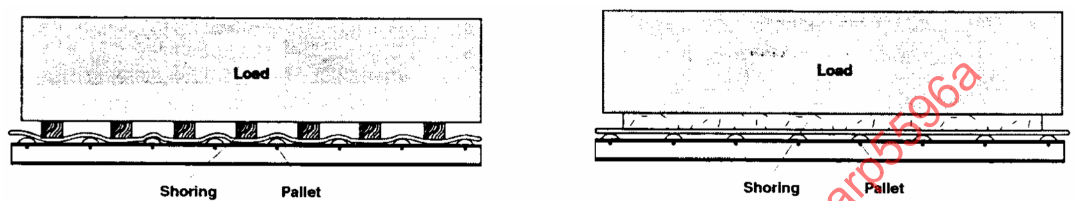


FIGURE 8

In order to avoid such an occurrence, shoring for very heavy loads shall always be with longitudinal beams set directly onto the pallet, with lateral shoring, if required, set above it.

A pallet core surface local deformation up to approximately 1.0 mm (0.04 in) is generally acceptable over typically 38 mm (1.5 in) diameter rollers (see 0.25 to 0.50 mm (0.01 to 0.02 in) objective recommended in 4.2.3 for the deflection calculation method). It is, however, difficult to measure. The easiest practical test is attempting to move the pallet by hand over a GSE roller bed: feasibility indicates the likeliness of acceptable load distribution, while serious to extreme difficulty indicates the shoring arrangement's design or implementation must be reviewed to eliminate uneven loading.

b. if the deformation occurs in the other direction, e.g., between parallel longitudinal shoring beams, it may not have adverse effects on pallet movement if this is always in length, but the same difficulties will be met if the pallet has to cross a bi-directional ball or caster mat, or to be turned in the aircraft. In this case, a square maximum bearing pattern should be the target, preferably with the free space between bearing elements not, or not significantly, exceeding the aircraft rollers spacing.

6.1.5 In the event of very heavy or concentrated loads, it may become advisable at either shoring design or implementation stage to obviate the imperfections of shoring design or implementation, e.g. by:

a. inserting, between primary shoring (longitudinal beams) and pallet, elements of hard (durometer 60 or equivalent) rubber mat, between 25 and 150 mm (1.0 and 6.0 in) thick: this will ensure more even load spreading, and reduce the impact of bridging and cresting situations at loading a very heavy pallet.

b. a similar result can be obtained by using at the same location a crushable cushioning material such as fiberboard honeycomb plates, that will locally crush till the loads are effectively equalized.

6.1.6 In addition to checking the load distribution's effectiveness, care should be taken to verify the stability of the shoring arrangement under in-flight loads: no potential risk of shoring elements tilting down should be identified, or these elements should be chocked or otherwise controlled (e.g., see NOTE in 4.3.7) to eliminate this risk. Particular attention should be brought to cargo with "feet", rather than skid, lower supports: such "feet" may be quite unstable when stacked over lumber or other shoring material, and it is generally preferable not to use them but to place cross members equivalent to skids immediately below the piece of cargo's bottom.

It should also be evaluated whether shoring elements present a potential risk of sliding over each other: high friction interfaces (e.g., unplaned lumber rather than smooth, etc.) should be preferred. Grease should be avoided on metal interfaces, particularly those with relatively low inertia (e.g., aluminum beams).

NOTE: In a few known instances, in-flight sliding of stacked shoring materials resulted in the fall of the piece of cargo, which thus became unrestrained. In at least one known case, friction from repeated sliding resulted in strong local heat release to the extent an aluminum pallet sheet was burned through.

6.2 Concentrated Loads:

One of the essential points to effectively protect aircraft structure against overloading is identifying, prior to palletization or loading, which cargo may present a risk of this nature and is subject to a shoring requirement. This may appear rather obvious when very heavy weights are involved, but weight criteria alone are misleading because certain pieces of cargo, though not extremely heavy in total, may include local load concentration at their base which does require appropriate shoring in order not to exceed the applicable floor loading maximum limits.

6.2.1 Examples of loads that may exceed either maximum area load or maximum running load or both, hence require shoring, regardless of their total weight are:

a. any cylindrical loads resting on a generating line only, such as: large size tubes, shafts or metal rods, cylindrical tanks, cable reels or spools when carried vertically rather than flat (the preferable method, but not always possible because it may damage the cable, e.g., optic fiber), etc.

b. machinery or equivalent presenting protrusions on its underside that require raising it in order to obtain a stable load and to avoid puncturing the pallet,

c. certain crates or equivalent resting on "feet" or skids, when the unsupported span between these is large enough in relation to weight,

d. trucks and heavy vehicles (e.g., public works equipment) resting on wheels or tracks,

e. industrial or aircraft engines,

f. etc. (a considerable variety exists).

6.2.2 Contrary to total piece weight, which is available throughout all shipping documentation, such items of load are usually not identified by the shipper, and can be identified only by a sufficiently trained person visualizing them. Accordingly, the operator's organization (see 7.4 hereafter) must include the presence at each cargo warehouse of at least one person sufficiently trained, though not necessarily at loadmaster's level, to detect potential shoring hazards, and his/her systematic visualization of any nonstandard type of load prior to palletization in order to clear it, or determine basic shoring requirements, or contact the appropriate load engineering office for guidance.

6.2.3 Within their dimension and load capacity (see 4.1.5) limits, industrial wooden pallets may be used for most such loads. When these limits are exceeded, shoring may be considered applying the calculation and design methods of the present document, but it may present difficulties due to the special shape of the load. In certain cases, the best practical solution will be to design and build a shoring stand appropriate to the load concerned. The stand may be built either by the operator, or a subcontractor, or the shipper, providing its design was reviewed and approved by the operator's load engineering office.

6.2.4 A shoring stand may, subject to the required strength and stiffness, be built of either lumber or metal, but is usually designed as a function of the shape, CG location and load distribution of the piece of cargo, and assembled in one piece by bolts, welding or equivalent in order to readily adapt it and be physically handled (lifting) together with it. In many cases, it is appropriate to design into it diagonal bracing members that will both stabilize the load and, if mechanically attached to the base beams, constitute part of the minimum required shoring stiffness.

NOTE: The existence of diagonal braces reaching up to a certain height considerably reduces the minimum stiffness requirement for the base beams, hence provides a lighter shoring arrangement. This is why, in addition to the case of odd shaped or very concentrated loads, this technique may also be used for very heavy "standard" cargo whenever the minimum EI value found as a result of shoring calculation (see 5.2.2.6) appears impractical. The EI value of the braced stand can be calculated using standard engineering formulas, considering the stand (including the load itself if it is attached to it by mechanical links) as a triangulated beam.

6.2.5 The various cases of cylindrical pieces of cargo resting on a generating line are known from experience to present a high risk of being improperly handled and overloading the aircraft floor's structure. They must generally be carried on either supporting cradles or stands, which both distribute the footprint load and prevent the piece from rolling or tilting on its side when submitted to transverse accelerations. Particular attention should be paid to the effectiveness of the piece's interface with cradles:

a. the length, spacing and stiffness of cradles should be calculated as per the present document,

b. they should be high enough to ensure the piece cannot roll out under the aircraft's limit side load factor,

c. the cylindrical interface should be carefully checked at implementation:

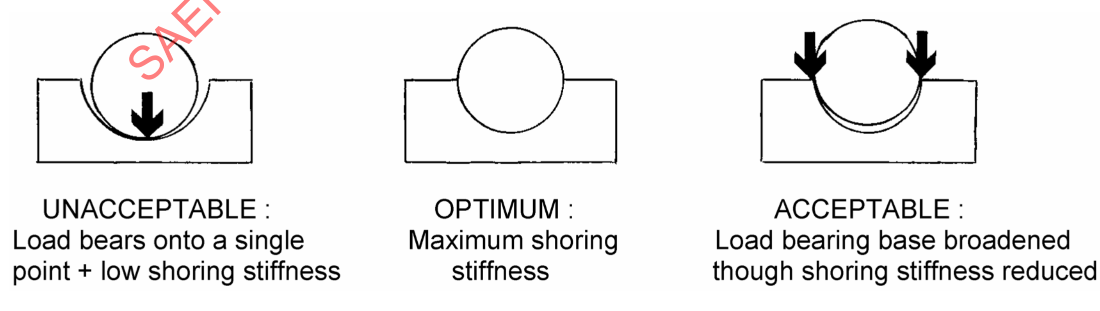


FIGURE 9