Perspectives on Material Handling Practice

Papers in the Perspectives series have appeared in conference proceedings of the Material Handling Institute between 1992 and the present. As such they provide a point of reference as to how the industry is changing as well as insight into accepted practice during this period. In many cases the authors credited have either changed jobs or are no longer in the industry. Some companies as well have been the subject of mergers or reorganization with a new corporate identity.

PLANNING AND ENGINEERING GUIDELINES FOR SPECIFYING STORAGE RACKS AND SHELVING SYSTEMS

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ABSTRACT

The paper points out the dimension, codes and loads that should be specified in order to have a storage rack or shelving system that is economical and safe. The important dimensions to specify are length and width of shelf, and the height between shelves. The RMI or Shelving Manufacturers Specification should always be specified for a supplier to adhere to. The loads that should be specified are the vertical shelf loads and the lateral loads such as seismic if required and side sway loads of 1 and 1-1/2 percent of the vertical load plus dead load as recommended by RMI.

INTRODUCTION

This paper contains planning and engineering guidelines for specifying storage racks and shelving systems. The paper points out that the size and shape of the product to be stored controls the plan size and height of the shelves for racks and shelving. Also the codes that should be specified to be followed are mentioned. Adherence to the national fire code (see reference 1 in the Appendix) for storage racks and shelving is also important. Safety procedures recommended by the Rack Manufactures Institute, (see reference 2), is pointed out.

The product loads are very important also because they obviously affect the cost of the storage rack or shelving system. This paper further stresses the effects of good planning on the design and analysis of beams, shelves and columns. Thus thorough planning of a storage system will produce a low cost system that will be reasonably safe for employees, and produce a system where the stored product will be protected from fire if required.

PLANNING GUIDELINES TO SPECIFYING RACKS

Pallet Racks

The first guideline to specifying a storage rack is to know the product that you wish to store. For example, products that could be stored on a pallet rack would be hardware, groceries, furniture, drugs, machine parts, tooling, paper products and appliances. A pallet rack is often referred to as a selective type storage rack, meaning that any product is readily accessible. It is the most common type of rack and probably the least costly. A pallet rack is shown in Figure 1. It is supporting groceries.

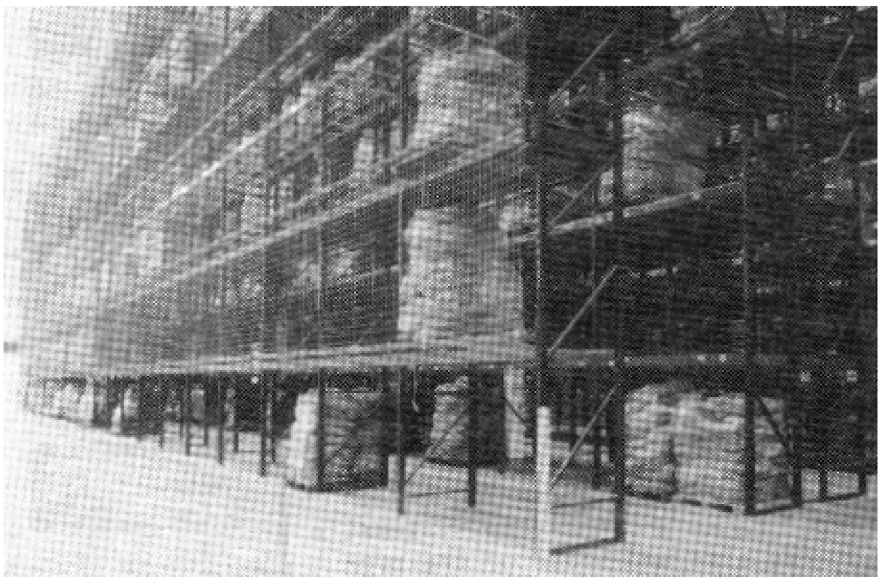


Figure 1. Pallet Rack.

Drive-in and Drive-thru Racks

The same type of stored product is usually stored on a drive-in or a drive-thru rack. The type of product stored on a drive-in or drive-thru rack is one that is in great demand and that remains on the rack for a short period of time. Produce is a good example of a product that would remain in the warehouse for a short period of time. Other products might be groceries, hardware, and building products. A drive-in rack supporting groceries is shown in Figure 2.

Figure 2. Drive-in Rack.

Cantilever Racks

Cantilever racks are normally used to support long, and often bundled products; such as pipe, metal sheet, steel plates, metal bars, furniture (such as sofas) and appliances. Figure 3 shows a cantilever rack supporting lumber.

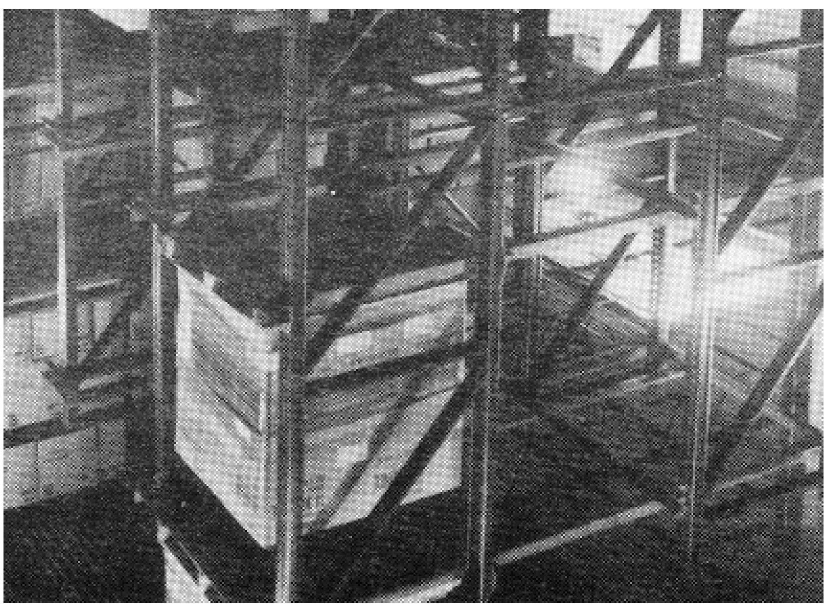


Figure 3. Cantilever Rack

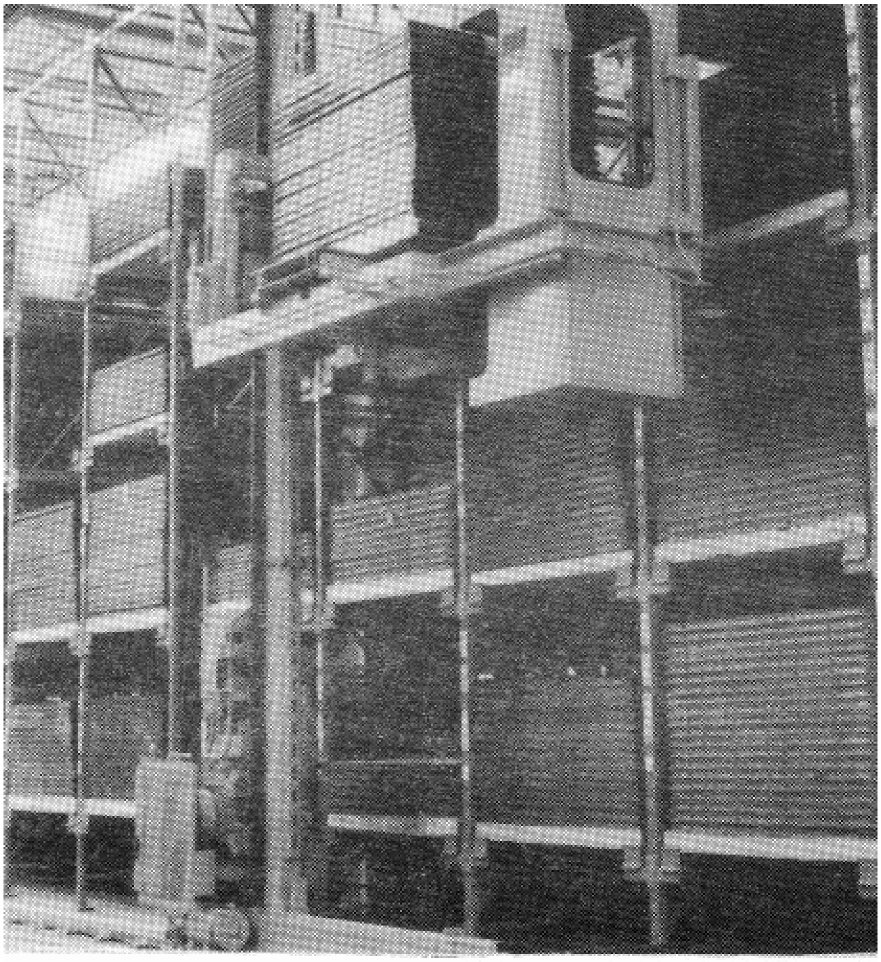


Figure 4. Flow Rack.

Flow Racks

Flow racks are normally used for the same stored product and for items that are often picked to fill a customer's order. The product may be picked by hand or by forklift truck. Such products might be groceries, hardware, drugs, and clothing. Figure 4 shows a pallet flow rack being loaded from the back.

Special Racks

Special racks are usually standard racks that are modified to suit a given stored product. For example, boat racks and carpet racks are usually modified pallet racks. Reel racks and coil racks can be either modified pallet racks or modified cantilever racks. Figure 5 shows a picture of reels of wire supported by a modified pallet rack, termed a reel rack.

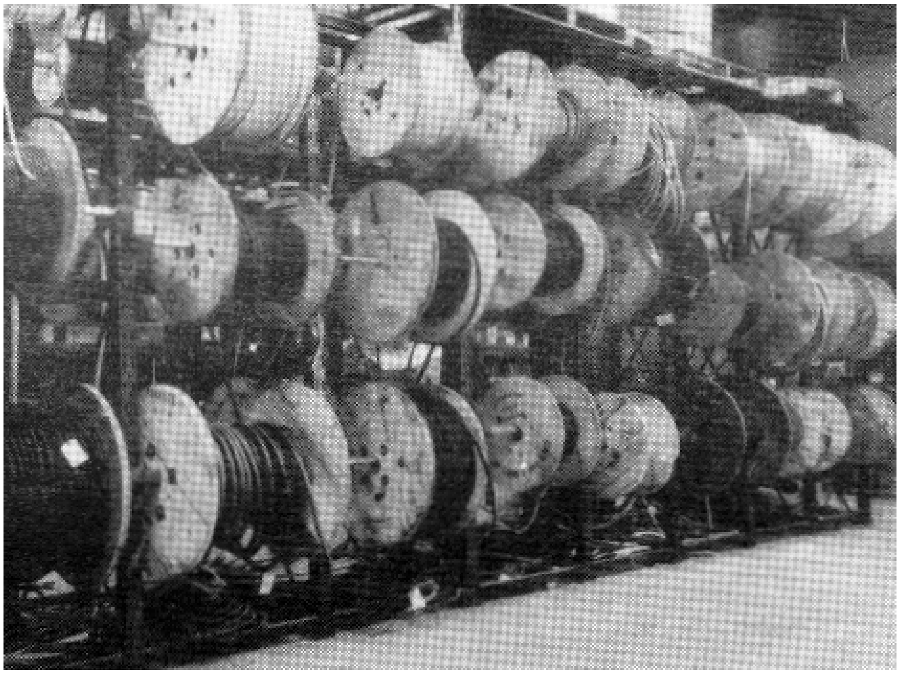
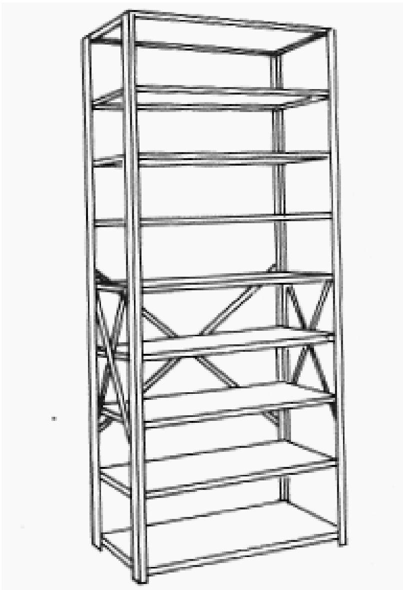


Figure 5. Reel Rack

PLANNING GUIDELINES TO SPECIFYING SHELVING

Standard Shelving

Again, knowing thoroughly the product or products to be stored is very important because most products can be stored on standard shelving units. Standard shelving units as used for the purposes of this paper are units, which use a shelf-plan size made by most shelving manufacturers. The purchase of standard units will of course keep the costs down as compared to non-standard units. (For example, an odd shelf-plan-size or equally as important a larger than necessary shelf height is considered non-standard in the opinion of the writer.) Books, paper products, canned goods, hardware, and any boxed-products can certainly be stored on standard shelving units. Figure 6 is a sketch showing standard MX" bracing shelving unit, whereas Figure 7 is a sketch showing a standard solid-panel-braced shelving unit. The choice between "X" braced and solid-panel-units depends on fire protection and cost. Obviously solid sides and backs on shelving units provide a greater degree of fire protection than do "X" braced units. Solid sides and backs on shelving units' cost more than the "X" braced side and back units.



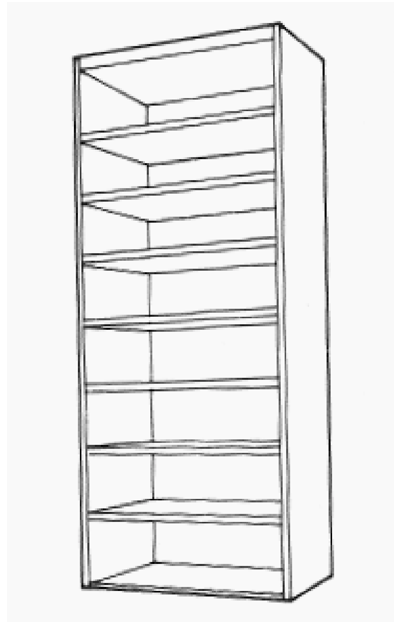


Figure 6. “X” Braced Shelving Unit. Figure 7. Solid-Panel-Braced Shelving Unit.

Drawer and Box, Bin and Library Shelving

Small product items such as bolts, screws, nuts and washers can be stored in drawer and box type shelving units and tools can be stored in bin type shelving units. Figure 8 shows a drawer and box unit and Figure 9 shows a bin type shelving unit. Then of course there are library shelving units manufactured especially for book storage. Figure 10 shows a library shelving unit.

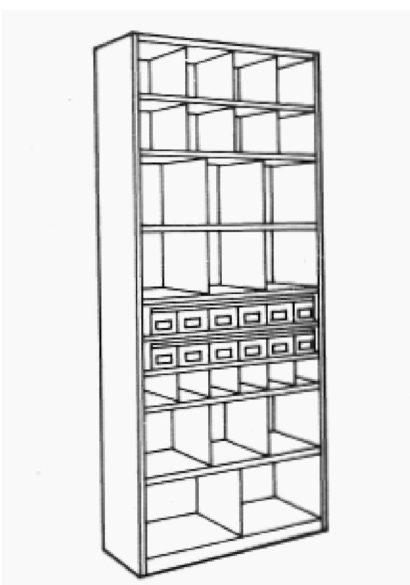


Figure 8. Drawer and Box Shelving Unit. Figure 9. Bin Shelving Unit.

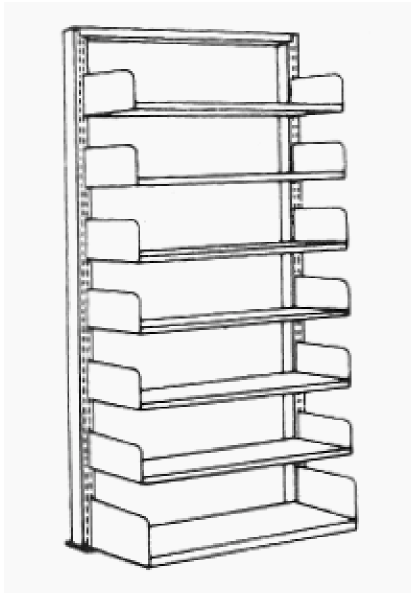


Figure 10. Library Shelving Unit.

ENGINEERING GUIDELINES TO SPECIFYING RACKS

Upright Depth for Pallet Racks

From the size of the product and pallet, one can determine the depth of the upright or truss. For example, assume that the pallet size is 42 inches wide by 48 inches deep (42 x 48). The upright depth would then be 48 inches minus the pallet overhang of the shelf beam at the front and the back. The minimum overhang recommended by RMI is a minimum of 2 inches; see paragraph 2.4.2 of reference 3. The overhang is required when the shelf beams are not covered with say a sheet of particleboard and the pallet and load could fall between the beams. The upright depth of back to back of column would then be 48 inches minus a total overhang of 4 inches or 44 inches back-to-back of column or rack post. If back-to-back rows are being considered, then one must consider the clearance between loads at the back in order to position the uprights for back-to-back rows.

The clearance between pallets or loads for back-to-back rows recommended by paragraph 2.4.2 of RMI reference 3 is 4 inches. If fire regulations are considered, then one must adhere to local codes, regional codes and/or the NFPA 231C (ANSI MH21.1) fire code, see reference 1. Adherence to the fire code obviously reduces insurance costs. Paragraph 4-3 of NFPA 231C recommends 6 inches between loads in the flu space or between columns in double rows without solid shelves and with height of storage up to and including 25 feet. For height of storage racks greater than 25 feet see the fire code reference 1. (The flu space is the beck-to-back clearance between loads or pallets so that the heat from a fire can rise and set off sprinklers in this space or at the ceiling.) Therefore, the overall depth of double rows for the assumed 48-inch deep pallet is twice the pallet depth plus the clearance between rows or 2 times 148 inches plus 6 inches equals 102 inches. Figure 11 is a sketch showing the recommended clearances by NFPA 231C and RMI.

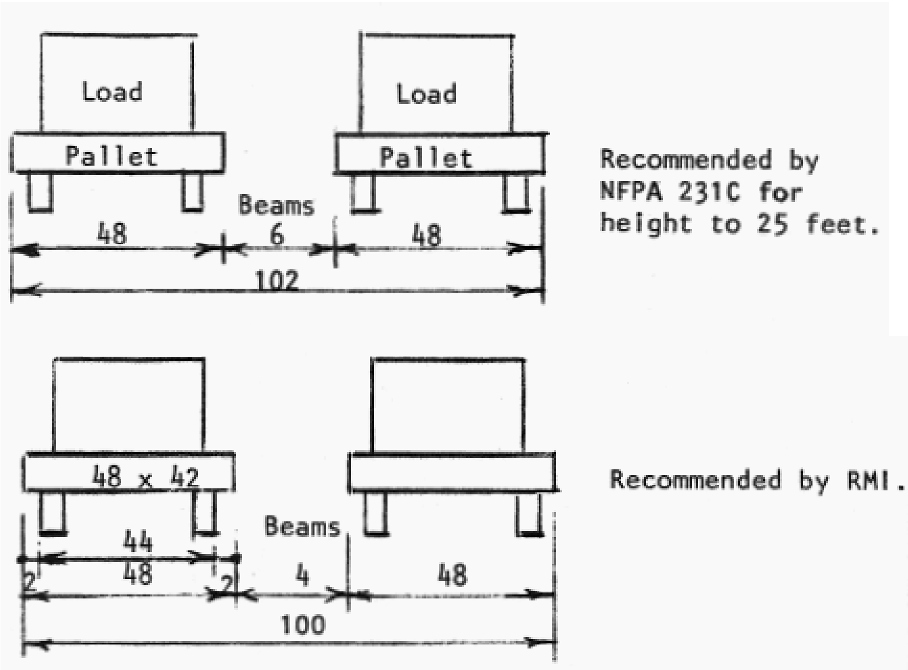


Figure 11. Recommended Clearances

Beam Length For Pallet Racks

From the product and pallet size, one can determine the beam length. Again, assume that the pallet size is 42 inches wide by 48 inches deep (42 x 48). RMI recommend mends that the horizontal clearances in the direction parallel to the aisle should be 3 inches or more between load and column or between load to load, see paragraph 2.4.1 of reference 3. Therefore, assuming two pallet loads on one shelf, the beam length from inside of column to inside of column would be 2 times 42 inches plus 3 times 3 inches of clearance or 93 inches.

Shelf Height For Pallet Racks

The clear shelf height will be the summation of the pallet height, the product height, and a clearance of 3 to 6 inches depending on the rack height. The greater the overall height of the rack, the greater the clearance should be in the upper shelves. If the shelf contains sprinklers, sprinkler water lines and sheet metal fire-stops, then allowance must be made for them, see NFPA No. 231C, reference 1, for fire prevention requirements. The overall height of the rack would then simply be the summation of the shelf heights. The overall height of the rack should allow for lights, fans, ceiling sprinklers and any other items that may be attached to the ceiling of the warehouse.

Aisle Widths For Pallet Racks

The aisle widths depend on the product and pallet size, the forklift truck and its turning radius, and clearances. The forklift truck manufacturer should be contacted for this information, if the buyer of the rack system does not have forklift trucks or if he plans to buy more trucks.

Rack Layout

It is recommended that a preliminary rack layout be made. To make a rack layout, it is most important to have a plan of the building floor. The building plan should show all building columns and any obstructions that would interfere with the rack layout. Such obstructions might be offices or other rooms, doors, and stairways. The rack manufacturer usually makes final rack layout drawings.

Upright Depths For Drive-In, Drive-Thru, And Pallet Flow Racks

The upright depth for drive-in, drive-thru and pallet flow racks again depends on the product and pallet size. A post of an upright should be positioned so that it supports one pallet load. By doing this, then all columns support the same load and the rails supporting the pallet-loads are not excessively loaded, and their deflection also will not be excessive.

The overall depth of the drive-in or drive-through usually depends on the number of pallets to be stored and on the available warehouse space.

Overall Height of Drive-In and Drive-Through Racks

Again the overall height usually depends on the number of pallet-loads to be stored, and on the clearance between product and rail. Usually, the maximum number of pallet loads high is six. Of courses the minimum number of pal-let loads high is two. The reason for the maximum number of pallet loads high is that the overall height of a drive-in or drive-through rack does not usually exceed 31 or 32 feet. The stability of the normal rack is not good above these heights. That is, the normal connection between the top tie beam and the column becomes too large to resist a specified lateral load. The column and top tie-beam moments become large also, which in turn require heavier columns and beams to support these moments.

Rails For Drive-In And Drive-Thru Racks

The common rails used for drive-in and drive-through racks are angles, C's, and pallet aligning rails. A problem with angles is that they rotate under load because they are usually loaded on one of the flanges. The advantage of the angle is that the upstanding leg of the angle centers the load for the forklift operator. The C-section normally will not rotate but it does not have the pallet-load centering capability that the angle has. Some manufacturers have developed cold-formed sections that have pallet centering capability and yet rotate very little under pallet loads. Figure 12 is a sketch showing the rotational characteristic of the angle, the non-aligning characteristic of the C-section and the self-aligning characteristic as well as the non-rotating characteristic of the developed cold-formed section.

Cantilever Column Depth And Base Design

The depth of the cantilever column is a function of this moment at the base of the cantilever rack. The depth of the column required to resist this moment depends on the manufacturer's design. Most column depths are somewhat different because of the different column designs. Most rack manufacturers use channel or C-sections for the bases of their cantilever racks. The size of the section depends on the maximum moment at the base of the column. Furthermore, the sections must be deep enough so that the connection between the column and the base will be sufficient to transmit the moment from the column into the base.

Beam Lengths For Pallet Flow-Racks, Special Racks; And Anchor Frames For Drive-In Racks

The beam lengths required for pallet flow-racks, special racks and anchor frames for drive-in racks depend on the size of the product or the size of the pallet if one is used to support the product, and the clearance between pallets or stored product, or the clearance between pallets and column. (The anchor frame of a drive-in rack is made up of the last upright on each side of the drive-in aisle plus beams that are connected to each upright to support the pallet rails.) The horizontal clearance in the direction parallel to the main aisle recommended by RMI is 3 inches or more between load and column and 3 inches or more between loads, see paragraph 2.4.1 of reference 3.

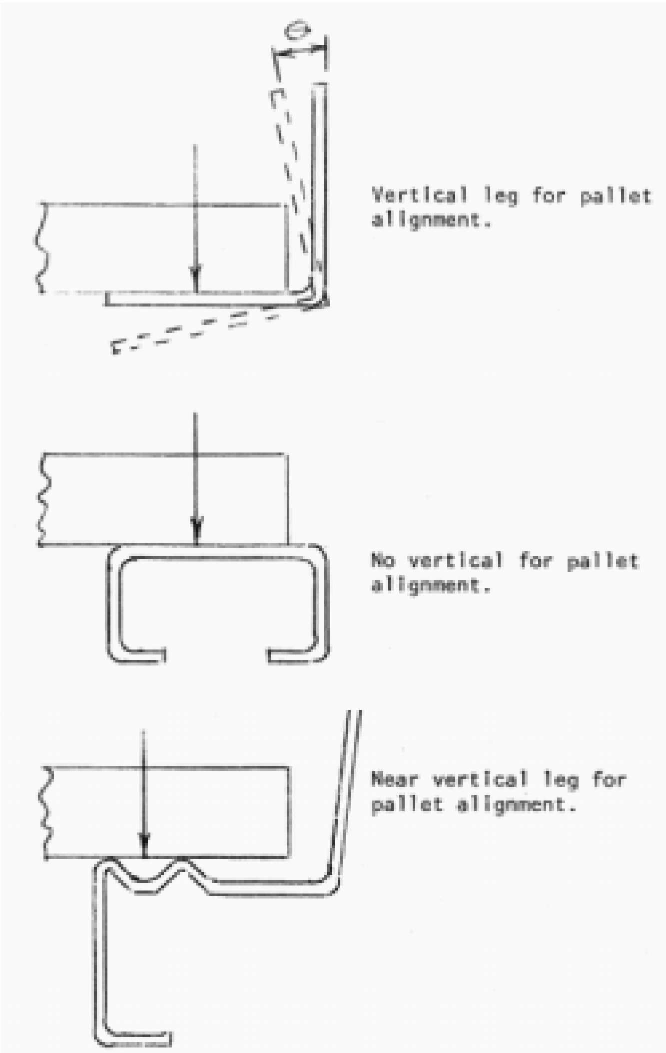


Figure 12. Rotational and pallet alignment features of an angle rail, of a C rail, and a developed cold-formed rail with little rotation.

What Code Should Be Specified?

The code to be specified should be the code that has jurisdiction in the locality in which the rack system is being installed. Generally, a local city or county building code will have jurisdiction. The regional building codes are the BOCA National Code in the Midwest and northeast, the Standard Building Code (SBCC) in the south, and the Uniform Building Code (UBC) in the west and southwest. In addition to a building code, the RMI code, reference 1 should always be specified. All of these codes specify the use of the cold-formed steel specification, reference and the hot-rolled steel specification reference 5.

What Loads Should Be Specified?
The obvious load to he specified is the product or pallet load. This load is not only important for determining the column or post size but is also important for determining the beam and beam-connector size. Paragraph 7.2 of the RMI' specification, reference 2, requires that load support beams, supporting arms (if any), and end connections are to be designed for an additional impact load of 25 percent of one unit load, placed in the most unfavorable position for the particular determination of moment or shear force. The reason for this impact factor is pointed out in paragraph 7.2 of the Commentary to the RMI specification, see reference 6. The reason is that it is impossible to load a shelf with a pallet-load by means of a forklift truck without applying some impact to the shelf.

The next load to be specified is the horizontal or lateral load. This lateral load is very important because it affects the lateral stability of any rack system. The magnitude of the lateral load is specified in paragraph 7.3 of the RMI specification and is 1.5 percent of the full maximum live load plus dead load for racks not braced against side sway and 1 percent for racks braced against side sway. This lateral load is to be applied simultaneously at each beam to column connection. That is the 1-1/2 percent load, is to be applied to each connection simultaneously in the down aisle direction for a pallet rack, and the 1 percent load is to be applied to each connection simultaneously in the cross aisle direction for a pallet rack. The cross aisle direction is braced by the vertical truss or upright, whereas, the down aisle direction is usually unbraced and relies on its beam to column connection to provide lateral stability.

It should be pointed out that in paragraph 1.1 of the RMI specification, that the specification applies to pallet racks, movable shelf racks, and stacker racks but does not apply to drive-in, drive-through, cantilever, portable racks and rack buildings. However, the writer recommends that these lateral loads be used in the design of drive-in and drive-through racks. This recommendation by the writer is because in paragraph 7.3.1 of the Commentary it is pointed out that this horizontal force is due to but not necessarily limited to, out-of-straightness of the members, out-of-plumb erection, accidental minor forklift truck abuse, uneven floors, initial connection looseness and conveyance imposed forces during loading and unloading of the rack. The drive-in and drive-through rack is particularly vulnerable to forklift truck damage in the down aisle direction. Therefore, using the critical horizontal loads for the design of drive-in or drive-through racks helps to protect the racks against collapse due to minor forklift truck coil collisions.

Other horizontal loads are wind loads if the rack is installed outdoors, and seismic loads. The seismic load will usually be specified by the regional code. The most critical lateral load should be used for the design, e.g. if the 1-1/2 percent lateral load is greater than .75 times the wind load or seismic load, then the 13 percent lateral load should be used. (The .75 factor is to account for the 33 1/3 percent increase in allowable stresses for wind loads and earthquake loads.) Another reason for the use of horizontal loads for the design of pallet racks is for overturning. Paragraph 8.1 of the RMI specification states that overturning is to be considered for the most unfavorable combination of vertical and horizontal forces. Stabilizing forces provided by the anchors to the floor are not considered for checking overturning, unless anchors and floor are specifically designed and installed to meet the upright forces due to wind or seismic forces.

If there is no wind or seismic forces, it certainly would be prudent to use the 1 percent lateral load in the cross aisle direction and the 1-1/2 percent in the down aisle direction in the design of the anchors and base plates if the anchors are to be used in the design to prevent overturning. If the anchors are not to be used in the design, then it would be necessary to use the 1 percent and 1-1/2 percent lateral loads in design to check for overturning. The minimum ratio of the restoring moment to the overturning moment must be 1.5 if the anchors are not used to prevent overturning.

ENGINEERING GUIDELINES TO SPECIFYING SHELVING

Upright Depth and Shelf Width For Shelving

The upright depth for shelving as well as racks depends on the product to be stored. For example, assume the product to be stored is a boxed item that is 22 inches long by 16 inches deep by 14 inches high. This item could be one or 20 items of say 200 items to be stored. Most shelving

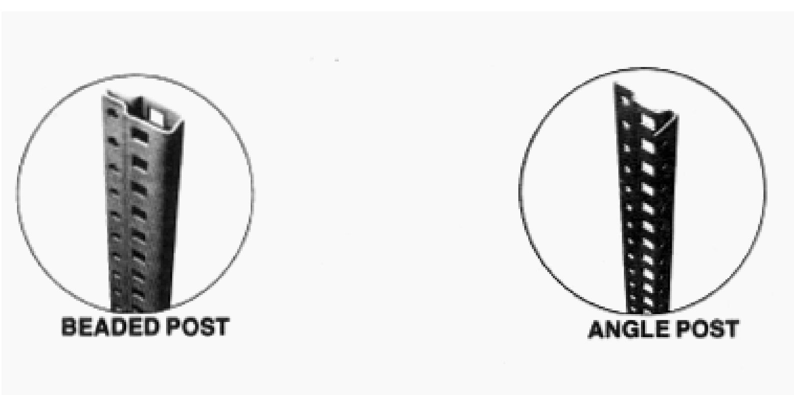


Figure 13. “Typical Beaded and Angle Post.”

manufacturers have standard sizes of shelves with usual lengths of 24, 30, 36, 42, and 148 inches and depths of 9, 12, 15, 18, 24, 30, and 36 inches. Thus for the example box depth of 16 inches, a shelf depth of 18 inches would be satisfactory. The upright depth would then be 18 inches. For the stored box of 22 inches long a 30-inch-long shelf could be used with an angle post with one-inch legs; or a shelf length of 214 inches could be used with a beaded post. The clearance at each end of the box would be about 3 inches for the angle post with a one-inch leg, and would be about 3-1/2 inches with the beaded post. Figure 13 is a sketch showing the shape of a typical beaded and angle post used in the industry.

Clear Height Between Shelves And Overall Shelving Height

The shelf height for a shelf will be the product height plus clearance plus shelf front-edge depth. For the 14-inch-height of the assumed boxed item above the shelf height would be 14 inches plus 3 inches of clearance plus about 1-1/4 inches for shelf front-edge depth resulting in a shelf height of say 18 inches. (The clearance is reduced to 2 2-3/4 inches in lieu of 3 inches to account for the 1/4-inch shelf front-edge depth.) If sprinkler heads are required between some shelves for product fire protection, then the height of the sprinkler heads would have to be included in determining the shelf spacing. The post length or height would of course be the summation of shelf heights plus 3 inches for the distance from the floor to the top of the bottom shelf.

What Code Should Be Specified?

Most local building codes as well as state and regional codes do not specify shelving. The only code dealing with shelving that the writer is aware of is the Shelving Manufacturers Association Specification for the Design, Testing, Utilization, and Application of Industrial Grade Steel Shelving, reference 7. This code should definitely be specified by a potential buyer or material handling consultant. The code is ten years old and has been updated. The latest copy has not been published but is expected to be published this year.

What Loads Should Be Specified?

Of course the product load or shelf load should be specified. The shelf load will then be used by the shelving supplier to determine the reinforcement, if reinforcing is necessary. Most manufacturers have members such as bars and angles that reinforce the front, back, and side edges; as well as hat shaped sections that reinforce the center of the shelf by spanning the length of the shelf at the center of the shelf. (The bars and angles usually are retained by mechanical interference with the edge members whereas the hat section is usually spot welded to the underside of the shelf.) Most manufacturers have determined their shelf safe-load carrying capacities by test. The Shelving Manufacturers Association specifies in paragraph 6.1 of the specification (reference 7) that shelf capacities shall be determined by physical tests or by calculations supported by test data.

The Shelving Manufacturers specification in paragraph 3.3 state that hand loaded shelves are not designed or tested to resist vertical or other impact loads. However, they specify in paragraph 3.4 under Horizontal Loads that manufacturers of storage/retrieval equipment (man aboard, hand-loaded applications) must supply to the shelving manufacturer, information on the maximum horizontal forces and their locations transmitted by equipment. Therefore, for horizontal forces caused by automated and non-automated storage/retrieval equipment, horizontal impact loads should be specified for safety reasons by the storage/retrieval manufacturers.

The specification does not specify the application of horizontal loads except for those mention in paragraph 3.14 and stated immediately above, and for those caused by an earthquake. The earthquake loads are not specified except that in paragraph 7.1 it is stated that installations over 8 feet 3 inches high to the top shelf must be designed and installed to sustain seismic conditions where required by local, regional, state or federal codes. It further states in paragraph 7.1 that all shelving sections shall be designed and installed to resist vertical and horizontal loads caused by initial out-of-plumbness, flexing of posts, reasonable impact, and snow and wind loads if outdoors. If no actual horizontal loads are specified including seismic loads, then the writer suggests that 1 percent of the vertical shelf load plus dead load be specified to be applied horizontally and simultaneously at all post-to-post shelf connections. These loads are the same as those specified as horizontal loads by RMI (see paragraph 7.3.1 of reference 2 and 6) to account for accidental collision from forklift trucks and for out-of-plumbness of posts. (The 1 percent lateral load is for shelving braced against side sway.) Furthermore, paragraph 7.4 of the specification requires that all installations be checked for overturning. No load criteria is mentioned so the writer recommends that a 1 percent lateral load be used. This is the lateral load recommended by RMI for braced systems subjected to side sway.

The summation of the vertical shelf loads plus dead load in any bay and horizontal loads acting on that bay are used by the shelving supplier to determine the post to be used. In addition to the loads, the shelf spacing is required to determine the post to be used. Most manufacturers have larger posts than the beaded and angle posts to support heavier loads than would be supported by the beaded or angle posts. Such a typical post is depicted in Figure 14.

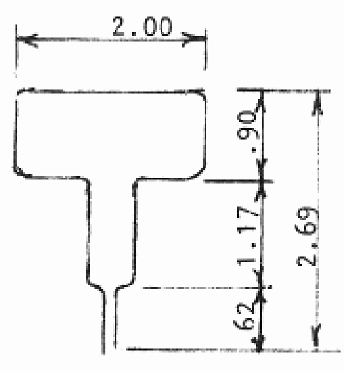


Figure 14. Typical heavy duty shelving post.

THE EFFECTS OF GOOD PLANNING OF RACK AND SHELVING SYSTEMS ON THE DESIGN AND ANALYSIS OF VARIOUS MEMBERS OF THOSE SYSTEMS

Effect of Beam Length On the Carrying Capacity of Rack Beams

The length of a rack beam significantly affects the moment and in turn the strength required that the beam must provide. The required moment that a beam must carry varies with length squared. Therefore, the beam length specified should be long enough to provide adequate clearances between pallet loads and between pallet loads and columns, but should not be longer than required for getting a pallet load on or off a shelf safely.

The allowable carrying capacity of a beam varies with the shape of its cross section, its laterally unsupported length of its compression flange, on the yield strength of its material, and on its width to thickness ratio of it’s stiffened or unstiffened compression flange. Thus the length of the beam also affects the allowable carrying capacity of the beam. The allowable carrying capacity again varies with the unsupported length of its compression flange squared. The shorter the unsupported length of the compression flange the greater the allowable carrying capacity of a beam. Thus this is one of the reasons for intermediate beams spanning between the primary rack beams. The other reason is that those intermediate beams prevent a pallet load from falling between the primary beams if the shelf is not covered with say particleboard. A sketch depicting two primary rack beams with two intermediate beams is shown in Figure 15.

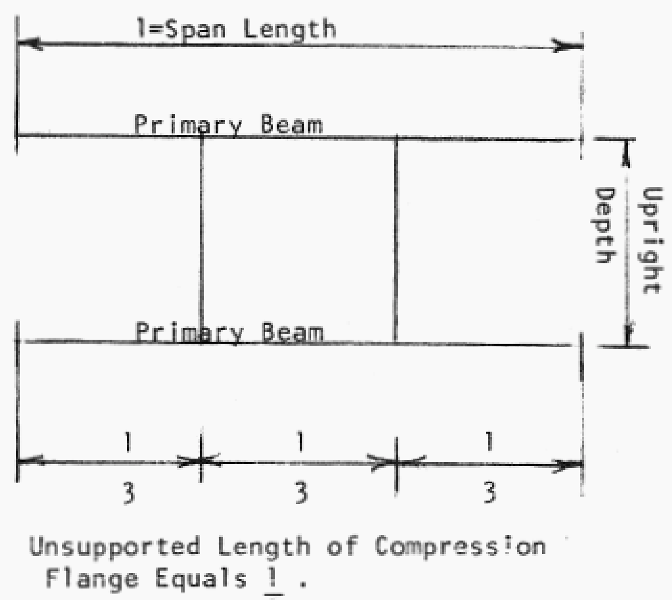


Figure 15. Two primary rack beams supported laterally by two intermediate beams.

Effect of Beam Length on The Deflection of Rack Beams

Again the beam length specified greatly affects the deflection of beams. The deflection of a beam varies directly with its length raised to the fourth power. Therefore, its effect on deflection is even greater than on strength. In paragraph 4.3 of the RMI specification, reference 2, it is stated that at working load (excluding impact) the beam deflections are not to exceed 1/180 of the span measured with respect to the ends of the beam. Therefore, to not exceed this specified deflection, one should specify a beam length that is not excessive.

Effect of Shelf Size On The Carrying Capacity of Shelving

The plan size or length and width of the shelf again significantly affects the carrying capacity of the shelf if one assumes that the shelf behaves as a plate simply supported at all four edges, then the required moment that an assumed beam along its diagonal must carry varies with the length of the shelf squared. The allowable carrying capacity of the shelf again varies with the length of the shelf squared.

If one assumes that the shelf behaves as a cable or rope suspended in both directions between edge supports, then the shelf takes the shape of a parabola and the tension in the shelf varies directly with the span length squared. (The tension in the shelf is assumed to be uniform through its thickness.) The behavior of the shelf probably starts out under initial loading as a plate and eventually with increased loading commences to act as a cable under uniform loading.

Effect of Shelf Length On The Deflection of The Shelf

The deflection of the shelf assumed to act as a flat plate varies with the length of the shelf raised to the fourth power. The deflection of the shelf assumed to act as a cable varies directly with the length of the cable (not the span of the cable). The shelving specification, reference 7, in paragraph 6.2.3 specifies that the allowable rated uniform load derived from test results shall not exceed the load at which maximum vertical deflection (width or depth) including deformations in the end connections, equals the effective shelf width or depth (span) divided by 140 measured at the center of the edge with respect to the position of that same point of the shelf at the beginning of the test. Therefore, again the shelf length and width specified should be great enough to provide adequate clearances between product and post in order to safely and carefully place the product on the shelf; but the length and width should not be excessive.

Effect of Shelf Spacing on the Carrying Capacity of a Rack Or Shelving Post

The carrying capacity of a post or column is dependent upon its cross sectional properties and its effective length "Kl". For a rack or shelving post "l" is the unsupported length of the post between beams or shelves and "K" is the effective length factor. The greater the effective length the smaller the allowable load that the post can carry. Thus it is obvious that the determination of the distance between shelves should be as precise as possible. That is, it is most important to know the height of the product to be stored and to allow no more clearance between product and the underside of a rack beam or shelf than say 3 inches for the lower shelves or 4 to 6 inches for the upper shelves of a rack; and say 3 inches for the shelving shelves. The constant 3-inch-clearance for shelving shelves is because those shelves are hand loaded at all heights for non-automated warehouses. For the special case of a shelving box-system loaded by a forklift truck, then the clearance between load and shelf should be 3 to 6 inches in the upper shelves as for a rack.

The effective length factor “K” is a factor that for rack and shelving frames in the down aisle direction depends on the stiffness of the beams or shelves and the stiffness of the posts or columns. For rack systems paragraph 5.3.1.1 of the RMI specification reference 2, states that for pallet racks not braced against side sway (down aisle direction) the column between the bottom beam and the floor as well as between the beam levels, the effective length factor K is defined as 1.7 or as otherwise determined by rational analysis or tests. For shelving systems in the down aisle direction, the effective length factor should be determined by rational analysis. The effective length factor in the cross aisle direction can be taken as one according to paragraph 5.3.1.2 of the RMI specification for a rack, and should be determined by rational analysis for a shelving post. The carrying capacity of a shelving post can also be determined by test.

It also should be mentioned that the heaviest loads should be placed on the lower shelves for either a rack or shelving system. The reason for this is that with the heavier loads on the lower shelves, the rack or shelving system is more stable than if the heavier loads were on the upper shelves. Furthermore, the portion of the post between the floor and the first beam for a rack or the portion of the Dost between the bottom shelf (at 3 inches off the floor) and the second shelf usually determines the size of post required to carry the total load on the post.

SUMMARY AND RECOMMENDATIONS

The types of products stored on pallet racks, drive-in and drive-through racks, cantilever racks, flow racks, and special racks; as well as those types stored on shelving units are described. The recommended horizontal and vertical clearances for racks and shelving are mentioned. The plan size of a shelf can be determined by adding the product plan size to the recommended clearances. Once the plan size of the rack-shelving shelf is determined, than a preliminary layout should be made for both racks and shelving systems. The overall height of racks and shelving systems is determined by the product height plus recommended clearances plus shelf depth. The recommended horizontal clearances are 3 inches between loads, and between loads and columns for racks. The recommended horizontal clearance for shelving between load and column is again 3 inches. The recommended vertical clearance between load and beam is 4 to 6 inches, and between load and shelf edge is 3 inches. The RMI recommended clearance between loads in double rows of racks is 4 inches whereas it is 6 inches via the fire code NFPA 231C for rack heights up to and including 25 feet.

For all types of racks and shelving, the RMI specification for racks, references 2 and 3 and the Shelving Manufacturers specification for shelving, reference 7 should be specified. The fire code, reference 1 for racks should also be specified if applicable. The procedure for determining the upright depth and overall height of drive-in and drive-through racks is described. The types of rails for drive-in or drive-thru racks and the advantages or disadvantages of each as well as the determination of the length of a rail is pointed out. The product loads and lateral loads for seismic or side sway should be specified for racks and shelving. A lateral load is required to determine overturning for both racks and shelving. That lateral load should be a 1 percent of the vertical load plus dead load as specified by RMI.

The effects of good planning of rack and shelving systems on the design and analysis of various members of those systems are discussed. The length specified for a beam or shelf significantly affects the carrying capacity of the beam or shelf because the allowable carrying capacity of the beam or shelf varies with the length squared. The deflection of a beam or shelf varies as the length of beam raised to the fourth power. Therefore, the length specified for a beam or a shelf is very important. The carrying capacity of a rack or shelving post depends on the cross sectional properties of the post and the effective length "Kl" between shelves. The "K" is the effective length factor discussed in the paper and "l" is the unsupported length of the post between shelves. Therefore, again the height between shelves is most important.

REFERENCES

1. National Fire Protection Association (NFPA), “Rack Storage of Materials’ 1980, number 231C, 470 Atlantic Avenue, Boston Massachusetts 02210. Also an American National Standard MH21.1.
2. Rack Manufacturers Institute (RM1), “Specification for the Design, Testing and Utilization of Industrial Steel Storage Racks”, 1990 Edition, 8720 Red Oak Blvd., Suite 201, Charlotte, North Carolina 28217.
3. Rack Manufacturers Institute “Manual of Safety Practices, 1979 Edition, 8720 Red Oak Blvd., Suite 201, Charlotte, North Carolina 28217.
4. American Iron and Steel Institute, “Specification for the Design of Cold-Formed Steel Structural Members”, 1986 Edition, with 1989 Addendum, 1133 15th Street, NW, Washington, DC 20005-2701.
5. American Institute of Steel Construction, Inc., “Specification for the Design, Fabrication and Erection of Structural Steel for Buildings, Ninth Edition, 1 East Wacker Drive, Suite 3100, Chicago, Illinois 60601.
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7. Shelving Manufacturers Association, “Specification for the Design, Testing, Utilization, and Application of Industrial Grade Steel Shelving”, 1982, ANSI MH28.1-1982 8720 Red Oak Blvd., Suite 201, Charlotte, North Carolina 28217.