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.

STORAGE RACK DESIGN CONSIDERATIONS

THE NORTH AMERICAN MATERIAL HANDLING SHOW AND FORUM
COBO HALL, DETROIT, MI
MARCH 30 – APRIL 2, 1998
DANIEL CLAPP
FRAZIER INDUSTRIAL CO
PO BOX F
LONG VALLEY, NJ
(908) 876-3001
DCLAPP@MSN.COM

Synopsis:

To do the job right, you have to know what the storage rack needs to do. Here are some of the guidelines that should be used to design your storage rack.

All storage rack should be designed considering three fundamental requirements. These considerations are the unit-to-be-stored, the method of handling and the installation area. This paper discusses these requirements and presents clear specification language to include in bid requests and purchase contracts.

Individual System Requirements

Unit to be stored

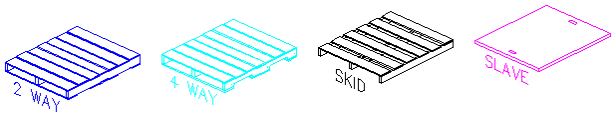
The unit to be stored refers to the product that is handled and stored in the rack system. The unit is usually comprised of product stacked and blocked, or interlocked, on a pallet or product in a container. The single most important consideration for selecting storage rack is the unit load. It is important to get as much information as possible about the units that will be stored in the system. Be realistic in your assessment of the requirements. Do not, for instance, assume that there will be only one type of pallet used.

Size

The correct specification of the size of the unit to be stored is critical to the success of the storage rack. The depth and width of both the pallet and the load must be indicated. When measuring the load dimensions be sure to measure at the widest point and include any mis-stacking tolerances that may take place.

Type of pallet

A pallet is usually made up of three front-to-back stringer boards that are approximately 2" wide by 4" high. These stringers are connected with smaller, more numerous top and bottom boards. The most common pallet size used in the United States is the 40" wide by 48" deep pallet. Although many other sizes



are becoming more prevalent. Be sure to check for all pallet configurations and sizes. Some of the most common types of pallets are:

The 2-way pallet:
The openings for fork truck use are only on the front and back. They are between the top and bottom boards of the pallet. There are no openings in the side stringer boards, therefore, the pallets can only be picked up from two ways.

The 4-way pallet:
There are openings for fork truck use in the front and back like the 2-way pallet and there are cutouts in the side stringers. These pallets can be picked up by the fork truck from any of four ways. The stringer cutout locations may interfere with the proper placement of the pallet on the shelf beams. The depth of the frame may need to be sized so the pallet will rest squarely on the shelf beams.

Skid pallet:
This pallet is similar to the 2-way pallet except it does not have bottom boards. This pallet should be used carefully as it will generally require special designs for gravity flow and push back. Further, this pallet cannot generally be used in drive-in or drive-thru rack.

Slave pallet:
The slave pallet is generally designated to remain with (as a slave to) the load through out the handling of the unit within the plant. It is typically a 1 ½" thick sheet of plywood. When this pallet is stored in a rack system special considerations must be given to fork access under the pallet.

Clearances

The dimensions of the pallet are often assumed to be the dimensions of the load. Careful evaluation of the product as it is stacked on the pallet is important. The load may overhang the

pallet edge, lean in the down-aisle or cross-aisle direction or bulge out more than the footprint. If these are not considered the clearances will be reduced.
The down-aisle clearance in a selective rack, gravity flow or push-back rack is commonly 5" between the load and the rack columns and 6" between the pallets. For drive-in and drive-thru rack the pallet must rest on no less than 1" of support rail when shifted as far as possible in the other direction.
In addition, consideration of the clearances for the fork truck must be included in the rack configuration.

Load Weight

When specifying the design requirements for a rack system several load weights must be evaluated and specified. The first is the maximum load weight that will be placed anywhere in the rack system. The second is the average load weight that will be placed in a rack row. The average load weight is found by add the weight of all loads that are stored in a rack row and dividing by the total number of load positions. This average load weight takes into account both the weight of the average load and the amount of load positions that are occupied at any one given time.

Once these load weights are determined, the maximum load weight should be used to evaluate the shelf strength. Every shelf should be able to safely carry all the pallets at the maximum load weight. Further, the upright frame should be designed to carry the maximum gravity load per bay, which is all load positions, at all shelf levels, at the maximum load weight in one bay. The average load weight is used to determine the lateral seismic force that acts on the rack row. This seismic force should be combined with the maximum gravity load when evaluating the rack for seismic conditions.

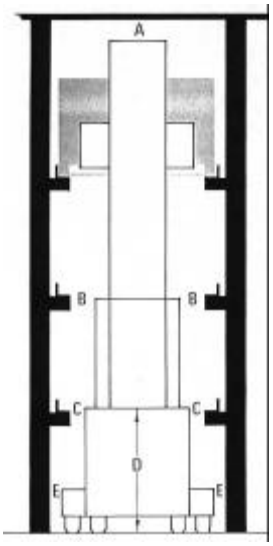
[I would like to point out that the average load weight is not part of a 50%or 67% factor commonly part of the seismic force calculation for storage racks. This factor is included because in, an earthquake, there is no coupling of the vibration of the pallet loads and the storage rack. It was also felt that there would be some loss of the horizontal force from the momentum of the pallet because of the friction only connection between the pallets and the racks. The average load weight is used in conjunction with the entire seismic force calculation.]

The determination and use of the average load weight will make a significant positive difference in the design of the storage rack components.

Method of Handling

The type of handling equipment is one of the basic decisions that must be made at or near the beginning of the system configuration. The choice of AS/RS, Very Narrow Aisle turret truck, reach truck, straddle truck sit-down counter-balance or any one of the many others will direct all of the other parts of the rack system design. The method of handling is not only important to insure adequate capacity and for determining the correct aisle size, but there are several other important considerations.

The maximum lift height of the truck should be checked to insure that it is greater than the top shelf height plus the required lift-off. The overall height of the mast and backstop with the forks fully raised must clear under building obstructions or the overhead tie beam (A below) in drive-in racks. When checking overhead obstructions be sure to check the roof at the lowest point, and anything hanging down from the roof such as lights, heaters, and/or pipes. The collapsed mast height should be checked to make sure it will fit through any tunnels in the system, and include the tunnel beam deflection when checking the available clear height.



An additional consideration is required if straddle or reach trucks are used. The truck may require a wider bay opening to allow the outriggers to enter the bay opening and clear the column and baseplate and the side of the pallet. For selective or deep reach rack, an alternative could be to elevate the first load on a shelf 10" – 12" above the floor so the base legs of the truck can go underneath. However, this will increase the overall height and may affect the downrating elevations.

In drive-in or drive-thru racks, several down-aisle fork truck dimensions must be checked as shown in the illustration on the right. The overall width of the back guard must clear the support arms and rails (B & C). The truck body width may, depending on the body height (D) and rail elevation, need to clear the support arms and rails at the lowest shelf level (C). The outrigger widths must clear the upright columns and the baseplates (E).

Area of the Storage System

The area of the storage system includes both the location and configuration of the building and the location in the country.

When a specific building is investigated it is important to consider the:

- Column size and spacing in both directions. Be sure to check the size and spacing of all the columns. Many buildings have irregular building column spacing or there may be internal roof downspouts on some columns.
- Obstruction hanging from the ceiling. Heaters, lights, pipes are all things that are not uniform and may cause interference or loss of storage locations.

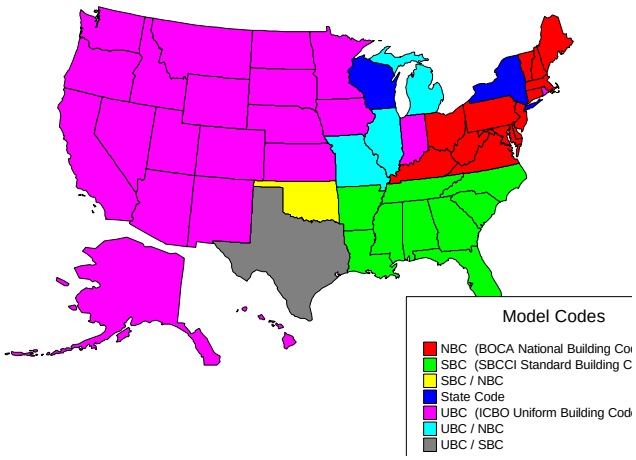
- Fire hose drop locations and sprinkler shut-off valves. The fire marshal requires specific clearances of all obstructions to allow access to hoses and/or standpipes.
- Utilities, including gas and electric, will also require clearances for access.
- Seams in the floor

When a building site is being considered it is important to include consideration of:

- The local building code requirements.
- The seismic design requirements.

Local Building Code

There are three Model Building Code Authorities in the Unites States. They are the International Conference of Building Officials (ICBO) that publishes the Uniform Building Code (UBC), the Building Officials and Code Administrators International (BOCA) who publishes the National Building Code (NBC) and the Southern Building Code Council International that publishes the Standard Building Code (SBC). There are two states, New York and Wisconsin, who write their own Building Code. The map two the right shows, in general, where each of the model codes are used.



These code-writing bodies are made up of voting and not-voting members. The voting members are Building Officials of jurisdictions that use that model code as their Building Code. The non-voting members are usually comprised of individuals or groups who cannot vote on any issues but can only propose code changes and watchdog the change proposals in the building codes that may affect a particular product, such as the Rack Manufacturers Institute. Further, the local jurisdictions may make modifications to the model code but the changes do not, usually affect the storage rack design.

Where is a Building Code Applicable

Everywhere in all 50 states and Puerto Rico the design and construction of most structures, major renovations of structures and the demolition of structures are governed by whichever of the model Building Codes has been enacted into law. A Building Official administers the Building Code. If there is not a local Building Official then the county or the State Building Code and Official governs the design requirements. Storage rack design, in particular seismic loading, is included in all three of the model Building Codes. However, the local administration and interpretation of the codes varies. In some jurisdictions, this is interpreted to mean that a building permit must be obtained for a storage rack installation. Only a few have required permits for reconfiguration and, to my knowledge, none have required a permit for the disassembly. In some areas, generally for new warehouse construction, the building official does not require a separate permit for the racks but will include them within the overall construction permit. In other areas the interpretation has been that storage racks are plant equipment and not required to be permitted at all.

This means that, for each installation, the local Building Official should be consulted to determine which model building code should be used and for information on the permit requirements.

What is covered by the Building Code

The Building Codes are intended to start where the local zoning leaves off. The Building Codes cover all phases of the construction process from clearing and site preparation through foundations, structural work, siding and roofing, fire protection, stairways, doors, floor, roof, wind and seismic loading requirements, etc. When undertaking the construction of a new or the substantial renovation of a warehouse, the first person that should be consulted is an Architect or Engineer experienced in commercial construction in the area where the facility will be built. These people know the local site conditions and the local building requirements.

Generally, the part of the Building Code that has the most impact on storage rack design is the seismic design requirements. Nevertheless, depending on the type of rack system that is being designed, the egress requirements, stairway and handrail design, floor loading requirements, and roof and wind loading may all become part of the overall design.

Seismic Design

What is an Earthquake

In the simplest terms, an earthquake is the vibration of the ground when the earth's crust breaks. Plate Tectonics is what geologists call the study of the movement of the various pieces of the earth's crust. The crust moves much like chunks of ice on a river. Where these chunks bump into each other is called a fault line. Probably the most famous fault is the San Andreas, but there are hundreds of faults outside California, in Utah, southern Illinois, upstate New York, and South Carolina, just to name a few.

The edges of these chunks are jagged and don't move smoothly against each other. As they shift, force builds up at the edges until they can no longer resist the pressure and the jagged edges snap just like a stick that is bent too far. The point of snapping is called the epicenter of the earthquake. When the edge of the crust breaks, vibrations radiate out from the epicenter like ripples on a pond.

Many things affect these ripples. The amount of force built up at the edge; the type of ground the ripples pass through; and the distance from the epicenter. All these factors, plus others (such as the likelihood of an earthquake) are combined into what are commonly referred to as Seismic Zones.

Where are Earthquakes

Below are the seismic maps from the NBC, SBC and the UBC. Many parts of the country have the potential of having an earthquake. The Building Codes require, in the UBC map areas of 1 or more and the SBC or NBC map areas of greater than 0.05, the storage rack to be checked for the affects of an earthquake.

You will notice that in the west, where there is a high probability of an earthquake, there are higher zonal factors. The geology is such that the ripples are not transmitted very far, so the zones are relatively narrow. In the east, there's a lesser chance of an earthquake so the zonal factors are lower; but since the ground transmits the earthquake further the zones tend to be wider.

You will also notice that the size, shape, location and magnitude of the seismic zones, although similar, vary on each map. The final determination of the zonal factor is the responsibility of the local officials (as enforced by the Building Inspector). In addition to the different maps, the

determination of the seismic force resulting from the earthquake is different with each of the building codes.

The seismic zones shown on the UBC map are like layers on a wedding cake. On one side of the line, the zonal factor is one value. Just on the other side of the line, the zonal factor doubles and remains constant across the whole zone until the next line. The dividers of the zones on the SBC and NBC maps are like contours showing the hills of seismic forces. On one side of the line, the factor is just a little bit smaller than the line and on the other side, it is just a little larger than the line. The factor gradually increases across the zone until it is the value of the next division.

Design Requirements
Steel Design

Hot-Rolled Structural Steel

The design requirements of hot-rolled structural steel is detailed in the **AISC** (American Institute of Steel Construction) "Specification for Structural Steel Buildings" June 1, 1989 and "Load and Resistance Factor Design Specification for Structural Steel Buildings" December 1, 1993.
These two structural steel design specifications are commonly referred to as the Allowable Stress Design (ASD) and the LRFD design. Either may be used for the design as long as any specific project is consistent. Most structural steel storage rack is currently designed using the ASD. For building type structures the LRFD design is resulting in more economical structures. Recent changes in the rack specification may make the LRFD Design more advantageous for storage racks.

The AISC specifications detail the required safety factors and limitations. For instance the factor-of-safety for beams of 1.65 loosely comes from the AISC requirements that properly braced channel shelf beams shall not exceed 0.6 x the minimum yield stress of the shelf material. However, there are several other requirements that AISC details that must be considered. Just specifying a 1.65 factor-of-safety is only part of the requirements and may result in an unsafe design.

Cold-Formed Sheet Steel

The design requirements for cold-formed sheet steel is detailed in the AISI (American Iron and Steel Institute) "Specification for the Design of Cold-Formed Steel Structural Members" 1996 Edition. This edition of the specification includes provisions for both ASD and LRFD integrated together in the same specification.

Cold-formed shapes are virtually unlimited in their shape and thickness. The AISI specification generally details the limitations caused by very thin material and the local affect of the thinness when subjected to the various types of loadings.

Welding

Welding design and application procedures are detailed in the AWS (American Welding Society" "Structural Welding Code". There are two parts that apply to storage racks. AWS D1.1-96 "Structural Welding Code – Steel" 1996 Edition is the code for the fabricating of all steel structures including storage racks. If the material is less than 1/8" in thickness then D1.3 "Structural Welding Code – Sheet Steel" supplements the provisions of D1.1.

These welding codes detail the joint design and how it should be specified, the proper welding procedures and qualification of welding personnel, and the visual and nondestructive testing of welded joints.

Storage Rack

Two specifications are applicable to storage rack design and use.

ANSI

American National Standards Institute MH 16.2 – 1984 (R1998) "For the Use of Industrial and Commercial Steel Storage Racks – Manual of Safety Practices / A Code of Safety Practices". This is a layman's guide for the use and hazard identification for storage rack installations. This manual should be a part of all warehouse operations handbooks and should be consulted periodically as warehouse storage rack safety audits are conducted.

RMI

The Rack Manufacturers Institute "Specification for the Design, Testing, and Utilization of Industrial Steel Storage Racks" 1997 Edition. This is the only storage rack specific design specification in the United States. This specification refers to and is a supplement to the steel specifications above. This RMI Specification has been unanimously approved by the RMI membership and it is a requirement of membership in the RMI that all products within the specification scope be designed in accordance with the RMI Specification. However, there are several companies that make rack that are not members of the RMI. The only assurance of a storage rack system designed to meet the RMI requirements is to buy from a RMI member or include specific RMI compliance in the purchase requirements. Further, it is up to the rack user to determine if the storage rack proposed meets the RMI requirements.

The RMI Specification includes many requirements that, if included in the storage rack design, will enhance the abuse resistance, increase the useful life and reduce the maintenance costs of the rack system.

There is a common misconception that there is an ANSI specification for storage rack design. A specification, ANSI MH-16.1 – 1974, was a duplicate of the 1974 RMI Specification that had gone through the ANSI approval process and accepted as an ANSI national specification. This approval was sponsored by the RMI. With the approval of the new RMI Specification the RMI has voluntarily withdrawn this standard and are in the process of trying to get the current RMI

Specification reviewed and approved as a new ANSI standard. The ANSI specification MH-16.1 is considered obsolete.

Other Specifications

OSHA

To the best of my knowledge there are two OSHA regulations that pertain to the design of a storage rack system.

2. Subpart N – Materials Handling and Storage
Paragraph 1910.176 Handling Materials – General

a. Use of Mechanical Equipment – Where mechanical handling equipment is used, sufficient safe clearances shall be allowed for aisles, at loading docks, through doorways, and wherever turns or passage must be made. … Permanent aisle and passageways shall be appropriately marked.

b. Secure Storage – Storage of material shall not create a hazard. Bags, containers, bundles, etc., stored in tiers shall be stacked, blocked, interlocked, and limited in height so that they are stable and secure against sliding or collapse.

There are other OSHA provisions for the operation and maintenance of the storage system that are beyond the scope of the design requirements.

What to Include in the Bid Specification

When preparing a specification for a storage rack bid request I recommend that the following codes and specifications be specifically listed and identified as part of the bid requirements.

- Local Building Code – Identify the model code used and the pertinent detail requirements such as the seismic zone, soil factor. If it is a rack supported building you should also specify the basic wind speed and exposure, and snow load for the roof. Each of these design parameters are available from the local building official.

- AISC 9th Edition for Hot-Rolled rack components –and/or- AISI 1996 Edition for Cold-Formed rack components

- AWS D1.1 for welding structural steel and D1.3 for welding sheet steel

- RMI 1997 Edition