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Designing and Evaluating Playground Equipment for Compliance with the Americans with Disabilities Act

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Designing and Evaluating Playground Equipment for Compliance with the Americans with Disabilities Act



Honors Thesis

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Department: Civil and Environmental Engineering

Advisor: Dr. Kimberly E. Bigelow, Ph.D.

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Abstract

The need for accessible playgrounds is more prevalent than ever before, with approximately 3 million children having disabilities and health issues that limit their ability to partake in play and school. The Americans with Disabilities Act (ADA) recently provided, for the first time, specific accessible design standards for playgrounds. All playgrounds must now comply with these rules that went into place on March 15, 2012. As it is vital that playgrounds undergo the necessary changes to come up to compliance, there is an opportunity to develop an accessible playground design which satisfies all ADA playground standards and requirements. The objective of this project was to design, develop, and analyze an accessible play structure that included; an elevated structure and a ground level component. This project utilized the engineering design process and civil engineering knowledge to develop computer aided drawings of the structures, structural analyses, complete construction plans, material lists, and cost analyses.

Disclaimer

The analyses that have been carried out in this thesis are based on the materials chosen and assumptions made by the author. Installation of these designs should not be carried out without additional structural analyses to ensure safety based on the specific materials used, and climate and geography of the installation site.



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I. INTRODUCTION

Benefits of Play

Play is the physical or mental activity that has no purpose or objective outside of pure enjoyment and amusement (Ray). Although children play without the intent or realization that they are building skills, many essential aspects of a child's development is being expanded during play. Play can be any activity from running and jumping, to reading for some children. As long as the child is having fun performing the activity, it can be considered play, and can ultimately build the necessary developmental skills.

Play is essential in the development of children's social, emotional, cognitive and physical growth (Allsop). It is through play that children grow and learn to interact individually, with others, and as part of a larger community (Ray). Social skills that are important to know in other aspects of one's life can be learned, practiced, and perfected through play (Gopnik). These important skills include; waiting in line, taking turns, initiating and sustaining conversations, accepting assistance and support from others, listening, and getting, accepting, and giving feedback, to name a few. When children interact with other children during play, they develop and improve their communication skills (Duerr Evaluation Resources). Cooperation through sharing and collaborating with other children is also an essential developmental social trait acquired through play (Duerr Evaluation Resources). Children learn to follow directions, play by the mutually agreed upon rules, and take turns. Feedback from others is an important social aspect of play, as well as learning to ask for help. While interacting and communicating with other children through play, friendships are created and strengthened (Gopnik). These friendships are

important in learning to be sensitive with other people's needs and perspectives, while requiring children to learn to work together towards a common objective and goal.

Overall, play will develop a sense of belonging, which increases a child's self-esteem, happiness, and confidence (Wolfgang). These social skills learned through play are the foundation to successful relationships and interactions that children will engage in throughout their life (Gopnik).

Emotional skills are also important developments of play. These emotional behaviors include sense of connection and self, expression of feelings, and the experience of happiness and joy. A child's recess or play time is often times the most important activity in determining whether they will have a good or bad day. When a parent asks a child, "How was your day at school? the babysitter? daycare? etc.", the child usually replies with an account of a recess activity or playtime story, as this is the most valuable and important part of children's day's growing up (Gopnik). When the child has fun and enjoyment in their playtime, they will feel good about themselves and what they're doing, which helps the child to gain self-confidence and increase self esteem. When children are able to achieve the goals that they set for themselves during play, it enhances their self esteem through sense of success and accomplishment (Cardinal, Lee and Loprinzi). Children often clap for themselves or become overly joyful and elated when a goal is met. This sense of pride and achievement enables the child to appraise their own strengths and abilities, and as a result they will develop a strong sense of accomplishment (Cardinal, Lee and Loprinzi). The experience of being successful in play builds self-confidence and self esteem that the child may not receive otherwise. If a child does not meet their goal, they may become frustrated and angry. This is still a healthy way for a

child to express their feelings, and through continuous experience, the child will learn how to express these negative feelings in a socially acceptable manner. This expression of feelings allows the child to work through their problems and reduce aggression, rather than internalizing them (Cardinal, Lee and Loprinzi). As they become frustrated with their failure, most children will continue to try and try again until the goal is met. This experience of determination to achieve a goal will lead children to accept future challenges in life. As they master new skills and play with other children they improve their competence and confidence in their own physical and social abilities (Gopnik). Play can produce these benefits that will stay with them throughout their lives.

The sense of failure, determination, trial and error, and eventually success are also large components in building a child's thinking and problem solving skills (Ray). As part of a successful play experience, children must be engaged and focused on the activity at hand, as many decisions and choices are made throughout any playtime experience. "Which puzzle piece goes in this space?" "What game do I want to play at recess?" "Who will I pick to be on my team?" "Can I make it all the way across the monkey bars?" Even a decision as basic as "Do I like this activity? Or would I rather play something else?" is made on a daily basis when children play. As children assess risks and tackle new challenges they learn about having a goal, persistence and perseverance, and about the success those attributes can bring (Allsop). When children ask themselves these questions, they are developing decision making and problem solving skills. If they do not enjoy the activity they are participating in, they may decide to solve the problem by moving on to a different activity. Sometimes the activity they wish to participate in is already occupied by another child, in which they must recognize this, and learn to

compromise and share. Playing with other children can help the child build more complex problem solving skills as now another child is involved and must be taken into account, rather than just themselves (Wolfgang). Imagination and creativity are large components of play that are crucial to children's mental development (Ray). Everywhere that you see children playing, you will observe imaginative play, sometimes such that adults cannot even understand what the child is doing. Children who are better at pretending can reason better, and are better at thinking about different possibilities (Gopnik). The ability to analyze different possibilities and outcomes of a situation is crucial in the development of problem solving skills.

It is clear that early childhood is the most rapid period of development in the human life, most noticeably so, the physical development (Ray). Physical development and growth is the fourth essential aspect of play. Play and physical activity helps build stronger, healthier bodies in children (Murphy). Running, jumping, climbing, crawling, etc. are just a few activities that help develop a child's heart and lungs, muscles, and entire body. Many think of strength, flexibility, and coordination as something only athletes would be concerned about, but these basic physical abilities are essential for almost all activities in day to day life. It is through the repetition of physical skills during play that children are able to perfect their abilities (Wolfgang). As adequate physical activity can reduce the risk of hypertension, diabetes, obesity, asthma, and other serious health problems, doctors recommend children participate in at least sixty minutes of play or moderate physical activity per day (Pollock and Missiuna). Along with the large-muscle activity, or gross motor skills, that play develops, small-muscle activity, or fine motor skills, is also learned (Snuggs). Getting the hands and eyes to work together is a

fundamental motor skill that children learn (Snuggs). This basic concept is the underlying skill for nearly all physical activity. Playing with small toys, using the fingers to grasp tug on items, coloring, putting puzzles together, and playing with play dough are all examples of activities that use fine motor skills. These are important in learning how to control the small movements of the hands, wrists, feet, and toes, which is also essential in learning to write and have legible handwriting (Snuggs). Motor skills and physical abilities are one of the most important benefits of playing, for children. Since children grow so much in their early years, it is essential to build and develop the small and large muscle memory that will, in many aspects, carry them throughout their life (Murphy).

Benefits of Playgrounds

It has been concluded that play is necessary and beneficial for a child's social, emotional, cognitive, and physical development, as outlined in the previous section. Playgrounds are the facilities in which children can express themselves through play on many different components and equipment (Lima). Most playgrounds encompass four main components; climbing, overhead equipment, swings, and sand and water play; each offering a different skill set development for children (Thornton and Frost).

Climbing has long been established as a developmentally beneficial activity for children. In order to climb a play structure children must use cognitive skills such as memory, problem solving, and imagery and visualization (Frost, Brown and Sutterby). A child must also combat the feelings of fear and stress, possibly from the height of the equipment, which promotes the proper management of emotions. Children also love climbing because it gives them the power to change their perspective, fostering their

natural curiosity (Thornton and Frost). Most children only stand about three to five feet tall, so climbing up another five feet gives them the ability to observe their surroundings from an entirely new perspective. Climbing also clearly sharpens physical developments through perceptual motor skills such as spatial, directional, and body awareness, and agility, balance, and coordination (Frost, Brown and Sutterby). Different types of climbing apparatus' also encourage and require children to engage in different types of behaviors. For example, the steeper climbing walls require more physical strength and agility, whereas the climbing domes require more coordination and balance.

Climbing can usually be done on many different surfaces not specifically at a playground, such as couches, beds, rocks, chairs, etc, but overhead equipment presents opportunities that can usually only be found on playgrounds. Overhead equipment, such as monkey bars, hanging rings, and gliders, are a main component of playgrounds that are essential for children's learning and development (Thornton and Frost). It presents an entirely different skill set for children, not found in other playground equipment. The motion of holding on and swinging from one arm to another is called brachiation (Frost and Therrell). Brachiation develops upper body strength and endurance, hand-eye coordination, visual perception of distance, and balanced locomotor patterns (Frost and Therrell). Most babies naturally develop sufficient grip and upper body strength to support their own body weight by the time they are two years old (Stoddard), but if this skill is not further practiced and developed, the necessary strength can be lost as their body weight increases. This is why overhead equipment and the act of swinging from one bar to the next are critical to a child's development.

Although swinging from one arm to the next is important, full body swinging also provides beneficial development opportunities in children. Swings are one of the most common and exciting pieces of equipment on a playground. Children can use swings in many different ways and for many different purposes. An over stimulated child might simply relax on a swing by gently rocking back and forth, while an under stimulated child might push to go higher and higher to get a feeling of excitement (Strickland). The act of swinging can be quite challenging to children just starting out. It requires rhythm, leg and arm strength, grasping, and balance (Kerniva). All parts of the body must be working and pumping together in perfect coordination to make the swing go higher. Once children become comfortable they may even start to jump out of the swing, requiring coordination, balance, landing strength, and timing (Kerniva).

Sand and water play is the fourth major component of many playgrounds (Thornton and Frost), and provides a different type of play experience than the previous detailed above. Sand and water play offers a more independent type of play as the materials and components can be interpreted and used differently by every child. The child is the “master” of the materials and can explore different ways to use the objects. Sand and water play fulfills a child’s kinesthetic need to touch through physical and tactile exploration (Thornton and Frost). It can also be beneficial for cognitive and academic learning through mathematical concepts such as, is the bucket is full or empty, is the water shallow or deep, how many scoops are there, how tall is the sand castle, etc (Thornton and Frost). Through this experimentation type of play children can learn concepts otherwise not offered by the other playground equipment.

Mainstream vs. ADA Accessible Playgrounds

It is clear that play is important for all children, but it is essential for children with disabilities in developing important skills that may otherwise be neglected. Disabilities are not always the obvious physical impairments that require assistive devices; children may be emotionally or learning disabled, or hearing or sight impaired (Ray). Many children with disabilities are left out of traditional play because they simply do not have the ability to participate, which only leads to further problems as they are being excluded from developing many necessary skills (Holt, Moore and Beckett).

Of the four previously detailed playground equipment; climbers, overhead equipment, swings, and sand and water play, many disabled children cannot participate in any. Many children using a wheelchair or assistive device would not have the physical capabilities to climb a climbing wall or structure, hang and swing from overhead equipment, or swing in a swing, which only leaves these children the option of playing with the sand and water, or watching the other children enjoy the playground equipment. This clearly presents a critical problem. Not only are disabled children missing the development and learning opportunities that the swings, overhead equipment, and climbers present, but they are also missing out on the fun that the other children are experiencing.

The Americans with Disabilities Act (ADA) used to only have guidelines stipulating what a playground needed to be deemed accessible, but on March 15, 2012, this law was changed to include specific standards for accessibility related to playgrounds (Kalscheur). Now all playgrounds must comply with these set standards (Kalscheur).

Even with this new law passed, many playgrounds have still not been able to adapt their structures to become ADA certified, as it is expensive to make the necessary changes.

With the unfortunate position of lacking funds for upgrades, many playgrounds are put at risk of a fine of approximately \$55,000 for not coming to compliance (Assitive Technology Partners).

The new standards now specify the percentages and types of both ground level and elevated play equipment that must be accessible (Assitive Technology Partners). As such there is a large opportunity in the accessible playground market for economical options for both types of designs. The objective of this thesis project was to develop ADA accessible play equipment of both types for playgrounds wishing to become compliant. Because of the complex nature of the elevated play structures, a primary focus of this thesis was the design and comprehensive analysis of the elevate structure, ensuring it met all ADA and ASTM standards. Additionally, a feasible, cost effective ground level structure was designed to bring the playground closer to compliance of the ADA guidelines and ASTM safety standards. The objective was to design a structure that will serve as an addition to all non-compliant playgrounds in order to provide a handicapped accessible component, which brings the pre-existing structure closer to ADA compliance. It was the goal of this project that sufficient design documentation be generated so that others could eventually adopt the designs for implementation, allowing children of all abilities to interact and play together in one playground structure, expanding the social, cognitive, mental, and physical development opportunities.

Current Accessible Playground Options

Currently, limited options exist for playground structures that are accessible to individuals with disabilities. A boundless playground is one of the more commonly used accessible playgrounds (Kodjebacheva). Boundless playgrounds seek to accommodate the play needs of children living both with and without disabilities, and generally satisfy all of the requirements set by the ADA for accessible playgrounds (Kodjebacheva). These types of playgrounds have aspects different than mainstream playgrounds that make them particularly beneficial for children in wheelchairs and children with visual and cognitive impairments. Boundless playgrounds are not obstructed by the use of gates for entry and exits. Wide, accessible paths allow for easy access to all sections of the playgrounds for children in wheelchairs. Instead of sandy and grassy surfaces that mainstream playgrounds use, boundless playgrounds utilize concrete accessible paths and rubber surfaces areas which still permit the maneuverability of wheelchairs (Kodjebacheva). Swings with special restraints and accessibility are also incorporated, while ring ladders and monkey bars are lowered to the recommended reach range for children using wheelchairs (Kodjebacheva). The use of sensory rich objects and environments are also important in boundless playgrounds.

Although boundless playgrounds may be a reasonable alternative to mainstream playgrounds for children with disabilities, studies have found many downfalls in these play structures. One such limitation is the large cost of around \$80,000 to \$150,000 associated with ordering and installing a boundless playground (Kodjebacheva). Another dilemma is that in order to try to accommodate to children of all abilities, boundless playgrounds have been excessively simplified to the point that they may no longer be fun

and engaging. Many children with disabilities may look at the large concrete playground with sparse ground level equipment, and immediately become disengaged (Kodjebacheva). This also presents the problem that many children without disabilities may not be interested in playing on the boundless playground, which reduces the opportunity for social play (Holt, Moore and Beckett).

Goals and Overview of the Current Project

Boundless playgrounds have made strides in the accessibility playground market, but there are still opportunities for improvement. The goals for the accessible playground to be designed in this thesis are for children with disabilities to be able to engage in the four types of development during play; social, emotional, cognitive, and physical, which are so important to a child's growth. The playground should be exciting and engaging to the point where children of all abilities are drawn to play. This increases the potential for social and parallel play between children with and without disabilities. A successful accessible playground design should also include the four main aspects of mainstream playgrounds; climbing, overhead equipment, swings, and sand and water play, in order to ensure all opportunities for a child's growth and development are met, although, in this project, only one aspect of a play structure will be assessed.

In order to bring a playground up to ADA compliance, both ground level and elevated play structures must be considered. This thesis will utilize the engineering design and innovation process to propose one new ground level structure (i.e. activity table/music station/etc.) and one elevated structure (i.e. raised structure with ramps,

bridges, slides, etc.). The focus on the ground level structure included designing a structure that provided multiple activities that meet otherwise unmet needs of children with disabilities. The focus on the more sophisticated elevated structure was to design a structure and evaluate it through structural analysis, computer aided drawings, material lists, and a cost analysis.

Per the engineering design process, the problem statement was refined through academic and community based research. As the problem was better defined, design objectives and constraints were determined. Next conceptual designs were generated using ideation methods. From all of the designs generated, three separate designs for ground level equipment and three designs for elevated equipment were chosen and evaluated based on the analyses of the given objectives and constraints. From those three designs, necessary modifications were made and one final ground level design and one final elevated structure was chosen based on a decision analysis to be refined. Analysis was then done on both chosen designs to ensure all aspects of the equipment was safe, feasible, economical, and ADA accessible.

In particular, a rigorous analysis and evaluation was done for the elevated equipment due to its complexity. First, a complete structural analysis was done to find the overall weight of the structure. In the load analysis, it was important to take into account the dynamic loads, such as any moving pieces like swings, as they require a different analysis than the static loads of the structure. From the calculated overall weight of the structure, the loads and stresses at each column were found, taking into account the factor of safety, live, dead, wind, rain, and snow loads. These loads and stresses were used to determine the necessary size and material of the supporting posts, and the required size,

number, and spacing of the bolts at the connections used to hold the posts and structure together. Dr. Toubia agreed to serve as a mentor for this portion of the project, assisting in structural analysis calculations. The completed analysis allowed for the determination of the bolt sizes needed to support the connections, the footer size and shape needed to carry the weight of the structure, and the column supports needed to support the loads.

Once the overall loads and stresses of the structure were evaluated, the subsurface investigation began to find whether the soil is strong enough to hold the structure, and what size, shape, and material for footers best supported the structure. When calculating the depth of the footers, the depth of the frost line was taken into account. Also, the footers must be buried deep enough to prevent uplift from rocking (such as experienced by swings) or exposure from children digging. The footers were designed based on various soil types and characteristics, taking into account different locations that the playground may be installed. Recommendations for footer sizing were then made based on the soil type that may be present. Various surfaces and materials were evaluated for ease of maneuverability for children with assistive devices to find the one that most successfully accommodated the accessibility needs of the children. Based on ADA recommendations, a poured in place rubber surfacing was chosen to be used in the design analyses. The rigorous structural analysis was not conducted on the ground equipment, due to the simplicity of the chosen design and time constraints. For future steps, a functioning prototype should be constructed. The prototype should then be tested through user feedback as children with and without disabilities interact with the assembled prototype.

For both the elevated and ground level designs, the sustainability was evaluated and achieved by designing cost effective, environmentally friendly, and easily maintainable structures. The goal of the project was to develop a cost effective ground level design that would bring pre-existing playgrounds closer to ADA compliance, and an ADA accessible elevated structure. A complete material list and cost analysis was done on each structure to ensure there were no excess costs and so both could be adapted by other playgrounds. Various materials were considered and assessed for safety and environmental impact to guarantee that the materials were safe for the children using the equipment and environmentally friendly. Ease of maintenance was also evaluated to ensure the playground could easily be taken care of and maintained. The playground structures were designed to bring the surrounding community together by providing accessible playground structures for its children and residents. Once the layout, cost analysis, selection of material, and full designs were complete, a safety and accessibility analysis was done to ensure the playground met all ASTM safety standards, ADA design regulations, and playground safety standards.

Objectives and Constraints

Before beginning to develop possible design ideas, the objectives and constraints of the project had to be established. The objectives and constraints were chosen based on the research of aspects that should and should not be included in playgrounds in order to maximize the development opportunities and safety of users of the playground. The elevated structure, which was designed as an entire playground, and the ground level structure, which was designed as a more feasible ADA accessible playground component,

had slightly different objectives and constraints. For the elevated structure, it was important to accommodate children of various abilities and provide play for over twenty children in order to maximize the inclusion of all children. It was also important to provide shade for a portion of the structure to protect the user from weather, and also as sun protection because some children with disabilities are more susceptible to overheating. It was vital that the structure be handicapped accessible and incorporate three main components of playgrounds in order to maximize the development opportunities of children. Different elevations were to be incorporated in order to make the playground more enticing and visually appealing for children. In order to extend the life of the playground, it was necessary to use durable and environmentally friendly material.

There were some differences in objectives and constraints with the ground level component, as it is a much smaller and simpler structure. The goal was to provide play for six or more children at one time. It would also be important to incorporate a theme, multiple textures, and bright colors into the design. This makes the structure more appealing to children and also helps develop cognitive skills such as knowing colors and shapes. The structure must again be handicapped accessible and meet all of the ASTM and ADA regulations, such as minimum ground clearance for the table and maximum reach distance. It was vital to have no exterior legs to the activity table structure to prevent injuries of children bumping their legs into them, and also to preventing obstructions while the user is moving to sit at the table. The fourth main component of playgrounds, sand and water play, was necessary to be incorporated into the design. The purpose of the ground level structure was to provide an ADA accessible playground

component which could be cost effectively installed into an existing playground to bring it closer to compliance. For many organizations, this is a more feasible alternative to installing an entire new ADA accessible playground. Therefore, ensuring that the cost be under \$1,500 was vital.

Elevated Structure:

Objectives:

- Accommodate sight and hearing impairment, as well as physical
- Incorporate social, emotional, cognitive, and physical play
- Provide play for 20+ children
- Provide a shade for part of the structure
- Should be an easily maintainable structure

Constraints:

- Must be handicapped accessible
 - Wheelchairs, walkers
- Provide three of the four main playground components
 - Climbing, swings, overhead equipment
- Must be no safety hazards (pinched fingers, trip, entrapment, strangulation)
- Must meet all ASTM and ADA design regulations
- Must incorporate different elevations
- Must be made of a durable material (weather resistant)
- Must be made of environmentally friendly material

Ground Level Equipment:

Objectives

- Accommodate sight and hearing impairment, as well as physical
- Incorporate social, emotional, cognitive, and physical play
- Provide play for 6+ children at a time
- Incorporate a theme (sports, cars, animals, music, etc.)
- Incorporate multiple textures
- Incorporate multiple, bright colors
- Provide shade or an awning for the structure

Constraints

- Must be handicapped accessible
 - Wheelchairs, walkers
- Must meet all ADA and ASTM design requirements
- Must have a minimum ground clearance of 30 in. in height
- The center must not exceed 24 in., the maximum reach of child in wheelchair
- Must have no exterior legs
- Must have no safety hazards (pinched fingers, burns, cuts, sharp edges)
- Must be on a wheelchair accessible surface
- Must incorporate a water and sand component
- Must be made of durable material (weather resistant)
- Must be made of environmentally friendly material
- Must be easily maintainable
- Must cost under \$1,500

A successful playground design should include the four main aspects of mainstream playgrounds; climbing, overhead equipment, swings, and sand and water

play, in order to ensure all opportunities for a child's growth and development are met. It was decided that the designed elevated equipment will include three of the four aspects; climbing, swings, and overhead equipment. While the ground level component will include the sand and water play feature. With the ground level component being an activity table, it was more logical that the sand and water aspect be incorporated into its design, while the overhead equipment, climbing equipment, and swings be incorporated into the elevated structure design since it featured playground equipment.

II. ELEVATED STRUCTURE

Generation of Design Alternatives

During the design process of the elevated equipment, three designs were drafted. Each design was then put through the design analysis process where each objective and constraint was analyzed based on the design. Below are the three original designs.

***Design 1:** A tri-level elevated structure connected with ramps and including swings.*

Design 1 features a tri-level structure connected by ramps. All three structures are completely covered by plastic roofs in order to keep the sun and weather away from the children. The first structure, which is circular, sits very low to the ground (1 ft.) and houses activity walls around the inside. A very shallow sloping wheelchair slide exits off of the platform. A ramp connects the lowest platform structure to the middle structure. This square platform is slightly taller at 3 feet and has a larger slide exiting from the side. The third structure is reached from another ramp. It is also a square shape and is five feet

off of the ground. An accessible overhead ladder runs the length of the underneath of the platform. The climber is at a lower height in order to accommodate children in wheelchairs. The tri-level design gives the children three separate play areas to use. The multiple elevations and areas makes a more enticing and interesting structure for children to play on. This design features four banks of swings; three handicapped accessible and one standard. The three handicapped accessible swing banks are wheelchair swings, which are used to swing the entire wheelchair with the child sitting in place. The other swing set bank features three standard belt seats and two fully enclosed seats to accommodate all age ranges of children. Figure 1 through 3 below shows the components of Design 1.

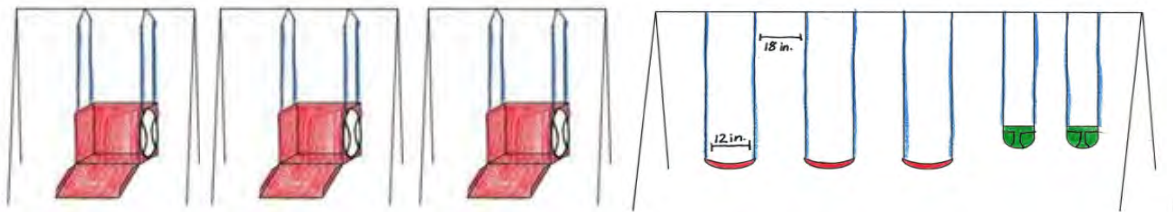


Figure 1. Envisioned Design for the Swing Sets Associated with Design 1

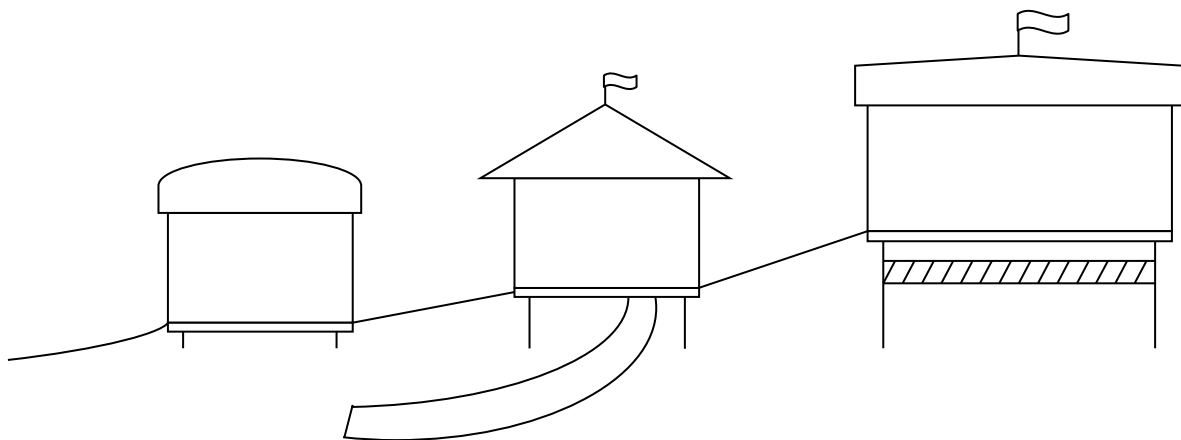


Figure 2. Profile View of the Envisioned Structure Associated with Design 1

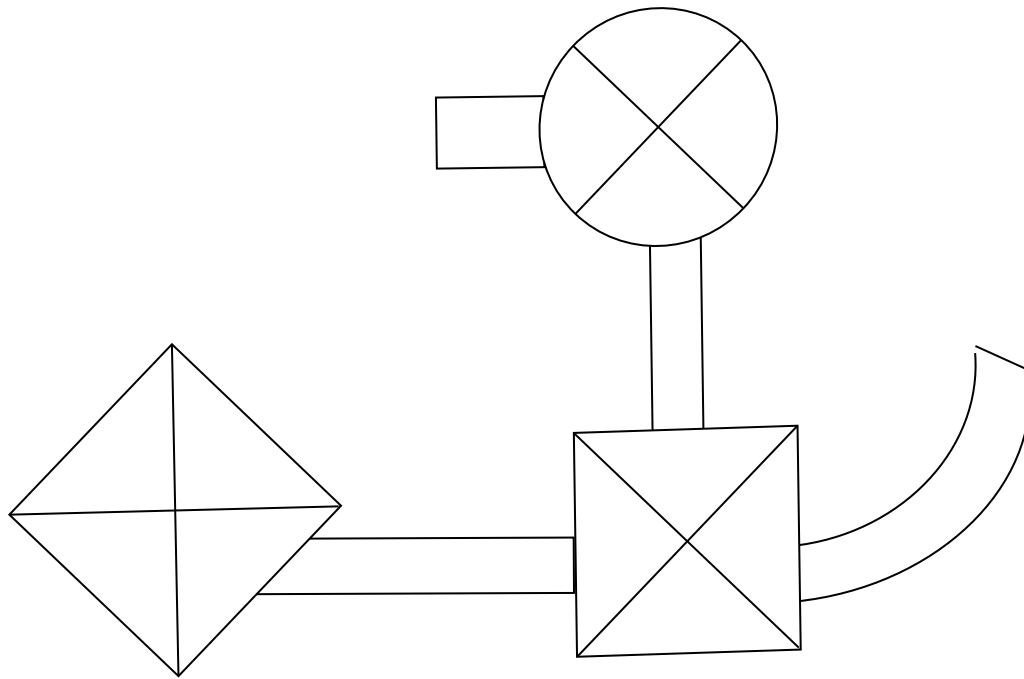


Figure 3. Top View of the Envisioned Structure Associated with Design 1

Design 2: *A dual-level elevated structure connected with a ramp and including swings.*

Design 2 is an elevated structure with two separate platforms connected with a ramp. The lower platform, which has an elevation of two feet, is accessible by a ramp from ground level. The first platform is square, and is completely covered by a plastic roof to protect the children and equipment from the sun and weather. An overhead ladder is attached to the back of the structure and can be accessed from the ground or the platform. A shallow sloping slide exits off of the opposite side. A ramp connects the lower structure up to the higher one. This platform, which is also covered by a plastic roof, is circular and has an elevation of four feet from the ground. A set of four steps leads up to the platform as an alternate means of access. The dual level design still incorporates the different elevations and play surfaces to make the playground interesting

to children, but is also more practical with fewer ramps tying the structures together. This makes it easier for disabled children to go from structure to the other. This design has the same set of swings as Design 1; three handicapped accessible swings and a bank of belt and fully enclosed swings. The main difference from Design 1 is that there are two platforms instead of three. This could be a construction and cost advantage as the design is less complicated. The disadvantage of the design is that there are now only two ramps going to the upper structure, so they must be longer in order to keep the required maximum slope for ADA compliance. Figures 4 through 6 below show the components of Design 2.

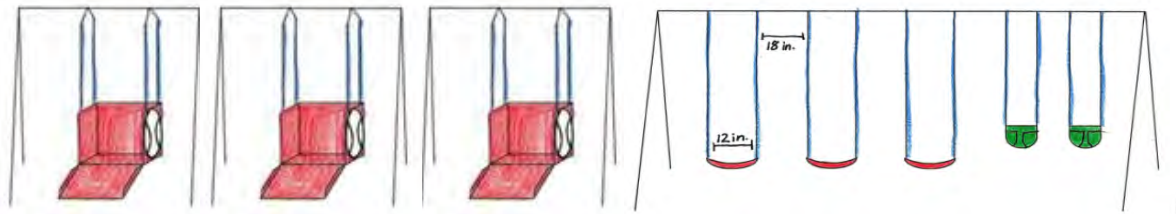


Figure 4. Envisioned Design for the Swing Sets Associated with Design 2

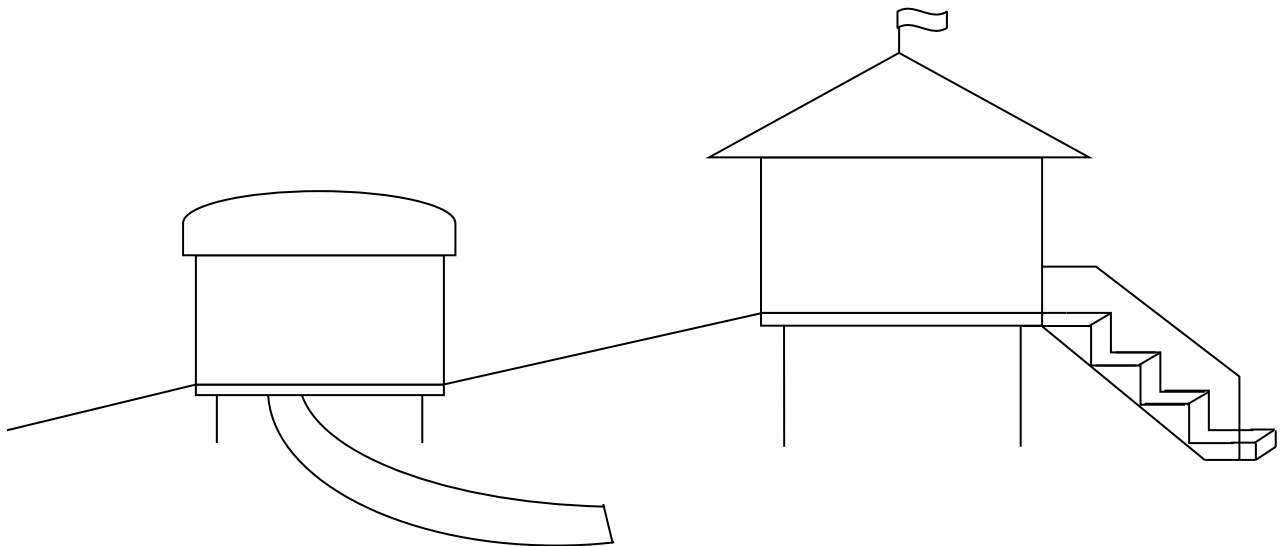


Figure 5. Profile View of the Envisioned Structure Associated with Design 2

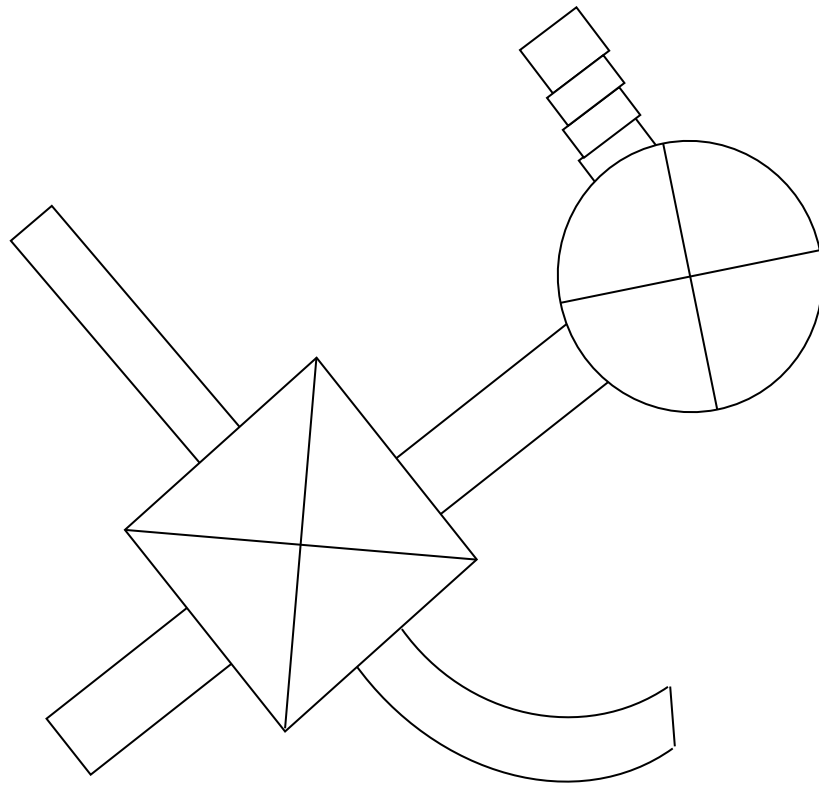


Figure 6. Top View of the Envisioned Structure Associated with Design 2

Design 3: A single level elevated structure with access ramps and including swings.

Design 3 featured a single elevated structure with dual means of access through a set of ramps and stairs. The two ramps come from ground level up to the four foot elevated structure. The two ramps are connected with a landing platform, which is required through ASTM standards when ramps are 12 feet long or greater, in order to keep the ramps ADA compliant. The large elevated platform is covered with a plastic roof for sun and weather protection. Stairs are incorporated into the design, so that there is a second means of access to the platform. Activity walls are incorporated throughout the structure walls for children to play with while they are on the structure. An overhead

climbing component attaches to the side of the structure, but is not accessible from the platform because the platform is too high off of the ground for safe accessibility. The same set of swings are also incorporated into this design; three handicapped accessible swings, and a bank of belt and fully enclosed swings. This single elevation design is fairly simple and straightforward, which would be a positive for design and installation purposes, but a downfall for children. It doesn't feature a slide or the multiple levels that children find fun and exciting to play on. All three designs feature the same swing sets. This is beneficial because they include swinging options for children of all abilities; belt swings, bucket swings, and wheelchair swings. Figures 7 through 9 below show the components of Design 3.

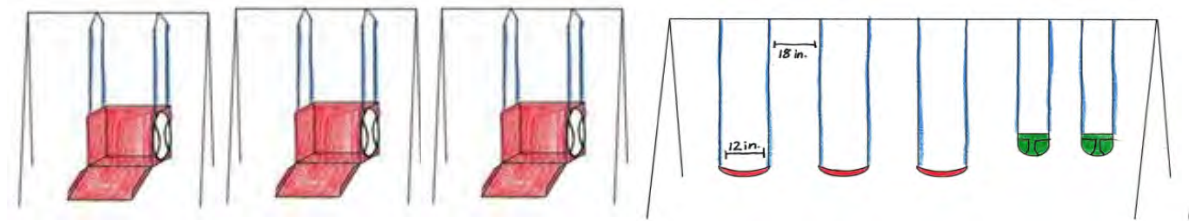


Figure 7. Envisioned Design for the Swing Sets Associated with Design 3

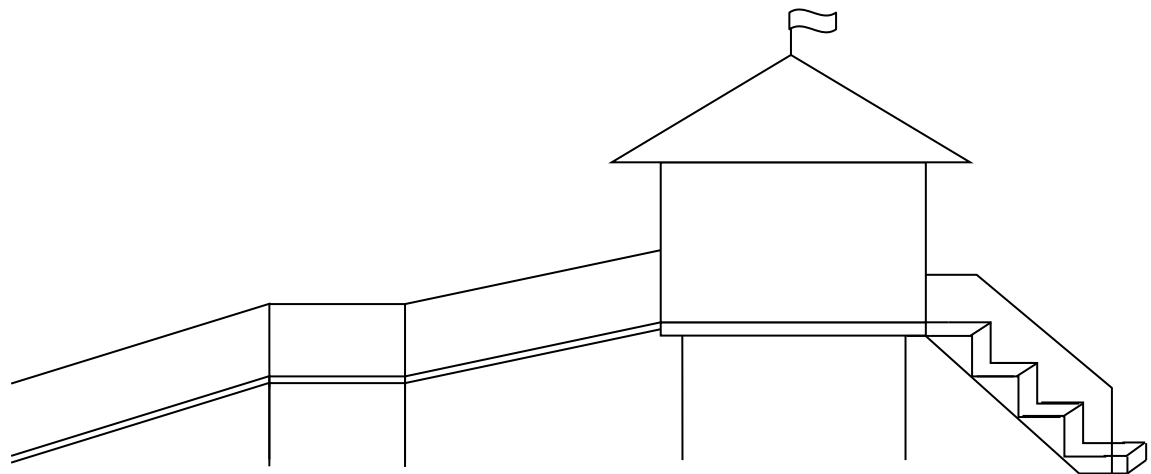


Figure 8. Profile View of the Envisioned Structure Associated with Design 3

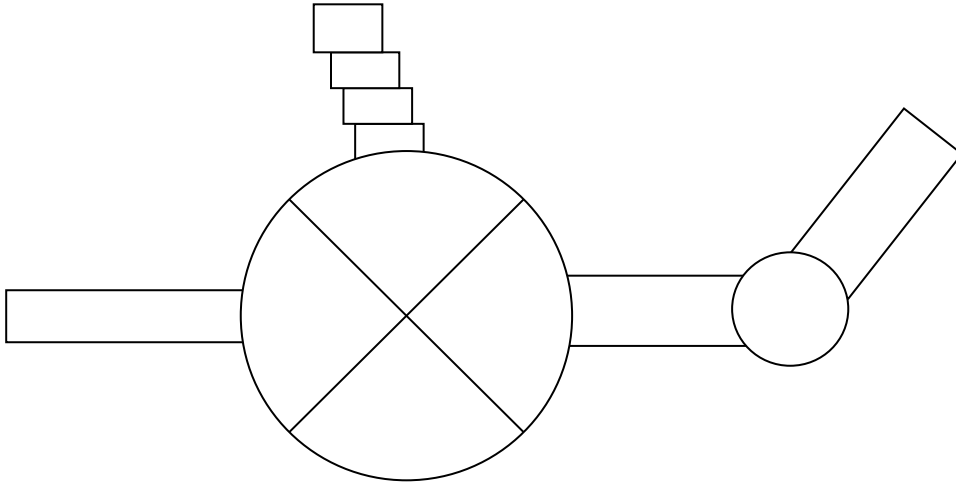


Figure 9. Top View of the Envisioned Structure Associated with Design 3

After analyzing the objectives and constraints that were fulfilled with each structure, Design 2 was chosen as the most suitable design. Design 2 was chosen primarily for its successful use of different elevations. Design 1 featured three elevations which would have complicated construction and increased costs. Design 3 only featured one elevation, which would have been advantageous for construction and cost purposes, but not as exciting and appealing for the user. The two elevations in Design 2 present a balance between ease of construction and cost, and the enjoyment of the user. Design 2 met all of the required constraints, except providing climbing equipment. Adding this component was a necessary change for the final design. Although Design 2 was chosen, more modifications were needed to bring the playground up to ASTM Standards for ADA compliance. The preliminary designs did not incorporate dimensions, so refinements to Design 2 were necessary. All of the dimensions shown in the final designed structure are compliant with ASTM Standards and ADA design regulations for

playgrounds. Below is the final elevated structure design that was then analyzed and evaluated through the rigorous structural analysis.

Refinement of Final Design

The main modification from the proposed Design 2 to the final design was the adjustment of dimensions to ensure the structure was ADA compliant. The final design still consisted of a dual level elevated structure. The first ramp, coming from the ground, leads to the lower elevated structure which is one foot off of the ground. An overhead climbing structure can be accessed from the back side of the platform. A shallow sloping slide can also be accessed from the lower platform. This structure is covered by a UV-resistant fabric awning, to protect the users from the sun and weather. The ramps, which connect the lower platform to higher three foot platform, were modified from Design 2. Instead of only one ramp from Design 2, two ramps were used to keep the slope under ADA accessible guidelines. An accessible platform connects the two ramps together. The elevated structure is also protected by a UV-resistant fabric awning. A set of three stairs provide an alternative means of access to the structure. A step climber, on the adjacent side of the platform, also provides the third means of access. Activity walls will fill the remainder of the wall space on the platform, providing another play component for the user. Along with dimension changes, the swing sets were modified for the final design. Two belt swings, two bucket swings, one accessible swing, and one handicapped swing are featured in the final design. Figures 10-12 below show the components of the final design.

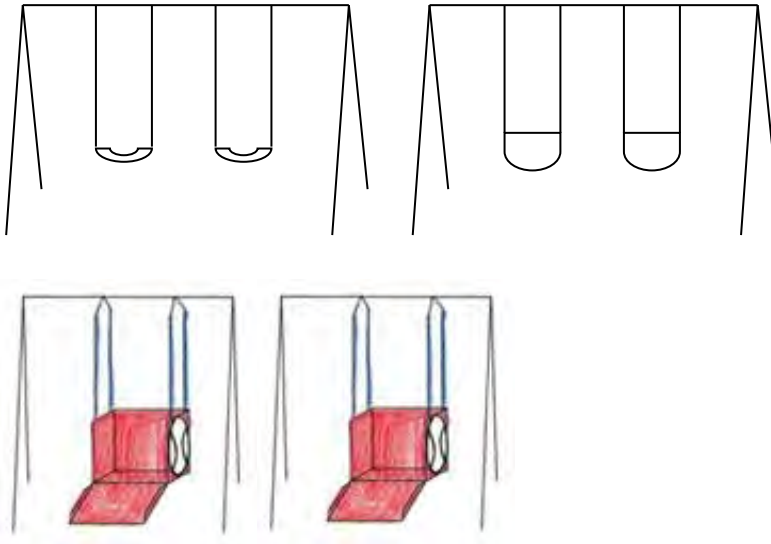


Figure 10. Envisioned Design for the Swing Sets Associated with the Final Design

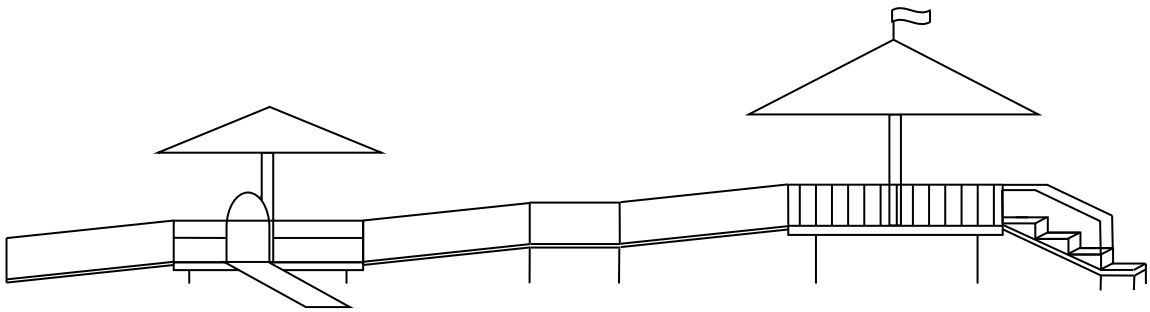


Figure 11. Envisioned Design for the Structure Associated with the Final Design

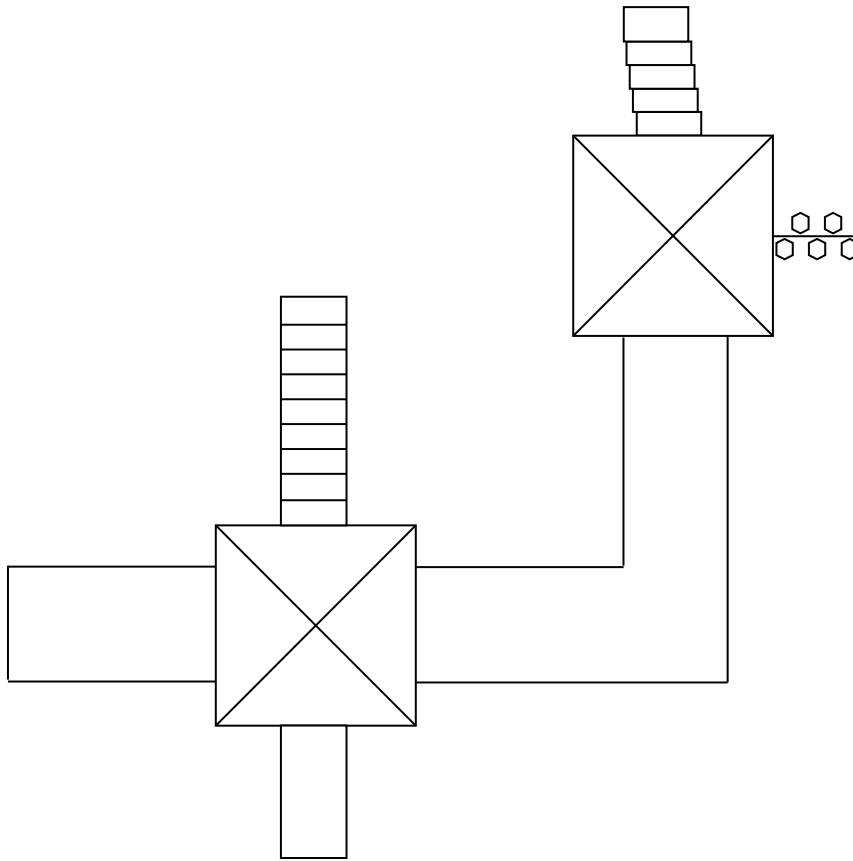


Figure 12. Top View of the Envisioned Structure Associated with the Final Design

This design was then refined to ensure that all measurements, dimensions, and layouts met the required standards. Outlined below is each element of the elevated playground structure, its modifications from Design 2 to the final design, and the ASTM standards that apply to each change. The required dimensions and standards used below come from the Certified Playground Safety Inspectors (CPSI) Course Manual (Christiansen and Hendy). This manual was obtained through the National Recreation and Park Association's CPSI course in Columbus, OH. My Certified Playground Safety

Inspector certification was also obtained through an examination following the CPSI course.

Swings

Design 2 featured a swing set bay of seven swings total; three belt swings, two enclosed bucket swings, an accessible swing, and a handicapped swing. Belt swings are simple, open swing seats that are ideal for children ages 5-12, while the enclosed bucket swings are used for younger children below 5 years old who need to be more seated more securely. According to the ASTM standards each swing bay may only contain two swings. This is so that if there is an open swing, a child who is running towards it will not have to cross in front of an occupied swing. Also, enclosed bucket swings may not be in the same bay as any belt swings. This is so that smaller children are not running in front of the older children using the belt swings. It is safer for the younger children to be in a separate bay. Following these guidelines, modifications were made for the final design. The single bay was separated into two; one holding two belt swings, and the other two bucket swings. Another modification made was removing one of the three accessible swings. This was done purely for space and cost savings. Figure 13 below shows the preliminary swing design in Design 2, while Figure 14 shows the final design.

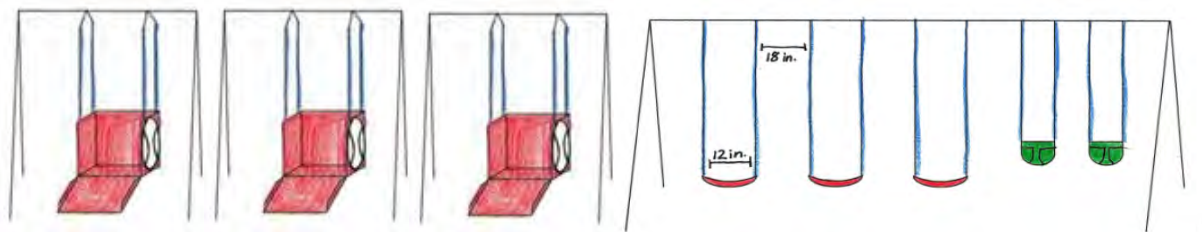


Figure 13. Envisioned Design for the Swing Sets Associated with the Design 2

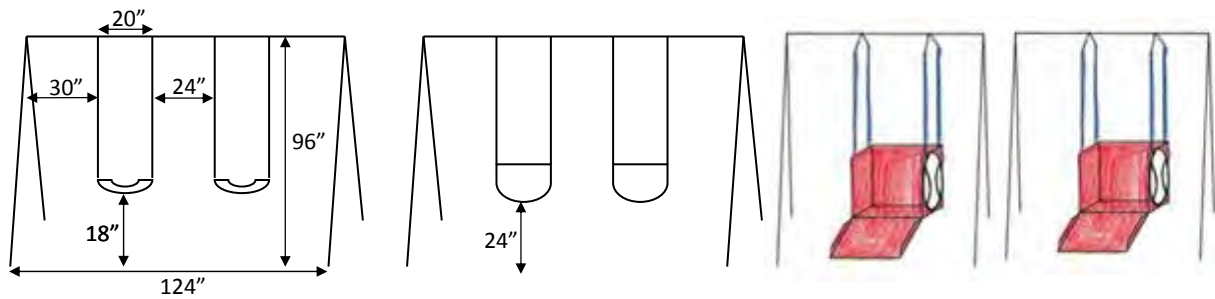


Figure 14. Finalized Swing Set Design

Following the ASTM standards, the spacing for the swings was determined (as seen in the figure above). For both belt and enclosed bucket swings, the ASTM Standards specify the minimum horizontal clearance between the support structure and the swing chain (measured 60" above the surface) is 30". The minimum splay distance between the swing chains is 20" (measured at the hangers). The minimum horizontal clearance between adjacent swing chains is 24" (measured 60" above the surface). The minimum distance from the seat to the surface of an enclosed bucket swing is 24", while it is only 12" for a belt seat swing. For the final design, all of the minimum ASTM dimensions listed above were used, except for the seat to surface clearance for the belt swing, which was designed at 18" instead of 12". This was done because 12" is simply the minimum height, and for children 5-12, a slightly taller height of 18" made more sense.

ASTM does not have standards for the accessible swings, so these dimensions will rely on the commercially manufactured swing designs. There are two kinds of accessible swings; one that straps disabled child directly into a structured swing and the other that actually swings the entire wheelchair. The Liberty Swing (Devine), seen in Figure 15 below, is the chosen manufacturer for the swing that encompasses the entire wheelchair, while Child Works (AAA State of Play), as seen in Figure 16 below, is the

manufacturer chosen for the adaptive, strap-in swing. Below are the two manufacturer designs that will be utilized in the playground.



Figure 15. Final Wheelchair Swing Design (www.libertyswing.com)



Figure 16. Final Accessible Swing Design (www.aaastateofplay.com)

The designed swing height for all bays (belt, bucket, and accessible) was 8'. This height was chosen as it is determined as most appropriate for children ages 2-5, while still accommodating children up to 12 years old. The fall height, or height of the pivot point to the protective surfacing is equal to the designed swing height of 8'. A use zone is the area beneath and immediately adjacent to a play structure whose surface it is predicted that a user would land when falling or exiting the equipment. Use zones, which function to reduce the severity of head injuries due to falls, are especially critical for swing sets since children are likely to jump off of the moving swings. An insufficient use zone is the leading cause of injury on playgrounds. The use zones to the front and rear of a belt swing is $2H$, where H is the vertical distance from the protective surface to the pivot point of the swing (an example is depicted in Figure 17 below). In the final elevated design, this distance is 13' in the front and rear of the swing. For enclosed bucket swings, the use zone is $2W$, where W is the vertical distance from the top of the sitting surface to the pivot point. This distance is 12'. The distance between all of the swing bays (including the accessible swings) also counts as the use zone. For any structure over 30" in height, the minimum overlap of use zones between structures is 108". No overlap is permitted to occur in the front and rear use zones.

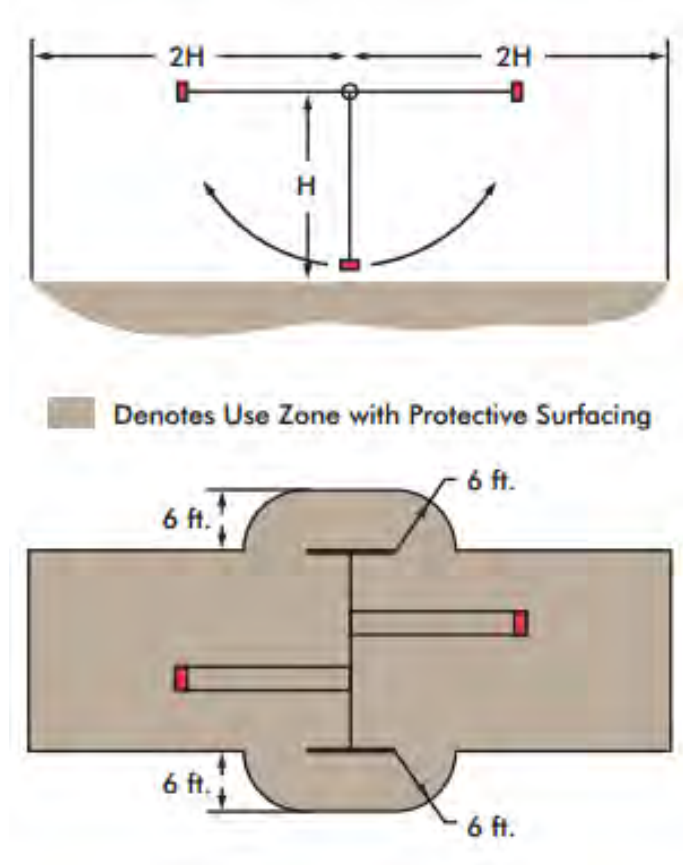


Figure 17. Swing Set Use Zone Example Diagram (U.S. Consumer Product Safety Commission)

Overhead Ladder

The design of the overhead ladder from Design 2 to the final design did not change much. The only aspect that was modified was the specific dimensions. Since the elevated play structure is to be ADA accessible, the overhead ladder is designed at a lower height in order to accommodate wheelchair users. According to ASTM standards the maximum height for wheelchair accessible overhead equipment is 54", which is used as the design height of the final overhead ladder. ASTM standards also specify that the maximum rung spacing for horizontal ladders is 15", which is what will be used in this

design. The handgrip diameter must be between 0.95” and 1.55”. The final design will use 1.25” diameter handgrips in order to better accommodate the hands of smaller children. The length of the overhead ladder is 12’, with ten ladder rungs. .

This overhead ladder will be attached to the lower level elevated component, making it part of the composite play structure. A composite structure is defined as two or more play structures attached or play functionally linked, to create one integral unit that provides more than one play act. A functionally linked play structure is a play structure that acts as a single unit in its physical form or sense of function as continuous play even if components are not physically linked. The minimum required use zones for these types of structures are 72” on all sides that are not connected to another structure. For my design, the minimum use zone of 72” was used. Figure 18 below depicts the final overhead ladder design.

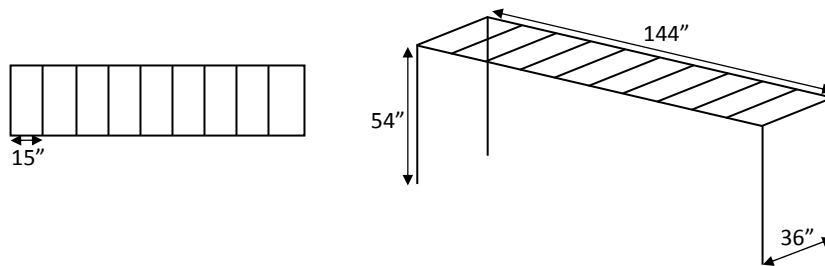


Figure 18. Finalized Overhead Ladder Design

Ramps

As can be seen from the below drawings, a significant amount of ramp area was added to the final design. In Design 2, there were two 12’ ramps, one from ground level to the first elevated structure at 2’ high, and the second connecting the first elevated

structure with the second at 4' high. This makes each ramp slope 1:6. This was a problem as ASTM standards determine that the maximum ramp slope to any elevated platform is 1:12. The ramp run length without a landing must be no longer than 12' (144"). The accessible routes must have a minimum width of 36", while the landings must have a diameter no smaller than 60". Taking these dimensions into consideration, the final design has two sets of ramps. The first ramp runs 12' from the ground up 12" to the first elevated component. This ramp has a 1:12 slope. The second ramp set has one 12' ramp from the first elevated component up 12" to a 60" diameter landing, where it then runs another 12' up to the second elevated component of the play structure. Both sets of ramps are 60" wide.

Per ASTM standards both ramps have a 2" curb along both sides in order to keep wheelchair and walker wheels from slipping off the edge. Both ramps also have a handrail at a height of 38" running along both sides for the length of the ramp. There is to be no more than a 0.25" vertical rise anywhere on the accessible route, including the connection points from the ramps to the elevated components. This means that there can be no bumps or rises in the ramp, and that the transition from the ramp to the flat surface must be smooth, also with no bumps or rises. This makes it easier wheelchair users to get from one structure to the next without needing assistance to get over the bumps in the ramp. Figures 19 through 22 below show Design 2 and the final design.

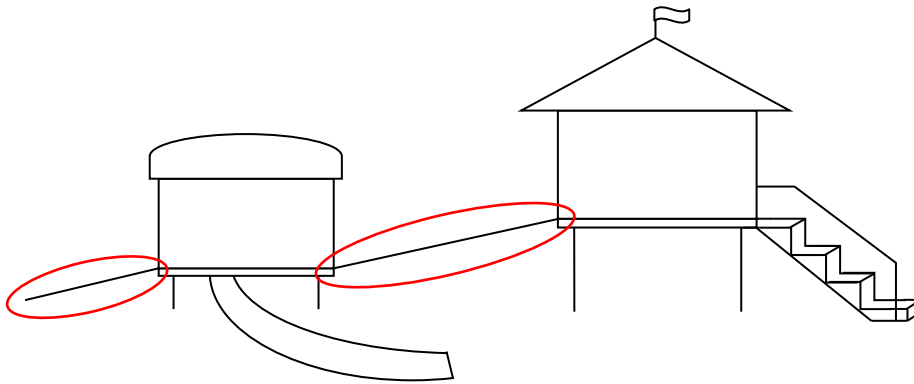


Figure 19. Profile View of Original Ramps Associated with Design 2

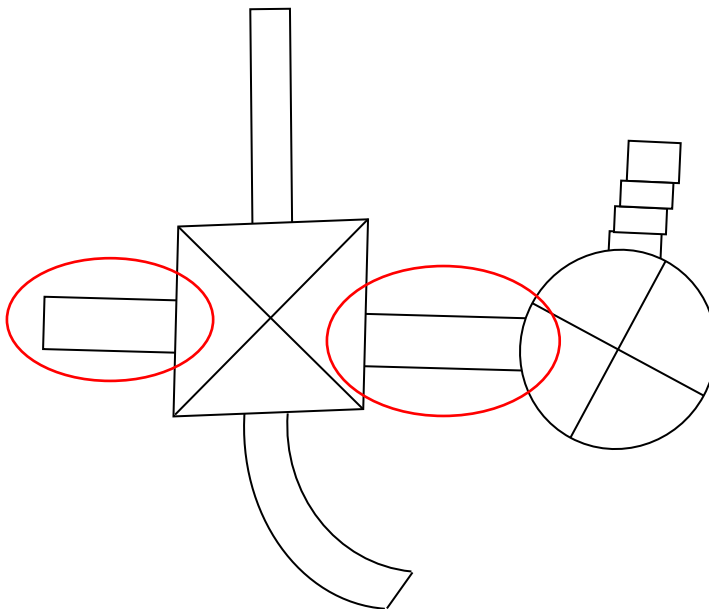


Figure 20. Top View of Original Ramps Associated with Design 2

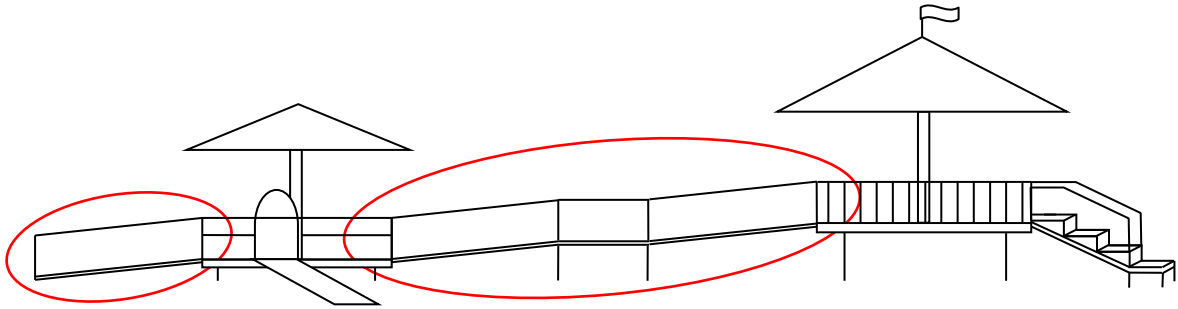


Figure 21. Profile View of Finalized Ramp Design

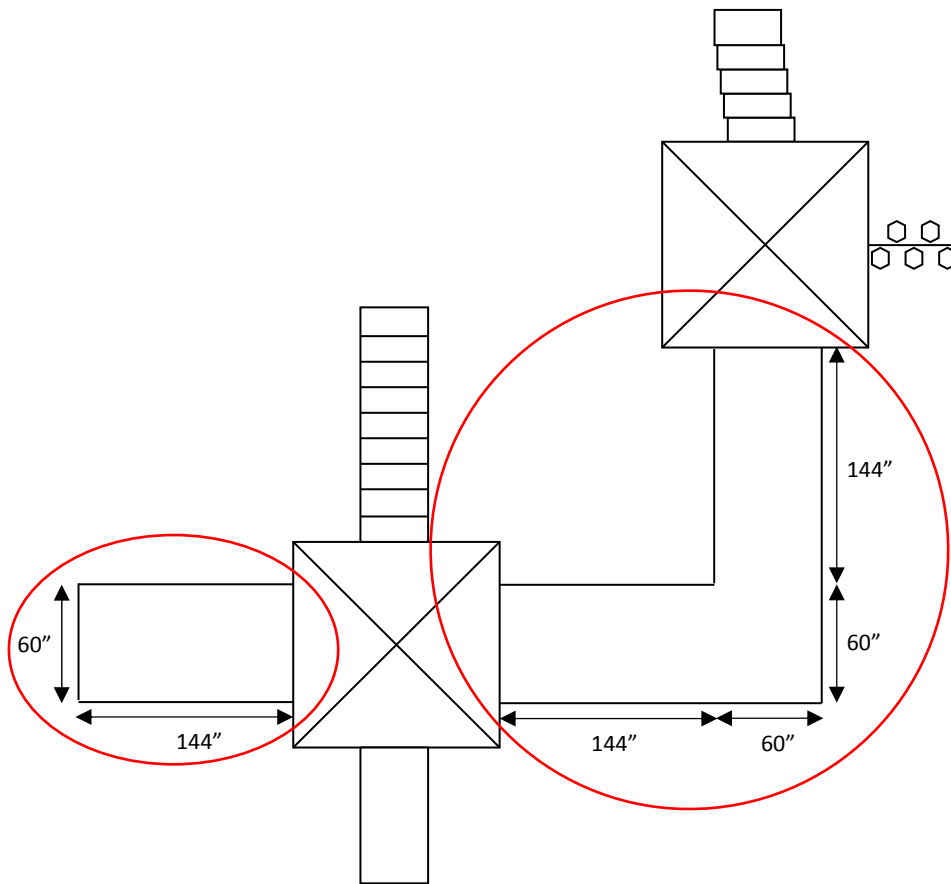


Figure 22. Top View of Finalized Ramp Design

Stairs

The stairs in the design lead up to the taller (3') elevated component. The steps in Design 2 were modified to become less steep and meet ASTM standards for the final design. In Design 2 there were four steps leading up to the play structure, making each step a 9" rise. In order for a staircase to be deemed accessible, some ASTM dimensions must be met. There must be a transfer platform, which is available for the child to transfer from the wheelchair onto the playground equipment. The height of this platform must be between 11" and 18". For the final design, a height of 12" was used. The width of the transfer platform must be at least 24" and the depth at least 14", and both dimensions were used for the final design. For the stairs to be considered accessible, an 8" rise with a 14" depth for each step must be used. A handrail running along both sides of the stairwell with a maximum height of 38" and a minimum height of 22" must also be present in the design. A height of 30" was used for the final design of the handrail. The second handrail, which was not present in Design 2, was added to the final design in order to make the design compliant. Figures 23 and 24 below show the stair designs for Design 2 and the final design.

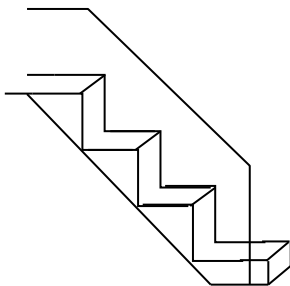


Figure 23. Original Stairs Associated with Design 2

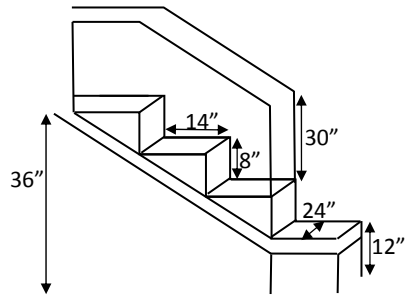


Figure 24. Finalized Stair Design

Elevated Play Structure Platforms

Various changes were made to Design 2 in order to make the final design compliant with ASTM standards. First, the shapes of the platforms were changed from a rectangle and a circle in Design 2, to two squares in the final design. This was done to give the playground a cleaner and sleeker look, and also to make the design more feasible. Each platform is designed to be 10'x10'. The lower platform is 12" (1') off the ground, while the higher platform has an elevation of 36" (3') from the surface. ASTM standards mandate an 84" overhead obstruction clearance zone up from the designated play surface of the structure. In order to become compliant with this standard, the overhead shade awnings were raised to a height of 84" in the final design. They were also changed from a rigid plastic overhead feature to a single post pyramid shade structure made of durable fabric. Besides, aesthetic reasons of the fabric being more visually pleasing, this switch was made since only one support post is necessary for the fabric shade, while four was necessary for the plastic roof. Also, the fabric roof is more durable and able to withstand weather better than the plastic. It will resist fade for a longer period of time and won't need to be repainted like the plastic roof would (Shade Systems, Inc.).

For Design 2, no guardrails or protective barriers were used on either platform. Starting with the lower platform, which is a height of 12" (1'), a guardrail was added. ASTM standards state that for a platform greater than 20" (for children 2-5 years) and greater than 30" (for children 5-12 years) a guardrail should be used. Even though the platform height falls below the minimum requirements, a guardrail was still added since the structure is to be accessible. The guardrail prevents wheelchair users from falling off the side of the platform. For children 2-5 years old, the minimum height of the upper rail is 29", while the maximum lower opening in the guardrail is 23". For children 5-12 years old, the minimum height of the upper rail is 38", while the maximum lower opening in the guardrail is 28". Taking into account the age ranges, the final design used an upper rail height of 38" and a lower rail height of 23". For the higher platform, which is a height of 36" (3') tall, a protective barrier was added to protect children from falls. ASTM standards state that for a platform greater than 30" (for children 2-5 years) and greater than 48" (for children 5-12 years) a guardrail should be used. For children 2-5 years old, the minimum height of the barrier is 29". For children 5-12 years old, the minimum height of the barrier is 38". Again, taking the age range of children to be using the playground, a barrier height of 38" was used in the final design. Figures 25 through 28 below show the structure platform designs for Design 2 and the final design.

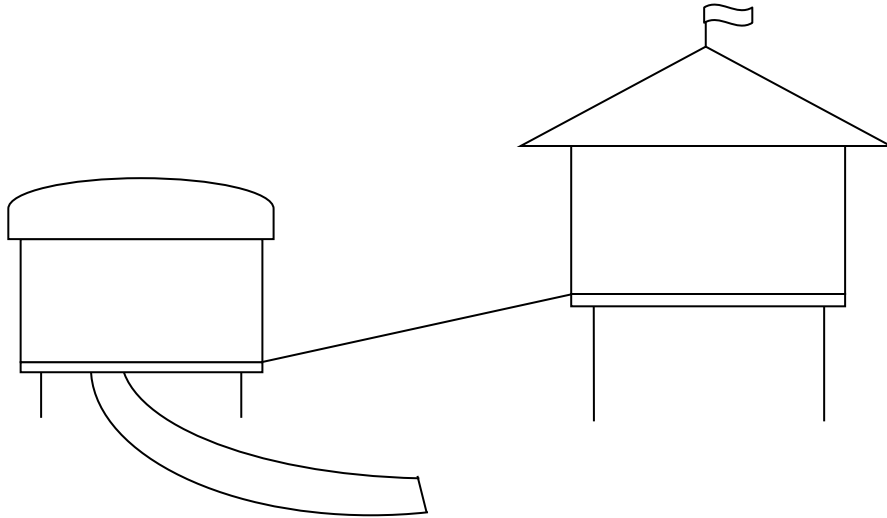


Figure 25. Profile View of Original Elevated Platforms Associated with Design 2

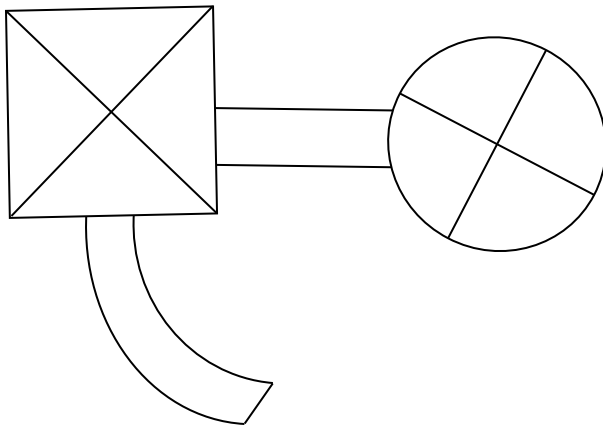


Figure 26. Top View of Original Elevated Platforms Associated with Design 2

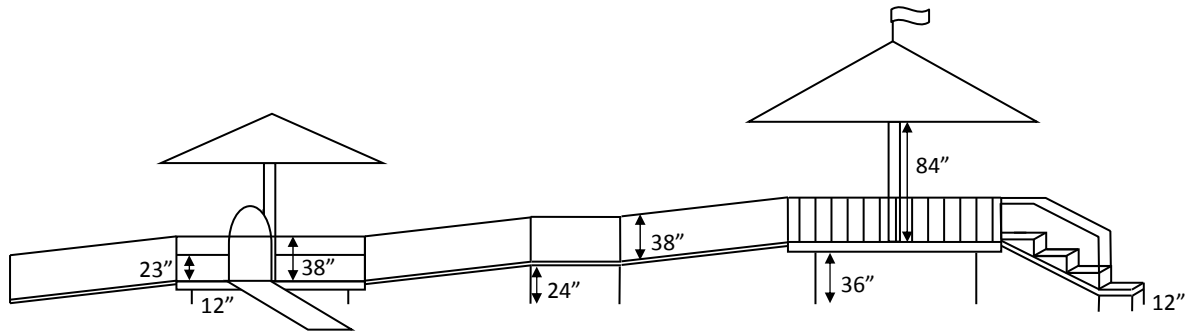


Figure 27. Profile View of Finalized Elevated Platform Design

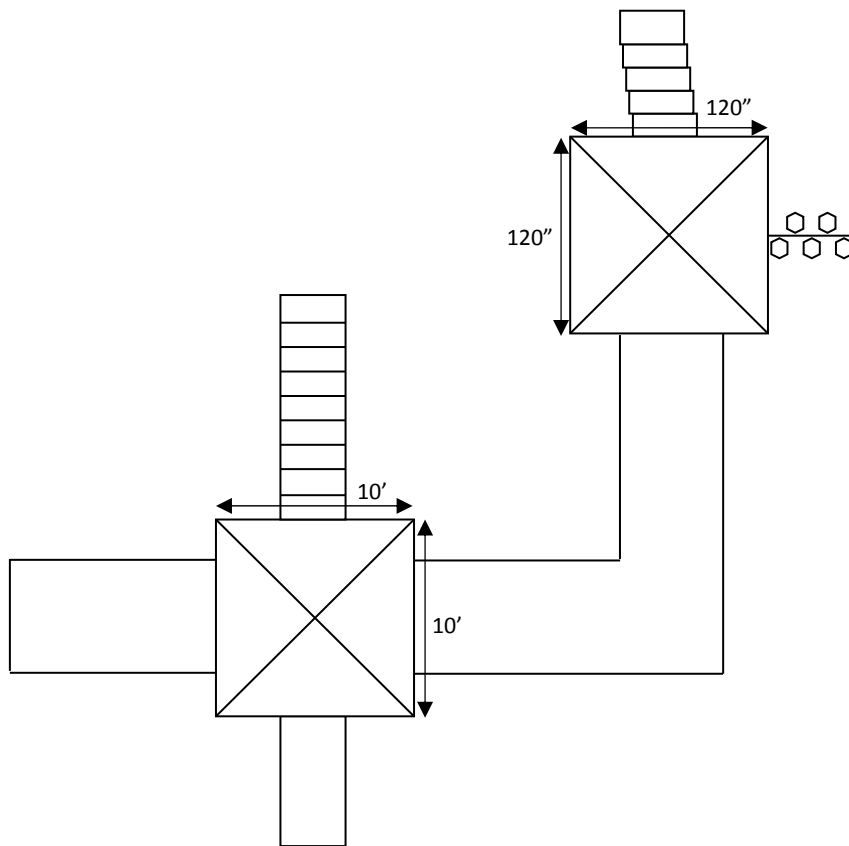


Figure 28. Top View of Finalized Elevated Platform Design

Slide:

The slide in the structure attaches to the lower elevated component and exits directly onto the ground. Design 2 featured a long, gently sloping design that was more like a ramp than a slide. This was done so that users in wheelchairs could use the slide without exiting their wheelchair. While the slide with a 1:12 slope would be a great component for children in wheelchairs to use, it is not necessary to have this gentle of a slope to be deemed accessible. In order to compromise and make the slide more fun for both disabled and nondisabled children, the slide was shortened, making it slightly steeper at a 1:6 slope. The slide dimension of 36" was kept the same for the final design. This width makes it easier for children with disabilities to get in the seated position in order to go down the slide. It also makes it usable for wheelchairs, if the user chooses to go down in the chair. Since the slide entrance is only one foot off of the ground, the exit region connects directly to the ground. This may make it possible for an individual in a wheelchair to wheel themselves down the slide if they choose, assuming the correct materials are used. Traditional plastic slides can cause static electricity when the child slides down, causing interference and malfunction of cochlear implants. This can cause the implant to shut down instantly, causing obvious problems and deafness for children with these hearing devices. For this reason, the designed slide bed is made of stainless steel. Stainless steel does not produce static as the child slides down, eliminating the risk for cochlear implant malfunctions. Figure 29 shows the final slide design.

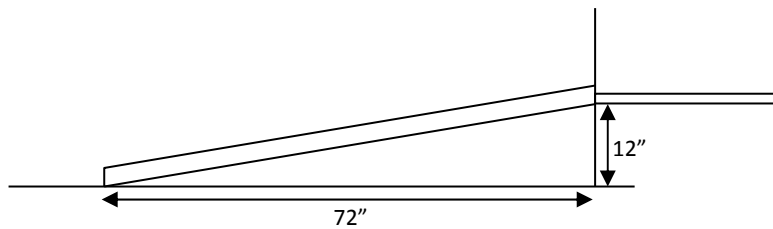


Figure 29. Profile View of Finalized Slide Design

Step Climber:

Design 2 did not feature a step climber at all. Only the stairs and the ramp were available to access the higher elevated component. The step climber was added to the final design to provide an alternate means of access up to the structure and satisfy the third main component necessary for a successful playground. The step climber features four foot pad components around a central beam for climbing up to the 36" elevated structure. The steps are spaced 8" apart vertically, providing an easy stepping distance for the user. Even though this component is not considered accessible, it is still acceptable for it to be included in an accessible playground. Every component of the playground does not have to be accessible, but $\frac{1}{2}$ of all elevated play components on the structure must be accessible (Department of Justice). The ramp and the stairs are both considered accessible means of access to the elevated structure; therefore the non accessible step climber is acceptable. Figure 30 shows the final step climber design.

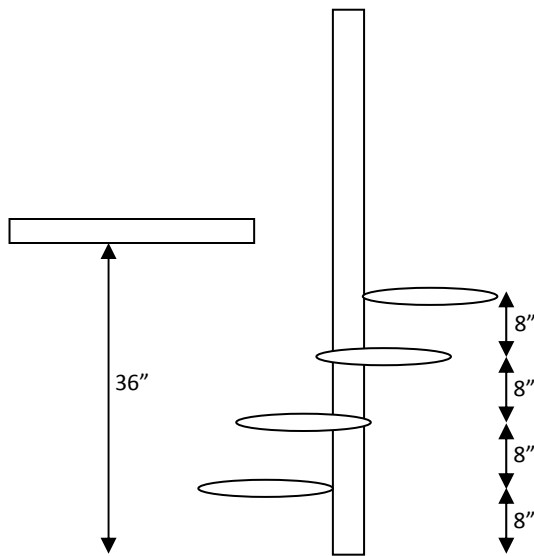


Figure 30. Profile View of Finalized Step Climber Design

Analysis of the Final Design

Structure Specifications

In order to perform the structural analysis on the elevated structure, the total weight of the structure had to be evaluated. This involved calculating the square footage, amount of materials, and weights for each individual component of the structure. The material that was used for each component was found by looking at various playground catalogs and determining what typical playground manufacturer's use. Once the materials were determined, the weight per square foot or linear foot was analyzed. These values were found from designer and manufacturer handbooks for the various metals used. Below, in Tables 1-8, are the tabulated results of each component's material and weight analysis.

Table 1. Materials and Associated Properties for the Slide Component

[illegible]

Table 2. Materials and Associated Properties for the Overhead Ladder Component

[illegible]

Table 3. Materials and Associated Properties for the Ramp Components

[illegible]

Table 4. Materials and Associated Properties for the Stairs Component

[illegible]

Table 5. Materials and Associated Properties for the Elevated Structure (Lower, 1')

Component

[illegible]

Table 6. Materials and Associated Properties for the Elevated Structure (Upper, 3')

Component

[illegible]

Table 7. Materials and Associated Properties for the Swing Set Components

Component	# of Components	Material	Weight (lb)	Total Weight (lb)
Structure	3	2 3/8" Galvanized Steel	200	600
Enclosed Seats	2	EPDM Rubber	10	20
Belt Seats	2	EPDM Rubber	4.5	9
Accessible Seat	1	Plastic	40	40
Chains	10	Galvanized Steel	1	10
Wheelchair Swing	1	Stainless Steel and Plastic	150	150
				829

Table 8. Materials and Associated Properties for the Step Climber Component

[illegible]

The total weight of the entire structure was calculated to be 5,841.79 lbs. For the engineering assessment aspect of the design, a factor of safety of 1.5 was added to the total structure weight.

Structural Analysis

Figure 31 below shows the layout of the playground structure. Because of the elevated nature of the play structure it is important to know that the supporting posts are strong enough to support the weight of the structure. The number and placement of these posts are related to helping ensure this.

As a first step, the number of posts needed in the final design was estimated based on the size and weight of each contributing elevated component. Each post is indicated with the black dot in Figure 31. In order to check if the design was adequate, the post circled in red, which was carrying the largest load was assessed. This post carries the load of the larger elevated structure, along with its canopy. If this post which carries the largest load can adequately function, then the remaining posts will also be able to carry their respective load. Several steps were taken to assess the adequacy of the design. First, the loads, bolt connections, and allowable stresses of the canopy were assessed. The loads of the decking of the elevated structure were calculated, followed by the assessment of the forces on the column and bolts. The footer for the column was then designed. All calculations, detailed in Appendix I, were assessed using the worst case scenario for loads in order to ensure the design would succeed.

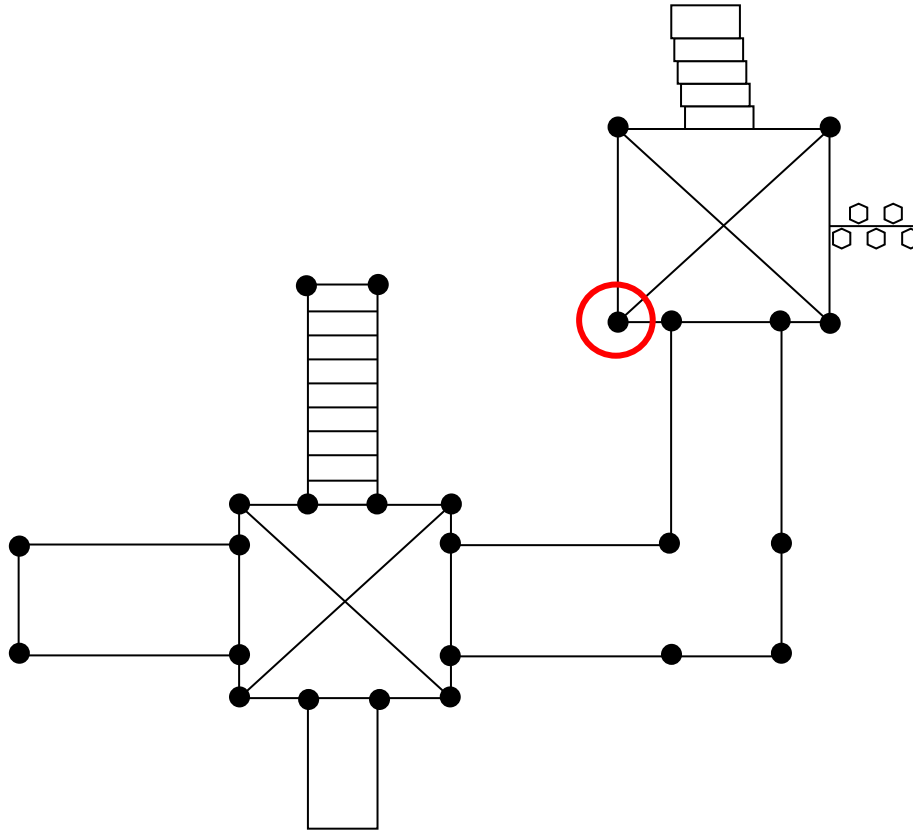


Figure 31. Top View of Finalized Structure and Post Layout

Analysis of the Canopy

Both elevated structures are covered by single post durable fabric canopies. These canopies protect the children playing from harmful UV rays, and weather such as wind, snow, and rain. The fabric, weighing 800 lbs. each is connected to a central 5 inch outside diameter aluminum post. This post is then connected to the decking by four ½ inch diameter bolts. These initial dimensions for posts and bolts were chosen based on standard stock dimensions, and the analysis performed helped determine whether these initial dimensions were acceptable.

First, the loads of the canopy were assessed. There are multiple types of loads that contribute to the overall load exerted on the structure. A dead load is the load from any permanent part of the structure. The dead loads, which totaled 817.8 lbs, included the weight of the canopy fabric (800 lbs.) and the central post (17.8 lbs.). The roof live loads were not necessary to include in the calculations as no one will be walking on top of the canopy. A snow roof load was included, which accounts for the load exerted by snow. According to ASCE 7-10, the average ground load of snow in the area is 20-25 pounds per square foot (psf) (American Society of Civil Engineers). This was multiplied by a factor of 1.7, which is given in the snow load equation, and the area of the canopy, in order to find the roof snow load of 4250 lb. The wind load was then taken into account, which is the pressure exerted on a structure from a wind gust. The canopy should be designed to withstand a maximum gust of 90 miles per hour, which is the design wind gust speed for Ohio and most of the Midwest based on ASCE 7-10 (American Society of Civil Engineers). The wind speed should be assessed and modified for the playground's location if it is not located in the Midwest. This value was used to find the wind pressure exerted on the canopy by using; $WL = 0.00256 \times 90mph^2 \times 100ft^2$. The wind load was calculated to be 2073.6 lbs. The total load combination (P_u), which combines the dead load, wind load, live load (which is zero), and snow load is assessed using the following equation;

$$P_u = 1.2D + 1.6W + 0.5L + 0.5S ; \text{ where,}$$

– D = Dead Load in pounds

- W = Wind Load in pounds
- L = Live Load in pounds
- S = Snow Load in pounds

The total load combination for the structure was calculated to be 6,420 pounds or 6.42 kips.

The load combination value was used to determine the necessary bolt size and number to ensure the canopy would stay in place. From Table 8-11 in the Aluminum Design Manual, it was found that ½” bolts can carry a load of 2.2 kips. The total load of 6.42 kips was divided by 2.2 kips per bolt. It was calculated that three, ½ in. bolts would be adequate, but the design utilizes four bolts for a safety factor and symmetry of the design. The central aluminum post was evaluated for slenderness and overall stress and allowable column stress to ensure that it would not fail under the exerted loads (Kissell and Ferry). The slenderness ratio of a column is the ratio of the effective length of a column to the least radius of gyration of its cross section (American Society of Civil Engineers). An adequate slenderness ratio ensures that the column will not buckle under the loads. The overall stress must be smaller than the allowable stress of the column to ensure that the column will not fail. The aluminum post, which was initially designed to have an outside diameter of 5 inches and inside diameter of 4.5 inches, was found to be able to withstand a stress of 3.97 kips per square inch (ksi). This was found using the equation;

$$F_c = (\pi^2 E) \div (n u (K L \div r)^2); \text{ where,}$$

- E = modulus of elasticity in pounds per square inch

- n_u = factor of safety on ultimate strength
- K = end connection of column (0.65 for both ends fixed)
- L = length of column in inches
- r = radius of gyration in inches

The overall stress was then calculated to be 1.92 ksi, using the equation;

$\sigma = P \div A$; where,

- P = load in kips
- A = area in which load is applied to in square inches

The central post is therefore deemed adequate as the allowable column stress is greater than the actual stress that the column will be exposed to.

Analysis of Elevated Structure

Decking

The deck of the elevated structure has an area of 10 feet by 10 feet, made of 12 gauge galvanized steel. The loads on the deck were first evaluated. The dead load, which totaled 7,594.5 lbs, included the weight of the deck (453.10 lbs.) and the weight from the canopy (7,141.4 lbs.). The live load was assessed considering that the deck was completely full with children in power wheelchairs. The weight of the child was assessed at 150 lbs. while 250 lbs. was used as the weight of a power wheelchair (Spin Life). Considering the size of the deck and the size of the average wheelchair, it was calculated that approximately 13 wheelchairs could fit on the deck. Therefore, the maximum live

load with 13 wheelchairs and children was found to be 5,200 lbs. The total load, including the dead load and live load, supported by the deck was calculated to be 12,800 lbs. Since there four posts supporting the deck (one at each corner), the load is to be evenly distributed between the four. This means that the load from the deck, which the post that will be evaluated holds, is 3,200 lbs.

The ramp, which butts up to the upper elevated structure, has four support posts on each corner carrying the load. The ramp will only be pinned to the elevated structure's deck, so that there is a continuous surface for children and wheelchairs to get from one to the next. Since the ramp has its own support posts and is only loosely connected, it was not necessary to take into account the loads on the ramp when assessing the deck post. But, as this design wants to assess the worst case scenarios, $\frac{1}{4}$ of the weight of the deck of the ramp (to account for the four support poles) was added to the point load that the deck post would carry. This added a load of 68 lbs. ($272.86 \text{ lbs}/4 \text{ posts}$) to the 3200 lbs. that was already being carried by the post. The moment about the post, $\Sigma MA = 0 = -(3200 + 68 \text{ lbs}) \times (2.5 \text{ feet})$, was calculated to be 8,170 ft·lb. This was used to assess the connecting bolts, which hold the deck to the post.

Bolts

Bolts will be used to firmly connect the deck to the load bearing posts, as seen in Figure 28 below. In order to assure that the bolts used in the design will be of appropriate strength and will not fail, an analysis was done to examine both the bearing and shear strength. First, during the final design refinement, initial specifications of the desired bolts to be used must be determined. It was assumed that $\frac{3}{4}$ inch diameter steel bolts would be sufficient. A larger size than the $\frac{1}{2}$ inch bolts used for the canopy was assumed

because the load of the entire structure is much larger than the load of just the canopy. To determine whether the $\frac{3}{4}$ inch bolts would be adequate, shear strength must be calculated, the actual bearing stress must be less than the allowable bearing stress on the bolts, and the bearing strength equation must be satisfied. To first calculate the actual bearing stress the force acting on the bolt was calculated using the equation;

$$F \times d = M_A, \text{ where;}$$

- F = force exerted on each bolt in pounds
- d = distance between bolts in feet
- M_A = moment in foot pounds

The actual shear strength of the bolt, f_v , was calculated by dividing the force on each bolt, by the area of the aluminum tube that the force will be exerted on using the equation $P = f_v \div (\pi d^2 \div 4)$. The shear strength of each bolt was found to be 19 ksi, whereas the allowable shear strength of the bolt was 65 ksi (Steel Construction Manual). Therefore, the designed bolt connections will be able to carry the load of the deck.

Next, the minimum bolt spacing and minimum edge distance, was assessed to ensure that the minimum distance was smaller than the designed spacing. The minimum bolt spacing; $S = 2.5d_b$, was calculated to be 1.875 inches, which was less than the design distance previously chosen at 6 inches. The minimum edge spacing; $S = 1.5d_b$, was calculated to be 1.125 inches, and the design distance used was 1.25 inches. Therefore, the bolt spacing is adequate.

Finally, the actual bearing stress of the bolt holes was calculated using the equation;

$$f_p = P \div (d_b \times t) , \text{ where;}$$

- f_p = actual bearing stress in pounds per square inch
- P = force applied to bolt in pounds
- d_b = diameter of bolt in inches
- t = thickness of aluminum column wall in inches

The actual bearing stress was calculated to be 22 ksi, while the allowable bearing stress of the designed aluminum was 24 ksi ((Kissell and Ferry). Since the actual bearing stress was less than the design bearing stress of the aluminum, the bolt holes will be sufficient.

The bearing strength at the bolt holes also satisfied the given equation;

$$R_n = 1.2L_c \times t \times F_u \leq 2.4d_b \times t \times F_u , \text{ where;}$$

- R_n = bearing strength in kips
- L_c = clear distance, in the load direction of the force, between the edge of the bolt hole to the edge of the material in inches
- t = thickness of aluminum column wall in inches
- F_u = tensile strength of connected material in kips per square inch
- d_b = diameter of bolt in inches

The equation resulted in $R_n = 48.75k < 58.5k$, which means that the bearing strength of the holes was also adequate. Since all of the calculated parameters satisfied the given

design parameters, the bolts were determined to be sufficient. Figure 32 below shows the bolt connections and Figure 33 shows the cross section of the aluminum columns.

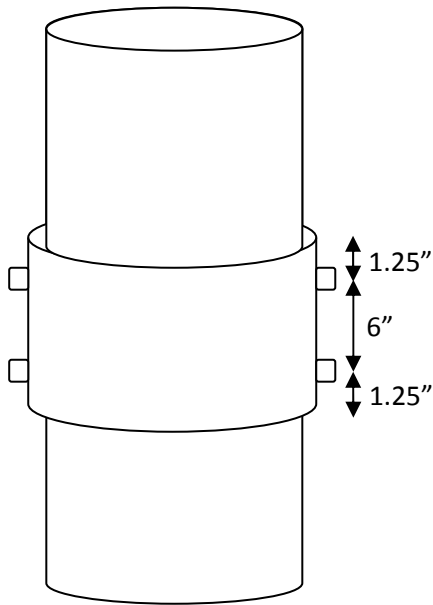


Figure 32. Profile View of Designed Bolt Connections

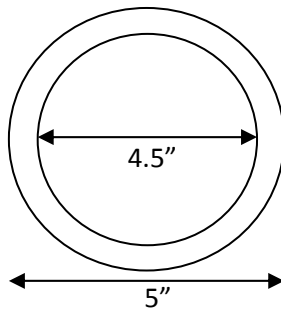


Figure 33. Cross Section View of Designed Aluminum Posts

Post/Column

Now that the loads of the structure have been found and the bolts designed, the aluminum posts of the structure had to be evaluated. The slenderness ratio of the

aluminum support post was assessed to confirm its adequacy. The slenderness ratio (Kl/r), which was calculated to be 20.19, was used to determine the overall allowable column stress. Using the equation $F_c = 20.2 - 0.126(KL \div r)$, the overall allowable column stress was found to be 17.67 ksi. This means that the column can withstand up to 17.67 ksi before buckling. The actual overall stress exerted on the column, $\sigma = P \div A$, was then calculated to be 0.85 ksi. The overall stress was significantly smaller than the allowable stress on the column, which means that the column will not fail and can adequately hold the given loads. Therefore, the column satisfies the requirements, and will be sufficient to carry the load of the deck.

Footer Design

Footers were designed in order to securely anchor the play structure to the ground. In Ohio, the depth of frost line is 30" (International Code Council). The bottom of the footer must be below this depth in order to ensure that no freezing happens below the footer. If freezing were to take place, expansion would occur below the footer, causing it to rise. This would cause problems, as the footings would not be adequately covered and the structure would no longer be level. A footer depth of 36" inches was used in order to be conservative. The footers were designed based off of the pole, which was checked above, that held the largest load.

In order to design the necessary dimensions of the footers, the bearing capacity was assessed using the following equations;

$$\text{Shear stress; } \sigma = Q / A$$

- σ = shear stress in pounds per square foot
- Q = factored load on column in pounds
- A = area of footer in square inches

Ultimate Bearing Capacity; $q_{ult} = cN_c + \frac{1}{2} B\gamma N_\gamma + \gamma D_f N_q$

- q_{ult} = ultimate bearing capacity in pounds per square foot
- c = cohesion of soil in pounds per square foot
- N_c = bearing capacity factor
- B = width of footing in feet
- γ = unit weight of soil in pounds per cubic foot
- N_γ = bearing capacity factor
- D_f = depth of footing in feet
- N_q = bearing capacity factor

Allowable Bearing Capacity; $q_{all} = q_{ult} / FS$

- q_{all} = allowable bearing capacity in pounds per square foot
- FS = factor of safety

If $q_{all} > \sigma$; therefore, acceptable

Bearing capacity factors were taken from Table 9 below, from the Foundation Engineering Handbook (Fang).

Table 9. Bearing Capacity Factors (Taken from Fang)

ϕ	N_c	N_q	N_{γ}
0	5.14	1.0	0.0
5	6.5	1.57	0.45
10	8.35	2.47	1.22
15	10.98	3.94	2.65
20	14.83	6.4	5.39
25	20.72	10.66	10.88
30	30.14	18.4	22.4
32	35.49	23.18	30.22
34	42.16	29.44	41.06
36	50.59	37.75	56.31
38	61.35	48.93	78.03
40	75.31	64.20	109.41
42	93.71	85.38	155.55
44	118.37	115.31	224.64

From the previous analysis of the loads of the structure, the factored load (Q) on the column was determined to be 4,360 lb. This was used to determine the available stress that the footer would be able to withstand. Footer dimensions of 12 inches x 12 inches were initially assumed in the calculation, resulting in an available stress of 4,360 psf. Three different soil types were assessed, in order to accommodate for variations in soil types where the playground might be constructed. First, soft glacial clay was evaluated. Soft glacial clay is soil left behind from glaciers, and can be found in places such as Cleveland, OH. As seen in Table 10 below for typical soil characteristics from the *Civil Engineering Reference Manual for the PE Exam*, soft glacial clay has a unit weight of 76 lb/ft³. This was used to calculate the ultimate bearing capacity of 5,600 psf. A factor of safety of 1.5 was used to determine the allowable bearing capacity of 3,733 psf. Since this value was not greater than the available stress of 4,360 psf for the 12" x 12" footer, the base dimension of the footer was increased to 16 inches. This, in turn, gave a new stress of 3,270 psf, which was less than the bearing capacity of 3,733 psf.

Therefore, the footer design of 16" x 12" was determined adequate for soft glacial clay soil.

Table 10. Typical Soil Characteristics (Taken from Fang)

Soil Type	γ (lb/ft ³)	γ_{sat} (lb/ft ³)
Sand loose and uniform	90	118
Sand dense and uniform	109	130
sand loose and well graded	99	124
Sand dense and well graded	116	135
glacial clay soft	76	110
glacial clay stiff	106	125

Loose, well-graded sand was the next soil to be evaluated. This soil type has a unit weight of 99 lb/ft³. This resulted in the calculated ultimate bearing capacity of 7,564 psf. With a factor of safety of 1.5, the allowable bearing capacity was found to be 5,042 psf. Since this value was greater than the stress for the 12" x 12" footer, these dimensions were deemed adequate for loose, well-graded sand.

Dense, well-graded sand was the third soil type to be evaluated for the footer dimensions. This soil type has a unit weight of 116 lb/ft³. The respective ultimate bearing capacity was calculated to be 8,862 psf. With a factor of safety of 1.5, the allowable bearing capacity was found to be 5,908 psf. This is also greater than the stress for a 12" x 12" footer. Therefore, this dimension was also used for the design of footers in dense, well-graded sandy soil.

The footer designs for all three soil types can be seen in Figures 34 and 3 below.

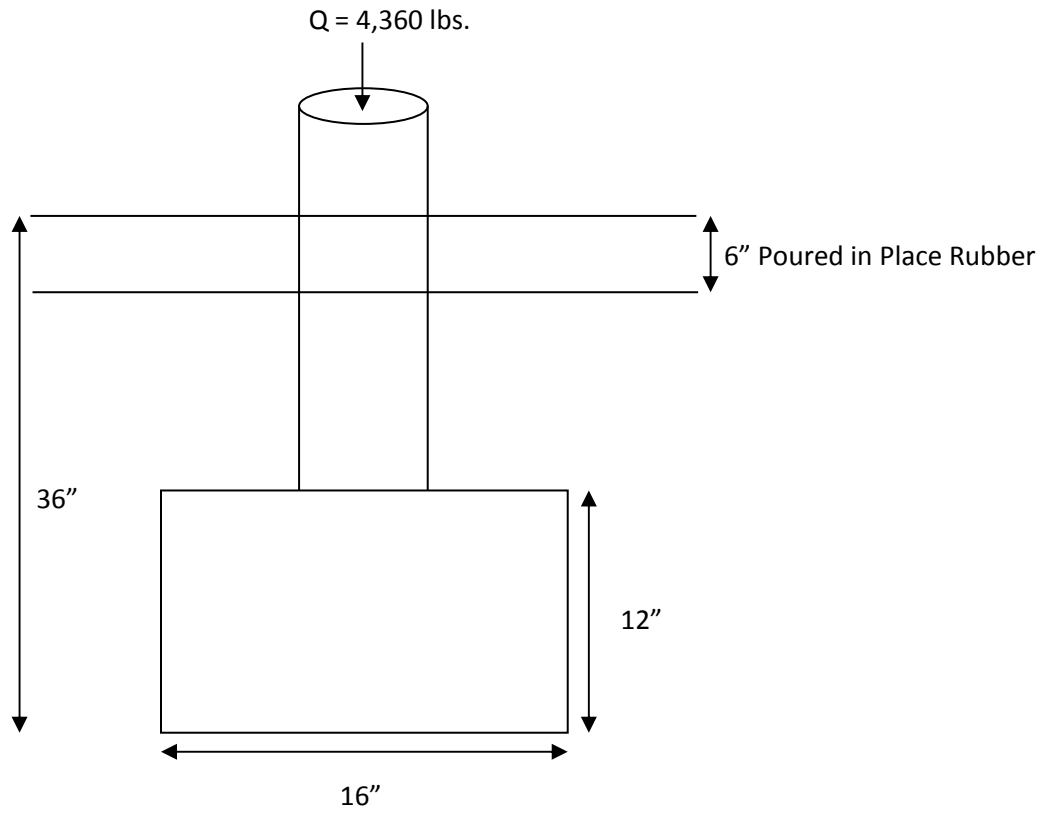


Figure 34. Foundation Design for Soft Glacial Clay

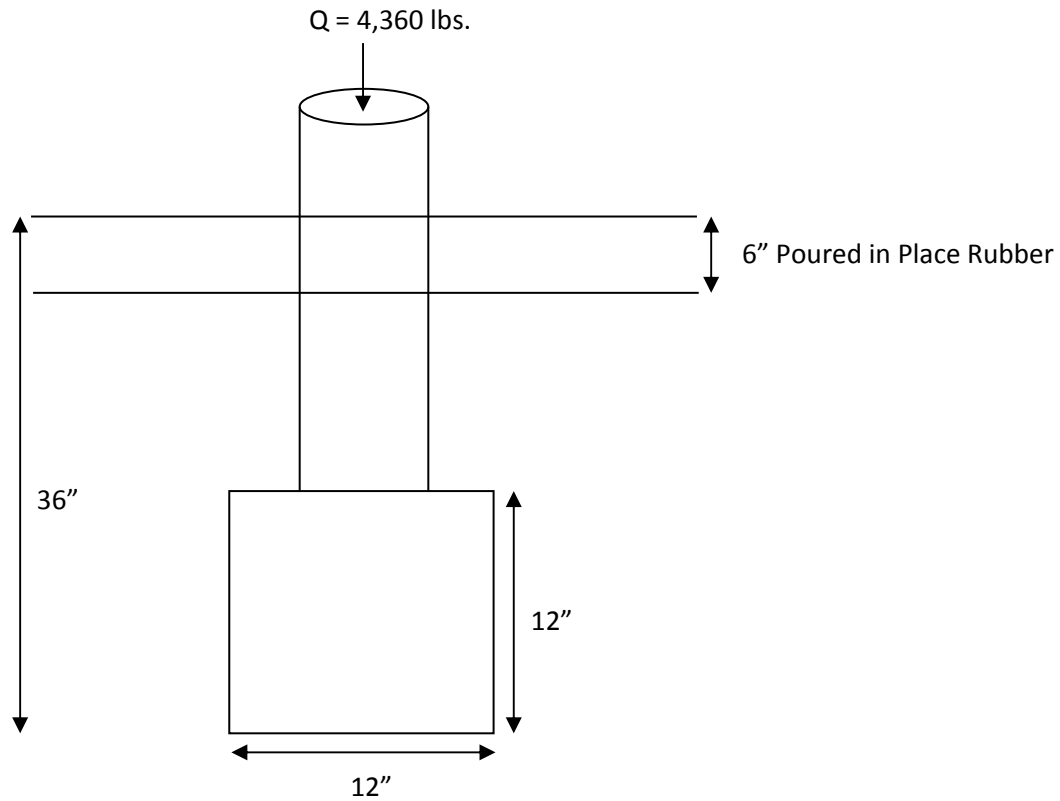


Figure 35. Foundation Design for Loose, Well-Graded Sand and Dense, Well-Graded Sand:

The footer is designed for the above three types of soils, which are observed in the Ohio region. To be conservative, the 16 inch by 12 inch footer could be used with all three soil types. Regions that do not have soft glacial clay, well graded sand, or dense, well-graded sand would need to be reconsidered before the playground can be safely installed on the designed footers.

Swings Set Footer Design

The swing sets for the designed playground will be bought directly from manufacturers. The two swing set bays which house the two belt seats and two enclosed seats will be purchased from LA Steelcraft, Inc. As can be seen in the figure below (LA Steelcraft), the manufacturer specifications recommend 18 inch x 24 inch concrete footers on each of the four posts in order to support the swing set. These footer designs will be checked by the structural analysis detailed below. Even though the swings are much lighter than the playground structure, the footers must be larger in order to prevent uplift from the rocking motion while the swings are in use. Uplift is prevented when the downward force of the swing set is greater than the upward lift created by the acceleration of the child. The acceleration of the swing while in use creates an upward force on the sets of legs directly below the swinger, and a downward force on the legs behind the swinger, as seen in Figure 36 below.

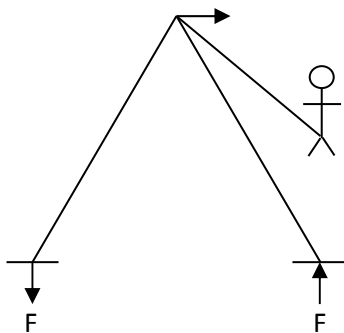


Figure 36. Diagram of Forces Exerted on Swings

The forces were calculated using $\text{Force} = \text{mass (of the child swinging)} \times \text{acceleration (of the child)}$. The footers were designed for the maximum force, which would be created when the child and swing is at the maximum height of swinging,

parallel to the ground. The static load of the swing set, strictly from its weight, must be greater than the dynamic load of the upward force from the rocking of the swing, therefore uplift is prevented and the swing set will be safely designed.

The weight of a child of weighing 150 lbs was used to make a conservative estimate. While some users may weigh more than this, a factor of safety will be used to prevent uplift and footer failure. Using the conversion from pounds to kilograms, it was found that a child weighing 150 lbs was a mass of 68.04 kg. The angular acceleration of the child swinging was then calculated using the following equations;

$$\omega = 2 * \pi * f$$

- ω = angular velocity
- f = frequency = 1/ period

$$v = \omega * R$$

- v = linear velocity
- R = distance to the axis of rotation

$$a = v^2 / R$$

- a = angular acceleration

The resulting angular acceleration was found to be 4.88 m/s^2 , based on a linear velocity of 3.11 m/s and an R of 1.98 meters , which is the length of the swing chains (6.5 feet). From the calculated acceleration, the upward lift force was found using $F = ma$. This resulted in a force of 332.37 N or 74.72 lbs . This upward lift force is not greater than the force exerted downward by the weight of the swing set, therefore no upward lift occurs.

From this analysis it was concluded that the upward lift force is not great enough to lift the swing set, therefore only the downward force from the rocking motion must be

taken into account. This was analyzed by adding the force to the dead load of the swing set, and using the foundation analysis that was detailed in the previous section. It was found that the manufacturers' recommendations for the footers of the swing set will be adequate based on the uplift force from the rocking. A footer of 18" x 24" will be used. Depicted below in Figure 37, is the manufacturer's footer dimensions for the swing set.

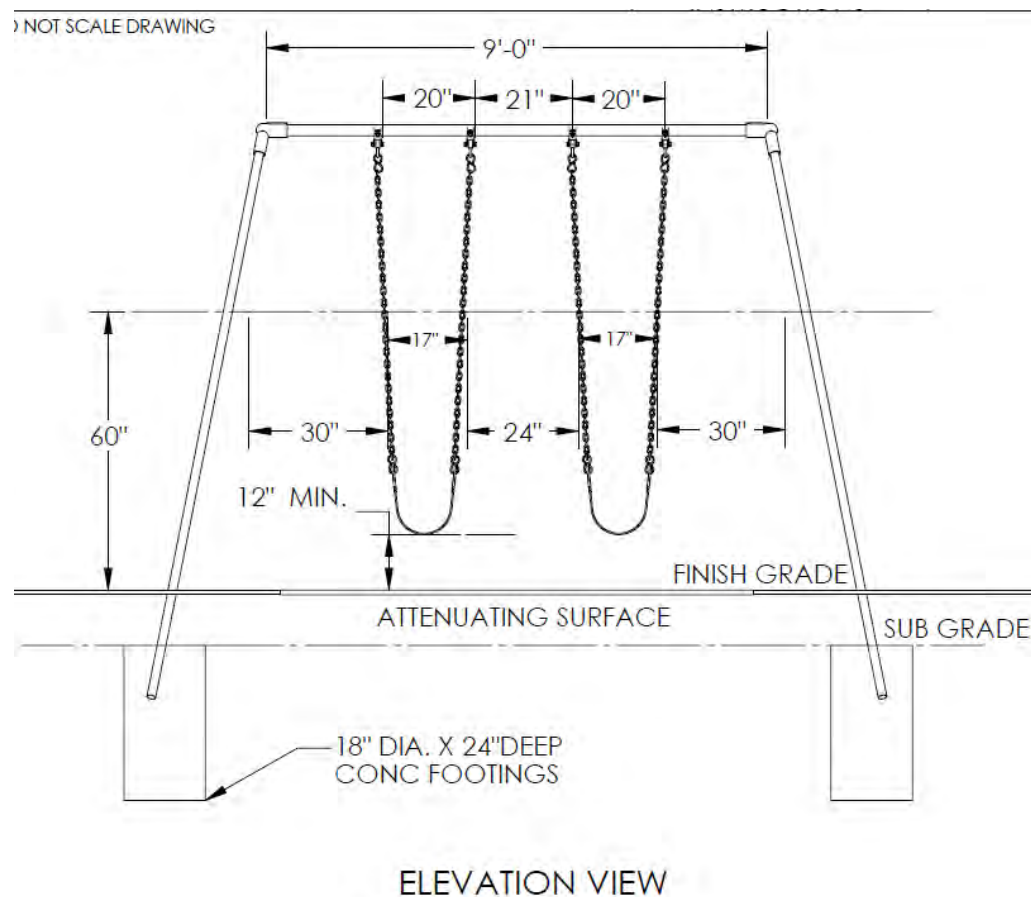


Figure 37. Swing Set Footer Design (Taken from (LA Steelcraft))

The Liberty Swing (Devine), which will also be purchased directly from the manufacturer, provided specifications for the necessary concrete footer dimensions to support the swing and prevent uplift. The figure below details the footer dimensions

based on five different soil types. The site soil should be evaluated before choosing the footer dimensions. The largest footer size based on sandy, undisturbed soil is 13 $\frac{3}{4}$ inches x 25 $\frac{5}{8}$ inches. Even though the Liberty Swing (including a wheelchair and passenger) is approximately the same weight as the two swing bay structure, the footers are designed to be slightly smaller. This is because the Liberty Swing is not designed to swing or rotate as high as the belt and enclosed swings that are housed in the swing bay. Since the load will typically be more centered on the structure's center of gravity, the footers are designed to be slightly smaller as they are not exposed to as large of an uplift force. The accessible swing was also designed with the same footers as the Liberty Swing. It is a lighter swing and also has a limited swing height; therefore, the Liberty Swing's footers will be adequate for the accessible swing also. Figure 38 below shows the footer design for the Liberty Swing and accessible swing sets.

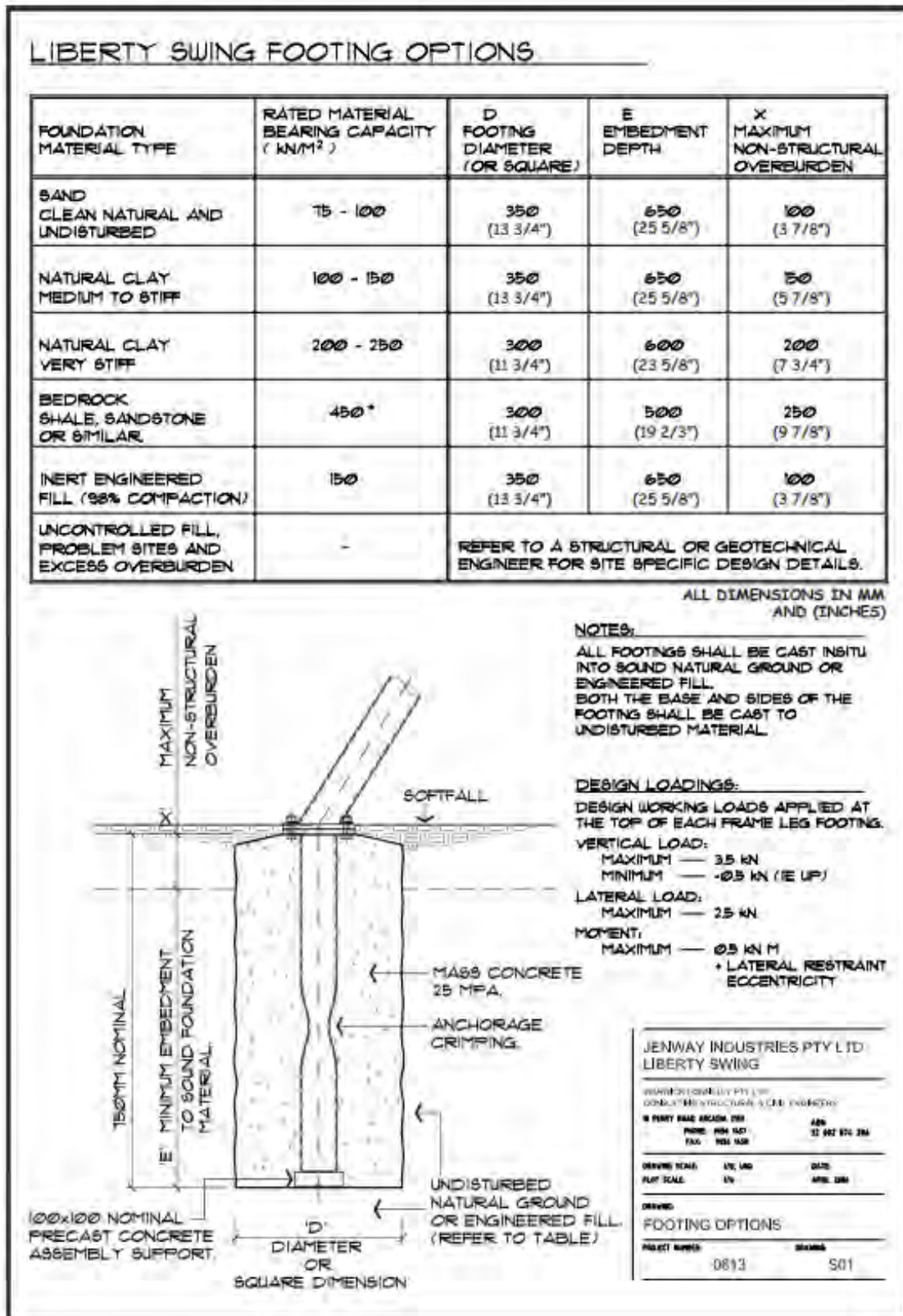


Figure 38. Liberty and Accessible Swing Footing Design (Taken from www.libertyswing.com)

The completed structural analysis proves that the structure will be safe and can adequately withstand the forces that would be exerted on it. The calculated results and final dimensions of the design are summarized. The canopies are supported by five inch outside diameter aluminum columns, and are attached to the deck with four ½ inch bolts. The loads of the decking are supported by twenty-seven load bearing five inch outside diameter aluminum columns. These support columns are securely fastened to the deck by four ¾ inch bolts spaced six inches apart at each connection. The footers were designed based on three soil conditions, with the conservative design being a 16 inch by 12 inch concrete footer. The swing set footers were evaluated for their success and resistance to uplift forces. The recommended manufacturers' dimensions proved to be adequate and will be used in the design.

Cost Analysis

Having calculated and confirmed all parts, dimensions, and materials as appropriate for an accessible playground, a cost analysis was performed. This was done by separately pricing the individual components that made up the final designed playground. The final estimated cost analysis for the designed playground can be seen detailed in Table 11 below. This final estimate totals \$50,588.84, but does not include the cost for the poured in place rubber surfacing of the playground or any site signage and benches. An estimate of these will be determined on a case by case basis by the layout, grades, and elevations of the proposed site. As stated in the introduction, a \$50,000 fine for not complying with the new ADA guidelines may be issued. The designed elevated structure provides an ADA accessible playground for almost the same cost as would be

spent on the fine. This represents a successful design, as a cost comparable alternative has been designed. The given cost estimates in the table were taken from various manufacturer websites. The units which were assessed include the following; play walls (Playbuilder), shade coverage (Shade Systems, Inc.), swing sets (Swing Set Stuff Inc.) (LA Steelcraft), overhead climbing ladder (LA Steelcraft), concrete footers (Cincinnati Ready-Mix Concrete Company), bolts (Suburban Bolt and Supply Co.), and all aluminum and steel pipes and metals (Metals Depot International).

Table 11. Elevated Structure Cost Analysis

Component	Quantity	Total Area (ft ²)	Material	Unit Cost	Unit	Total Cost
Ramps						
Straight Run	3	180.00	12 gauge perforated steel	\$ 18.00	SF	\$ 3,240.00
Landing	1	25.00	12 gauge perforated steel	\$ 18.00	SF	\$ 450.00
Railing	-	164 LF	1 1/4" OD round steel tube	\$ 12.00	LF	\$ 1,968.00
Posts	2	8 LF	5" Aluminum tubing	\$ 25.00	LF	\$ 200.00
Posts	4	20 LF	5" Aluminum tubing	\$ 25.00	LF	\$ 500.00
Posts	4	24 LF	5" Aluminum tubing	\$ 25.00	LF	\$ 600.00
Posts	2	14 LF	5" Aluminum tubing	\$ 25.00	LF	\$ 350.00
Elevated Structure (Lower: 1 ft)						
Platform	1	100.00	12 gauge perforated steel	\$ 18.00	SF	\$ 1,800.00
Shade Coverage	1	100.00	Fabric	\$ 2,696.00	Unit	\$ 2,696.00
Guardrail	1	48 LF	1 1/4" OD round steel tube	\$ 12.00	LF	\$ 576.00
Posts	4	20 LF	5" Aluminum tubing	\$ 25.00	LF	\$ 500.00
Elevated Structure (Higher: 3 ft)						
Platform	1	100.00	12 gauge perforated steel	\$ 18.00	SF	\$ 1,800.00
Shade Coverage	1	100.00	Fabric	\$ 2,696.00	Unit	\$ 2,696.00
Barrier	1	434 LF	1 1/4" OD round steel tube	\$ 12.00	LF	\$ 5,208.00
Play walls	2	-	Plastic	\$ 500.00	Unit	\$ 1,000.00
Posts	4	28 LF	5" Aluminum tubing	\$ 25.00	LF	\$ 700.00
Stairs						
Steps	3	13.33	12 gauge perforated steel	\$ 18.00	SF	\$ 240.00
Transfer Platform	1	2.33	12 gauge perforated steel	\$ 18.00	SF	\$ 42.00
Posts	2	14 LF	5" Aluminum Tubing	\$ 25.00	LF	\$ 350.00
Railing	2	18 LF	1 1/4" OD round steel tube	\$ 12.00	LF	\$ 216.00
Overhead Ladder Unit						
Overhead Ladder Unit	1	-	Stainless Steel	\$ 1,206.00	Unit	\$ 1,206.00
Slide						
Slide bed	1	18	16 gauge stainless steel	\$ 14.00	SF	\$ 252.00
Sides of slide	2	4.5	16 gauge stainless steel	\$ 14.00	SF	\$ 63.00
Posts	2	10 LF	5" Aluminum tubing	\$ 25.00	LF	\$ 250.00
Climbing Tree						
Foot Steps	3	-	Plastic	\$ 100.00	Unit	\$ 300.00
Railing/Reinforcement	1	8 LF	1 1/4" OD round steel tube	\$ 12.00	LF	\$ 96.00
Central Post	1	7 LF	4" OD round steel tube	\$ 41.00	LF	\$ 287.00
Swings						
Belt Swing Set	1	-	Powder Coated Steel	\$ 1,011.00	Unit	\$ 1,011.00
Enclosed Swing Set	1	-	Powder Coated Steel	\$ 1,243.00	Unit	\$ 1,243.00
Accessible Seat Swing Set	1	-	Plastic	\$ 450.00	Unit	\$ 450.00
Wheelchair Swing Set	1	-	Stainless Steel and Plastic	\$ 20,000.00	Unit	\$ 20,000.00
Miscellaneous						
Footers	27	1 CF	Concrete	\$ 88.00	CY	\$ 88.00
Bolts	300	-	Galvanized Stainless Steel	\$ 70.28	per 100	\$ 210.84
Final Cost Estimate						
					Total	\$ 50,588.84

Elevated Playground Benefits

With the elevated play structure complete and analyzed, it was then important to reflect on how well it met the needs of the children who would play on it and suggest any necessary improvements or refinement. As described in the introduction, an important component of playgrounds is that they incorporate climbing, overhead equipment, swings, and sand and water play. The designed elevated equipment purposefully includes three of the four aspects; climbing, swings, and overhead equipment. An accompanying ground level component, described in the next portion of this thesis, will encompass the sand and water play feature. Playgrounds are the facilities in which children can express themselves through play on many different components and equipment (Lima). Each playground aspect offers a different skill set development while a child is at play. The four types of play; social, emotional, cognitive, and physical, are also put into use on various playground components. The elevated playground structure was designed to incorporate accessible components into as many of the components as possible.

The elevated play structure features a step climber. The step climber goes from the ground up to the higher elevated platform. Climbing has long been established as a developmentally beneficial activity for children, as climbing a play structure involves many skills. The child must use cognitive skills in order to climb the structure as it does not come with any set instructions. Therefore, the child must figure out where to put each hand and foot to get to the top. Although the designed step climber is not every complex and only reaches a height of four feet, spatial, directional, and body awareness are still required from the child in order to decide how to maneuver their body on the structure. This maneuverability also requires physical skills such as strength, balance, and

coordination. A child must also combat the feeling of fear from being at a height that is taller than what many children are used to, which promotes the proper management of emotions. Although the height may be intimidating at first, this can also be a reason why children enjoy climbing as it allows them to change their perspective, fostering their natural curiosity (Thornton and Frost). Most children are only three to five feet tall, so climbing to a four foot increase in height gives them the ability to observe their surroundings from an entirely new view point. While these are important developmental skills, many children with disabilities may miss out as the step climber is not accessible. It would be ideal to develop an accessible climbing structure, but it is not critical to the accessibility of the playground. An accessible playground must have at least $\frac{1}{2}$ as many accessible components as non accessible components. So while the step climber is not accessible, more than half of the other components of the playground are accessible, which makes the playground compliant.

Climbing can usually be done on many different surfaces on and off of a playground, but overhead equipment presents opportunities that can usually only be found on playgrounds. The designed overhead climbing ladder, which connects to the lower elevated platform, represents a playground component that is essential for children's learning and development (Thornton and Frost). The overhead climbing ladder was incorporated into the elevated playground design because of the crucial skill sets it develops in children that were laid out in the Introduction. The proposed design, though, particularly seeks to accommodate children with disabilities who may not otherwise be able to utilize typical overhead climbing structures. While most children develop the skill of supporting their own body weight by age two, many disabled children do not receive

the play assistance necessary to develop these same skills. The height of the overhead ladder is 54”, making it accessible for children using wheelchairs. Although some children using wheelchairs may not be able to fully swing from one bar to the next, they are still able to grasp the overhead bars, pull their body weight up, and move across the ladder. The designed overhead ladder therefore utilizes an important skill set, specifically for children with disabilities, that is not developed on any other play equipment in the playground design.

Although the act of swinging from one arm to the next is important, full body swinging also provides beneficial development opportunities in children. Children can use swings in many different ways and for many different purposes, which makes them one of the most exciting pieces of equipment on a playground. Swings were incorporated into the design because of the important skill sets that full body swinging provides, as detailed in the Introduction. For this reason, the playground design features one wheelchair swing and one accessible swing. The wheelchair swing allows a child to stay in their wheelchair while still swinging. The accessible swing requires the child to sit in a more supportive seat while swinging. This allows the children to still utilize physical skills such as grasping as the swing is being pushed. It also allows the child to experience the sensory stimulation which is important for cognitive development. Both of these swings allow children with disabilities to build their social skills by participating in activities that the other children on the playground are able to do. With the swing design, disabled children will no longer feel left out or excluded from their able bodied peers on the playground, building their confidence and emotional well being. The designed swings therefore utilize physical, cognitive, social, and emotional skills in children.

Although the step climber, overhead climbing ladder, and swings cover the three main playground components on the elevated structure, other aspects of the playground were designed to accommodate and benefit children with disabilities, so that they too are exposed to the developmental skills outlined in the Introduction. The steps on the playground providing access to the highest elevated structure are actually accessible stairs. This is because the first step, which is called a transfer platform, is at a height of 12 inches. The transfer platform makes the stairs accessible as they allow a child in a wheelchair to transfer themselves onto the platform and scoot up the stairs on their backsides. Using the stairs allows children with disabilities to be exposed to the physical developmental skills.

The slide can also develop valuable skills in children such as physical and social development. The designed slide was made to slope gradually enough that it may also be used by children in wheelchairs, provided that the correct material be utilized. This is important to once again provide an inclusive environment, encouraging parallel play and the interaction between children of all abilities. The designed playground includes various features which encourage the development of essential skills in children of all abilities. A successful playground design utilizes the development of skill sets without children even knowing that they are learning. The designed playground utilizes the four types of play through social, emotional, cognitive, and physical skill development by encompassing three of the main playground components of climbing, overhead equipment, and swings.

III. GROUND LEVEL COMPONENT

As the previous sections detailed, the designed elevated equipment includes three of the four aspects of mainstream playgrounds; climbing, swings, and overhead equipment. While the ground level component will encompass the sand and water play feature. To be considered an accessible playground, standards specify that for every elevated piece of equipment, even those that are fully accessible, there must be $\frac{1}{2}$ the number of ground level pieces of equipment. It would be necessary for a ground level structure to accompany the elevated structure for it to be fully compliant. In the initial design stages of the thesis, the intent was to collaborate with a local organization to design and install the ground level component on an existing playground, bringing the playground closer to ADA compliance. While the installation was not be feasible in the given time period, the ground level component was still designed and finalized for future installation.

During the design process of the ground level component, three designs were drafted. Each design was then put through the design analysis process where the objectives and constraints were analyzed based on the design. Below are the three original designs.

Design 1: Six Sided Table with Play Wall

Design 1 features a six sided table with a play wall. Five of the sides will be used for children to sit or stand around. The five sides are each 36 inches wide. A standard wheelchair width is 30 inches wide (Department of Justice), so utilizing a width of 36 inches allows enough space for five children in wheelchairs to comfortably sit around the

table at a given time. The height of the table is 30 inches from the ground to the bottom of the table surface. The height of the seat of a standard wheelchair is 19 inches

(Department of Justice), bringing the height of the child's lap to about 25 inches.

Therefore, 30 inches is the minimum clear floor space height to meet ADA requirements, allowing for adequate clearance for the child in a wheelchair to comfortably sit without the surface being too high or low. 30 inches also provides a suitable surface height for children who are standing at the table. The average height of children five to twelve years old is 40 to 60 inches tall (Disabled World). A 30 inch table height allows for the surface to be within the chest to waist height range for the average standing child. The table will have only a central support leg. Utilizing central support will prevent the need for support legs around the perimeter corners of the table. This is beneficial in an accessible table in preventing injuries from children bumping their feet and legs into the support legs. It also prevents the need for a wheelchair to accurately maneuver between the supports in order to move forward to sit at the table. The five sides of the table encourage interaction between the children through parallel play, which assists in the development of social skills in children. The center of the table features a globe. 24 inches is the maximum allowable horizontal reaching distance for a person sitting in a wheelchair (Department of Justice), therefore, the edge of the globe will sit 24 inches from the edge of the table. This will encourage children to reach and touch the globe, assisting with physical development. The globe will be colorful and textured, in order to stimulate the children's sight and touch senses, while also encouraging cognitive development by learning the geography of the world. The sixth side of the table features a play wall. The play wall will include different activities, puzzles, buttons, and gears to stimulate a child's

cognitive learning skills and development. Various textures, colors, shapes, and sizes will also be incorporated to attract the interest and attention of children. The play wall will begin nine inches off of the ground and span to a height of 54 inches, which are the necessary heights to meet ADA standards. Nine inches above the ground is the minimum low reach, while 54 inches is the maximum vertical reach height for a person in a wheelchair (Department of Justice). Figures 39 and 40 below show the components of Design 1.

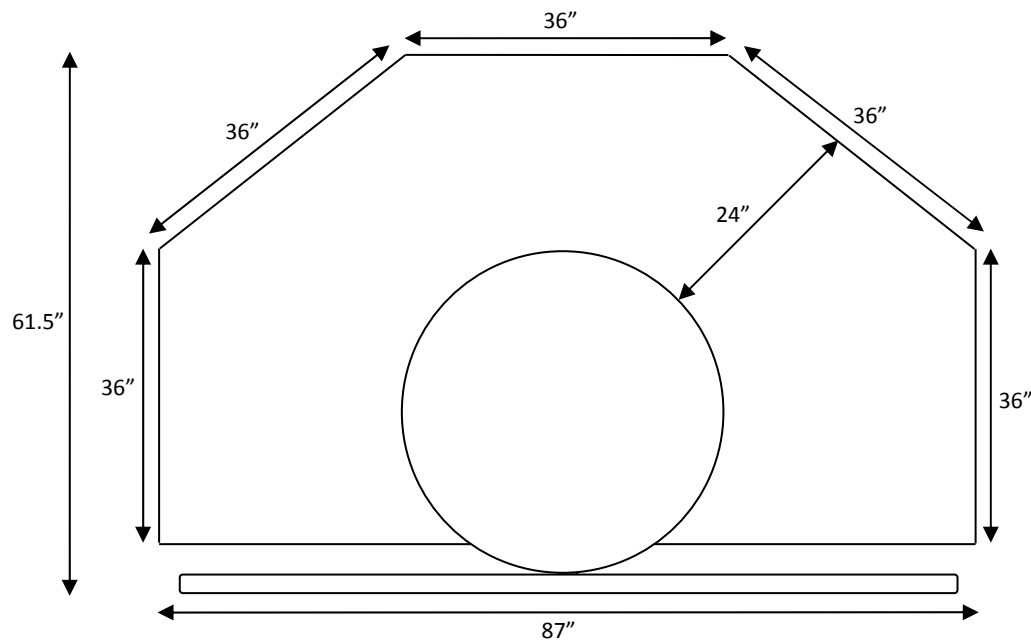


Figure 39. Top View of the Envisioned Activity Table Associated with Design 1

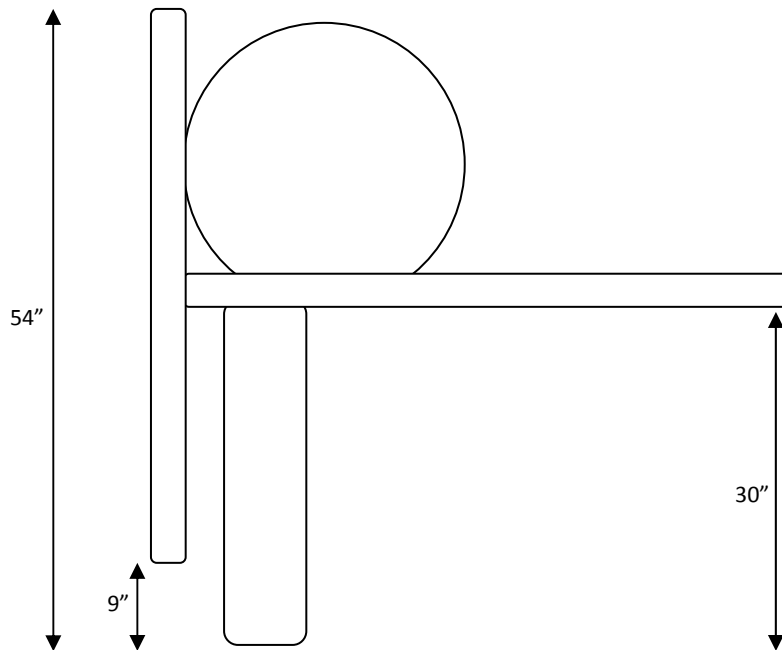


Figure 40. Profile View of the Envisioned Activity Table Associated with Design 1

Design 2: Circular Table with Four Play Stations

Whereas Design 1 allowed children to work and play together on primarily the same activity, Design 2 will feature a circular table with four separate play stations. The diameter of the table is 84 inches (7 feet). This results a circumference of 264 inches, which provides enough space for eight children, all in wheelchairs, to sit around the play table at a given time. The clear space height is 30 inches to comply with ADA standards. A central support leg will also be utilized in this design to prevent unnecessary obstructions for children and wheelchairs moving up to and sitting at the table. The table surface will be 24 inches from the edge of the table to the edge of the central dome shape, utilizing the maximum forward reach requirements for ADA design standards. This

design also features central dome shape, but it will not be world globe, but rather the focal point for the four play stations around the table. The four play stations are a water station, sand station, music station, and driving station. The water station will be a shallow, four inch basin of water, with a water fountain flowing from the central dome into the basin. The water fall will provide continuous circulation of the water in the basin, aiming to keep it clean and prevent the growth of bacteria from stagnant water. An edge or lip around the basin, along with dividers separating the water station from the sand and music stations, will aim to keep the water contained predominately within the station. The sand station will feature a shallow sand pit for the children to play in. The top of the sand pit will sit flat with the surface of the table, allowing for the excess sand to be easily swept back into the pit. Plastic buckets, hand shovels, and cups will be provided for both the sand and water stations. These play tools can be beneficial for developing cognitive and academic learning through mathematical concepts such as, is the bucket full or empty, is the water shallow or deep, how many scoops are there, how tall is the sand castle, etc (Thornton and Frost).

The third station featured in Design 2 is the driving station. A steering wheel, gears, and buttons will be incorporated into this station. The steering wheel will functionally rotate, which allows children to use imaginative play in pretending that they are actually driving a vehicle. The buttons are various shapes and colors, which is beneficial in a child's cognitive development in learning to recognize and differentiate their shapes and colors. A mirror will be mounted on the central dome directly in front of the driving station. This will serve as the "cars" rear view mirror, and also provides the children with entertainment when playing with their reflection.

The fourth station of Design 2 is the music station. This station features a xylophone and five drums. Some children with disabilities, such as Cerebral Palsy, have trouble with muscle control, which causes a difficulty in grasping objects. In order to accommodate children who have these difficulties, the drums will be a plastic surface that can be used and beat on with a child's fist or hand. A drumstick will not be provided, nor will it be necessary to make noise on the drums. A typical xylophone is used by hitting a mallet on the keys, but as mallets also require muscle control to grasp, this was not desired for the design. In order to provide a way for the xylophone to be played without the use of a typical hand held mallet, a lever-like reverse mallet, first proposed by the University of Dayton EGR 103 Engineering Innovation team of Leigha Brisco, Debbie Kinor, Sarah Oliveri, and Marissa Winschel will be implemented. As seen in the figures below, this reverse lever mallet attaches to the underside of each key on the xylophone. The end of the mallet has a flat circular surface, which protrudes out from the edge of the table. When a force, such as a child's palm or fist, is applied downward to the surface of the mallet (Figure 41), it acts as a lever and the opposite end moves upward, striking the underside of the key (Figure 42). This reverse lever mallet allows a child to play the xylophone and hear the music notes created, without requiring the muscle control to grip a conventional mallet. Figures 43 and 44 show the components of Design 2.

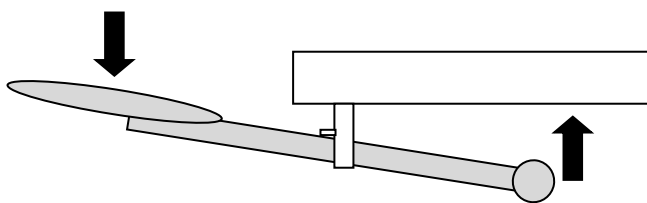


Figure 41. Downward Force on Mallet

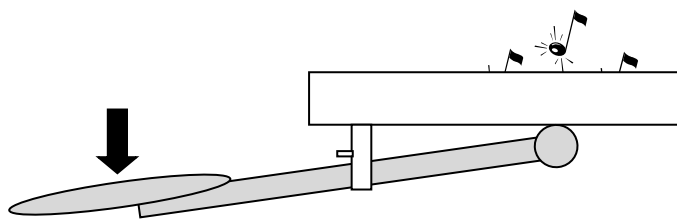


Figure 42. Upward Strike of Mallet on Key

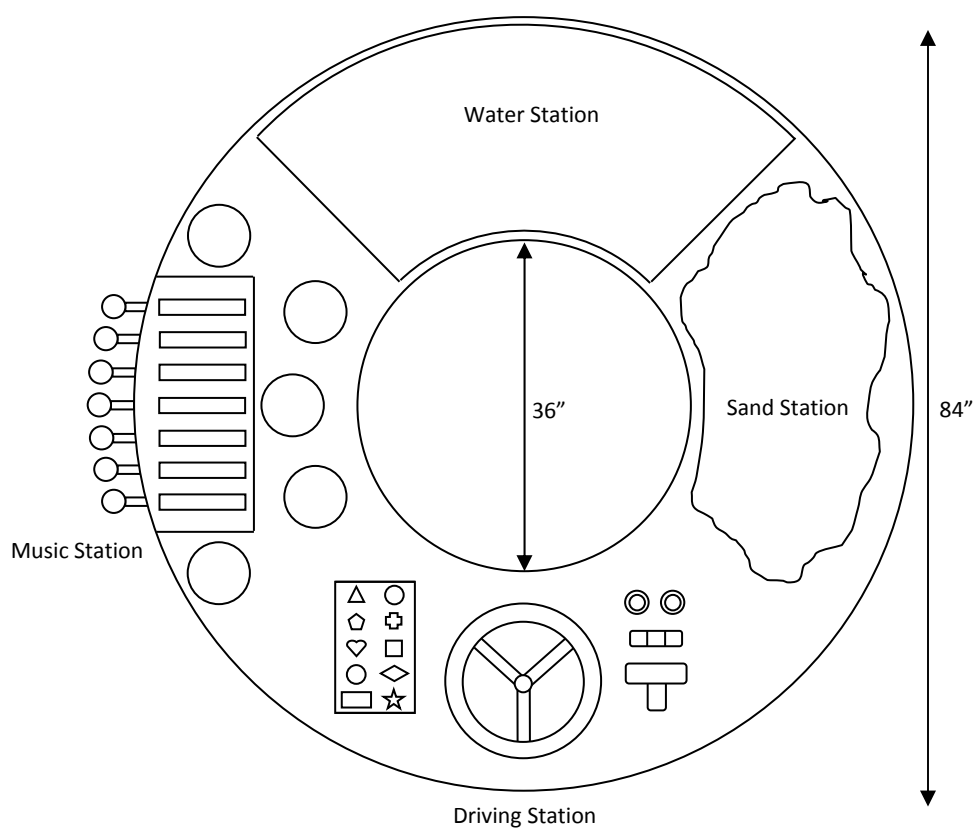


Figure 43. Top View of the Envisioned Activity Table Associated with Design 2

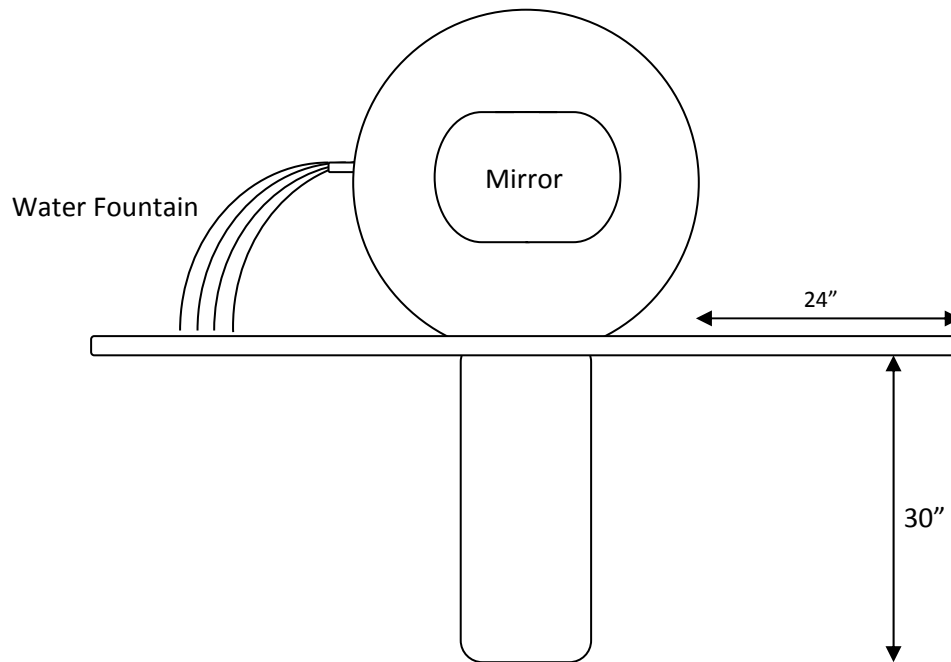


Figure 44. Profile View of the Envisioned Activity Table Associated with Design 2

Design 3: Semi-Circular Table with Three Play Stations

Design 3 features a semi-circular or moon shaped table with three separate play stations. The table has a diameter of 96 inches (8 feet). The semi-circular shape allows children to sit or stand on both sides of the table. This is beneficial in allowing more children to play on the table at once, increasing the social benefits of parallel play. The table shape also allows for parents or supervision to be directly across the table from the child, making it easier to provide guidance or assistance if necessary. The table width is 24 inches. This width was chosen in order to comply with the maximum forward reach requirements for ADA standards, as if children were only sitting on one side of the table. The clear space height of the table is 30 inches to also comply with ADA design standards. The majority of the underside of the table will be completely obstruction free,

utilizing two support legs on each end of the table. This will allow for clear leg space through the central portion of the table, where most of the children will be sitting. The three play stations that are featured in Design 3 are the water station, sand station, and music station. The water station is designed with the same set up as Design 2, with the exception of the water fountain feature. Without this feature, more vigorous maintenance will be required to prevent stagnant water from growing mold and bacteria. The sand and music stations are also designed with the same set up as previously seen in Design 2. The music station utilizes the drum stick free drums and reverse lever mallet in order to prevent children without adequate muscle control from being excluded in playing the instruments. Two talking tubes will be located at opposite ends of the table. These talking tubes, which are connected underground, come up out of the ground with a megaphone shaped speaker on each end. Children can talk into the speaker and interact with a child who is positioned at the other talking tube. This is beneficial for children experimenting with sounds and developing their imaginary play. Figures 45 and 46 below show the components of Design 3.

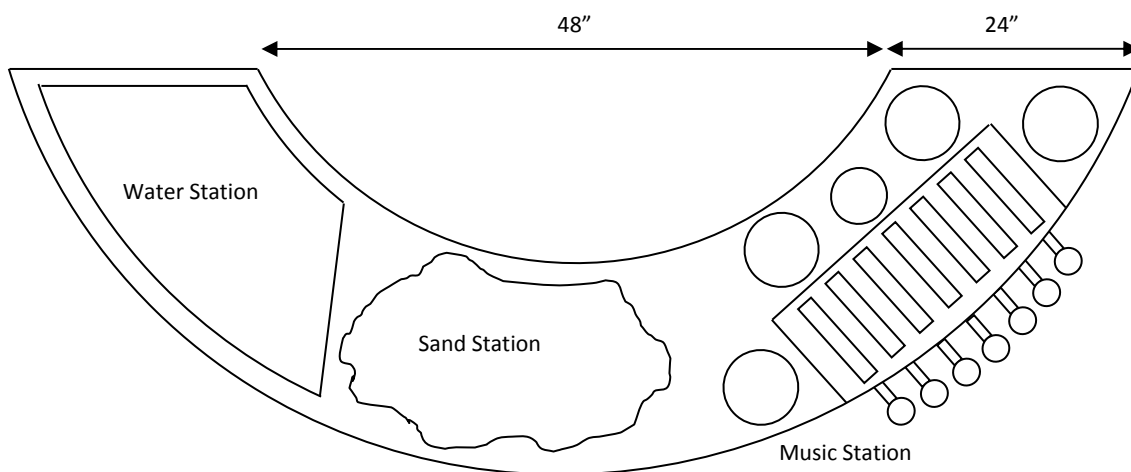


Figure 45. Top View of the Envisioned Activity Table Associated with Design 3

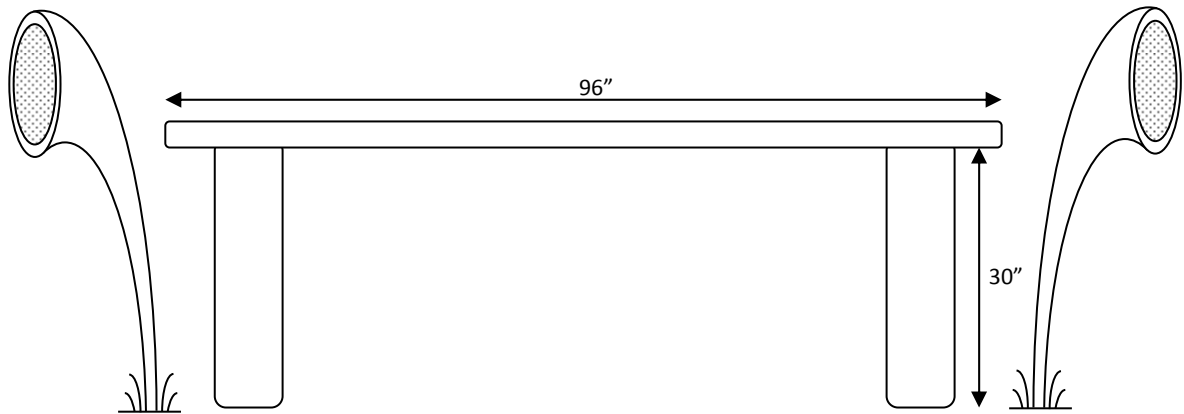


Figure 46. Profile View of the Envisioned Activity Table Associated with Design 3

Design Selection

The objectives and constraints for each of the three ground level designs were analyzed in order to choose the final design. Design 1 was excluded as it did not fulfill the design constraint of including a water and sand component. Design 3, although satisfying the majority of the objectives and constraints, featured two support legs that were on the exterior edges of the structure. This caused the design to fail a constraint, excluding it from being chosen as the final design. Although the table design was excluded, the talking tubes from the design will be used in the final component. Design 2 was ultimately chosen as the final ground level component design. It satisfied all of the given constraints, while fulfilling the majority of the objectives. Design 2 is accessible for individuals in wheelchairs, while also accommodating children using walkers. The activity table has a ground clearance of 30 inches, while the width does not exceed 24 inches, the reaching distance of a person in a wheelchair. A central leg supports the table, preventing the need for any legs around the exterior which would cause obstructions. The

diameter of the leg was increased in the final design, in order to account for the weight of the table and to ensure a stable table surface. The design presents no safety hazards such as pinched fingers, burns, sharp edges, etc. Although the water and sand features of the design will require routine maintenance, the water fountain feature in Design 2 allows for the circulation of the water, keeping the water fresh and slowing the growth of bacteria caused by stagnant water. This will reduce the frequency of the required maintenance, as opposed to Design 3 without the water fountain feature. Durable and environmentally friendly material will be utilized throughout the design. The final constraint was that the activity table be economical, costing no more than \$1,500. This constraint will be proven and detailed in the cost analysis in the following section.

Along with meeting all of the required constraints, Design 2 fulfilled the majority of the objectives. The chosen design incorporates social, emotional, cognitive, and physical play through its various features. The design provides enough space for eight children using wheelchairs to play at a given time. This encourages parallel play and interaction between children, developing valuable social skills. Four play stations, sand, water, music, and driving, are utilized in the design. These four stations provide a variety of activities for all children, accommodating users who may be sight and hearing impaired, as well as physically handicapped. Multiple textures, bright colors, and sounds are all incorporated in the design.

The water station with the water fountain stimulates the touch sense by through the feeling of wetness. It also stimulates a child's sense of hearing as the water fountain splashes into the shallow pool, especially for a child who is sight impaired. The sand station provides another texture stimulant as the child touches and digs in the sand. Both

the water and sand stations will be equipped with plastic buckets, hand shovels, and measuring cups. These play tools build a child's cognitive skills by developing a sense of measurement, mathematical, and space relationships, while also developing emotional and social skills through sharing. The driving station encourages imaginative play as children pretend they are driving a vehicle, making dramatic car noises and swerving motions. The gears and buttons on either side of the steering wheel provide a variety of bright colors and shapes. They are also texturally appealing as children can feel and outline the shapes with their fingers, grab and twist the gears, and press the buttons. The fourth play station is the music station. This station stimulates a child's sense of hearing, as different notes and sounds can be played. The instruments were designed to specifically accommodate children with physical disabilities which may prevent them from having the necessary muscle control to grip a drum stick or xylophone mallet. Both instruments can be played without any gripping motions. The drum can be played simply using one's hands and the xylophone utilizes reverse lever mallets on each key so that a child simply has to apply pressure to the end of the mallet for the key to be struck. The instruments also incorporate multiple bright colors for aesthetic appeal. The talking tubes from Design 3, which were chosen to be incorporated in the final design, also provide stimulation to a child's sense of hearing and experimentation with sound, by speaking and listening to another child on the other end of the tube. Although this design has two main aspects that rely heavily on sound, there are still more components that rely strictly on sight and feeling senses. These components were included to ensure there was no exclusion for children with hearing impairment.

Final Design

Figures 47, 48, and 49 show the final design, which features slight modifications from Design 2. All of the dimensions and layouts were the same as described above, with the exception of the addition of talking tubes, and the widening of the central leg support to thirty inches. It is envisioned that the ultimate design to be installed would be custom manufactured with durable, weather resistant materials. The activity stations will all be made of sturdy plastics of various bright colors. The table top will also be plastic. The central leg support would either be made of heavy duty plastic or concrete, depending on the necessary strength and support. Elements that would be needed are described in more detail in the cost analysis section that follows. A structural analysis, similar to that done for the elevated structure, should be performed especially focused on ensuring that table would not tip. As a first step for moving forward with this final design creating a prototype would be beneficial.

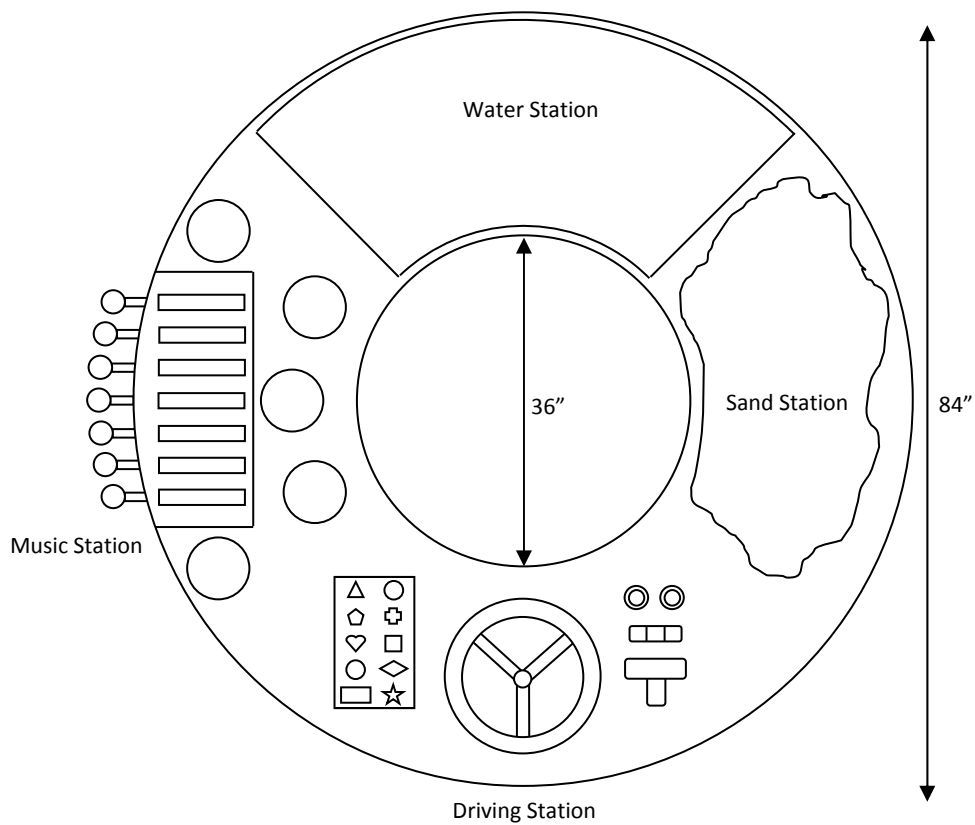


Figure 47. Top View of the Finalized Activity Table Design

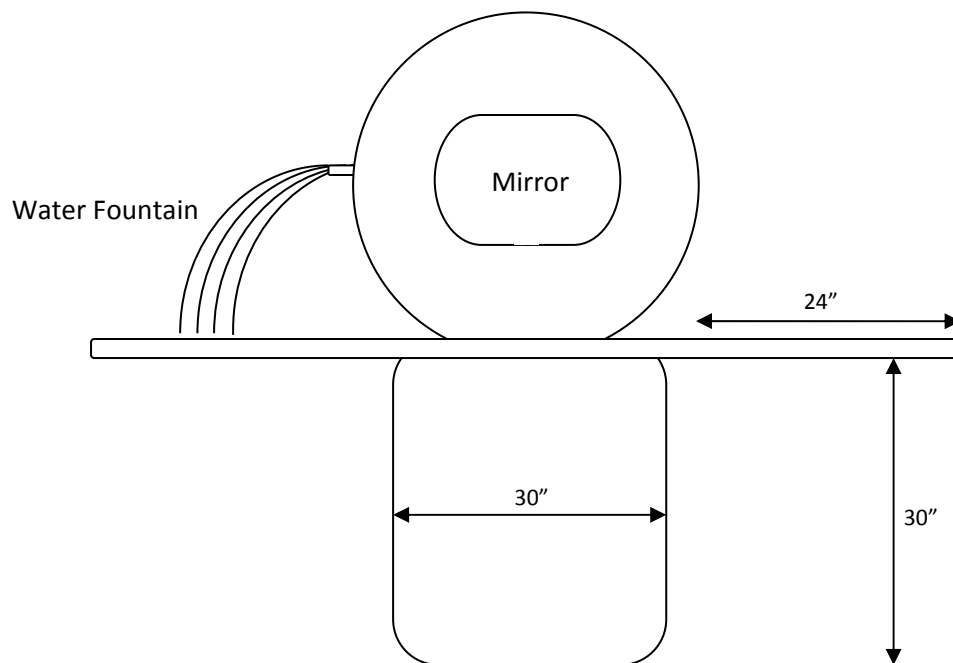


Figure 48. Profile View of the Finalized Activity Table Design



Figure 49. Finalized Talking Tubes Design

Cost Analysis

The final estimated cost analysis for the designed activity table can be seen detailed in Table 12 below. This final estimate totals \$1,232.61. This represents a successful activity table design, as the initial design constraint was to ensure that the table could be constructed for under \$1,500. The cost estimate does not include the talking tube set, which costs \$704.00. The talking tubes are a desired part of the complete ground level component, but are separate from the activity table. The given cost estimates in the table were based on the construction of a prototype, with pre-manufactured equipment, such as the xylophone, drums, and driving station. The real cost of installation of the activity table may be higher based on the construction of individual components. The units which were assessed include the following; table top, concrete support leg, central dome, water station, sand station, driving station, music station, and talking tubes. The

given cost estimates in the table were taken from various manufacturers websites; table component; table top (Classroom Essentials Online), central leg (Concrete Network), support bracing (Hooten's LLC), and dome (Online Science Mall), water station; tub (The Container Store), water fountain (Walmart), sand station; sand (Lowe's), sand tub (The Container Store), bucket, hand shovel, and measure cups (ToysRus), driving station; dashboard driving wall panel (Wayfair) and mirror (United States Plastic Corp.), music station; drums (Remo Inc.), xylophone (Pottery Barn Kids), and mallets (Music & Arts), talking tubes (Today's Classroom).

Table 12. Ground Level Cost Analysis

Component	Quantity	Description	Retailer	Unit Cost	Unit	Total Cost
Table						
Table Top	1	High-density polyethylene, 8' Diameter	Classroom Essentials Online	\$ 389.00	Unit	\$ 389.00
Leg Support	1	Concrete, 1 CY	Concrete Network	\$ 75.00	CY	\$ 75.00
Support Bracing	8	Powder coated steel bracket	Hooten Steel	\$ 3.29	Unit	\$ 26.32
Dome	1	3' Diameter Plastic Globe	OnlineScienceMall	\$ 99.99	Unit	\$ 99.99
Water Station						
Water Tub	1	4" Deep Plastic Tub	The Container Store	\$ 14.99	Unit	\$ 14.99
Water Fountain	1	Tetra Water Filtration Fountain Kit	Walmart	\$ 86.99		\$ 86.99
Sand Station						
Sand	1	Quikrete Play Sand, 50 lbs.	Lowes	\$ 3.69	Unit	\$ 3.69
Sand Tub	1	4" Deep Plastic Tub	The Container Store	\$ 14.99	Unit	\$ 14.99
Bucket	2	Plastic	ToysRUs	\$ 5.99	Unit	\$ 11.98
Hand Shovel	2	Plastic	ToysRUs	\$ 4.98	Unit	\$ 9.96
Measuring Cup Set	2	Plastic	ToysRUs	\$ 11.98	Unit	\$ 23.96
Driving Station						
Steering Wheel	1	Dashboard Driving Wall Panel	Anatex Driving Wall Panel	\$ 175.99	Unit	\$ 175.99
Buttons		Included in Wall Panel above				\$ -
Gears		Included in Wall Panel above				\$ -
Mirror	1	12" x 24" Plastic Mirror	U.S. Plastic Corp	\$ 16.35		\$ 16.35
Music Station						
Drums	1	Set of 5 drums	Amazon	\$ 152.75	Unit	\$ 152.75
Xylophone	1	Outdoor Jumbo Xylophone	Pottery Barn	\$ 89.00	Unit	\$ 89.00
Mallet	7	Kids Hand Mallet, 10" Handle	Remo Kids	\$ 5.95	Unit	\$ 41.65
Talking Tubes						
Talking Tubes	1	Talk Tubes Set	UlaPLAY	\$ 704.00	Unit	\$ 704.00
Final Cost Estimate						
					Total	\$ 1,936.61

The completed ground level component included a designed accessible activity table with four distinct stations. Sand and water play, a driving station, and a music station were featured. Talking tubes were added to the design to provide another accessible component which could be utilized. All dimensions of the activity table and talking tubes meet ASTM standards and ADA guidelines. The ground level component successfully provides a cost effective means to incorporating an ADA accessible component into a playground. This allows organizations to come closer to ADA compliance for a much lower cost than constructing the complete new playground. Two viable options have now been designed accommodating a large range of the user's budget and needs.

IV. RECOMMENDATIONS AND NEXT STEPS

Although much was accomplished in the research, development, design, and analysis of both the elevated and ground level playground structures, further progress is still possible. Various improvements to this project are recommended. For the ground level component of the designed playground, an analysis to ensure the feasibility of the design will be necessary. Because of the table's size and shape, the connection bolts and braces will need to be assessed to ensure the success of the structure. The table's central support leg should also be analyzed to determine its slenderness and ensure that it is adequate to support the table and the forces that will be exerted on it. The footer of the table should also be designed and evaluated to ensure that the structure is firmly secured to the ground.

Once each design is finalized and has been comprehensively evaluated for its engineering success, community feedback of the design should be assessed. Since playgrounds are designed in order to provide the greatest amount of fun and learning for all abilities and ages of children, it would be beneficial to survey children on the effectiveness of the designed playground structures. Feedback from children on whether or not the playground looks fun and inviting should be assessed. Improvements to the designs should then be recommended based on the children's feedback of designs. Adults and caregivers should also be surveyed for their opinions and takes on the effectiveness of the learning and independent play aspects of the design. A successful final design would be one in which the children feel they can have the greatest amount of fun, and also one that the parents and caregivers feel comfortable taking their children to play on.

Once the feedback from the designs is assessed, improvements should be made to the playground structures. The engineering process should be completed with the improved design, to ensure that the structure can still be successfully built. During the engineering process, ADA standards must also be assessed in order to ensure that the new design is still ADA compliant.

Along with the engineering evaluations, community feedback, and finalization of the design, the feasibility of the installation based on the costs of the playground must also be assessed. Is economically feasible for a community organization, church, or school to buy the playground and install? Would the community be willing to fundraise and pay for the new playground structures? If the answer is no, further assessment of the design is necessary. Parts of the design should be reevaluated and removed in order to make the structure more cost effective. The parts chosen to be removed should be based

on the cost analysis of the design, as well as the child and parent feedback. Any sections of the design which received the lowest reviews, or ones that prove to be more expensive than their reviews are worth, should be removed. An option for allowing the playground to be more economically feasible would be to lower the three foot high elevated structure to two feet, so that only one ramp would be necessary to connect the two structures. Also, the wheelchair swing could be omitted from the design if absolutely necessary for budget constraints. An accessible swing would still be available on the playground.

The last step that could be taken to finalize the project would be the construction and implementation of the modified and improved ground level component activity table. The initial goal of the project was to collaborate with a local organization in the physical implementation of the activity table. With time constraints, this implementation was not possible. Therefore, the final step in the completion of the project would be to find an organization in need of an ADA accessible playground component, and install the activity table in order to bring their playground closer to ADA compliance.

V. CONCLUSION

The need for accessible playgrounds is more prevalent than ever before, with approximately 3 million children having disabilities and health issues that limit their ability to partake in play and school. The Americans with Disabilities Act (ADA) recently provided, for the first time, specific accessible design standards for playgrounds. There is an opportunity to develop an accessible playground design which satisfies all ADA playground standards and requirements. The objective of this project was to design,

develop, and analyze an accessible play structure for future construction. This project utilized the engineering design process and civil engineering knowledge to develop a complete ADA accessible playground from the conceptual design to the development of computer aided drawings of the structures, structural analyses, complete construction plans, material lists, and cost analyses.

An elevated playground structure consisting of two levels and designed to be accessible for individuals of all abilities was designed and analyzed. CAD drawings, materials lists, and costs analyses were finalized and are included for individuals wishing to move forward with this design. It was calculated that the design as specified is compliant with ASTM standards and ADA design regulations. The total cost was found to be almost \$50,600. A ground level playground structure was also designed to be a feasible addition to playgrounds to bring them close to ADA compliance. Though further work is necessary to analyze and refine the structure prior to implementation, the drawings, materials list, and cost analysis were completed. The total cost for the activity table was found to be about \$1,300. Overall, the thesis was successful in designing and evaluating two separate playground components for compliance with the Americans with Disabilities Act.

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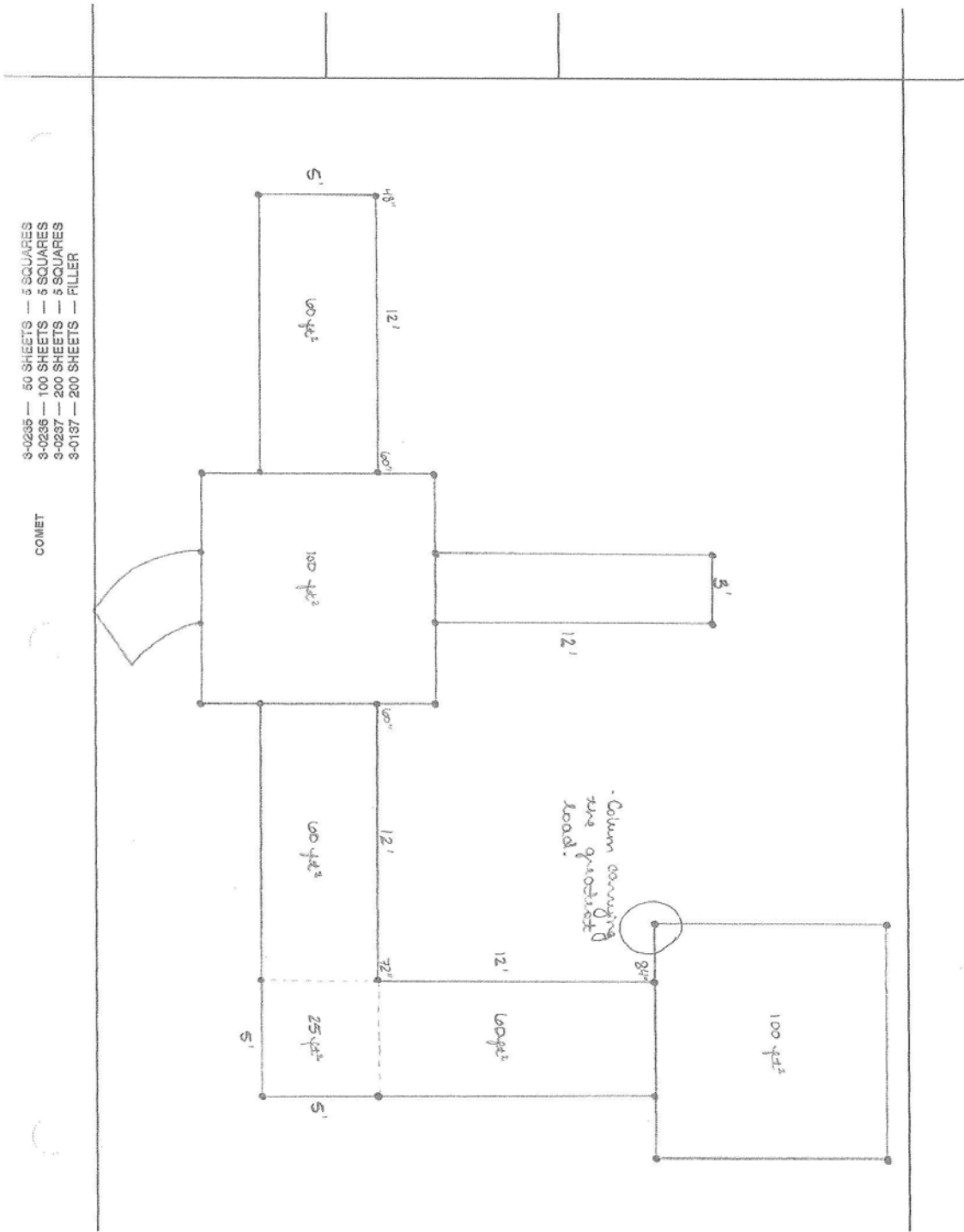
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Appendix I: Detailed Calculations



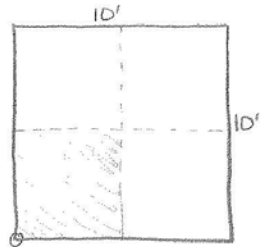
	<p><u>Canopy</u></p> <p><u>Dead loads</u></p> <ul style="list-style-type: none"> Canopy fabric = 800 lb. post = $10(1.78 \text{ lb/ft}) = 17.8 \text{ lb.}$ $\Sigma = 817.8 \text{ lb.}$ <p><u>Roof Live Loads</u></p> <ul style="list-style-type: none"> not necessary b/c no one will be on top <p><u>Snow Roof Load</u></p> <ul style="list-style-type: none"> Montgomery Co. <ul style="list-style-type: none"> ground load = 20-25 psf Roof load $\Rightarrow 1.7(20) = 34 \text{ psf}$ $\Rightarrow 1.7(25) = 42.5 \text{ psf (100 ft}^2\text{)} \Rightarrow 4250 \text{ lb.}$ <p><u>Wind Load</u></p> <ul style="list-style-type: none"> Wind pressure = $0.00256 (\text{wind speed})^2$ $\Rightarrow 0.00256 (90 \text{ mph})^2$ $\Rightarrow 20.736 \text{ psf (100 ft}^2\text{)} \Rightarrow 2073.6 \text{ lb.}$ <p><u>Load Combinations (P_u)</u></p> <p>4) $1.2D + 1.6W + 0.5E + 0.5S$</p> <ul style="list-style-type: none"> $\Rightarrow 1.2(817.8 \text{ lb}) + 1.6(2073.6 \text{ lb}) + 0.5(0) + 0.5(4250 \text{ lb})$ $\Rightarrow 6424.12 \text{ lb}$ $\Rightarrow 6.42 \text{ K}$ <p><u>Bolt Connections</u></p> <ul style="list-style-type: none"> from Table 8.11 - use $\frac{1}{2}$" bolts = 2.2 K allowable $\frac{6.42 \text{ K}}{2.2 \text{ K/bolt}} \Rightarrow 2.92 \text{ bolts} \approx \text{use 4 bolts for safety + symmetry}$ <p>Table 8.12</p> <ul style="list-style-type: none"> Minimum Bolt Spacing <ul style="list-style-type: none"> $\Rightarrow S = 2.5D$ $\Rightarrow 2.5(\frac{1}{2}) \Rightarrow 1.25 \text{ in.}$ Minimum edge Distance <ul style="list-style-type: none"> $\Rightarrow 1.5D$ $\Rightarrow 1.5(.5) \Rightarrow \frac{3}{4} \text{ in.}$ 	<p>①</p>
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Decking

③

- Avg. Power wheel chair = 250 lb. (500 lb. weight capacity)

$$\Rightarrow \text{Dimensions} = 41.5" \times 26.5" \Rightarrow 1099.75 \text{ in}^2$$



$$\Rightarrow \frac{14400 \text{ in}^2}{1099.75 \text{ in}^2} \Rightarrow 13.09$$

DR

$$\Rightarrow \frac{120 \text{ in}}{41.5 \text{ in}} \Rightarrow 2.89$$

$$\Rightarrow \frac{120 \text{ in}}{26.5 \text{ in}} \Rightarrow 4.5$$

$$\left. \begin{array}{l} 2.89 \\ 4.5 \end{array} \right\} \approx 3 \times 4 \Rightarrow 12 \text{ wheelchairs}$$

- Design for 13 wheelchairs w/ 150 lb. children

$$\Rightarrow 13(250 \text{ lb.} + 150 \text{ lb.})$$

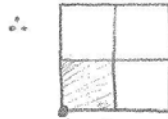
$$\Rightarrow \boxed{LL = 5200 \text{ lb.}} \Rightarrow 52 \text{ lb/ft}$$

Dead Load

$$\begin{array}{l} \text{canopy} \\ 453.10 \text{ lb (deck)} + 817.8 \text{ lb (DL)} + 4250 \text{ lb (SL)} + 2078.6 \text{ lb (WL)} \\ \Rightarrow 7594.5 \text{ lb.} \end{array}$$

Total load

$$\Rightarrow P = 5200 \text{ lb} + 7594.5 \text{ lb} \Rightarrow 12794.5 \text{ lb.} \approx \boxed{12,800 \text{ lb.}}$$



$$\rightarrow \text{Post carries } \frac{1}{4}(12,800 \text{ lb}) = \boxed{3200 \text{ lb.}}$$

$$\begin{array}{l} P_u = 1.2 w_p + 1.6 w_L \\ \Rightarrow 1.2(7594.5 \text{ lb}) + 1.6(5200 \text{ lb}) \\ \Rightarrow 17433.4 \text{ lb} \\ \frac{4 \text{ posts}}{\Rightarrow} \boxed{4360 \text{ lb}} \end{array}$$

3-0235 — 50 SHEETS — 5 SQUARES
3-0236 — 100 SHEETS — 5 SQUARES
3-0237 — 200 SHEETS — 5 SQUARES
3-0137 — 200 SHEETS — FILLER

COMET

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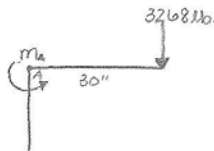
COMET

Forces on Column

$$\bullet \text{ Ramp load} = (4.52 \text{ lb/ft}^2)(100 \text{ ft}^2) \Rightarrow 271.80 \text{ lb}$$

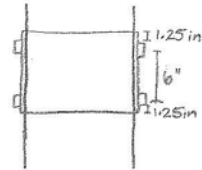
$$\Rightarrow \frac{271.80 \text{ lb}}{4 \text{ posts}} = 68 \text{ lb/post}$$

$$\bullet \text{ Deck load} = 3200 \text{ lb/post}$$



$$\Rightarrow \sum m_A = 0 \Rightarrow m_A - 3268 \text{ lb}(2.5 \text{ ft}) = 0$$

$$\Rightarrow m_A = 8170 \text{ ft}\cdot\text{lb}$$

BoltsShear Stress

$$F \rightarrow d = 6" \quad Fd = 8170 \text{ ft}\cdot\text{lb} \Rightarrow F(1/2) = 8170 \text{ ft}\cdot\text{lb} \Rightarrow F = 16340 \text{ lb} / 2 \text{ bolts}$$

$$\Rightarrow \boxed{8170 \text{ lb/bolt}}$$

Using 3/4" diameter bolts

$$\bullet \frac{8170 \text{ lb}}{\left(\frac{\pi d^2}{4}\right)} \Rightarrow \frac{8170 \text{ lb}}{\left(\frac{\pi (0.75)^2}{4}\right)} \Rightarrow 18493.1 \text{ psi} \Rightarrow \boxed{19 \text{ ksi}} < 65 \text{ ksi} \therefore \text{OK} \checkmark$$

↳ bolt strength

Check Spacing: Min Bolt Spacing

$$\bullet S = 2.5D$$

$$\Rightarrow 2.5(3/4") \Rightarrow \boxed{1.875 \text{ in}} < 6 \text{ in} \therefore \text{OK} \checkmark$$

Min. Edge Distances

$$\bullet 1.5D$$

$$\Rightarrow 1.5(3/4") \Rightarrow \boxed{1.125 \text{ in}}$$

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COMET

Bearing Stress of Bolt Holes

$$S_p = \frac{P}{d_b t}$$

$$\Rightarrow \frac{8170 \text{ lb}}{(.75 \text{ in})(.5 \text{ in})} \Rightarrow 21786.67 \text{ psi} \Rightarrow \boxed{22 \text{ ksi}} < 24 \text{ ksi (design strength } \therefore \text{ ok)} \\ \text{of aluminum}$$

Bearing Strength at Bolt Holes

$$R_n = 1.2 L_c t F_u \leq 2.4 d_b t F_u$$

$$L_c = 1.25 \text{ in}$$

$$t = 0.5 \text{ in}$$

$$F_u = 65 \text{ ksi}$$

$$d_b = 0.75 \text{ in}$$

$$\Rightarrow 1.2(1.25)(0.5)(65 \text{ ksi}) \leq 2.4(.75 \text{ in})(.5 \text{ in})(65 \text{ ksi})$$

$$\Rightarrow 48.75 \text{ k} \leq 58.5 \text{ k} \therefore \text{ ok}$$

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Slenderness

$$\left. \begin{array}{l} S_1 = 2.2 \\ S_2 = 141 \end{array} \right\} \text{Table 7.2}$$



• fixed-pin $\therefore k = 0.7$

• $L = 3 \text{ ft}$

$$K = 0.25D \Rightarrow 0.25(9/12) \Rightarrow 0.104$$

$$\frac{KL}{r} \Rightarrow \frac{0.7(3)}{0.104} \Rightarrow 20.19$$

$$\frac{KL}{r} = 20.19 < S_2 \therefore \text{use } F_c = \frac{1}{n_u} \left(B_c - D_c \frac{KL}{r} \right)$$

Overall Allowable Column Stress

$$F_c = 20.2 - 0.126 \left(\frac{KL}{r} \right) \Rightarrow 20.2 - 0.126(20.19) \Rightarrow 17.67 \text{ ksi}$$

Overall Stress

$$\sigma = \frac{P}{A} \Rightarrow \frac{(12800 \text{ lb} / 4 \text{ posts}) / 1000}{\frac{\pi}{4} [(5^2) - (4.5^2)]} \Rightarrow \frac{3.2 \text{ k}}{3.73 \text{ in}^2} \Rightarrow \boxed{0.85 \text{ ksi}} < 17.67 \text{ ksi} \therefore \text{ok} \checkmark$$

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3-0137 — 200 SHEETS — FILLER

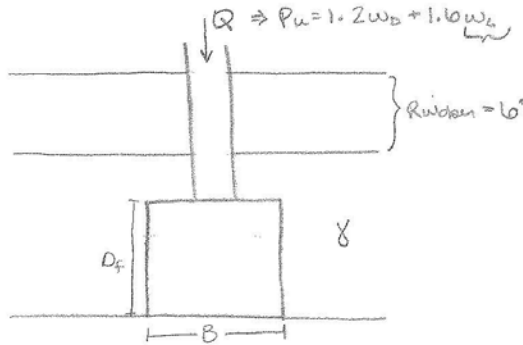
COMET

Foundation

(7)

3-0235 — 50 SHEETS — 5 SQUARES
 3-0236 — 100 SHEETS — 5 SQUARES
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 3-0137 — 200 SHEETS — FILLER

COMET



- $B = \min 12"$
- Bottom of footer must be below 30" to prevent freezing below

$$\sigma = \frac{Q}{A} = \frac{Q}{B^2}$$

$$q_{ult} = cN_c + \underbrace{\frac{1}{2} B \gamma N_\gamma}_{\text{Below}} + \underbrace{q N_q}_{\text{above}} + \gamma D_f$$

— $c = 0$ (unless clay), $\phi = 30$

• 3 types of soil

$$q_{all} = \frac{q_{ult}}{FS}$$

$$q_{all} > \sigma \therefore \text{OK} \checkmark$$

Bearing Capacity

$$\begin{aligned} Q = P_u &= 1.2W_d + 1.6W_u \\ &\Rightarrow 1.2(7594.5 \text{ lb}) + 1.6(5200 \text{ lb}) \\ &\Rightarrow 17433.4 \text{ lb} \\ &\quad \text{4 posts} \\ &\Rightarrow \boxed{4360 \text{ lb}} \end{aligned}$$

$$\sigma = \frac{Q}{A} \Rightarrow \frac{4360 \text{ lb}}{12 \text{ in} \times 12 \text{ in}} \Rightarrow 30.28 \text{ psi} \Rightarrow \boxed{4360 \text{ psf}} \Rightarrow \begin{array}{c} 12'' \\ \square \\ 12'' \end{array}$$

$$\sigma = \frac{Q}{A} \Rightarrow \frac{4360 \text{ lb}}{16 \text{ in} \times 12 \text{ in}} \Rightarrow 22.71 \text{ psi} \Rightarrow \boxed{3270 \text{ psf}} \Rightarrow \begin{array}{c} 12'' \\ \square \\ 16'' \end{array}$$

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 3-0137 — 200 SHEETS — FILLER

COMET

For Soft Glacial clay

- $\gamma_d = 76 \text{ lb/ft}^3$
- $C = 50 \text{ kPa} \rightarrow 1045 \text{ psf}$
- $\phi = 0^\circ$
- $N_c = 5.14$
- $N_q = 1.0$
- $N_\gamma = 0.0$

$$q_{ult} = CN_c + \frac{1}{2} B \gamma N_\gamma + \gamma D_s N_q$$

$$\Rightarrow (1045 \text{ psf})(5.14) + \frac{1}{2} (14 \text{ ft})(76 \text{ lb/ft}^3)(0) + (76 \text{ lb/ft}^3)(3 \text{ ft})(1.0)$$

$$\Rightarrow 5371.6 + 0 + 228$$

$$\Rightarrow 5600 \text{ psf}$$

$$q_{all} = \frac{q_{ult}}{FS} \Rightarrow \frac{5600 \text{ psf}}{1.5} \Rightarrow \boxed{3733 \text{ psf}} > 3270 \text{ psf} \therefore \text{OK} \checkmark$$

For loose, well-graded sand

- $\gamma_d = 99 \text{ lb/ft}^3$
- $C = 0$
- $\phi = 30^\circ$
- $N_c = 30.14$
- $N_q = 18.40$
- $N_\gamma = 22.40$

$$q_{ult} = CN_c + \frac{1}{2} B \gamma N_\gamma + \gamma D_s N_q$$

$$\Rightarrow 0(30.14) + \frac{1}{2} (1 \text{ ft})(99 \text{ lb/ft}^3)(18.40) + (99 \text{ lb/ft}^3)(3 \text{ ft})(22.40)$$

$$\Rightarrow 0 + 910.8 + 6652.8$$

$$\Rightarrow 7564 \text{ psf}$$

$$q_{all} = \frac{q_{ult}}{FS} \Rightarrow \frac{7564}{1.5} \Rightarrow \boxed{5042 \text{ psf}} > 4360 \text{ psf} \therefore \text{OK} \checkmark$$

For Dense, Well-graded Sand

- $\gamma_d = 116 \text{ lb/ft}^3$
- $c = 0$
- $\phi = 30^\circ$
- $N_c = 30.14$
- $N_q = 18.4$
- $N_\gamma = 22.4$

$$q_{all} = cN_c + \frac{1}{2} \gamma D_f N_\gamma + \gamma D_f N_q$$

$$\Rightarrow 0(30.14) + \frac{1}{2}(1\text{ft})(116 \text{ lb/ft}^3)(18.4) + (116 \text{ lb/ft}^3)(3\text{ft})(22.4)$$

$$\Rightarrow 0 + 1067.2 + 7795.2$$

$$\Rightarrow 8862 \text{ psf}$$

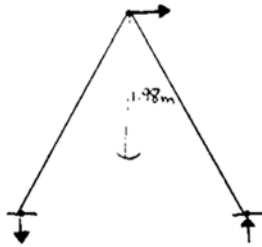
$$q_{ult} = \frac{q_{all}}{FS} \Rightarrow \frac{8862 \text{ psf}}{1.5} \Rightarrow \boxed{5908 \text{ psf}} > 4360 \text{ psf} \therefore \text{OK} \checkmark$$

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3-0137 — 200 SHEETS — FILLER

COMET

Swings

10



Child mass

$$150 \text{ lb.} \left(\frac{0.454 \text{ kg}}{1 \text{ lb.}} \right) \Rightarrow 68.04 \text{ kg}$$

Angular acceleration of child swinging:

$$\omega = 2\pi f \Rightarrow 2(\pi)(1/4\text{s}) \Rightarrow 1.57/\text{s}$$

Linear Velocity:

$$v = \omega R \Rightarrow (1.57/\text{s})(1.98\text{m}) \Rightarrow 3.11 \text{ m/s}$$

Angular Acceleration:

$$a = \frac{v^2}{R} \Rightarrow \frac{(3.11 \text{ m/s})^2}{1.98\text{m}} \Rightarrow 4.88 \text{ m/s}^2$$

Upward lift force:

$$F = ma \Rightarrow (68.04 \text{ kg})(4.88 \text{ m/s}^2) \Rightarrow 332.37 \text{ N} \Rightarrow \boxed{74.72 \text{ lb. f}}$$

Uplift force < weight of Swingset \therefore ok✓

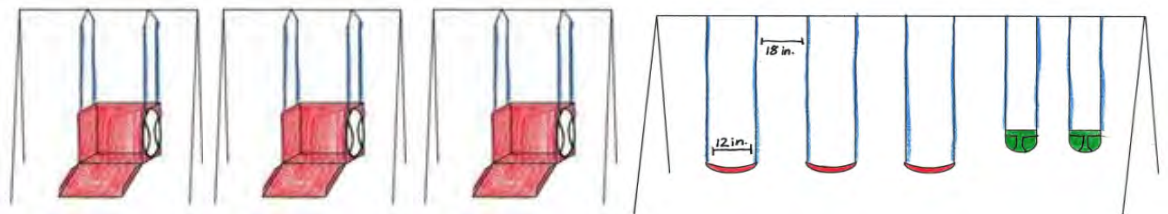
$$74.72 \text{ lb} < \frac{200 \text{ lb}}{2} = 100 \text{ lb.}$$

Appendix II: Construction Drawings

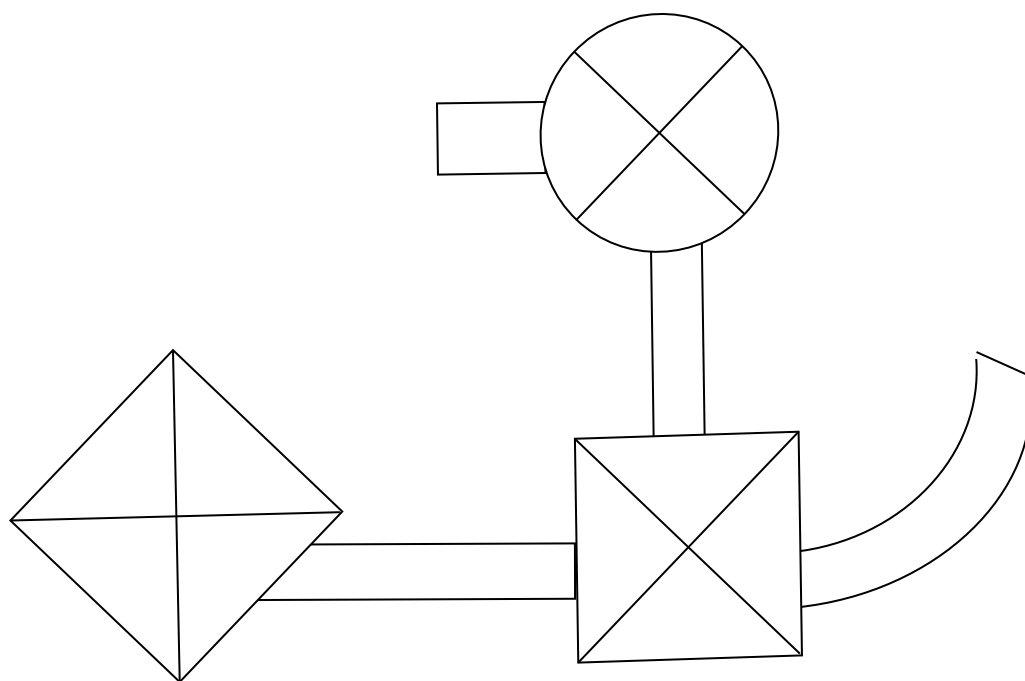
Elevated Structure:

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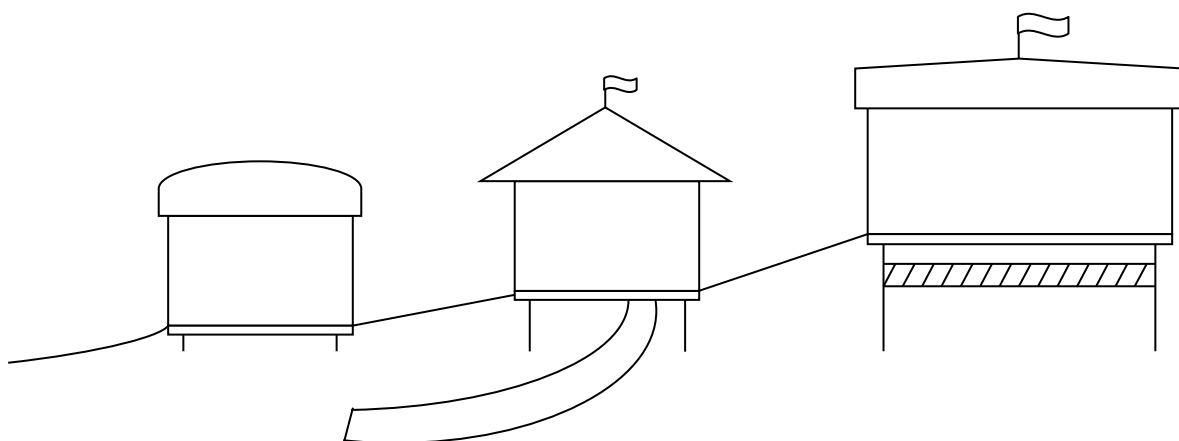
Swings:



Top View:

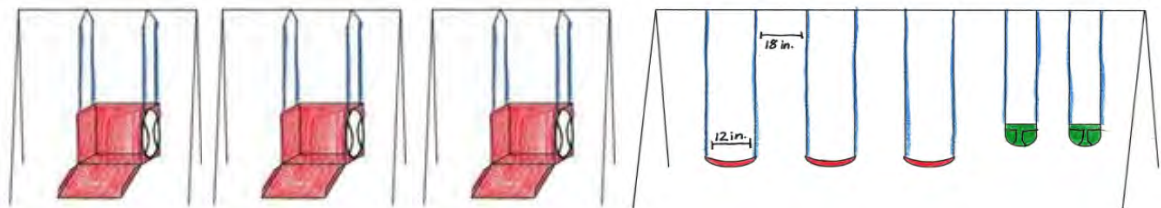


Side View:

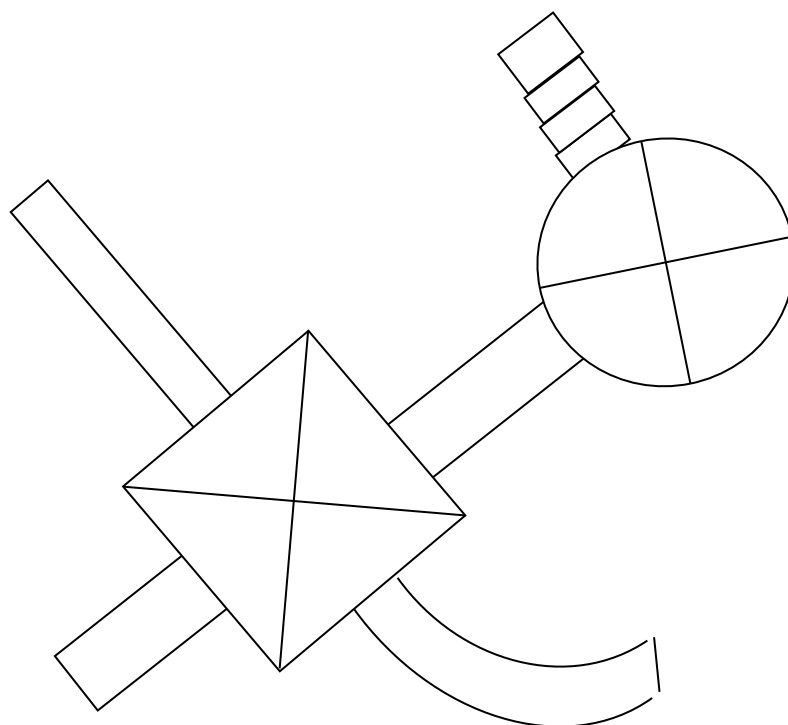


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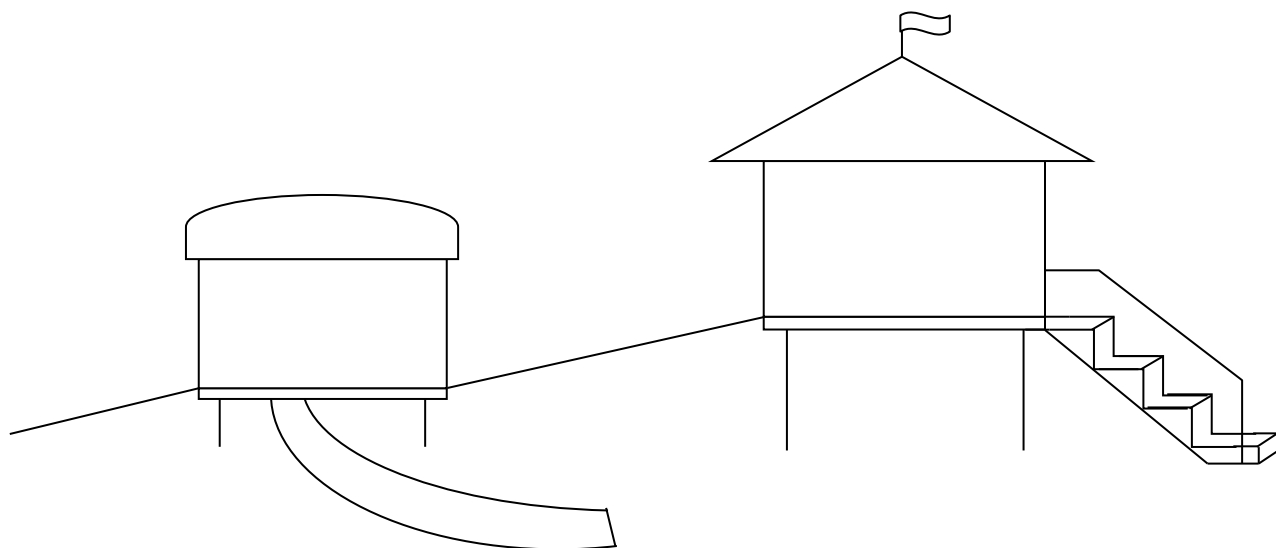
Swings:



Top View:

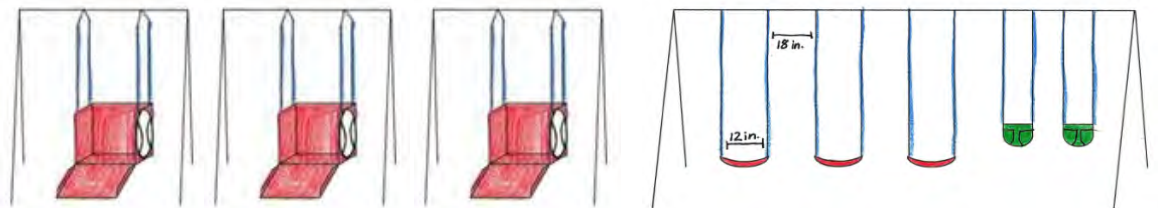


Side View:

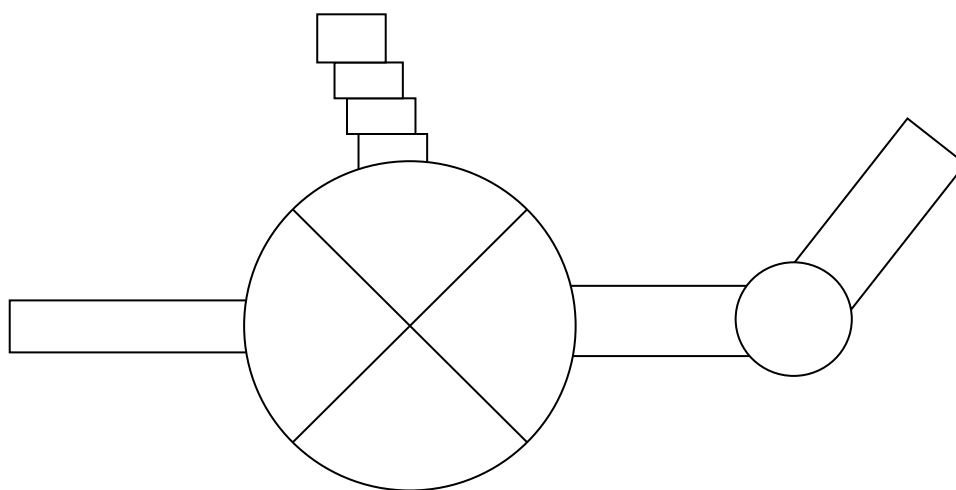


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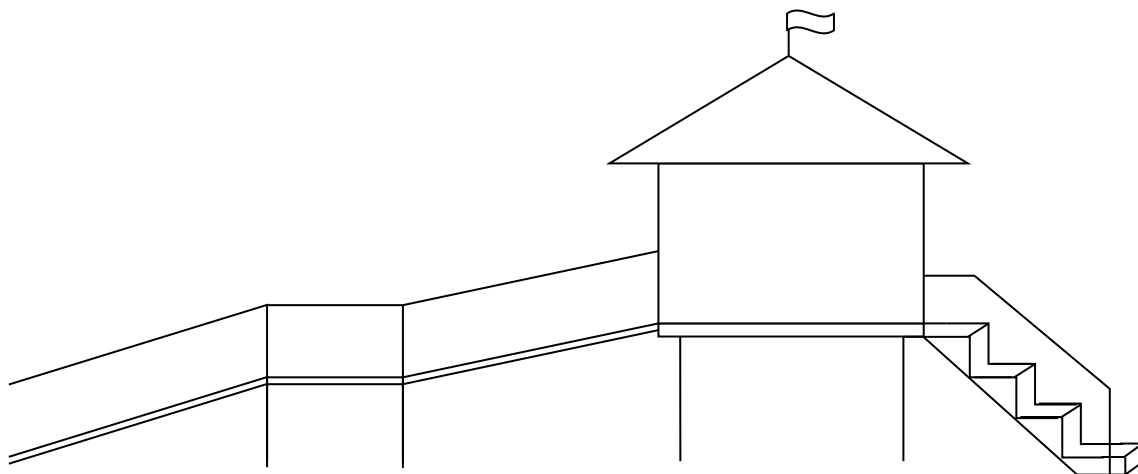
Swings:



Top View:

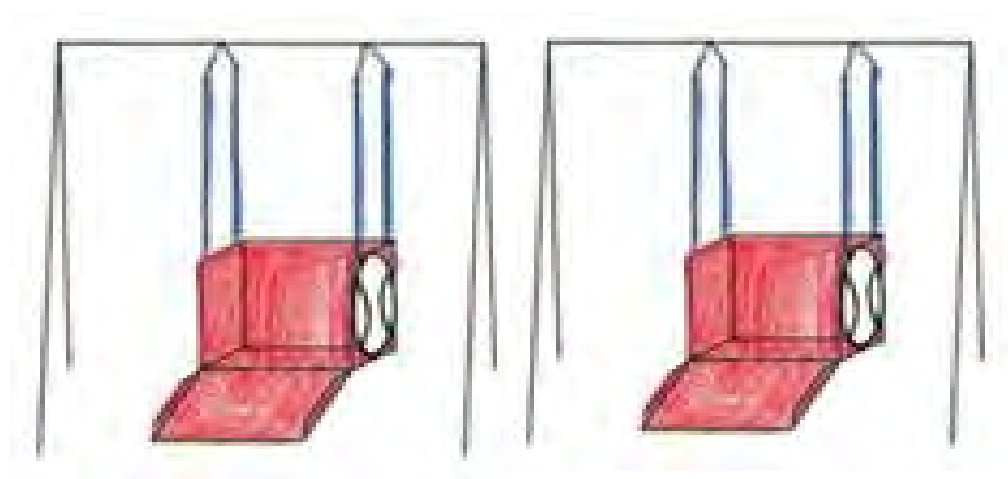
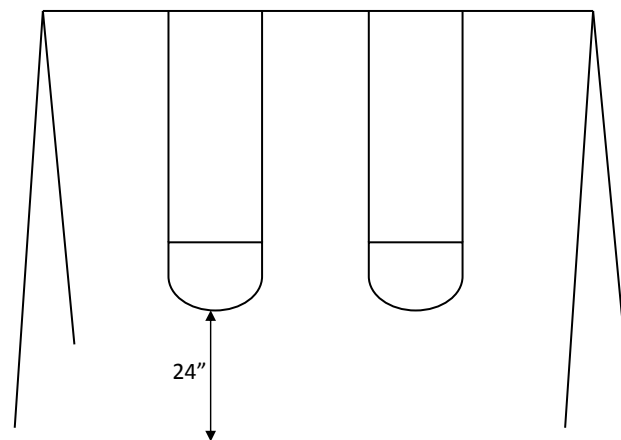
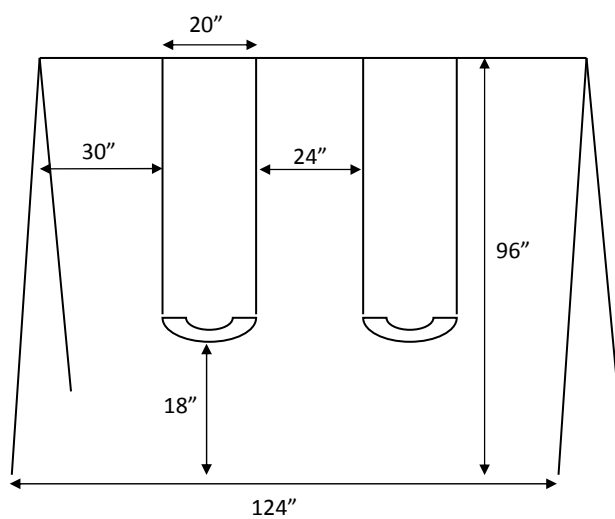


Side View:

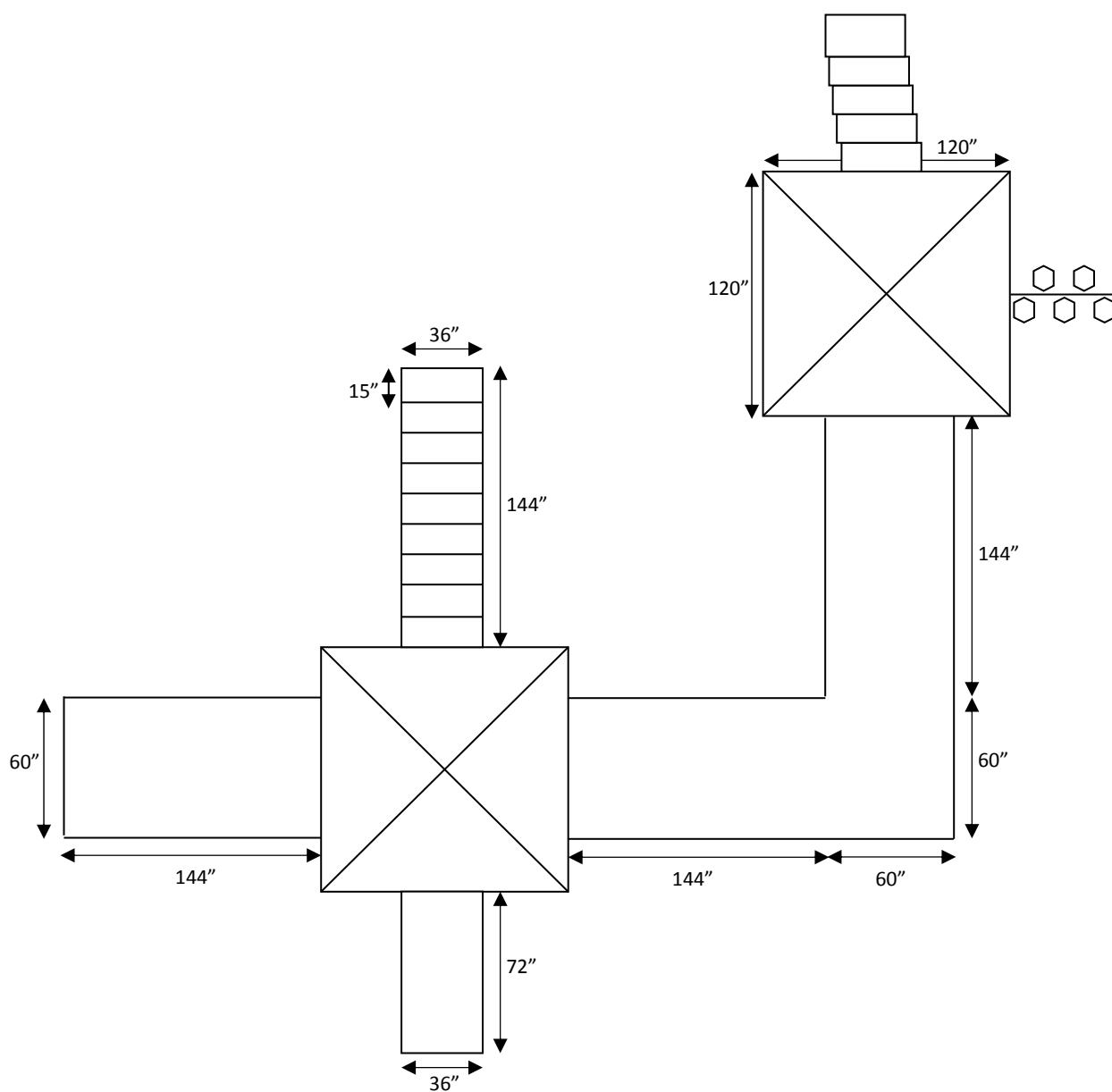


Final Design:

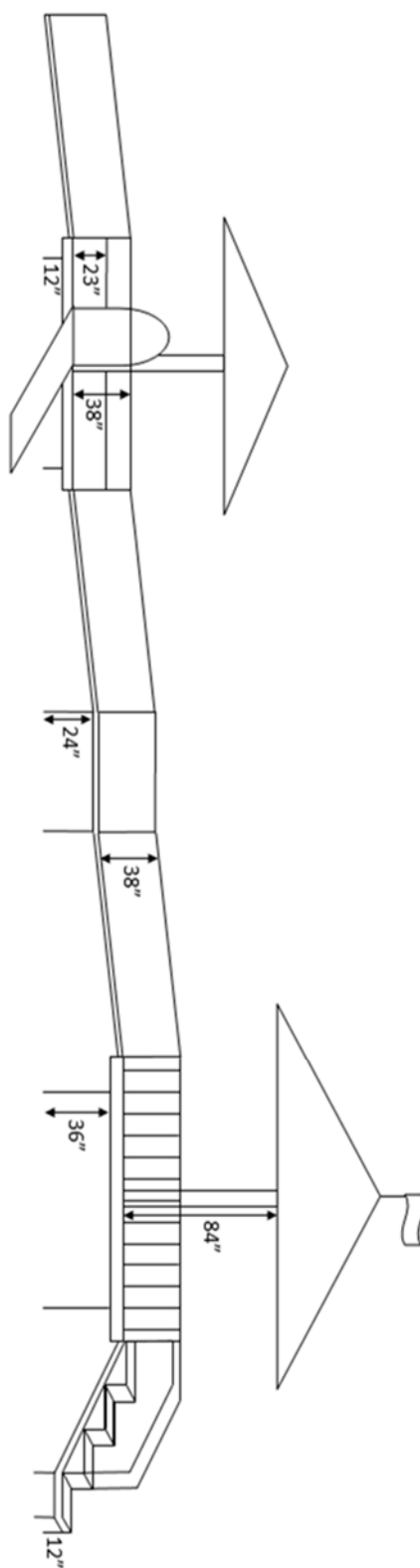
Swings:



Top View:



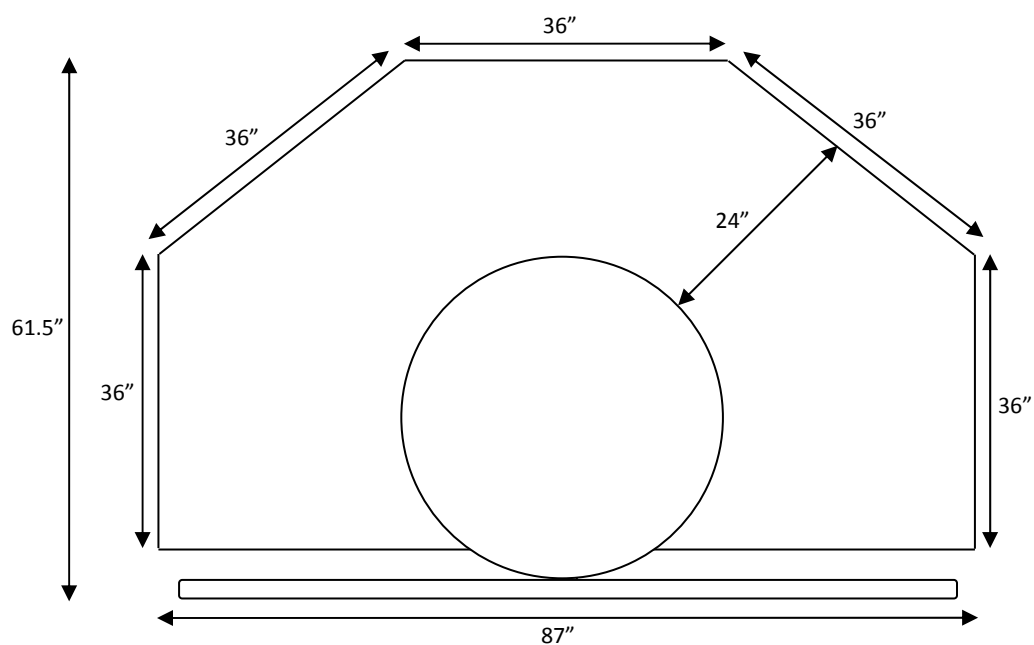
Side View:



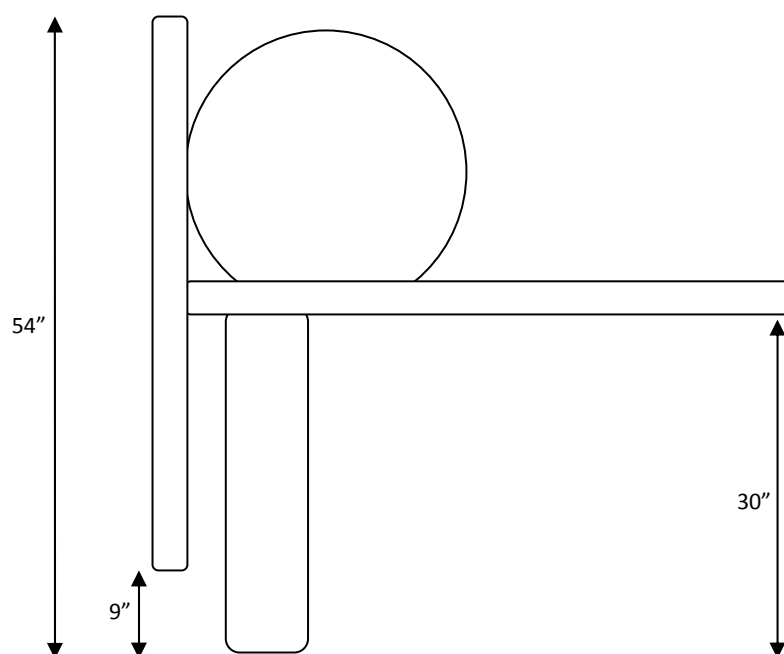
Ground Level Component:

Design 1:

Top View:

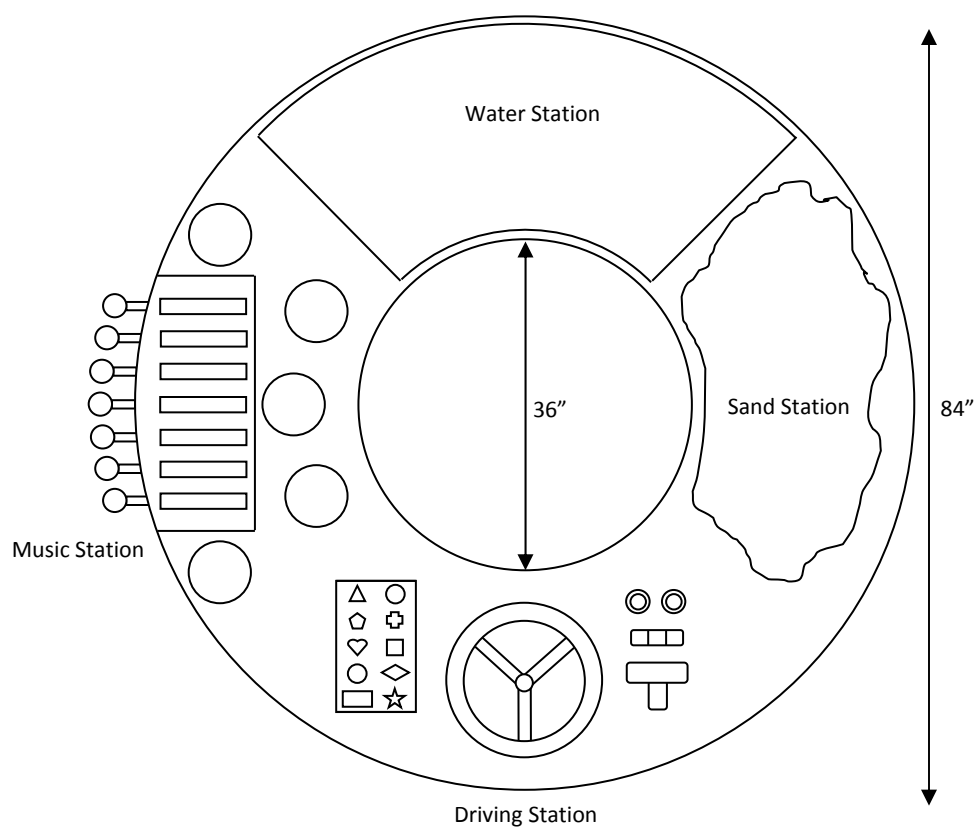


Side View:

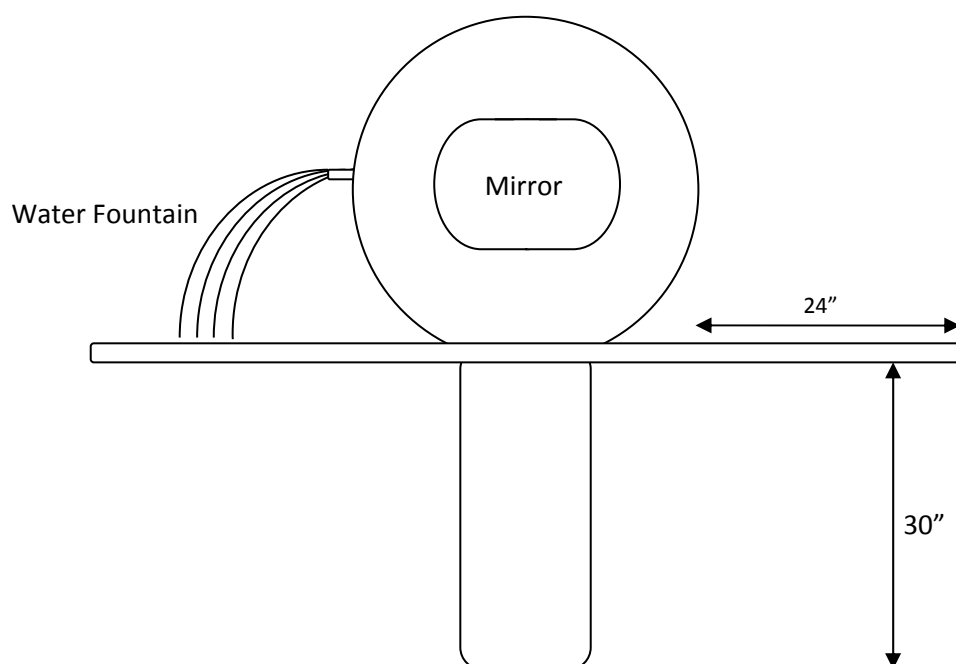


Design 2:

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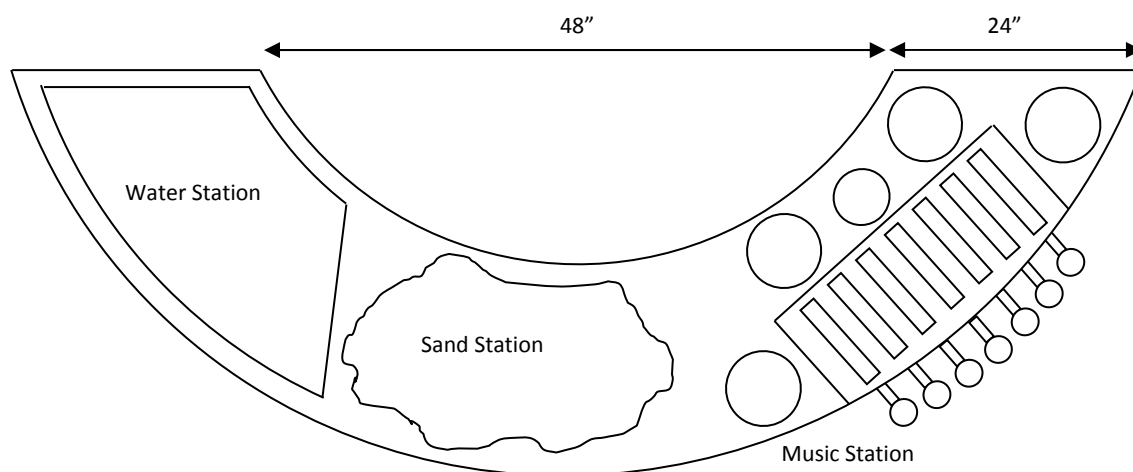


Side View:

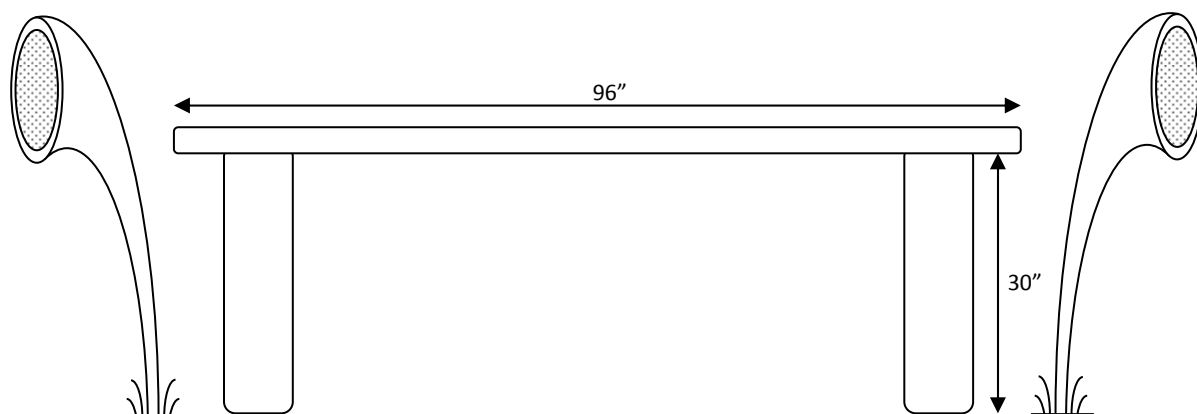


Design 3:

Top View:

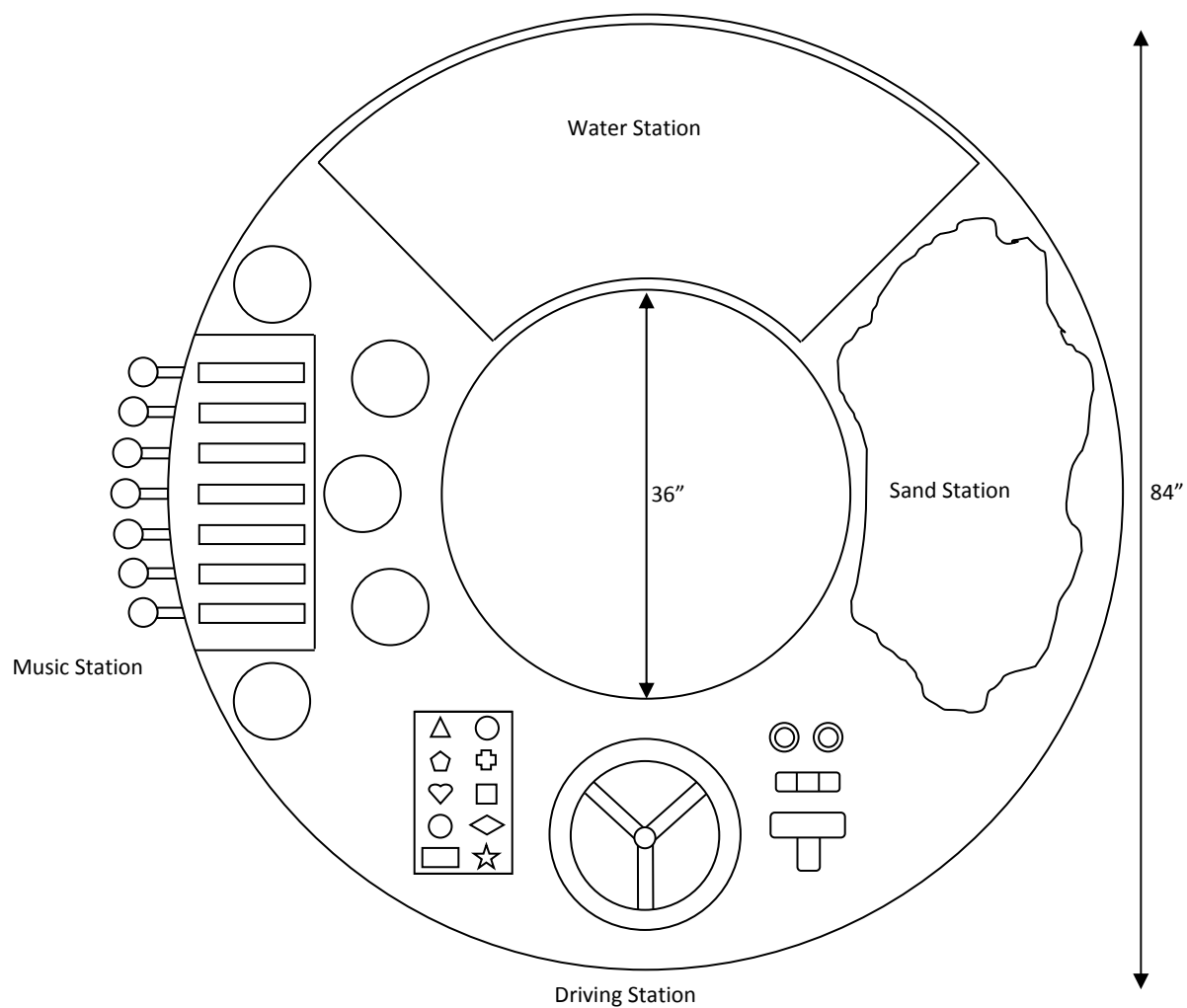


Side View:

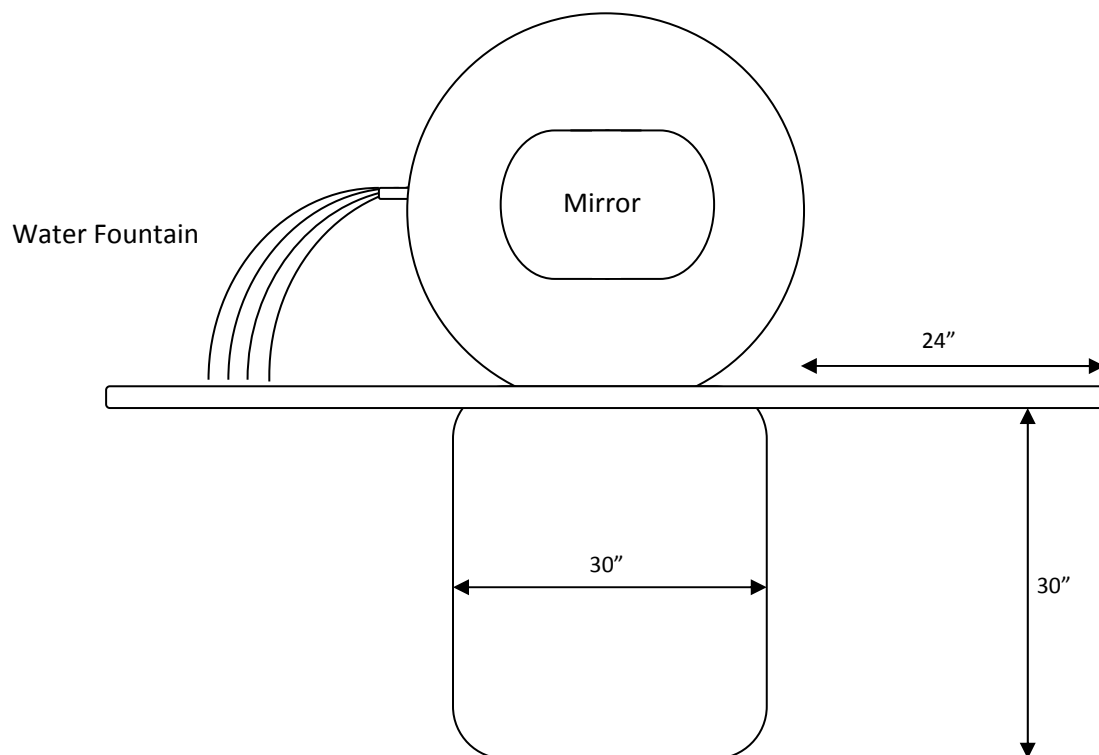


Final Design:

Top View:



Side View:



Talking Tubes:



Mallets:

