Water Closets

The impact of static and dynamic loads in the commercial restroom environment.

By Mark Lawinger

The commercial restroom is one of the only public places where people interact with the products within them in such an intimate way. One product always found in these restrooms is the water closet — more commonly known as the toilet. In many instances this product is installed in the wall-mounted method where it projects outwards without vertical support. The wall-mounted closet is frequently subjected to controlled forces such as sitting on a toilet as well as uncontrolled forces such as those generated by someone falling, dropping or even jumping onto the fixture.

There has been growing interest and demand for products that can handle increasingly larger loads. This has been driven by the steady increase in the average weight of the general population as well as the concern for safety. As this topic is discussed more frequently and more claims are being made about wall-mounted water closet strength, there is growing confusion over how to interpret the various load tests and so-called 'ratings' that are associated with sanitary fixtures. Misunderstanding of these terms and ratings can lead to potentially serious injury to a user.

This article will explore the issue by describing the types of forces wall-mounted closets are subjected to in the commercial restroom environment and the implications they have on the product design, specification and standards that govern them.

Understanding relevant loads, material properties and design principles found in the commercial restroom

As people interact with the various fixtures within a commercial restroom they apply both intentional and unintentional loads to them. These loads can be categorized and defined by physics and engineering principles. Each type of load has a different effect on the objects to which they are applied. It is important to understand these terms and principles so that proper interpretation and planning can be performed. The following section identifies these loads and describes the definitions of each.

Static loads

A static load is a mechanical force that is applied to an assembly or object in a controlled, steady manner and does not change over time. Tests that use static loads are useful in determining the maximum allowable loads an engineering structure or objects can withstand before failure. They are also useful in discovering the mechanical properties of materials and are especially useful in testing because they can be controlled and therefore be repeated with minimal variation. This provides a good basis with which to compare effects of different loads on the same object or the same load on different objects. Any load that is applied as a constant force to an object is considered a static load, and the knowledge of how much loading a structure can handle is useful for setting safety margins for the structure.

Dynamic loads

A dynamic load is an applied force to an object that varies over time. The change in force can be in the magnitude, location, direction or a combination of all of these. These forces also include those that are applied at a rapid rate. The effects of dynamic loading over time can also have a cumulative impact on an object depending on its construction. For example, a steel rod that is supported at both ends with an oscillating load applied at a location between the supports can cause the rod to deform over time. Yet that same maximum load statically applied to the same location may not have any effect at all.

One specific type of dynamic load is categorized as an 'impact load'. In mechanics, an impact is a high force applied over a short period of time such as when two bod-

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ies in relative motion to one another collide. Such a force has a greater effect than a smaller force applied over a proportionally longer period. The effect depends critically on the mass of the bodies, their relative velocity to one another and their material of construction. A common type of impact load occurs when a falling (dynamic) object makes contact with a stationary (static) object. This is a very important topic that has significant implications in the commercial restroom and will be discussed in greater detail later in this article.

Moment arms and torque

The moment arm (a.k.a lever arm) of a force system is the perpendicular distance from an axis to the line of action of a force. When this force is applied it results in a load described as torque. Torque(t) is calculated by multiplying the force (F) by the perpendicular distance from the axis (r) and therefore is expressed as inch-pounds (in-lb) or newton-meters (N-m).

$$t = F * r$$

As you can see, the magnitude of the torque increases proportionally with the length. This is easily observed in everyday life through the use of shovels, pipe wrenches and crowbars. The longer the handle is the more torque that can be applied with the same effort. You can calculate the equivalent force required to produce a given torque. This can be expressed as:

$$t_1 = t_2$$
$$F_1 * r_1 = F_2 * r_2$$
$$F_2 = F_1 * (r_1 / r_2)$$

Conservation of energy

In physics, the law of conservation of energy states that the total energy of an isolated system remains constant — it is conserved over time. This is true for an impact force created when a falling object hits the ground. In this situation all of the potential energy (PE) of the object is converted into kinetic energy (KE). The magnitude of the impact force is greatly affected by the distance it takes for the object to come to rest. The shorter the distance it takes to stop the object the greater the impact load. This is a critically important factor to understand as we discuss the tests and standards that apply to carriers and fixtures later in this article.

The following is a simplified summary of the equations that can be used to estimate the impact load of a falling object.

The potential energy (PE) of an object is PE=m * g * h where m=the mass of the object (lbs or kilograms), g=the gravitational constant (32.17 ft/s^2 or 9.8 m/s^2) and h=the vertical distance that an object falls (feet or meters). It is easy to see that for a given object the higher it is from the ground the higher its potential energy.

As the object falls the PE is converted into Kinetic energy (KE) until it finally reaches the ground where the KE is equal to the original PE. The kinetic energy of the object is $KE=½m * v^2$. Where v=velocity of the object just as it reaches the ground. If we neglect air friction as negligible we can calculate the velocity – and in fact, this will be the same for any object regardless of its mass for a given height:

$$KE = PE$$
$$½m*v^2 = m*g*h$$
$$½*v^2 = g*h$$
$$v = \sqrt{2gh}$$

Once the object makes contact with the ground it begins to slow down but can continue to move some distance depending on what material the ground or object it strikes is made from until it comes to a full rest.

Let's call the kinetic energy of the object just as it touches the ground KE1 and the kinetic energy of the object after it hits the ground KE2. Because the energy must be conserved we can conclude that the potential energy of both situations is also equal - PE1 and PE2. The equation that represents this would be as follows:

$$PE_1 = PE_2$$
$$m*g*h_1 = m*g*h_2$$

In order to estimate this value as an equivalent impact force we can assign a new 'equivalent mass' to the object after it made contact with the ground.

$$m_1*g*h_1 = m_2*g*h_2$$

Since the gravitational constant is the same the difference between the two states is simply the ratio of the two heights times the mass of the object.

$$m_2 = m_1 * (h_1/h_2)$$

Tensile, shear and compressive strengths

All materials such as steel, wood, plastic or vitreous china possess different characteristics that define how they will react under different conditions. One of these conditions occurs when a load is applied to them. There are material properties that define how resistant they are to breakage or deformation when a load is applied. Standardized test procedures have been developed to accurately measure the properties until they break and are represented by various values. These properties together define how 'strong' they are and are used by engineers to properly select materials for the product they are designing depending on the type of loads they are expected to experience during use. Three material properties that are used frequently are known as compressive, tensile and shear strength:

- Compressive strength is the capacity of a material or structure to withstand loads tending to reduce its size.
- Tensile strength is the capacity of material to withstand loads tending to elongate its size.
- Shear strength is the capacity of a material to withstand sliding loads that act in different parallel directions along a plane.

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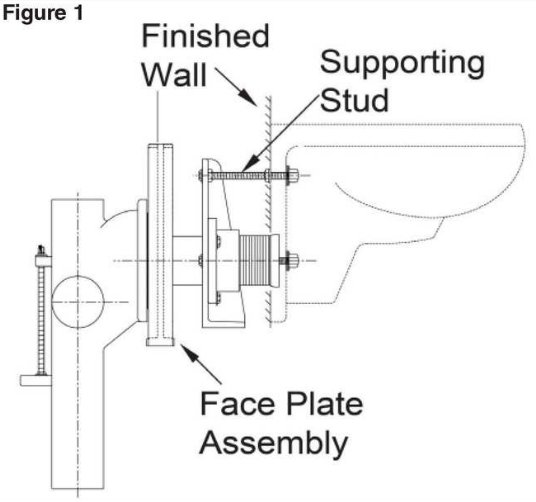
Figure 1



Materials of construction

The vast majority of closet fixtures are made from a material known as vitreous china, commonly referred to as ceramic, which is comprised of several earthen materials mixed with water. After being molded into various shapes and covered with a silica-based coating known as glaze, which is a form of glass. When this material is exposed to extremely high temperatures it becomes very hard and attains high compressive strength properties. Conversely this material is also very brittle which contributes to moderate to low tensile and shear strength properties. This combination of properties prevents vitrified china from bending before failure. Once the maximum load is reached it will generally break suddenly and completely. Because the outermost layer is made from glass the edges of broken vitreous fixtures are extremely sharp and dangerous.

Carbon steel, on the other hand, has excellent tensile strength properties as well as significant compressive strength. Unlike vitreous china, steel will generally deform or bend under extreme or repetitive loads before it fractures or breaks. Many types of steel alloys are used in combination with materials such as concrete, ceramic and vitreous china to obtain complimentary properties. A common example of this is when steel rebar is used with concrete as road beds and building infrastructure.

Sanitaryware system design and installation process

Wall-mounted closets, also known as wall-hung closets, are installed using the cantilevered method. A cantilever describes a projecting structure that is supported at one end and that carries a load at the opposite end or along its length. A perpendicular force applied to a cantilever creates a torque load through the moment arm concept described previously. These fixtures utilize a support system that is commonly referred to as a carrier that provides off-the-floor support and directs the fixture waste discharge into the drainage system. Carriers are available in several different configurations that can accommodate many installation circumstances such as back-to-back closets, adjustable vertical positions and direction of waste flow. In all cases the carrier's primary function is to provide a stable mounting system for the closet. Carriers are usually constructed of cast iron and steel and are located just behind the wall in the restroom where the closet is located. These carriers must be securely mounted to the flooring via appropriate fasteners such as lag bolts.

The governing ASME standards have specific dimensional and performance requirements for both the wall-hung closet and the carrier mounting apparatus that assure secure mounting and dimensional consistency so that all carrier and closet manufacturer's products can mount with one another interchangeably. These standards will be discussed in greater detail later in this article.

From a structural standpoint, the carrier is mounted to the flooring of the building and is piped into the horizontal or vertical drainage pipes behind the wall. It is critical that the installation procedure to mount the carrier to the floor is performed according to the carrier manufacturer's instructions. The carrier uses four, 1-inch threaded mounting rods arranged around the outlet entrance that protrude through the finished wall. (see Figure 1). A bearing nut and washer are threaded onto the rod near the wall that provide a mounting surface for the closet. The washer should always have a small gap approximately 1/16-inch to 1/8-inch from the finished wall. These should be located so that all fall within the same vertical plane and the top of the closet is level. The backplate of the closet has four, 1-inch diameter mounting holes that these rods pass through during installation and rest against the washers. Four closet cap nuts included with the carrier are screwed onto the rods to hold it in place. A final bead of caulk is then applied around the perimeter of where the backplate meets the wall for a clean finished look.

During installation it is important to know that the cap nuts should always be installed to a specified torque and in in a specific order. They should be installed in a counterclockwise order starting with the upper right location when facing the closet from the front. The first three nuts should be tightened to the carrier manufacture's specification, but the last nut should only be tightened about one-half turn past hand tight. This is an important aspect that many installers are unaware of this and can result in breakage during installation or while in use. For this reason, we will take some time to explain how this works.

Previously we explained that vitreous china has high compressive strength. Compressive loads must have a fully supported static surface acting in an opposite direction. The mounting method of a closet against the carrier bearing nut and washer applies a compressive load to the backplate. For take advantage of the vitreous china's high compressive strength there cannot be any gaps between the supported bearing washer and closet backplate while under load. The backplate of a wall hung closet can be considered what is known as a plane in geometry. A plane is defined as the 2-dimesional space/area created between any three points. The backplate is mounted against four bearing nuts and washers on the carrier rods. It very difficult to position four points exactly in the same plane. We have all experienced this when we encounter a table

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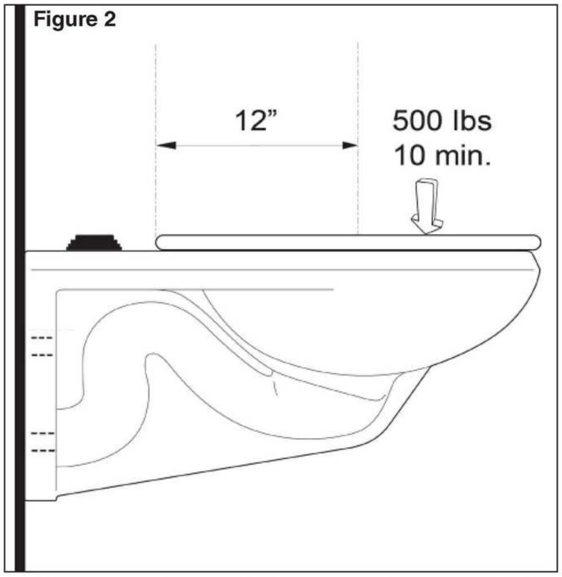


with four legs that rocks back and forth. Tables with just three legs do not experience this issue because all three legs are always in contact with the floor – a good example of a plane.

In the wall-hung closet example, if just one of those bearing nuts is not in alignment with the other three, which is not uncommon, it will leave a small gap and when the cap nut for that hole is tightened it generates a shear load on the backplate that can exceed the maximum load and break. By tightening the first three cap nuts they will always be in the same plane and therefore be in a compressive load situation. By leaving the last cap nut hand tight the installer will avoid applying a tensile load to the backplate and risk breakage.

When viewing the installed closet from the side as weight is applied, the resulting load on the two top locations is away from the wall against the washers and cap nuts. The load on the bottom two locations is in the opposite direction toward the wall against the bearing nuts and washers. This puts much of the top portion of the closet in tension while much of the bottom portion is in compression. The backplate is designed to distribute the resulting load across as much of the area as possible to prevent breakage. (see Figure 2)

Industry standards

Before we discuss the specific standards related to wall-mounted closets, it is important to recognize that the tests and standards developed do not necessarily correlate to specific real-world situations rather, general conditions and user expectations. There are simply far too many potential variables and scenarios to anticipate and replicate in a series of tests. In a sense these can be considered minimum requirements.

It is the manufacturer's responsibility to design their products to meet or exceed these standards as they see fit and put manufacturing and testing control plans in place to ensure they continue to meet them. It is also the responsibility of the specifying architects, engineers and building owners to understand these standards and their implications in the real world before selecting products that are appropriate for their specific application.

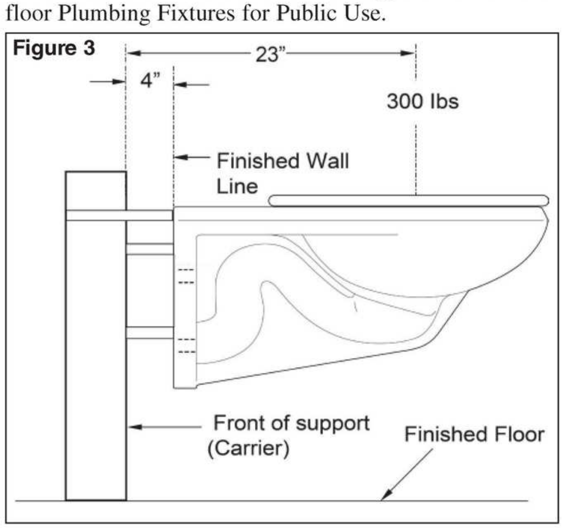
Vitreous china fixtures

The most recognized and widely accepted standard in the commercial restroom industry as it relates to vitreous china fixtures is ASME 112.19.2-2013/CSA B45.1-2013 – Ceramic Plumbing Fixtures. This standard sets a variety of dimensional, mechanical and hydraulic performance requirements for vitreous china fixtures. These standards are provided so that architects, engineers and building owners can have a common understanding of their installation and a certain level of performance expectations. It also aids in the ability of these stakeholders to more easily specify and install products so that different manufacturer models can be exchanged for another without undue effort and expense.

The relevant section regarding loads is 6.7 - Structural integrity tests for wall mounted plumbing fixtures. Subsection 6.7.2 applies to wall-mounted water closets. In 6.7.2 the closet is mounted to an apparatus and, a vertical static load of 500 pounds is applied for 10 minutes at 12 inches from the centerline of the seat holes for an elongated bowl (10 inches for a round bowl) while a plastic seat with bumpers is installed on the closet (unless the closet is not intended to be used without a seat) (see Figure 3). If the water closet does not fail or exhibit visual structural damage it is considered to have met the requirement. It is important to recognize that the standard does not have a section dedicated to load requirements for floor mounted fixtures.

Fixture supports (a.k.a carriers)

Dimensional and performance requirements for wall-mounted fixtures share, by definition many common requirements and/or rely on the carriers used to support them. The standard that governs these carriers is ASME A112.6.1M-1997 – Floor Affixed Supports for off-the-floor Plumbing Fixtures for Public Use.



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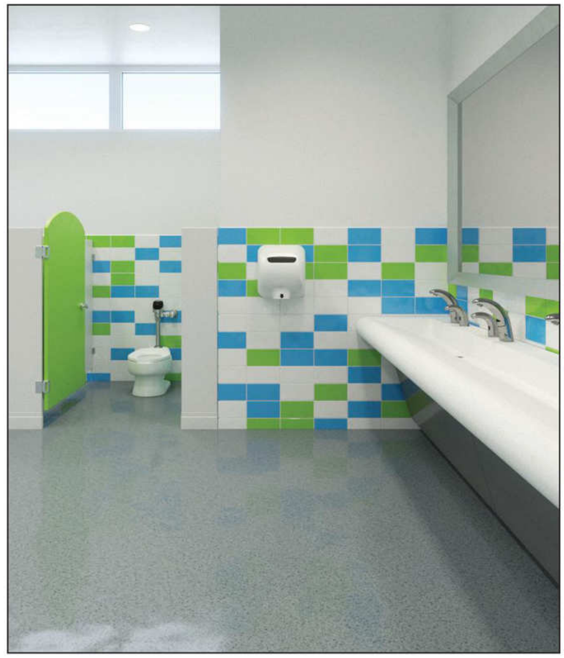

The relevant section regarding loads is Section 11 – Strength and Deflection. Sub-section 11.2 and Table 2 describe the test parameters required to pass. For wall-mounted closets a vertical static load of 300 pounds is applied 23 inches from the front of the carrier faceplate. The top surface at the furthest point away from the carrier faceplate may not deflect vertically more than 0.375 inches and the forward horizontal deflection of the top rear portion of the fixture backplate may not deflect more than 0.125 inches. If the carrier withstands the maximum static loading without failure, permanent distortion, or deflection in excess of those described, it is considered to have met the requirements. Note that this static load rating for carriers is 200 pounds less than the load requirements for the fixtures they are intended to support. Depending on the carrier manufacturer's own specifications, it is entirely possible that the carrier is the determining factor of whether a failure may occur during use.

Pulling it all together

Now that the various factors and forces involved with the design, installation and testing of wall hung fixtures is understood, let's investigate how these principles are applied in the real world commercial restroom environment.

For the vast majority of uses, wall hung closets experience little undue stress or strain. They are installed adequately, used by typical people and as intended. It is, however, when the product is not installed correctly, the user is not 'typical' or the fixture is not used in exactly as intended that are cause for attention and concern. Excessive loads can be applied to fixtures in a multitude of ways. The following are just a few examples of factors and variables that occur in a real-world environment that may fall outside of the parameters that the standards were developed:

- Size and weight of users exceeding 350 pounds, 400 pounds or more;
- Cultural differences in bathroom use such as users squatting on top of a toilet;
- Non-standard uses such as standing on toilet to reach something; and
- Slipping or prematurely dropping onto the toilet while preparing to sit.

The increase in overweight users has gained much more attention in public restrooms and hospital settings in the past 10-15 years. There are now design recommendations by various organizations to address aspects of obese and morbidly obese users that affect restrooms in a variety of facilities. These aspects cover features such as size of openings, strength of products as well as additional accessories and devices that may help these individuals or their caretakers access and use products.

A load requirement for water closets that has been increasingly cited in various publications for obese people, generally referred to as bariatric patients in a healthcare setting, is 1,000 pounds static load. However, to date there are no independent organizations that have officially recommended, endorsed or defined this value further. No documentation or rationale for using this figure is available other than it is twice the ASME standard for wall mounted closets. In addition, this commonly referenced load figure is not restricted to floor mounted or wall hung closets. This has major implications if applied to wall mounted closets. It is reasonable to believe that most users, intentionally or otherwise, do not always lower themselves onto the seat in a controlled manner and this

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themselves onto the seat in a controlled manner and this may be especially true for those that are very heavy. When a user drops or falls onto the seat even for a short distance, it creates a dynamic, or impact, load. As discussed previously, for the same mass an impact load will, by definition, be larger than if applied in a static manner due to the effects of gravity.

To illustrate this concept, the formula for potential energy and impact loads listed earlier can be used. Let's assume there is a 300-pound user that drops the last 4 inches to the seat. In order to calculate the impact load, we also need to estimate the distance it takes for the person to come to a full rest on the toilet. This distance is comprised of two elements that help to slow and somewhat cushion the impact. The first element is straight forward and easy to understand. It is the downward deflection of the toilet during impact. While the ceramic fixture itself does not deflect, the carrier system does. The second element involves a biological element of the human body and a straight face while considering it. It is the amount that the user's buttocks compresses. These two aspects both help cushion the impact load like a shock absorber. Per the fixture support standard, the toilet and carrier cannot deflect more than 0.125 inches, so we will use that value for the first element. As for the human factor we'll use 1.5 inches for this example. The impact load can then be approximated as follows:

$$300 \text{ lbs} \times (0.33 \text{ ft} / 0.135 \text{ ft}) = 733 \text{ lbs}$$

Furthermore, the torque at the prescribed distance of 12 inches in this example would be 3,600 inch-pounds per the standard. However, if the center of gravity for that same person in the example above made impact just 2 inches further away from the wall at 14 inches the resulting torque would be:

$$733 \text{ lbs} * 14 \text{ in} = 10{,}262 \text{ in-lbs}$$

These are simplified illustrations. Additional variables and environmental factors can be used to understand different scenarios such as location and angle of the applied load, larger drop distances or heavier individuals that may mitigate or exacerbate this effect. (see graph below for other examples).

Conclusion

Commercial water closets are in use in many environments and there have been hundreds of thousands installed over the years with little thought about their static load rating. After reading this article it should be clear that these values do not simply indicate the maximum weight of the user. If you are specifying or installing a wall mounted water closet always keep in mind the following three important aspects:

Know that a true static load situation in the real-world environment is not nearly as common as a dynamic load and that in all cases the dynamic load will be larger and potentially many times higher.

Be aware of what the static load standards and ratings mean — and what they don't. The ASME standard of 500 pounds for wall-mounted closets and 300 pounds for carriers are just what they say without any inferences that this value correlates to a specific user application.

If there is a likelihood that a closet will be used by either bariatric patients or even exceptionally larger individuals the safest approach is to use a floor mounted water closet. These closets have typical static load capacities that are 2 or 3 times higher than a wall mounted closet and provide much more stable support to the user.

As this article has shown, it is not unlikely that wall-mounted water closets over the years have been exposed to loads greater than 500 pounds. Despite this, there have been very few reported instances of broken closets or carriers during use. This is likely due to product designs that have higher load ratings than the minimum required. However, it is important to be aware the increase in heavier people coupled with more requests for 'bariatric rated closets' and more manufacturer's publishing 1,000-pound static load ratings the potential for misapplication is growing which could lead to a tragedy. ●

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