Guide to Effective Warehouse Design, Maintenance, and Modernization

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The **Global Cold Chain Alliance (GCCA)** exists to help its members build and strengthen the temperature-controlled supply chain worldwide. We do this by bringing third-party warehouse and transportation business leaders together in events and networking activities, providing advisory and educational services, and being a voice of cold chain to government regulators and other influencers around the world.

The **Global Cold Chain Foundation's (GCCF)** mission is to strengthen the global cold chain through education, research, and international development. Cold Chain Institute trains industry practitioners in the best practices of temperature-controlled product storage, handling, and transportation. Research manuals developed by the foundation serve as the definitive guide for the proper handling, storage, and freezing of perishable products as well as energy and facility management.

International development projects engage industry professionals in the development of cold chain infrastructure in emerging markets.

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Acknowledgement

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Executive Summary

This Design Manual establishes a unified set of standards and technical guidelines to support the planning, construction, operation, and maintenance of facilities, aligning with best practices in safety, efficiency, and performance. The manual is intended for engineers, facility managers, designers, and technical consultants who require clear, actionable direction across the full range of facility systems.

To improve accessibility and operational efficiency, this latest edition is being published in a modular format—organized into 15 focused chapters. Each chapter addresses a core system or component of facility design and management, enabling users to quickly reference specific content and apply standards directly to their area of responsibility.

1. Design – Foundational planning principles and performance objectives
2. Maintenance – Preventive strategies and operational reliability standards
3. Structural – Load-bearing frameworks and compliance specifications
4. Walls – Materials, insulation, and environmental controls
5. Floors – Surface treatments, drainage, and durability
6. Roofs – Construction systems, weatherproofing, and safety features
7. Refrigeration – Temperature control systems and efficiency metrics
8. Doors – Selection criteria, access control, and insulation
9. Lighting – Illumination standards, energy use, and fixture design
10. Material Handling – Flow optimization and equipment interfaces
11. Batteries – Storage, charging protocols, and hazard mitigation
12. Fire Protection – Risk reduction measures and system integration
13. Racking – Load standards, anchoring, and spatial planning
14. Dock Equipment – Levelers, seals, and operational safety
15. Automated Systems – Integration of robotics, controls, and data systems

This format enables continuous updates and targeted usage while reinforcing technical consistency across disciplines. The manual is designed to serve as both a foundational reference and an evolving toolset for ongoing facility innovation and compliance.

What follows is Chapter 3
Structural– Load-bearing frameworks and compliance specifications

Chapter 3: Structural

3.1 Design

3.1.1 Introduction

The primary goal of any structural design is to assure human safety. The secondary goal is to minimize property damage and remain functional if the structure must withstand a critical natural event. Structural design of a cold storage distribution warehouse is straightforward in comparison to many buildings. However, combining all structural elements and considerations specific to cold storage warehouses can become a complex task.

3.1.2 Types of Design Options for Construction

Low rise distribution centers require large open floor spaces and clear heights up to 60’ to accommodate storage systems. Therefore, the most suitable structural system is ~~invariably~~ an open space frame consisting of steel columns supporting structural steel and open web steel joists and joist girders. The system allows large bay spacing which provides maximum flexibly for storage rack layout. Alternatives to conventional structural steel buildings do exist, most notably pre-engineered metal buildings (PEMB).

Exterior walls in cold storage warehouses are most commonly insulated metal panels which rely on steel members called girts to support the panels against deflection due to thermal bow and wind loads. Exterior steel columns carry the girts and perform efficiently by supporting vertical roof loads and lateral loads from wind.

For an option different from IMP walls supported by steel framing, insulated precast walls can be considered. However, most distribution warehouses have clear heights that make precast walls impractical without the use of girts and columns to carry wind load. Furthermore, creating a continuous thermal and vapor envelope at the interface between concrete panel and roof/underslab insulation can become problematic.

Another option is precast or concrete tilt-up walls, lined with IMPs. This is often utilized for dock faces, to increase durability. It may also be selected for aesthetic reasons. As with insulated precast, this structural system does also create challenges for thermal and vapor barrier continuity at the junction between wall and roof.

The structure remains stable against lateral loads through a resisting system consisting of a roof diaphragm and vertical resisting elements which carry lateral loads into the foundations. Steel roof deck serves as a horizontal diaphragm and gains stiffness with fasteners into the roof framing system. An alternative to steel deck diaphragm is a horizontal truss system which consists of steel tension members – often angles- attached below the roof framing system and forming a truss to transfer loads to the vertical resisting element. Steel deck is most often used as the diaphragm in low rise warehouses since it can provide excellent stiffness with a relative small increase in fasteners.

Another alternative to steel deck diaphragm is insulated roof deck systems. These roof panels combine insulation and structural properties to replace steel deck.

Several options are available for vertical resisting elements. Concentric steel braced frames are often chosen over steel moment frames and concrete shear walls. Concentric cross-braced frames provide excellent stiffness against building drift and are more economical than moment frames especially considering the height of most warehouses. Moment frames may be necessary to allow maximum flexibility in utilization of the space, however. Concrete shear walls are a good option for economics and stiffness, but the connection to the foundational systems may be problematic in freezer slabs.

Although there are various options, the preferred structural system for low rise cold storage warehouses remains structural or PEMB steel space frames, steel deck diaphragms and vertical cross braced frames or moment frames.

High rise or high bay cold storage warehouses differ, as a conventional structural frame only works up to approximately 80 feet. Over 80 feet, rack supported structures are usually considered. IMPs are hung from girts attached to the racking. Steel deck is supported on a framework above the racks.

3.1.2.1 Foundation Systems

A geotechnical exploration and evaluation must be performed at each site to determine a suitable foundation system to support the building structure. The two most common foundation systems for low rise distribution center building structures are shallow support systems and deep support systems.

Shallow systems consist of independent spread footings to support building columns, reinforced grade beams spanning between spread footings to support perimeter wall loads, and shallow retaining walls to support unbalanced grades such as found a dock face.

Deep support systems come in several forms. Drilled piers are generally large diameter reinforced underground columns. They are on the order of 24 to 60 inches and extend to depths ranging from 12 feet to 40 feet below the ground surface. These systems are often used in areas where expansive soil is prevalent and the depth is as required to penetrate the expansive layer. Under reamed bells, enlarged bell-shaped concrete bases, may be required to increase bearing area and provide an anchor against expansive soils attempting to lift the pier by means of skin friction on the straight sides.

Auger cast piles are slender underground cast-in-place concrete columns with minimal reinforcing - normally one bar. They are of smaller diameter on the order of 12 inches, and reach much deeper on the order of 60 feet or more. Steel or precast driven piles are similar to auger cast piles in size and depth. They are pre-manufactured and are installed by driving, or “hammering” into the ground. Groups of piles are required to support concentrated loads such as at building columns. Pile groups are always encased at the top with pile caps and or grades beams to equally distribute the loads and provide lateral support.

Freezer floors are insulated, and to provide continuity of insulation the steel columns are typically placed on thermal insulation blocks. Concrete shear walls cannot be placed on blocks, and are thus not preferred for freezer applications.

Storage rack systems within the structure are supported by mat foundations most notably concrete slabs on grade. Sub-base preparation is all important in the performance of a slab on grade. If a strong base can be prepared, the mat slab on grade can be designed as unreinforced. Otherwise, a structural slab supported by piles, a post-tensioned slab, or a ribbed waffle slab must be used. Obviously, this is necessary in rack supported buildings.

Slab design is also influenced by other aspects of the material handling systems. Jointless slabs, or slab with high levels of floor flatness, may be required for different equipment. When high performance slabs are required, alternatives to a traditional rebar reinforced slab are often explored, and various engineered slabs have been developed that may be desirable.

3.1.2.2 Seismic Zone Consideration

The United States has two systems of classisfication for seismic structural design. They are Seismic Performance Category (SPC) and Seismic Design Category (SDC).

SPC considers not only the site seismicity but also the occupancy of the structure. The development of SDCs resulted from the recognition that forces imparted to a building during an earthquake stem not only from sub-surface rock motion, but also the site-specific type of soil upon which the structure is directly founded. Local and national building code requirements for seismic detailing are based upon the new classification of SDC.

Each assigned SDC has its own economic impact. SDC “A” is the least restrictive and SDC “E” (or even “F” in extreme cases) is the most restrictive. Buildings in SDCs D and higher are required to be detailed using an additional national steel code. Some structural systems are not permitted in the higher SDC categories. Furthermore, mechanical, electrical, and architectural components Have their own restrictions that accumulate as seismic design categories magnify.

While the West Coast is known as a hot bed for seismic activity, geographic areas centered near Memphis, TN and Charleston, SC can have building sites situated in high SDCs.

3.1.2.3 Clear Heights

Building clear height requirements are a function of the owners planned storage requirements. Almost all building elements are effected as the structure grows taller. Longer columns require more stiffness to carry the same weight. Wind loads are greater at higher elevations therefore the lateral stiffness of the roof diaphragm and vertical cross-braces needs to be increased. Wind uplift (suction) on the roof is greater requiring stiffer roof elements and larger footings to anchor the roof structure against wind uplift. Perimeter columns are deeper to resist wind loads against the walls. Seismic loads are effected as the majority of the building weight is raised higher above the base.

Storage and distribution facilities have been growing taller and taller. Not many years ago, 40 feet clear was considered a tall building. Recently 40 feet clear has become the norm and heights as tall as 60 feet are more common for structural steel buildings. Above 60 feet, the economics of an open space frame are reduced more rapidly and rack-supported structures become an attractive alternative.

3.1.2.4 Pallet Weights

Pallet weights in storage systems have a common range of 1500 pounds to 3500 pounds per pallet. The weights influencethe rack structure and can affect the building structure most notably the slab on grade. The heavier pallets weigh, the thicker and/or more reinforced a slab must be to support the rack leg loads.Heavier pallet weights also mean higher seismic loads must be considered. In the case of self-supporting racks inside an open space frame structure, separation of the racks and building columns must be addressed to prevent damage from swaying members in a seismic event.

3.1.3 Checklist of Items to Consider

- Governing building codes and local amendments
- Special design loads required by the owner or insurance underwriters (FM; UL)
- Required or desire R-Values or U-Values
- Effect of all equipment on the structure
- Areas of intended future expansion
- Geotechnical recommendations
- Availability of materials
- Thermal conducting through steel elements into the sub-slab and warmer rooms
- Roof slope and drainage
- Rain ponding stability
- Roof deflection
- Wall support and girt deflection
- Building frame drift
- Building expansion joints.
- Slab on grade control joints
- Building expansion joints
- Vibration of elevated equipment and mezzanines
- Corrosion and moisture control

3.2 Structural Design of a Warehouse Building

Industrial warehouse buildings are facilities designed to accommodate the durable goods intended to be stored. Generally, the overall facility complex includes receiving and shipping docks, warehouse areas, and infra-structure support spaces to service the operation such as maintenance shop, refrigeration engine room, electrical, etc. and a welfare area for the employed staff. Some warehouse spaces are designed for specific temperatures while others are convertible, or have the ability to alter the operating temperature based on the perishable product requirements. The building structures and associated materials of construction are selected for performance and longevity, availability, speed of construction and economics.

The four most common superstructures are:

1. Conventional Steel
2. Rack Supported
3. Pre-engineered Metal Buildings
4. Pre-cast Concrete, or Site-cast/Tilt-up Concrete.

3.3 Conventional Steel Warehouse Building Overview

Conventional warehouse building structures are characterized by their use of steel frames comprised of standardized structural steel members that support the building envelope's roof, walls, and utility equipment at the superstructure level, and use of cast in place concrete foundation elements at the substructure level. These conventional buildings generally do not exceed heights above 60' and achieve additional storage space by expanding horizontally. When building floor space accommodates multiple types of operations and uses such as production lines, cold and dry warehousing, distribution docking, and office space, conventional buildings become an attractive option due to their flexibility in usage. It is advantageous to space the interior building columns anywhere from 40' to 60' away from each other in order to maximize unobstructed floor area. This unobstructed floor area could accommodate freestanding racking systems that are independent of the building framing.

3.3.1 Roof Framing

Working from the top down, the roof of a conventional building serves two primary structural purposes, the first of which is the vertical support of sustained dead loads such as roof membranes, insulation, and the deck, and the support of transient live loads, such as snow and human traffic. The second primary purpose of a roof is the horizontal transmission of lateral wind and seismic forces through diaphragm action. Corrugated metal roof deck attached to the roof framing system with screw fasteners, powder actuated fasteners, or puddle welds is a common deck system, and can serve as rigid diaphragm with a concrete topping and studs, or as a flexible/pseudo flexible diaphragm as is. The metal deck and fastening system is an example of an element within the roofing system that contains the structural shear capacity necessary to transmit these forces to the vertical braces and/or moment frames.

The roof system and rooftop utilities are supported by framing members such as open web K-type and LH-type joists and standard AISC wide flange sections. Generally, for large open bays on the order of 1600 to 3600 sq. ft., primary joist girder and secondary joist members are most economical for vertical gravity load support. In some instances, wide flange girder primary members and wide flange beam secondary members are used for their resisting capacity of inconsistent and heavily concentrated loading patterns. A common rule of thumb for wide flange beam design, assuming moderate uniform loading, is the depth of the beam in inches should be roughly the span of the beam in feet divided by two.

3.3.2 Columns

Columns are used to support the roof and roof framing systems and are generally hollow structural steel (HSS) or wide flange (WF) sections, with HSS columns generally being the more economical choice. In addition, exterior columns also serve as the support system for the vertical building envelope. The vertical building envelope of a conventional building is generally comprised of a skin such as an insulated metal panel, and a secondary horizontal spanning member supporting the skin called a girt. Girts can be wide flange or channel sections, and are generally oriented with the strong axis facing the exterior of the building to provide maximum resisting capacity to out of plane wind loads and other lateral loads the building envelope may be exposed to.

3.3.3 Lateral Bracing

Designated columns and roof members in addition to bracing members and/or specially designed moment connections can be utilized as lateral frames for the purpose of resisting wind and seismic lateral forces. The bracing members can be angle, rod, or HSS members, and effectively serve as web members in vertical truss systems that transmit tension and compression forces to the foundation system. Various configurations of bracing systems exist, such as concentrically braced, x-bracing as an example, and eccentrically braced, k-bracing or v-bracing as examples. Depending on the bracing configuration, the lateral forces can travel through the frame in different load paths. The ideal bracing configuration is the x-brace, which is due to its high stiffness and corresponding deflection resistance. In addition, the x-brace has the ability to yield more economical brace sections due to possible tension only bracing load paths.

In the case that there is limited room for bracing members within a frame, utilizing moment frame connections is recommended. However, when possible, the use of moment connections is usually avoided due to their limited resistance to lateral deflection and labor intensiveness. These connections consist of an arrangement of plates, bolts and/or welds. The strategic placement of these elements achieves a fixed type of member fixity, which transmits lateral forces to the foundation through the development of moment, or torque, in frame members.

3.3.4 Foundations

When soil conditions are optimum, conventional building columns are generally supported on shallow spread footings, and building walls on continuous footings. For interior building elements such as floor mounted equipment and storage racking, a slab on grade or structural slab generally serves as a foundation. When overturning forces and/or high concentrated forces are applied to slab foundations, top and bottom reinforcement is generally provided to assist in resolving the tension component of flexural bending. For many applications with moderate and uniform loading, a simple slab on grade with minimum temperature and shrinkage reinforcement will be sufficient. Different racking systems and arrangement patterns may be used for warehouse operations; therefore, a thorough slab analysis is required to determine which system is necessary.

3.3.4 Geotechnical Implications and Considerations

When project site native soils have undesirable characteristics such as high fine grain content, organic content, and low bearing capacity, advanced foundation systems such as drilled piers, helical auger piles, micropyles, and rammed aggregate piers are often utilized. These alternative foundation solutions enable the superstructure loads to be transmitted to competent soil strata, or spread the loads out over a larger surface area. In some cases, when shallow spread footing and continuous footing foundations bear on clayey and silty fine grained soils, differential settlement, hydrostatic uplift and frost heaving, and in extreme cases liquefaction may occur leading to structural failure. In cases where unsuitable soils exist in isolated areas, it is possible to economically remove and replace localized portions of the deficient subsurface soil with compacted structural fill of acceptable soil properties. Project site subsurface characterization information is obtained from a geotechnical report, and is crucial for the determination of applicable and feasible foundation systems.

3.4 Rack Supported Warehouse Building Overview

Rack supported buildings are very efficient when it comes to the utilization of space for the purposes of storage and retrieval operations. Often, these buildings utilize an automated storage and retrieval system (AS/RS), characterized by its use of automated cranes, elevators, carts, product racking, and software control systems. Rack supported warehouses can be constructed as high as 140 feet, and in many cases, accommodate over 20 vertical pallet levels. This type of technology enables the building footprint to be condensed into a smaller area, which is highly beneficial in areas where land is expensive. On the other hand, the possibility of multiple operation types is unavailable due to the highly-specialized nature of this building type. Possibly the most unique element of a rack supported building is its use of the rack system to support not only itself, but the building envelope's walls and roof. Because the building structure and racking system in a rack supported building are integrated, the possibility of depreciating the combined system as equipment, as opposed to a building, exists. If this potential tax benefit is utilized, the rate of depreciation could be much steeper, making this building type an attractive option for warehousing applications.

3.4.1 Roof Framing

The structural roof system of a rack supported building is generally the same as that of a conventional building, utilizing corrugated metal deck as a diaphragm, and open web trusses or standard AISC sections as roof framing members. One distinct characteristic of rack supported buildings is the large number of framing members with short unbraced lengths.As the unbraced length, defined to be the greatest distance between points of buckling resistance in a member with compressive forces, of a structural member decreases, the section properties, such as linear self-weight and cross-sectional area, necessary to prevent failure tend to decrease as well. The approach can lead to cost-effective assemblies. Because of the close proximity of rack columns to each other, the horizontal primary and secondary framing members can achieve light and condensed section dimensions.

3.4.2 Columns

The columns in a rack supported building can vary between being hot rolled or cold formed, standard tubular or built-up sections The columns may occur as simple gravity members or as part of a tower braced frame. In addition, columns are generally spaced closely together, which distributes superstructure loads more evenly across the foundation system in comparison to other building types. Due to the numerous pallet levels these buildings accommodate, the columns are laterally braced against buckling very frequently, thus allowing the sections to be light and condensed. This is in stark contrast to columns of a conventional building which are routinely only braced at the foundation and roof levels, yielding heavy and broad sections.

3.4.3 Lateral Bracing

The lateral bracing system of a rack supported building is characterized by the use of tall and slender bracing towers, comprised of many light and condensed members. Generally, angle members are utilized as both tension and compression diagonal braces, as well as struts to transfer load and engage adjacent braces. With the many pallet loading configurations possible, the analysis complexity can be extensive. For this reason, far more load combinations may apply in contrast to other building types, in particular in high seismicity zones where the product mass magnitude, configuration, and proximity to bracing towers can be highly variable.

3.4.4 Foundations

In the construction phase of a rack supported building project, high wind uplift forces may be generated and imposed on foundation elements, as pallet loads may not be present to counteract overturning forces. Generally, a structural slab on grade with top and bottom reinforcing bars is utilized to resist these types of concentrated overturning forces. An alternative to standard reinforcing bars is fiber reinforcement such as steel fibers. The use of fibers gives an opportunity to reduce installation labor and time for rebar placement especially for large concrete pads. The rack / building columns generally do not have their own dedicated foundation system, such as shallow footings, because of the high number of column locations and relatively uniform spreading of loads a mat-slab foundation can be constructed near the ground surface. In cases where an automated storage and retrieval system is used, slab levelness is critical, as these systems are very sensitive and may derive their precision from laser systems referenced to the finished slab elevation.

3.4.5 Geotechnical Implications and Construction

Subsurface characterization from geotechnical reports is crucial for the determination of applicable and feasible foundation systems. When project site native soils have undesirable characteristics such as high fine grain content, organic content, and low bearing capacity, soil improvements are consistently essential. Thus advanced foundation systems such as matt or raft foundations, drilled piers, and rammed aggregate piers are often utilized. These alternative foundation solutions enable the superstructure loads to spread out over a larger surface area.

3.5 Pre-Engineering Metal Warehouse Building Overview

A pre-engineering metal building (PEMB) is generally characterized by its use of cold-Formed metal Primary and secondary members ~~light gauge metal roof and wall cladding members~~, low cost of materials, fast erection times, and large clear spans between columns. PEMBs typically utilize moment frames as the primary lateral load resisting system; therefore, these types of buildings are relatively flexible and can have significant lateral drift. This inherent lateral flexibility can have detrimental implications for sensitive finishes and/or equipment if not carefully addressed. Therefore it is critical to address all required deflections and loadings the same as any structural steel based on both Roof and Wall Cladding systems along with all required point loads.

3.5.1 Roof Framing

The roof framing and roofing system dead loads of a PEMB ~~are~~ may be very light, on the order of 3 PSF, in comparison to other warehousing building types. This lightweight nature can be attributed to the marginal overdesign of roof framing members, often containing just a few percentage points of additional stress capacity beyond the minimum loading requirements. Deck System are ~~is~~ commonly used for most Cooler and Freezer applications., Standing seam metal is commonly used for dry storage and some Cooler applicstions, which utilizes a horizontal bracing system to transfer lateral loads to the vertical bracing system.

Secondary roof framing members are usually cold formed c- or z-section purlins, and are generally spaced closely, at 5’ on center, due to their relatively small flexural capacities. In addition, primary roof framing members are commonly constructed out of steel plates, forming custom or built-up I-sections. As mentioned earlier, these members are designed as requested deflections and contain multiple tapers along their span in order to conform specifically to shear and moment envelope demands. Additionally, Striaght-Column or Super-Market Columns can be speced.

3.5.2 Columns

PEMB columns are typically built-up sections, similar to the primary roof framing members, or standard AISC wide flange sections. Frequently, columns will have a haunch and stiffener plates at the beam connection point in order to eliminate buckling failure points and develop shear and moment forces through the connection. Because of the light nature of these buildings, there can be high net uplift forces transmitted through the columns and into the foundation system. A robust column anchorage system, consisting of a base plate, anchor bolts, and possibly tension and shear reinforcing bars, is often required to resist the high concentrated wind and/or seismic forces at the column base.

3.5.3 Lateral Bracing

As mentioned earlier, the lateral bracing system in a PEMB often consists of moment frames, but can also include x-bracing, Portal Frames or shear walls to form a hybrid system if lateral deflections become excessive with just moment frames. In general, as the clear span of a PEMB increases, roof framing and column members increase in size due to higher gravity flexural stresses. This increase in member sizes is directly proportional to an increase in frame stiffness, which ultimately translates into a reduction in lateral building drift. On the other hand, as frame member spans decrease, they become more flexible and produce higher deflections.

In addition to resisting lateral forces such as those developed during wind and seismic events, the bracing system also needs to resist the horizontal component of the roof gravity loads. This is due to the fact that common gabled roof configurations impose a lateral thrust force. A common lateral drift consideration when dealing with PEMBs, is the interaction between the framing and wall systems. In cases where masonry walls are utilized as the building's vertical envelope, it is imperative that lateral drifts are even further minimized, so as to eliminate failure at wall corners.

3.5.4 Foundations

PEMB foundation systems can effectively utilize a structural slab on grade system with thickened edges at column locations, or a slab on grade with minimum shrinkage and temperature reinforcement and dedicated column footings. Because superstructure dead loads can be very small, large net uplift forces must be counteracted by the foundation system self-weight. In many cases, the design of the foundation system is controlled by the counteracting weight requirement over soil limitations. In addition to vertical superstructure loads generated by overturning forces, horizontal shear reactions generated by lateral wind, seismic, and gravity thrust forces also need to be resisted by the foundation system. In order to resist these lateral shears, a combination of hair-pin reinforcing bars and the slab on grade act as tension members to resist the shear in the direction where concrete edge distances are the shallowest. Hair-pin bars are typically bent around the anchor bolt group, and develop the shear forces imposed at the column base into the slab on grade along their lengths. Further, a thickened slab or grade beam may be necessary to transfer shear forces along braced sections. Coordination and care must be taken to ensure continuity of the slab system.

NOTE: All Some clear-spans; Tie-Rods can be utilized to further help decrease the size of the sidewall foundations.

3.5.5 Geotechnical Implications and Considerations

When project site native soils have undesirable characteristics such as high fine grain content, organic content, and low bearing capacity, advanced foundation systems such as matt or raft foundation, drilled piers are often utilized. These alternative foundation solutions enable the superstructure loads to be transmitted to competent soil strata, or spread the loads out over a larger surface area. In some cases, when shallow spread footing and continuous footing foundations bear on clayey and silty fine grained soils, differential settlement, hydrostatic uplift and frost heaving, and in extreme cases liquefaction may occur leading to structural failure. In cases where unsuitable soils exist in isolated areas, it is possible to economically remove and replace localized portions of the deficient subsurface soil with compacted structural fill of acceptable soil properties. Project site subsurface characterization information is obtained from a geotechnical report, and is crucial for the determination of applicable and feasible foundation systems.

3.6 Precast Concrete, or Site-cast/Tilt-up Concrete Warehouse Building Overview

Precast / prestressed structural elements typically utilize high tensile strength prestressed reinforcing strands, which increase load carrying capacities, and enable longer clear spans that may not be possible and/or feasible with sections utilizing just conventional reinforcing bars. Because of the strict manufacturing and quality control procedures typically utilized in plant casting of precast concrete products and the durable nature of the constituent elements, these buildings can reduce maintenance costs and achieve long service lives.

Local material sourcing and manufacturing, high thermal mass and insulation properties, use of recycled materials, such as fly ash and silica fume, and ability to be recycled, once crushed, into road base and construction fill, enable precast or tilt-up concrete to be a sustainable and environmentally friendly alternative to other warehouse building types.

Construction times for precast concrete buildings can be short, as superstructure members can be fabricated while foundation work is being performed. In addition, the manufacture of precast components in factory-controlled conditions enables uninhibited production, regardless of weather conditions or site staging requirements. An inter Wythe consisting of ridged insulation can be cast into the elements along with a vapor barrier for the purposes of developing a thermal wall element. Lastly, aesthetic features such as embedded stone, brick, or tile veneers, texturing and profiling, and coloration can be integrated into precast / prestressed structural elements. This type of flexibility may generate economical and effective ways of achieving architectural function and appeal for a building.

Tilt-up concrete walls are preferred in areas where precast walls are not readily available. It is also subject to weather conditions while being cast, making it preferable in temperate climates.

The sections below outline requirements for a fully precast structure. However, it is not uncommon to combine precast or tilt-up walls with conventional steel framing as outlined above.

3.6.1 Roof Framing

The roof framing system in precast concrete warehouse structures is generally comprised of double-T beams and inverted-T girders. The double-T beams serve as both the secondary framing members, as well as the roof deck itself. Stitching the flange portion of double-T sections together creates a rigid diaphragm, capable of transferring high shear loads to the vertical bracing system. The roof insulation and membrane can simply be adhered to the top of the double-T flange, creating a simple yet effective roofing system. Depending on the clear span of the framing members, beam camber could pose an issue at the beam to girder connection, where a significant valley might form. In these cases, it might be necessary to provide a cast in place concrete topping in order to maintain a continuous slope of proper proportions for drainage.

Secondary double-T beams are generally supported by primary inverted-T girders, where the stems of the double-T bear on the flange ends of the inverted-T. Clear spans on the order of 60’ to 80’ are possible due to the prestressed effect of the high tensile strength reinforcing tendons on the surrounding concrete. Specifically, prestressing induces a larger and stronger compressive stress zone within the member section, which serves to overcome higher tensile stresses developed through flexural bending. This revolutionary technology enables concrete to overcome its inherent weakness to tensile stress.

3.6.2 Columns

Precast concrete building columns are typically square in section, and utilize vertical and horizontal reinforcing bars to resist horizontal shear and bending moment. Typically, a cage of reinforcement is utilized within the column profile, comprised of vertical bars, which resist lateral flexural bending, spaced close to the perimeter of the column section, and horizontal ties, which resist horizontal shear, wrapped around the vertical bars. Since columns primarily act as compression members, there generally is not a need for prestressing strands to offset any high tensile stresses. However, prestressing tendons may be used in axial load bearing members along the building perimeter, where high out of plane wind loads may generate tensile stresses as a result of flexural bending. Precast columns are typically cast monolithically with a corbel, which is a short hunched cantilever bracket extending off of the column face. Corbels require precise reinforcement detailing, as significant loads must be transferred, through bearing, from the primary girder members to the column through these elements. Precast concrete columns typically resist very high vertical roof dead loads on the order of 60-70 PSF. By contrast, conventional steel framed building roof dead loads generally do not exceed 20-30 PSF. As a result, precast concrete column sections are generally no smaller than 18 inch or 24-inch square.

3.6.3 Lateral Bracing

Precast concrete buildings typically utilize shear walls as their lateral resisting system. Shear walls effectively serve as vertical cantilever beams, transferring superstructure lateral forces down to the foundation system. Because the roof diaphragm is rigid, non-uniform loading will generate torsional forces, therefore it is recommended that two shear walls, at each extreme of the diaphragm be provided, with their principal axes perpendicular to the lateral loads they are designed to resist. Further, designing shear walls as load bearing is highly advantageous, as vertical gravity loads assist in resisting uplift and overturning forces. Shear walls can come in many forms, such as insulated sandwich wall panels, litewalls, or solid wall panels. In addition, a hybrid lateral bracing system, comprised of both steel x-braces and shear walls is also an effective option. Precast concrete buildings are generally subject to significantly higher seismic demands, as member weights are considerable higher than those in other building types. As a result, more robust lateral resisting systems are typically required in high seismicity zones.

Insulated sandwich panels are an effective option for cold storage warehouse applications due to their high thermal insulation properties. These panels are generally constructed out of one layer of high-performance insulation, sandwiched in between two layers of concrete. The composite section yields a highly energy efficient system, and is a popular alternative, even in non-precast warehouse projects.

3.6.4 Foundations

As with other building types, columns are typically supported on cast in place spread footings, and bearing walls on cast in place continuous footings or grade beams. Because superstructure loads are generally significantly higher than those of other building types, larger foundation members are usually necessary to distribute loads out over more soil surface area. For moderate and uniform equipment and racking loads, a slab on grade with minimum shrinkage and temperature reinforcement will generally be sufficient.

3.6.5 Geotechnical Implications and Considerations

When project site native soils have undesirable characteristics such as high fine grain content, organic content, and low bearing capacity, advanced foundation systems such as drilled piers, helical auger piles, driven piles and rammed aggregate piers are often utilized. These alternative foundation solutions enable the superstructure loads to be transmitted to competent soil strata. Project site subsurface characterization information is obtained from a geotechnical report, and is crucial for the determination of applicable and feasible foundation systems.

Building Type vs. Typical Structural System Matrix

		Building Type			
		Conventional	**Rack Supported**	**Pre-Engineered Metal Building**	**Precast**
Typical Structural System	**Roof Diaphragm**	Corrugated Mt'l Deck	Corrugated Mt'l Deck	Standing Seam & Horiz. Bracing or Corrugated Mt'l Deck	Double-T Beam Flange w/ or w/o Concrete Topping
	Roof Framing	WF Section and/or Joist / Joist Girder	Open Web Steel Truss or Standard AISC Section	Light Gauge C- or Z-Purlin, Built-Up I-Section, or Open Web Joist / Joist Girder	Double-T Beam & Inverted-T Girder
	Lateral Bracing	Braced Frame, Moment Frame, and/or Shear Wall	Braced Frame and/or Moment Frame	Moment Frame, Braced Frame, and/or Shear Wall	Shear Wall and/or Braced Frame
	Vertical Gravity Framing	WF, HSS Column, and/or Wall Panel	Rack Post / Column	WF, HSS, and/or Built-Up Section	Concrete Column and/or Wall Panel
	Foundation	Shallow & Continuous Footing w/ Slab-on-Grade	Structural Slab-on-Grade	Structural Slab-on-Grade and/or Shallow & Continuous Footing	Shallow & Continuous Footing w/ Slab-on-Grade

Table 3. 1

3.7 Rack Supported Building Versus Conventional Building

Rack supported buildings have become a popular approach to modern warehousing techniques. Emphasis is placed on the advantages of this concept, which is relatively new to refrigerated warehouses.

3.7.1 Discussion

There are quite a few similarities between rack supported buildings and conventional constructed buildings. They can both utilize any style of racking. Both can also be serviced by any type of material handling equipment. The method of refrigeration can be the same for either concept. The use of standard insulation and roof construction can be used on either.

Rack supported buildings offer a better utilization of the cube than does conventional construction. This is accomplished by eliminating the duplication of building steel. Elimination of the steel reflects a reduction in square footage required. This reduction in square footage reduces both time required to construct the facility and the overall cost of construction.

Foundation loads are greatly reduced due to the dispersion of wind and roof loads over many rack columns. Distribution of floor loads will reduce the foundation design and minimize site work. Not only does this reduce the cost of the foundation but also the time required to do the site work.

Roof trusses are also affected by the dispersal of load over all of the rack columns, reducing the depth required to carry the roof. This will reflect in vertical space reduction, thus requiring a shorter building than conventional, with a reduction in the cost of building steel.

The design of the rack supported building is the responsibility of the engineering staff of the rack manufacturer and not the responsibility of the customer's architect.

Numerous styles of storage systems can be incorporated into a rack supported building. Any type of outer material can be applied to the building. It is suggested that height be dictated by the design of refrigeration offered to avoid the stratification that can be a problem in high-rise systems and in compliance with local building codes. Expansion of a rack supported building is economical in comparison to a conventional building.

Although there have been numerous installations to form a procedure to offer incentives, to date, the Internal Revenue Service has not formally adopted a standard for rack supported buildings. A rack supported building is generally considered capital equipment and the cost of the structure can have an accelerated write off, unlike conventional buildings.

Conventional construction, unlike rack supported buildings, offers flexibility in allowing the owner to re-arrange the racking system after the facility is constructed. This single source concept of a rack supported building makes the financing of a rack supported building more difficult than a conventional structure.

3.7.2 Conclusion

There are many advantages for public refrigerated warehousemen to seriously consider rack supported facilities for their future plans. In public refrigerated warehousing, the maximum utilization of the cube is the major concern. A rack supported structure will offer better utilization of the cube than a conventional structure offers. There is a large misconception that rack supported buildings are used solely with high-rise applications. As you see, any racking concept can be offered in a rack supported building.