Design Considerations for the Construction and Operation of Malting Facilities. Part I: Planning, Structural, and Life Safety Considerations

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Abstract. Malt production facilities are the producers of ingredients for our baking, beverage, and specialty food industries. To date, information about the unique design requirements of these facilities has been limited. In an effort to summarize state of the art design procedures for malting facilities constructed in North America, an overview of accepted standards and procedures has been assembled. With this paper engineers should become more familiar with specific design considerations for malting plants and develop appropriate references to expand their knowledge base. Educators may find this paper useful too.

Keywords. Agri-Industry, Concrete, Malting, Life-Safety, OSHA, Planning, Steel, Sanitary Design, Structural Design.
Introduction

The malt industry produces ingredients for a number of food and beverage industries, including baking, brewing, breakfast cereals, and distilled products. It represents a first-tier food ingredient processing segment and plays a key role in the North American food and fiber production system. According to the Census Bureau, there are 16 companies that operate 34 establishments with a total of 1300 employees in the United States (US Census Bureau, 2004). Total revenues in this industry exceed $775 million annually.

Like many industries that are involved in the post harvest processing of agricultural and biological commodities, a number of unique and special storage and handling requirements exist which influence design and operation functions. Concurrently the number of contractors and engineers that service this industry are diminishing. To date, the unique design requirements for this industry sector have not been documented. This article is one of a series of articles that summarize design criteria for various agri-industrial facilities. The scope of agri-industry is defined in Williams and Bohnhoff (2004). In this article we will examine the life-safety, planning and structural aspects of a malt production facility. The second article in this series by Rosentrater and Williams (2005) will examine the process design aspects of malting facilities.

Overview of Malt Production Facilities

Malting is defined as the limited germination of cereal grains (Briggs, 1998). The most commonly malted cereal grain is barely, but other cereal grains such as corn, wheat, rice, sorghum, rye, and oats have been used to make malt also. In some instances peas and beans have even been malted. The steps in the malting process include: (1) receiving and storage, (2) cleaning, (3) storage, (4) steeping, (5) germination, (6) kilning, (7) dressing, (8) storage and blending, and (9) shipping. Contemporary production of malt is an ancient process which is augmented with the benefits of modern technology. Figure 1 shows a block flow diagram for a typical malt production facility.

There are two major types of facility layout for malting facilities: horizontal or vertical. Horizontal plant layout takes advantage of space. In this type of facility layout, personnel supervision is enhanced. Additionally, maintenance and sanitation are improved. Disadvantages of this type of facility arrangement include increased equipment costs and heavily congested ceilings with greater than average heights. In a vertical plant arrangement there is reduced conveying machinery cost due to the use of gravity to convey the materials. Also, less physical space is required for the plant. Disadvantages of the vertical plant layout include difficulties moving ingredients and people from floor-to-floor. Additionally there can be greater maintenance costs. Additional information on plant layout is contained in Briggs (1988) and Imholt and Imholt (1999). Figure 2 shows a possible horizontal plant layout and figure 3 contains a possible vertical plant layout.

Plant construction materials vary by processing area in malt production facilities. As a food production facility with harsh interior environmental conditions, selection of materials for construction is critical for proper sanitation and operation. When sanitation, temperature, or moisture is a concern, stainless steel, galvanized steel, or smooth finished concrete are more commonly used. When the built environment is not as harsh, materials such as mild steel or regularly finished concrete may be used; however, good sanitation practices still must be followed.
Figure 1 - Malting process block flow diagram.

Storage types for malt production facilities include (1) smooth wall steel bins, (2) corrugated steel bins, and (4) concrete silos. Smooth wall steel bins are typically used when smaller quantities of grain or malt are stored or where specific sanitation requirements must be met. Corrugated steel bins offer economical storage in large quantities and are represented by a large number of commercial manufacturers in the United States, but should only be considered for the storage of raw grain. Concrete silos are initially a more expensive option, but generally are least subject to wear, thus lasting longer. They also have the advantage of having a sanitary finish when troweled smooth. Recently, they have become even more economical than steel with the higher prices of structural steel.

Facility Planning Considerations

Proper planning is an important aspect of long-term profitability for a malting facility. It is important for engineers of these facilities to minimize these costs to increase value for owners and shareholders. A major part of effective planning is considering items such as: (1) long range corporate planning, (2) economic factors, (3) regulatory issues, (4) location/site, (5) facility expansion versus new construction, and (6) energy and water usage. Optimal planning should lead to lower life cycle costs. These are detailed as follows:

- Long range or strategic planning is a function of the strategic vision and objectives of an organization. It generally reflects the mission of the company and how it will proceed toward achieving its business objectives. For optimization of long-range profitability, capital spending on a new facility needs to reflect the strategic planning objectives of the organization.
Economic considerations for the operation of a facility can have a major impact on its profitability. Local issues such as barley quality or variety and volumes produced in a particular geographic location, the availability of transportation, and the number of existing facilities in a particular geographic area will directly affect the economic success of a malt production facility. Global economic issues such as long-term increases in population, which in turn can increase demand, can also be a consideration. Additionally, the consumption habits of the demographic population or the processing capabilities of regional industries may have an influence on production demand. Finally, Return on Investment, or ROI, should be a major consideration in the decision to build and operate a new facility.

Governmental regulations and political issues can have a significant effect on the need for a malting facility in a particular region. FDA regulations from Title 21 of the US Code of Federal Regulations (Nara, 2004) could have an effect on planning issues. In addition, global issues such as GMP and identity preservation can have an effect on international demand for product. Finally, there are a number of regulations from the EPA (Title 40 of the US Code of Federal Regulations (NARA, 2004)) that must be followed relating to plant omissions (Nara, 2004).
• Selection of an appropriate site is an important consideration for the profitability of a malting facility. Locations close to applicable transportation and infrastructure are essential for product distribution and raw grain receiving. Functional rail facilities are essential for most grain handling operations and, thus, important for malting facilities. Appropriately rated roads and highways are also essential. The availability of existing storage or processing systems may be beneficial for an owner if they are in good condition. Finally, barely production, a major source ingredient for malt production, is limited to certain geographical locations in the United States, thus transportation infrastructure will be key.

• Once a decision has to be made to build a facility in a specific geographic region, the owner and engineer must examine whether a currently existing facility in the area can be expanded or upgraded first. If the discounted cash flow of the cost of the upgrades is greater than new construction then consideration should be given construction of a new facility.

• Facility layout and design is a key consideration in the operation of a functional facility. Careful consideration should be given to plant layout style relative to the site. As discussed
in the previous section, plant layout styles consist of both horizontal and vertical layouts. The relative location between physical locations of the various portions of the facility and the possibility of double duty for selected components can play a role in the operational and maintenance costs of running the facility. The type of construction and the amount of available land can have major role in the physical layout of the facility. Finally, the budget that the facility owner has available can dictate the types and sizes of construction that can be pursued.

- The final, and most important issue for a malting facility, is waste and energy planning. The malting process can use vast quantities of water and power, so heat energy recovery systems must be planned for the system. Energy efficiency is also a critical operating element to plant design. In addition to energy efficiency, water treatment can be an issue because of high BOD effluent, so an owner should give serious consideration to an onsite wastewater pretreatment or recovery system. Extensive discussions of waste and energy are contained in Briggs (1998) and Rosentrater and Williams (2005). Proper input in the design phase can have a substantial impact on the profitability of the proposed facility.

**Life Safety Design Considerations**

Once the decision to build has been made by the owner and engineer, the life safety and structural planning can begin. Life safety codes are administered at state, local, and federal levels. Federal regulations, such as Occupational Safety and Health Administration standards from Title 29 of the US Code of Federal Regulations (NARA, 2004), and state-adopted model codes, such as the International Building Code (ICC, 2003a) dictate how facilities are planned and constructed. Highlights of these codes, as they relate to malting facilities, are discussed in the following sections. Figure 5, at the end of this section provides, a flow chart showing the interrelationship of the life safety concepts. Table 1, at the end of this section, summarizes the major sections of the life safety codes.

**Model Building Codes**

The main building code in the United States is the International Building Code (IBC) (ICC, 2003a), which is the model code for 48 states and for all fifty states beginning in 2007. The IBC defines a number of life safety and fire code related issues including occupancy types, construction types, height and floor area, egress, stairs, access, and a number of other major life safety issues. Some of the major items of consideration in the IBC are summarized in table 1 and detailed in the following subsections. The reader should note that these discussions are not necessarily all inclusive, and they should consult the building code and other references for further details.

**Use and Occupancy Classification**

Chapter 3 of the International Building Code specifies ten major Use and Occupancy Classifications for facilities. For specifics, the reader is referred to the IBC, but these categories range from residential to hazardous industrial. Each of the major occupancy types are further subdivided. Occupancy loads are defined in table 1004.1.2 of the IBC. A typical industrial occupancy load for an industrial facility is 100 square foot per occupant. Other occupant loads for industrial buildings must be approved by building code officials. Common Use and Occupancy Classifications typical for malting facilities include:
- Group B - Business - The business or laboratory sections of a malting facility may fall under this occupancy.
- Group H - Hazardous – Hazardous processing areas with a risk of explosion fall under the classification. The storage areas for agricultural commodities that shed substantial levels of fine dust fall also under this category (specifically H-2). In a malting facility, the raw barley storage or finished malt storage would be under this classification. Under the
appropriate conditions, grain dust can be highly explosive. Additionally, cleaning and dressing areas are typically given this classification.

- **Group F - Factory and Industrial** – Non-hazardous building processing operations would fall under this category. Examples include further processing that does not produce explosive dust such as packaging or cooking operations that exist in many agri-industrial facilities. These areas are usually classified as category F-1. Most portions of a malting facility would fall under this classification. For example, the malting process areas that house the germination and steeping vessels are Category F-1.

- **Group S – Storage** – Generally this classification is used for the noncombustible storage of products. If the dust produced by the stored commodity in a grain storage area were non-explosive, it would be category S-1. Areas for storage of bagged malt product would typically be category S-1.

**Construction Type and Fire-Resistance-Rated Construction**

Construction type influences allowable height and area of buildings in a facility. Chapter 6 of the IBC (ICC, 2003a) defines four major construction types. These vary from a highly protected Type I construction to the least protected Type IV construction. They are further divided into subcategories of A and B, which define additional levels of added fire protection. Generally, construction Types II and I consist of masonry, steel, and concrete structures. Type III construction has noncombustible exterior walls and interior materials of any material (e.g. timber). Type IV construction, heavy timber, is not commonly used in agri-industry anymore. Type V construction is construction where any combustible or non-combustible material is used for construction and is applied to construction types that do not qualify for Types I to IV construction. Construction type determines fire ratings which are influenced by many other areas of the life safety planning for the facility.

Chapter 7 of the IBC discusses specific aspects of fire-resistant-rated construction. Fire-resistant-rated construction procedures give the design engineer the details to obtain the fire ratings required in chapter 6 of the IBC. Specific elements that the engineer must examine include horizontal elements such as floors and roofs (IBC section 711) and vertical assemblies such as fire walls (IBC Section 705), exterior walls (IBC section 704), and fire partitions (IBC section 708) and barriers (IBC section 706). Additional discussions of shafts (IBC section 707), penetrations (IBC section 712), and smoke barriers (IBC section 709) are made in chapter 7. Finally, section 721 of chapter 7 discusses the calculation of the individual resistances of fire rated assemblies. Table 302.3.2 describes the fire wall ratings required for separation of occupancies and table 602 describes fire-resistance rating requirements for exterior walls based on fire separation distance. Additional information of the calculation of fire resistant elements is provided by the American Society of Civil Engineers in ASCE 29-99 entitled “Standard Calculation Methods for Structural Fire Protection” (ASCE, 1999). For specifics, including other additional requirements, the reader is referred to Chapter 7 and other relevant sections of the International Building Code (ICC, 2003a) and the International Fire Code (ICC, 2003b).

**Height and Floor Area**

Table 503 of the International building code defines the allowable height and areas of buildings of various fire rating classifications and occupancy types. As previously discussed the various areas of a malting facility are likely to obtain a Type I, or II construction with occupancy classifications that could include: F-1, H-2, B, or S-1. As with most special industrial processes, section 503.1.2 of the 2003 IBC allows for low hazard industrial processes that require large
areas that accommodate crane ways or special machinery are allowed to be exempt from the height and area limitations in table 503. This should be coordinated with building code officials early in the project, if required.

Location on Site

As outlined under the special requirements section, grain storage and malt houses cannot be closer to the edge of a property line or adjacent structures than 30 ft except in cases where the railroad right of way can run adjacent to the structure. The engineer should be aware of the required rail clearances and work closely with the railroad to define these necessary clearances. Site location for other structures of a malting facility is shown in Table 602 of the IBC (ICC, 2003a) and is dependent on the fire ratings of the exterior walls of the building or area under consideration.

Special Requirements in the IBC

Once the occupancy and type of construction are established, then the engineer will need to determine specific special occupancy requirements that relate to the special features of the facility. Chapter 4 of the International Building Code outlines a number of building code requirements relating to malting plant design and construction. These special requirements are discussed in Section 415.7 of the 2003 IBC for facilities that process grain and are as follows:

- IBC 415.7.1.5 - States that grain elevators, malt houses and similar structures must be located at least 30 ft from a lot line, or adjacent structures, except at the railroad right of way. This requirement allows grain storage and malt houses to be adjacent to rail lines, which is a major mode of commodity transportation, but keeps the facility away from adjacent structures where the hazards of a dust explosion could cause an injury.

- IBC 415.7.1.1 - States that Type I and II construction for grain elevators, malt houses and similar structures is unlimited. For other construction types the engineer should follow use table 503. Type I and II construction includes all metal and concrete grain elevators and malt houses, thus effectively including the all constructed malting facilities. Type IV construction may be increased to 65 feet and 85 feet in isolated areas. Since the early 1960’s very few grain storage facilities have been constructed using wood.

- IBC 415.7.1.3 - Requires dust tight spouting and conveyor covers where they pass from room-to-room or processing area-to-processing area. This requirement reflects the inherent explosion hazard in grain handling and storage facilities.

- IBC 415.7.1.4 stipulates that explosion control must follow the International Fire Code (ICC, 2003b)

- IBC 415.7.1. - States that facilities producing combustible dusts form grain storage and processing must follow NFPA 61, 120, 651, 655, 664 and 85, where applicable. In addition the provisions of the International Fire Code (ICC, 2003b) must be met. The major standard fundamentally related to grain handling facilities is NFPA 61, which addresses the dust handling hazards in agricultural and food process facilities. Applicable NFPA standards are discussed at the end of this section.

Guard Rails

Guard rails are an important feature for roofs, elevated platforms, equipment access platforms, and mezzanines. Section 1012 of the IBC gives specific design requirements for railings. In most industrial situations, the guards must be arranged such that a 21-inch diameter sphere
cannot pass through the rails. This usually requires the use of a mid rail. The requirements for guards and stair handrails are different and should be noted by the engineer before proceeding with the project. Section 1607.7.1 discusses loadings for guard rails. Rails should be designed for a 50 lb/ft load or 200 lb point load acting on any point of the assembly.

Stairs and Handrails

For most situations, IBC section 1009.1 requires a 44-inch wide stairway. When the occupant load is less than 50 people, a 36-inch wide stairway is acceptable. Stair slopes in the IBC (Section 1009.3) are more restrictive than older building codes or OSHA with a typical 7-inch rise as the maximum rise and an 11-inch run. For steeper stair slopes, such as an 8-inch rise with a 9-inch run, a variance must be obtained. The engineer should coordinate with the local building code officials as early as possible during the project planning phase, to help with this important issue. Additionally, the engineer should be aware that stair landings will be required every 12 feet (Section 1009.6); again this varies from the historical OSHA and older building code requirements. Thus, a variance must be obtained. This has a substantial impact on the resulting height of a structure, due to the size of the stairwell and the need for additional landings. Finally, section 1009.11 of the IBC gives the handrail requirements for stairs. These requirements vary significantly from guardrails. Loading requirements for handrails, however, are identical to guards and are detailed in section 1607.7.1 of the IBC (ICC, 2003a).

Exiting and Egress

Exiting and egress has extensive requirements. They are covered in detail in chapter 10 of the International Building Code. Section 1003 of the IBC describes the general requirements of exiting and egress such as height, clearances and continuity of the exit path. Another critical aspect of exiting and egress is corridor width which is usually 44 inches for most conditions, except when occupant load is less than 50, in which case it can be as low as 36” wide (IBC section 1016). Section 1008.1.1 of the IBC limits the width of doors to not less than 32”. Generally speaking, for occupancy type H, with an occupancy load of three or more people (Table 1014.1), there must be two independent exits from each floor or area. For other occupancy types such as F or B the occupant load can increase up to 50 before requiring a second exit discharge. For occupancy type S the occupant load can be 30 people before requiring a second exit path. Exit discharge is described in section 1023, occupant loads is defined in table 1004.1.2 and travel distance is described in section 1015 of the IBC. Two areas of concern for facility engineers and operators are the egress from the roof of the structure and from reclaim tunnels. Possible egress options include an exterior ladder system, an internal or exterior stair system or a man lift or elevator. As discussed in section 1003.2, egress ceiling heights should not be less than 7 feet. For other specific details the reader is referred to chapter 10 of the IBC.

Mezzanines

Section 505 of the IBC discusses mezzanine design and construction. In general, it states that a mezzanine should not be counted as part of the floor below and shall not cover more than 1/3 of the floor area of the room it occupies for purposes of building classification, but, similar to other areas of the building, is required to have two independent means of egress.

Industrial Equipment Platforms

Equipment access platforms are a special form of a mezzanine and are discussed in section 505.5 of the IBC. In general, the total of all equipment platforms should occupy less than two-
thirds of the building area at each level, and for purposes of occupancy classification shall not add to the floor area of the building. Access equipment that is attached to the platform such as stairs, ladders, walkways, and similar access shall not serve as part of the egress system for that building level.

Building Envelope and Energy Usage

Building envelope design for thermal resistance, air leakage, and heating or cooling of structures is governed by the International Energy Conservation Code (ICC, 2003c). The IECC references ASHRAE 90.1 (ASHRAE, 1999) as the governing document when calculations are made. Although some industrial buildings are exempt from the IECC, it is good business practice to minimize energy use for businesses, including process plants. Rosentrater and Williams (2005) provides an in-depth discussion of energy usage and minimization for malting plants. Required heating and cooling load requirements can be determined from ASHRAE Handbook of Fundamentals (ASHRE, 2001). A common problem in industrial process buildings is excess heat. This may require exhaust fans or ventilation, which is also discussed in Rosentrater and Williams (2005). Excess heat may be recovered for additional use in processing operations. Proper planning and design of these systems can have a major influence on the building envelope design. Ventilation design is discussed in chapter 4 of the International Mechanical Code and Moisture requirements are covered in chapter 12 of the International Building Code (ICC, 2003a).

For all buildings, the wall envelope must satisfy good thermal and moisture control. Chapter 14 of the IBC (ICC, 2003a) describes the thermal and moisture requirements of the building envelope. This chapter indicates that facility elements built to chapters 19 and 21 (masonry and concrete construction) of the IBC automatically satisfy the thermal and moisture requirements of this chapter. Wall or other building elements built to this standard must be moisture resistant.

The grain storage portion of a malting plant is unheated and does not need to meet any special energy requirements with respect to the energy portions of the building code. The engineer should be aware that the temperature may affect the quality of the contents, however.

Fire Protection Systems

Although rare, the use of active fire protection systems in industrial facilities such as malting plants can be used in increasing allowable floor area or height as described in the various sections of the IBC. They generally are not used because of the floor area exemption rule (IBC section 503.1.2) or cost.

OSHA

OSHA standards are set out in Title 29 of the Federal Code of Regulations (NARA, 2004). These standards set workplace safety, and are considered a minimum that must be met for non-public operational areas of facilities. They cover a number of construction-related issues such as access, exits, fixed ladder construction, stairs, ships ladders, guardrails, equipment access, and tunnel construction. Most items relating to constructed facilities are in section 1910 of Title 29. OSHA standards are also of significant importance to facility operators as they influence a number of operational items relating to worker safety. OSHA standards are only enforced if more stringent than the controlling building code. These items are outlined in Table 1 at the end of this section.
Sanitary Requirements

As a malting plant is a food manufacturing facility, it is governed by Title 21 of the US Code of Federal Regulations (Nara, 2004). These regulations spell out the broad objectives of good sanitary operation. A number of these provisions affect how a plant is designed and constructed. Good housekeeping, moisture resistance, cleanability, and dust accumulation prevention are key elements of good sanitation.

In storage areas of malt facilities the prevention of explosions and fire hazards are important. Key to this issue is adding dust sheds to roof beams, receiving pit beams, and other areas where significant amounts of dust will accumulate. Dust control also involves the addition of baffles in the receiving areas. The engineer plays a major role in assisting the owner with good housekeeping techniques during design and construction.

In the processing areas of a malting facility high moisture environments exist that require corrosion resistant materials of construction such as stainless steel or galvanized steel construction. Attention should be paid to room finishes and details for general cleanability. For example closed shapes such as HSS tubes should be considered for both beams and columns. Alternately, open shapes can be closed with plates. Seal welds should be considered to keep dirt and infestation out of walls, cavities, or other elements. Alternately, cavities can be filled with inert sanitary material. In the storage areas smooth finishes are desirable. Programs and methods should be developed for rodent and insect infestation control. For specific recommendations the reader is referred to Imholt & Imholt (1998).

Supplemental Codes and Standards

The International Building Code (ICC, 2003a) specifies that specialty facilities must incorporate a number of special design provisions. Chief among these is the Nation Fire Protection Association (NFPA) documents outlined below:

- NFPA 68 – Guide for venting of deflagrations (NFPA, 1998a) - This standard covers the design and installation of devices and systems to relieve pressures and gasses that result from explosions. It also includes information on the calculation of explosion pressures. This standard is commonly used in the malting industry to determine bucket elevator venting and venting for silos that contain powder-like agricultural substances, such as grains.

- NFPA 69 – Standard on explosion prevention systems. (NFPA, 1998b) This standard covers the design, construction, operation, maintenance, and testing of systems for the prevention of explosions. This document covers the prevention of explosions by the following methods: (1) control of oxidant concentration, (2) control of combustible concentration, (3) explosion suppression, (4) deflagration pressure containment, (5) spark extinguishing systems.

- NFPA 61 – Standard for the prevention of fires and dust explosions in Agricultural and Food Products facilities. (NFPA, 1999) As the name implies, NFPA 61 is a standard that relates to dust explosion safety in agri-industrial process facilities that handle bulk materials. This document covers construction requirements such as egress, interior wall construction, building fire protection, and equipment including: dryers, venting, heat transfer operations, dust control, pneumatic conveying, and building fire protection.
Table 1. Design matrix for malting plant life safety considerations.

<table>
<thead>
<tr>
<th>Code Item</th>
<th>Description of Application</th>
<th>Code Section/Requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>IBC</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Occupancy</td>
<td>Determined based on the use of the structure. E.g. hazardous, manufacturing, business office. Methods of calculation for mixed occupancy</td>
<td>Chapter 3 outlines occupancy types. Grain storage is typically Group H-2. All other processing is Group F1. Business office is group B. Group S occupancy for general storage</td>
</tr>
<tr>
<td>Detailed Requirements Based on Use and Occupancy</td>
<td>Special requirements for the construction of hazardous facilities such as grain elevators, feed mills, or malt plants</td>
<td>Chapter 4 section 415.7</td>
</tr>
<tr>
<td>Types of Construction</td>
<td>Based on the materials used and the fire resistance of the components. Most grain elevators are Type I and II construction</td>
<td>Chapter 6.</td>
</tr>
<tr>
<td>Location on Property and exterior fire wall rating</td>
<td>Location of the structure on the site. Influences the fire rating. Special lot line distances are defined in Section 415.7.1.5</td>
<td>Chapter 6 table 602</td>
</tr>
<tr>
<td>Floor Area</td>
<td>Maximum floor area is a function of construction type and occupancy</td>
<td>Chapter 5, table 503</td>
</tr>
<tr>
<td>Height and Number of Stories</td>
<td>Influenced by floor area, construction type and fire protection. See Section 415.7.1 for height requirements</td>
<td>Chapter 5, table 503</td>
</tr>
<tr>
<td>Fire-Resistance-Rated Construction.</td>
<td>Code prescribed requirements for materials and assemblies used to separate adjacent areas and prevent the spread of fire and smoke</td>
<td>Chapter 7 Table 302.3.2</td>
</tr>
<tr>
<td>Stairs</td>
<td>Design of stair stringers, rise and run, and stair construction details</td>
<td>Chapter 10, section 1009</td>
</tr>
<tr>
<td>Guard Rails</td>
<td>Design of guard rails, construction requirements for walkways, stairs, and</td>
<td>Chapter 10, section 1012</td>
</tr>
<tr>
<td>Mezzanines and industrial access platforms</td>
<td>Special construction applications</td>
<td>Chapter 5 section 505.1 and 505.5</td>
</tr>
<tr>
<td>-------------------------------------------</td>
<td>----------------------------------</td>
<td>----------------------------------</td>
</tr>
<tr>
<td>Egress</td>
<td>Egress fire ratings, size, occupant loads, arrangement</td>
<td>Chapter 10</td>
</tr>
</tbody>
</table>

**OSHA**

<table>
<thead>
<tr>
<th>Egress</th>
<th>Egress fire ratings, size, occupant loads, arrangement</th>
<th>Section 1910.37</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tunnels</td>
<td>Noted in the egress section. Two methods of exit required.</td>
<td>Section 1910.37</td>
</tr>
<tr>
<td>Guard rails</td>
<td>Structural design of guard rails, construction requirements for walkways, stairs, and openings</td>
<td>Section 1910.23</td>
</tr>
</tbody>
</table>

| Man lifts and Powered Platforms           | Section 1910.66                                      |                                   |
| Fixed Industrial Stairs                   | Structural design of stair stringers, rise and run, and stair construction details | Section 1910.24                   |
| Fixed Ladders                            | Features, clearance, hatches, cages, offsets, and landings | Section 1910.27                   |

**NFPA**

<table>
<thead>
<tr>
<th>61 – Dust and Fire Control in Agricultural Facilities</th>
<th>A major design requirement for equipment such as bucket elevators, conveyors and the like.</th>
<th>NA</th>
</tr>
</thead>
<tbody>
<tr>
<td>68 – Guide for venting of Deflagrations</td>
<td>A guide for the design and construction on explosion forces and explosion panels</td>
<td>NA</td>
</tr>
<tr>
<td>69 - Standard on explosion prevention systems</td>
<td>A guide for the design of explosion prevention systems</td>
<td>NA</td>
</tr>
</tbody>
</table>
Figure 5 - Flowchart of life safety design considerations.

**Structural Design Considerations**

Typical major structural elements of a malting facility include: (1) malting buildings or towers, (2) kiln vessels, (3) germination and steeping vessels, (4) grain storage, reclaim and distribution systems, (7) cleaning & dressing towers, and (6) load out and receiving buildings. The loads on a malting facility are unique and require special attention by the engineer. Because of the
specialized design requirements for malting facilities, which are currently undocumented, this section will examine several commonly used design procedures.

**Overview of Malting Plant Loads**

Before the actual structural analysis and design is undertaken, the loads on the total system must be determined. Items such as structural tower weights, equipment weights, snow, and floor and roof live loads must be determined. This information can be gleaned from equipment vendors and from the building code documents such as ASCE 7-02 “Minimum Design Loads for Buildings and Other Structures” (ASCE, 2002). Additionally, bulk solids loadings for grain or other materials must be determined using ACI 313 (ACI, 1997) or ASAE EP 433 (ASAE, 2001). Table 2 provides bulk solids properties for malted and unmalted barley which are crucial for structural design considerations. Although many methods exist for the determination of the vertical and lateral loads, the most commonly used equation for bulk solids loading is Janssen’s equation:

\[
q = \frac{\gamma R}{\mu k} \left( 1 - e^{-\frac{-\gamma R}{\mu k}} \right)
\]  

(1)

where:
- \(q\) = vertical pressure (lb/ft\(^2\))
- \(R\) = hydraulic Radius (ft)
- \(\mu\) = coefficient of friction
- \(k\) = lateral to vertical coefficient \((1 - \sin M)\)
- \(\gamma\) = density (lb/ft\(^3\))
- \(Y\) = depth of product (ft)

And the lateral wall pressure, \(p\) (psf), from bulk solids is given by:

\[
p = kq
\]

(2)

Finally, wall friction, \(V\) (psf), from bulk solids can be determined as:

\[
V = (\gamma Y - q)R
\]

(3)

Janssen’s equation is dependent on the coefficient of friction of the material, the bulk density, the lateral to vertical pressure coefficient, and the depth of the grain. Janssen’s equation represents the static pressure of the grain in a silo. It is necessary to adjust the pressures for the dynamic effects of filling or discharging of the grain. This is commonly done in practice by multiplying the lateral wall pressure by an overpressure factor. Common values for overpressures are shown in Table 3. Recommendations for overpressures vary by country, standard, and material.
Table 2. Estimated physical properties of grain and malt essential for structural design.

<table>
<thead>
<tr>
<th>Commodity</th>
<th>Density (lb/ft³), γ</th>
<th>Angle of Internal Friction (degrees), θ</th>
<th>Effective Angle of Internal Friction (degrees)</th>
<th>Coefficient of Friction Against Corrugations, µ</th>
<th>Coefficient of Friction Against Concrete, µ</th>
<th>Coefficient of Internal Friction Against Steel, µ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Barley</td>
<td>45 – 54</td>
<td>20</td>
<td>26 – 33</td>
<td>Varies</td>
<td>0.46 - 0.62</td>
<td>0.32 – 0.51</td>
</tr>
<tr>
<td>Malt</td>
<td>28 – 35</td>
<td>26</td>
<td>26</td>
<td>Varies</td>
<td>0.5 – 0.66</td>
<td>0.35 - .0.55</td>
</tr>
<tr>
<td>Green Malt</td>
<td>40</td>
<td>40</td>
<td>40</td>
<td>Varies</td>
<td>0.60 - 0.70</td>
<td>0.40</td>
</tr>
<tr>
<td>Malt Culms</td>
<td>15</td>
<td>45</td>
<td>45</td>
<td>Varies</td>
<td>0.6</td>
<td>0.5</td>
</tr>
<tr>
<td>Dust</td>
<td>20</td>
<td>35</td>
<td>35</td>
<td>Varies</td>
<td>0.50 – 0.60</td>
<td>0.40 - 0.50</td>
</tr>
</tbody>
</table>

Table 3. Recommended overpressure factors.

<table>
<thead>
<tr>
<th>Material/Construction Type</th>
<th>Minimum Over Pressure Factor, C_d</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concrete</td>
<td>1.5, 1.4</td>
<td>ACI 313-97, ASAE (2001)</td>
</tr>
<tr>
<td>Smooth Wall Steel</td>
<td>1.35 min, 1.4</td>
<td>Rotter (2002), ASAE (2001)</td>
</tr>
<tr>
<td>Corrugated</td>
<td>1.5, 1.4</td>
<td>Rotter (2002), ASAE (2001)</td>
</tr>
</tbody>
</table>

Lateral loads from wind or seismic forces can have an impact on the design of a malting facility. In the latest versions of the Chapter 16 of the IBC (ICC, 2003a) and ASAE-7 (ASCE, 2002), there are extensive sections for determination of wind and seismic loads for non-building and building structures. Williams and Rosentrater (2004) have a discussion on lateral loads on silos. Consultation with the building code official on snow loads is not uncommon due to local variations.

Live loads for malting facilities include worker platform loads, movable and fixed equipment loads, and liquid vessel loads in addition to grain loads. Liquid loads are typically based on the density of water. Some equipment imparts dynamic or vibratory loads onto the supporting floor or structure that the design engineer will have to consider. Table 4 outlines typical live load conditions that the design engineer must consider.

**Grain Storage, Reclaim, and Distribution Design**

Whole grain storage, malt analysis, and blending bins may be either concrete or steel in a malting facility. Raw barely can be stored in bulk in flat storage, corrugated steel tanks, smooth wall steel tanks, or in slip form silos. Finished malt can be stored in smooth wall slipform silos or smooth wall steel tanks. Key elements of grain storage are the distribution and reclaim systems which are discussed in Rosenttrater and Williams (2004). The engineer must carefully plan the structural elements, which include the foundation and reclaim tunnels, storage wall construction, roof systems, and equipment supports. Foundation types include mat, ring, and pile type foundations which may be designed by conventional or numerical methods. Tunnels and pits must be designed for surcharge loads from the silo in addition to any soils loads. Silo walls must be investigated for hoop tension, bending and shear in addition to vertical axial capacity. Extensive details of structural and planning design considerations of these elements are discussed in Williams and Rosentrater (2004).
Table 4. Typical live loads for malting facilities.

<table>
<thead>
<tr>
<th>Area</th>
<th>Uniform Load</th>
<th>Concentrated Load</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roof</td>
<td>Greater of 50 psf live on storage silos, 20 psf min on other buildings, snow load, or rain</td>
<td>Actual equipment or tower loads</td>
<td>Can eliminate point load reactions by adding floor beams under reaction point</td>
</tr>
<tr>
<td>Vessels</td>
<td>Roof live load of 20 psf or snow load if outside</td>
<td>Any special equipment or point loads</td>
<td></td>
</tr>
<tr>
<td>Misc Platforms</td>
<td>60psf live loads are typical depending on situation.</td>
<td>Equipment loads or supports usually are part of platform design</td>
<td></td>
</tr>
<tr>
<td>Elevated Bin Floor Bottoms</td>
<td>Per modified Janssen’s equations</td>
<td>Usually there are none</td>
<td>Don’t forget the sand fill slick coat</td>
</tr>
<tr>
<td>Cleaning and dressing towers</td>
<td>100 to 200 psf Live loads are typical depending on the situation. Additional support may be required for equipment</td>
<td>Per equipment vendor see flow diagram for location. Vibration can be a concern</td>
<td>Locate near beam supports to limit effects of punching or additional flexural loads and to increase vibration resistance</td>
</tr>
<tr>
<td>Stairs</td>
<td>100 psf</td>
<td>1000 lb point load</td>
<td>OSHA</td>
</tr>
</tbody>
</table>

**Germination and Steeping Vessel Design**

Most modern germination and steeping vessels are constructed from stainless steel. Some are occasionally constructed from concrete. Both rectangular and circular germination and steeping vessels may be constructed (Briggs, 1998), although circular vessels make more sense from both a structural and a process standpoint, they make less sense from a layout or space usage viewpoint. Figure 6 shows typical circular and rectangular germination vessels. A recent revival in the use of stainless steel cylindrical-conical steeping vessels is occurring because of water and malt recovery advantages. Figure 7 shows both circular and cylindrical-circular steeping vessels. Concrete vessels that contain liquids should be designed in a manner to properly contain water. The design engineer should reference ACI 350-01 “Code requirements for Environmental Engineering Concrete Structures” (ACI, 2001a). For seismic loads on concrete structures the reader should examine the provisions outlined in ACI 350.3-01 “Seismic Design of Liquid Containing Concrete Structures” (ACI, 2001b). Concrete wall forces on rectangular tanks can be analyzed using methods described in Timoshenko et al (1959).

Most steel vessels are constructed using stainless steel and care must be taken when specifying construction procedures for these vessels. Stainless steel can be welded using shielded metal arc welding, gas tungsten arc welding, or gas metal arc welding. Stainless is not much more difficult to weld than mild carbon steels, but the reader should be aware that there are a number of physical properties that may vary from mild carbon steels including lower melting temperature, lower coefficient of thermal conductivity, higher coefficient of thermal expansion, and higher electrical resistance. These properties require adjustments in welding technique.
The structural design of stainless steel is different than that of mild steels. Physically, stainless steel exhibits different stress-strain behaviors than mild steel. The controlling document for stainless steel tanks should be API 620 “Recommended Rules for the Design and Construction of Large, Welded, Low Pressure Storage Tanks” appendix S or ASCE 8-02 “Specification for the Design of Cold Formed Stainless Steel Structural members. AWWA D100-96 “Welded Steel Tanks for Water Storage” should be consulted for additional design requirements. Seismic design provisions are outlined in ASCE 7-02 “Minimum Design Loads for Buildings and Other Structures” (ASCE, 2002). ASCE 7-02 references API 620 “Recommended Rules for the Design and Construction of Large, Welded, Low-Pressure, Storage Tanks” and API 650 “Welded Steel Tanks for Oil Storage” which contain extensive seismic design outlines the requirement for the consideration of sloshing effects from liquids. It should be noted that the liquid load design requirements in ACI 350.3 apply equally to all materials of construction and are nearly identical to the API provisions. Vessels containing liquids should be designed for hydrostatic load distributions (based on water density) and those with grain only should be designed for deep or shallow grain pressures as dictated by conditions. Gaylord et al. (1997) outline procedures for granular loads for both deep and shallow bins. API 620 (1998) and API 650 (2002) give details of how to design for hydrostatic loads.

Vessel roof construction, if required, can be an inverted conical roof or rafter type construction. Details of design methods are described in Gaylord and Gaylord (1984). Not all vessels have roof systems. Floors are generally constructed of steel and can be flat or inclined. Careful resolution of forces on the vessel walls is important at the perimeter and may require the use of stiffening elements and intermediate radial columns can carry load down to the ring or mat style foundation.

Figure 6 – Typical germination vessel configurations (adapted from Briggs,1998).
Malting Building/Tower Design

The malting building can utilize either horizontal or vertical layouts (figures 2 and 3). With a horizontal design the building is likely to be low rise steel or precast construction. When the building is constructed from steel, it is likely that the structural members will be galvanized or otherwise protected from the high moisture environment. A concrete building will most likely be precast or tilt-up concrete. Details of precast design are given in the Precast Concrete Institute Design Handbook (1999) and tilt-up construction details are given in Tilt-Up Construction Seminar Course Manual (ACI, 1989). Sanitation is a concern and the design engineer must pay attention to how easy the surfaces are to clean, resistance to cleaning solvents and collection of dust, dirt or food residue. Steel construction is designed in accordance with the AISC Manual of Steel Construction (AISC, 1989). Steel or Stainless steel liner panels will be required in the facility as sanitation dictates. Platforms and catwalks should be of sanitary construction. Specific details for sanitary conditions are given in Imholt and Imholt (1998) for both steel and concrete buildings.

When a vertical layout is used, a slip form tower is often the best choice for the construction method. Slip forming is a vertical extrusion like construction method for concrete. As figure 3 shows, the tower is typically round. Rectangular shape can also be used, but walls must be stiffened by using integrated wall columns known as pilasters. Rectangular walls are flat elements and are designed by chapter 14 of ACI 318 (ACI, 2002). Pilasters are designed as beam-columns using chapter 10 of ACI 318 (ACI 2002). Circular walls are circular shell type elements that should be designed to meet the applicable requirements in chapter 19 of ACI 318 (ACI, 2002). Gaylord et al. (1997) contains a number of additional design recommendations for
shells of revolution. Foundations may be mat or ring type foundations supported by soil or piles. Foundation design details are nearly identical to grain elevators and are discussed in Williams and Rosentrater (2004). Other design options include towers constructed from structural steel. Design requirements for structural steel towers would follow the recommendations of the American Institute of Steel Construction (AISC, 1989) and the analysis of shell and plate elements would follow provisions in Timeshenko (1959).

**Kiln Vessel Design**

Kiln vessels may be located in the malt building or as independent pieces of equipment. Almost all kilns are towers constructed from steel and may be single or multiple levels (figure 8). Kiln vessels use both mild and/or stainless steel as a construction material. Procedures for designing stainless steel are examined in the section for steeping and germination vessels. Similar to steeping or germination tanks, kilns can be of circular or rectangular construction. The same design procedures outlined in the germination and steeping tank design sections. The only additional design requirements is that the temperatures in kiln buildings are likely to vary significantly, so attention must be paid to thermal expansion of the steel and concrete.

Some kilns are contained in buildings, while others are built as independent pieces of process machinery. When isolated from the primary structure, the most common foundation types would include thickened mat/ring foundations or mat foundations. Frost depth is usually not a major concern unless the kiln will be shut down for an extended period of time, thus the slabs are not built below frost depth. The reason for this is that the there is a tremendous amount of waste heat produced. Recovery techniques for heat are covered in Rosentrater and Williams (2005). When extended shut down periods and ground freezing are anticipated frost mitigation techniques for mats and grade beams are recommended; these are discussed in ASCE 32-01 “Design and Construction of Frost-Protected Shallow Foundations” (ASCE, 2001).

When designing the walls for kilns the machine will experience both vertical (axial) and lateral loads. Lateral loads are introduced from the turning equipment and the stored product. Vertical floor loads are carried by the elevated floor which carries the load to the columns. Floor systems are constructed from mild steel and covered with stainless steel. Floors may flat or inclined. Where lateral loads are high the designer should consider adding a stiffening ring to the outside of the vessel. Similar to the germination and steeping vessels, kilning vessels are covered by a rafter, cone, or dome roof systems. Details of these roof systems are discussed in Gaylord and Gaylord (1984). For input into the design of these vessels the reader is referred to the AISC manual of Steel Construction (AISC, 1989).

**Cleaning and Dressing Tower Design**

Dressing and cleaning towers are tall vertical structures that can be constructed from concrete or steel. Most towers are very tall and take advantage of gravity flow. They are usually rectangular in shape. Due to their height most concrete dressing and cleaning towers are constructed using slip form concrete methods, although it is possible to build steel towers utilizing stick-built steel systems. Rectangular walls of slip formed towers are flat elements and are designed by chapter 14 of ACI 318 (ACI, 2002). Integral wall pilasters are designed as columns using chapter 10 of ACI 318 (ACI 2002). Design requirements for structural steel towers would follow the recommendations of the American Institute of Steel Construction (AISC 1989) and the analysis of shell and plate elements would follow provisions in Timeshenko (1959). Sanitary details for both concrete and steel wall, ceiling, and floor elements are discussed in Imholt and Imholt (1998).
Cleaning towers house many types of equipment, including grain cleaners, deawners, magnets, aspirators, cleaners, screeners, graders, cyclones and debearders, which are common machinery in these towers. On the dressing side, deculmers, screeners, aspirators are common pieces of equipment. For specific details on equipment, consult Rosentrater and Williams (2005). Depending on arrangement of the process flow, it is possible to combine cleaning and dressing into a single tower. Equipment can range from a few kips to 50 kips per machine. Certain machines such as cleaners and screeners rely on regular motion of beds or rotating masses and may impart dynamic or vibratory loads onto the floors. Good practice dictates that the dynamic effect of the floors accounted for in the design. Dynamic magnification effects can be avoided by making the natural frequency of the floor 50% greater than the operating frequency of the equipment. Discussions on machine base design are included in Clough and Penzien (1975).

Floor elements may be constructed from precast concrete, cast-in-place concrete, or structural steel with solid floor plate elements. Care must be taken to design the primary and secondary floor framing elements for both operating and plugged or overflow conditions as they arise. Surge bins are commonly used in the cleaning and dressing towers and often are integral to the facility when the tower is slip formed. Alternately, steel bins on legs can be set on the floors or elevated as an integral cluster. Steel hoppers are essential elements for both concrete and steel bins. Gaylord and Gaylord (1984) and Gaylord et al. (1998) contain extensive details on steel bins and hoppers. ACI 313 (1997) and Gaylord et al. (1998) contain extensive discussions on concrete hopper design.

Foundations for tower type structures can include strip, spread or mat type foundations. Details of strip and mat foundation design are found in most elementary design text books. ACI 336.2
“Suggested Analysis and Design Procedures for Combined Footings and Mats” (ACI, 1988) provides recommended analysis and design procedures for combined footings and mats.

*Figure 9 – Typical pilaster arrangement for straight walls.*

**Load Out and Receiving Building Design**

Steel is the most common structural material for the design and construction of a rail load out or receiving facility. Precast building construction is a close alternative. The load out portion of the facility must be food grade, so attention to sanitary construction methods is important. Building foundation types would typically consist of standard shallow or deep foundations depending on soil conditions. Typically, most foundations are spread footings.

Platforms would typically consist of galvanized on painted bar grating or plate floor deck. Attention must be paid to the possibility of contamination, though. Platforms typically allow for direct access on top of rail cars or trucks for loading. Anytime there is a chance of a fall hazard the there must be a fall protection systems designed to meet the requirement of OSHA (Nara, 2004).

Pits will be located under the rail or truck lines for receiving, and will extend via tunnel to the distribution system pit to be conveyed into the raw barley storage. Conversely, the finished malt will be recovered via the reclaim system and loaded into truck or rail for shipment in bulk. Details of pit and tunnel construction are discussed in Williams and Rosentrater (2004). Grating over the pits must have baffles to prevent dust from escaping. Additional details are included in Rosentrater and Williams (2005).

**Summary**

This paper summarizes design procedures related to the construction, planning, and operation of malting facilities. In particular, the life safety, planning, and structural provisions were discussed. Standards, procedures, and methods of design and construction were discussed, including state of the art procedures. Both engineers as well as educators should find this paper useful.
References

ACI. 1989. Tilt-up Construction Seminar Handbook. Detroit, MI.: American Concrete Institute
ACI. 1988. Suggested Analysis and Design Procedures for Combined Footings and Mats. ACI 336.2-88. Detroit, MI.: American Concrete Institute
ACI. 2001b. Seismic Design of Liquid Containing Concrete Structures. ACI 350.3-01 Detroit MI.: American Concrete Institute.


Precast/Prestressed Concrete Institute. 1999. PCI Design Handbook. Chicago Illinois


