ABSTRACT

This paper discusses the design of a collapsible ocean shipping container. An ISO 1AA container was used as the starting point for the design. The goal is to design a collapsible container which will revolutionize the intermodal shipping industry. The design must fit the intermodal framework already in place, but provide advantages over a non-collapsible container economically, socially, and environmentally. A goal of 4:1 volume reduction was achieved and can be accomplished in an estimated collapse time of approximately four minutes by two workers and one forklift.

INTRODUCTION

Rising homeland security risks, increasing congestion at port facilities, and rising transportation costs all contribute to the need for collapsible ocean shipping containers. The need is primarily driven by an imbalance in the global trade markets, which requires that empty containers be shipped back to a region with higher export than import requirements in order to be reloaded and shipped again. Valuable space is wasted on containerships and in ports due to transport and storage of empty containers. Collapsing or folding the container to a smaller volume allows multiple containers to be stacked in the space needed by one non-collapsible container. There are two existing designs for containers which can be collapsed; however, they are not widely used for several reasons, which include excessive cost, excessive weight, and lack of robustness.

To sufficiently satisfy the existing need for collapsible containers, the additional process of collapsing/erecting must be safe, relatively fast, moderately automated, cost effective, and reliable. In addition, the robustness, rigidity, and reliability of the container must not be compromised.

The critical specifications of the container design, which make it suitable for intermodal transportation are the ability to be stacked nine high when fully loaded, a minimum carrying capacity of 45,000 lbs, an average life-span of seven years, and liftable by overhead crane at full capacity weight.

The primary objective in designing the collapsible container is to achieve a minimum 4:1 volume reduction which is obtained through an automated process. The design will be submitted for patent by the sponsor and the deliverables include design drawings, design animations, scale model for demonstrating the design, and a technical paper to summarize the project.

The specifications for the 1AA classification of intermodal containers are the specifications adopted...
for the project. The 1AA classification of containers are 40ft(\textit{w}12.192m) in length, 8ft(\textit{w}2.4384m) wide, and 8.5'(\textit{h}2.5908m) high with a load rating of 67200 maximum gross pounds. The approximate container tare weight is 6800lbs for a non-collapsible container [1].  

CONCEPT DEVELOPMENT AND DESIGN  

Concept development consumed the majority of the time spent on the project. Since nothing exists which achieves the specified objective, this was essentially a clean sheet design, with nothing to directly compare the results against. Nearly eight weeks of intense concept development passed before an acceptable design was arrived upon.

Automation System  

Automation is the most important facet of the design as it is the primary difference between existing designs and this project. The design of the automation system and the sequence with which the container collapses are interdependent and therefore the design process had to reflect that relationship. As the automation system concepts progressed, so did the order of the steps taken to collapse or erect the container. Once an automation system and sequence of collapsing/erecting were decided upon, the details of the structural design of the container could be engineered.

Multiple modes of automation were researched to determine the best solution. The ultimate goal of all concepts was for it to require only one operator and need only existing equipment that would either be found at a shipping area or contained within each collapsible container. The process of developing the automation system proved to be somewhat cumulative as the final design is a system with aspects taken from several preliminary designs.

Methods such as cables and pulleys, levers, cams, and hydraulics were looked at throughout the concept development and design phase. Each system had its limitations and its benefits. Given the weight and size of the container, no designs which use a standalone unit to collapse and erect the container could be developed with reasonable confidence. This led to the use of a forklift as the power source. Forklifts are a viable option due to their availability at shipping yards and port facilities. Again, simple mechanical devices were looked at, now in conjunction with a forklift to create a one step process which would allow the forklift to collapse the entire container in one motion. After several geometry studies and force analyses, it was proven that a one step process was not feasible, which led to the final concept.

Collapsing and erecting is achieved using a forklift directly and also utilizing its hydraulic system through auxiliary ports. The forklift is used to raise and lower the top and sides in unison [Fig. 1]. Once the top and sides have been moved, hydraulic cylinders which are attached to the forklift’s auxiliary hydraulic ports are activated to move the ends [Fig. 2]. This process proved to be the most feasible and this design is the safest and most robust system that was considered throughout concept development.

Structure Design  

The current design of standard containers was closely studied prior to and throughout concept development. Many components of the standard container were directly utilized in all concepts due to intermodal infrastructure requirements and structural integrity needs of the containers. Due to time constraints, no new structural materials were considered, although there is potential to do so.

Bottom  

All concepts considered leave the bottom portion of the container virtually unchanged from the current standard container. Its structure consists of two 6in
(152.4mm) longitudinal channels; five transverse, load bearing 4in (101.6mm) S-section I-beams; fourteen transverse 3in (76.2mm) S-section I-beam floor supports; sheet steel to seal the bottom; 1.125in (28.575mm) 7-ply marine grade ply board; and end transverse extrusions. The bottom structure must be able to support the internal load and loading equipment, be lifted from the bottom corner fittings, stack on top of other containers, and be watertight. Although no major changes were made, the hydraulic cylinders used in collapsing and erecting the container necessitated some minor changes. The changes include altering some of the floor supports and adding reinforcement bracing for the hydraulic cylinder mounting points. Two load bearing I-beams closest to the ends were replaced with C-channel to facilitate component mounting. Also, the floor supports in the region of the hydraulic components were changed from transverse to longitudinal and reduced to lower profile square tubing. Slots were cut in the main C-channels to allow for connection to the ends, and steel plates were added in these regions to restore their strength. Figure 4 shows these changes.

Fig. 4 Bottom structure

Ends
There are two main variations on the ends that remained common with nearly all of the concepts. A one-piece end design and a two-piece split end design. The front-end concepts consist of the corner posts, one or two sets of corner fittings, doors, and a top cross member. Back-end concepts utilize corner posts, one or two sets of corner fittings, a center panel, framework, and a top cross member.

The final design utilizes two-piece split ends that are split 25.5in (647.7mm) from the bottom of the container. The bottom portion of the ends are welded directly to the bottom structure, while the top end portions are attached to the main bottom channels utilizing J-hinges and levers which are actuated with hydraulic cylinders. The J-hinges are designed to match the geometry of the end posts and be welded via a combination of plug and conventional welding, thus making the posts and hinges one solid structure. ISO corner fittings are permanently attached to the bottom portion of the ends at all four corners to provide the top fittings when the container is collapsed. When erected, the two end portions (upper and lower) lock together utilizing a standard twist lock that engages the mid-post ISO fittings.

Sides
The sides must be impact resistant, capable of supporting internal load shifts against them, and be watertight. Through a structural analysis of non-collapsible containers, the sides were determined to be non-load bearing and thus various new ideas and geometries were analyzed. Steel was still the target material, but aluminum, canvases, composites and others were considered. Concepts that lacked adequate rigidity and water resistance were deemed unfeasible and the heavily pursued concepts were sides comprised of multiple sections. These sections consist of a structural framework, hinges, and corrugated sheet steel panels. The final concept utilizes two panels per side that are hinged at the top, middle, and bottom and fold inward when the top is lowered as shown in Fig. 1. The folding is accomplished using custom designed hinges and all framework is constructed out of 1.50in (38.1mm) x 3.00in (76.2mm) steel tubing.

Side Hinges
Several hinge types were researched as a method of joining the side panels, including everything from piano hinges to fully concealed hinges which recess into the jam of a panel. No existing hinge design provided the necessary motion for the folding sides, so custom models were designed to fit the container. The result is an assembly consisting of two pins, one centered in each side panel and constrained by a hoop structure. The pins essentially float within the hoop to account for the change in distance between the side panels when collapsing or erecting [Fig. 6].

Fig. 5 End panel construction

Fig. 6 Middle side hinge
Five hinges are placed at the top, middle, and bottom of each side. The result is ten hinges around the parameter of the container in each of the three locations (top, middle, and bottom) which are strong enough to withstand the stress of lifting the container off the ground to account for misuse. Simple static analysis shows that modeling the 3/16in (4.7625mm) x 4in (101.6mm) hinge steel in tension and the 3/8in (9.525mm) steel pins in shear results in stresses less than 700psi and 4600psi respectively. Given that 1018 steel has a yield strength of 32ksi, it will be more than adequate for the average life-span of a container and most impact loading the hinges could experience.

Top
The top structure must provide longitudinal rigidity to the container and be watertight. Most concepts utilized rigid panels ranging in number from one to four, although other types such as soft and accordion style were also considered. Approximately fifty percent of the concepts had the ISO corner fittings attached to the top panel, while the other fifty percent had them attached to the end posts. The main benefit of having the corner fittings attached to the top is that the top corner fittings are the same in both erect and collapsed forms, and thus there is no need to add additional fittings. However, there is a large disadvantage to having the corner fittings attached to the top as well. If attached to the top, all top lifting would place stress on all collapsing joints, and there is a risk of severely degrading the structural integrity of the container. Having the corner fittings attached to the ends seemed to be the most viable solution and thus, the top design does not include corner fittings. The established structure utilizes a perimeter framework constructed out of 3.00in (76.2mm) square and 3.00in (76.2mm) x 5.00in (127mm) rectangular tubing, ISO approved forklift pockets, and intermediate structural members that support the sheet metal skin.

Also incorporated into the top structure is the mechanical top-to-end locking mechanism that is engaged and disengaged by the forklift. Many possibilities were considered to lock the container in an erect position such as solenoids, electromagnets, electrical systems, purely mechanical systems, and even human actions. Mainly due to the expense of some of these systems, and the desire for simplicity, the decision to aim at a purely mechanical locking system became the preferred choice. The mechanical locking mechanism must securely lock the container into a rigid and solid container that will not fail when in use. The system utilizes four locking pins which slide from the top structure through the end structures to lock them into an immobile position. The locking pins are automatically retracted from the ends when the forklift is inserted through levers and connecting rods. See Fig. 7 for a top structure view.

**Doors**
Every effort possible was made to maintain the current door design, although it is not entirely possible with all design concepts. Originally a variety of vertically opening doors were considered, including roll-top, “garage door”, and one piece panels, but due to the reduction in interior volume created by such designs and existing infrastructure constraints, it was determined that the current door design should be maintained as much as possible. One piece and split door designs were considered. The vertical locking bars were difficult to implement in all collapsed designs, so other alternative locking mechanisms were considered. The split door design was deemed most applicable to the preliminary design and was developed further leading to a design modeled after the current door structure, with very few modifications other than those required by the split at 25.5in (647.7mm). Additions include framework at the split, cutouts for the mid ISO fittings, and the addition of hinges.

**Water Sealing**
The containers must be water tight and by making the container collapsible, many challenges arise in the area of sealing. Several different sealing methods and seal materials have been considered. Seals researched include o-rings, weather-stripping, edge seals, flap seals, and compression gaskets. Neoprene, nitrile, and silicon material seals were considered. The most important needs for a sealing material in this application are water sealing, resistance to outside elements, long-life, and temperature stability. Minor concerns include resistance to acids, oils, greases, or any other chemicals that could come into contact with the container.

The interface where the sides of the container meet the ends will be sealed with a “D” shape extruded rubber element [Fig. 8]. It will be attached on one of the surfaces with an adhesive. A common adhesive that is used with these types of elements is the 3M Acrylic Automotive tape. This provides an airtight seal and is rated for very high peel and shear resistance and is also rated for use at temperatures ranging from -20F to 158F [2]. The “D” element would provide effective sealing and allows some change and deflection in the dimensions of the container. The curved portion of the seal provides a higher-pressure contact surface than a flat element, and the hollow design allows for a high compression of the seal with a larger tolerance...
for the distance between the surfaces. These elements are designed to provide good sealing when compressed 15-30% which, depending on the height of the element, can still seal given ¼ inch or more worth of change in seal height [3].

Fig. 8 Trimlok OW135BT Seal

For the hinged seams along the sides of the container the most feasible seal is a flap that covers the length of the seam [Fig. 9]. The flap would be attached to the container above the hinges and extend over it. Since nearly all the water pressure will be coming from the top or side of the seal, there would be little need for a tight seal at the bottom of the flap. The flap would work similar to shingles on a house, with rain water running down it and away from the seam. The problem with this method would arise in very stormy weather, where high wind speeds send water in from all directions and could cause the flap to move out of position. The flap would need to either be fairly stiff to resist bending in high winds or have an attachment at the bottom of the seam.

Fig. 9 Trimlok Flap Seal

DESIGN SPECIFICATIONS

Volume Reduction
For a collapsible container to be viable in the intermodal industry and justify the extra cost, it must be capable of significant volume reduction. A volume reduction of 4:1 was established as a minimum goal and was also a minimum requirement of the project sponsor. It was also established that in collapsed form, the height should be a fraction of the height of a standard container such that, for a 4:1 reduction for example, four collapsed containers stacked on top of each other are the equivalent height of a standard container (8.5 ft). A quick analysis of the height of each panel of the container in collapsed form showed that a volume reduction of 4:1 was the most feasible reduction.

Table 1 Design Component Thicknesses

<table>
<thead>
<tr>
<th>Panel</th>
<th>Approximate Thickness Collapsed (in)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Top</td>
<td>5</td>
</tr>
<tr>
<td>Sides</td>
<td>4</td>
</tr>
<tr>
<td>Ends</td>
<td>9</td>
</tr>
<tr>
<td>Bottom</td>
<td>6</td>
</tr>
<tr>
<td>Total</td>
<td>24</td>
</tr>
</tbody>
</table>

Table 2 Volume Reduction Heights

<table>
<thead>
<tr>
<th>Volume Reduction</th>
<th>Collapsed Height (in)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1:1</td>
<td>102.0</td>
</tr>
<tr>
<td>2:1</td>
<td>51.0</td>
</tr>
<tr>
<td>3:1</td>
<td>34.0</td>
</tr>
<tr>
<td>4:1</td>
<td>25.5</td>
</tr>
<tr>
<td>5:1</td>
<td>20.4</td>
</tr>
<tr>
<td>6:1</td>
<td>17.0</td>
</tr>
</tbody>
</table>

A volume reduction over 5:1 is virtually impossible utilizing a vertically collapsing design. With a volume reduction of 4:1, a typical container ship capable of holding approximately 1500 containers would be able to carry 6000 empty collapsed containers, a double-decker rail car could carry eight empty collapsed containers per car, and a truck chassis could carry four empty collapsed containers, resulting in substantial transport savings. The fully collapsed container is shown in Fig. 10

Fig. 10 Collapsed container

Operation Time
It is very important to keep the time of operation (collapsing or erecting) to a minimum in order to prevent congestion at the ports. Typical handling time of a container from ship to ground is two minutes or less and ground handling typically ranges from five to ten minutes. A time of fifteen minutes or less was established as a goal to achieve and the final design should be able to achieve a much shorter time. Estimates put the time to operate at approximately 3.5 minutes utilizing two trained and skilled operators and one forklift.

Stacking
Stacking of the containers is a critical portion of the design for both erect and collapsed containers. The design must incorporate ISO corner fittings at the standard location on both the top and the bottom. When collapsed, ISO corner fittings must remain the highest surfaces of the container and they must be in the ISO specified location. The bottom four ISO corner fittings remain unchanged in either state. The top four ISO corner fittings’ vertical location changes when the container is collapsed. An additional four ISO corner fittings (for a total of 12) located in between the top and bottom fittings were implemented to meet the ISO requirements. These fittings are exposed when the container collapses and become the top corner fittings in the collapsed form. This allows for the container to be lifted from either the top or bottom corner fittings in either state.

WATER SEAL TEST

To provide proof-of-concept on providing adequate sealing on the container design, water sealing tests have been performed on the proposed sealing designs. There are two areas on the container that require different sealing techniques than a standard container. One is the seams where all of the separate panels meet and the other is the area around the middle hinges on the sides.

**Mating Surface Seals**
The seal chosen for the mating surfaces is a synthetic rubber compression seal. This seal is laid down in strips along one surface and seals the gap between the surfaces. The sample chosen was a Trimlok “Rubber Seal” Model OW135BT [Fig. 8]. It is an EPDM “double-D” shape with a 3M Bonded Tape seal. It is designed to seal gaps with heights in the range of 0.30in (7.62mm) - 0.44in (11.176mm).

The sealing requirement for an intermodal container is to resist water spray at moderate pressure and temperature and not allow visibly detectable moisture to reach the inside of the container [1]. The test setup consisted of two plates of 16 gauge steel held together with bolts. The sealing sample was laid down across the bottom plate with its adhesive and the other plate was pressed down on top until the gap reached an acceptable dimension. A dry piece of paper was placed on one side of the seal while the other was exposed to moderate pressure water spray for several minutes. The test was repeated at several gap heights within the specified range. There was no detectable moisture on the paper when examined after any of the tests.

To test for compression set and elastic recovery, the test setup was allowed to sit highly compressed for several days and then taken apart. The seals recovered to their original height and were able to make a good seal when recompressed.

**Hinge Seals**
The test sample for the hinge seals is a Trimlock X-2064 EPDM Flap Seal [Fig. 9]. For the test, a 3in (76.2mm) square hole was cut in a piece of steel sheet metal and the hole was covered by the flap seal. The seal was attached and fully sealed by using a silicone sealant. A mechanical attachment would be used in addition to the sealant on a container, but was not needed for the test as it would not affect the sealing properties. Again a strip of paper was laid across the opening on the side opposite to the seal as the seal was exposed to a moderate pressure spray. This seal also showed no detectable leakage.

STATIC STRUCTURE ANALYSIS

Pro-Engineer Mechanica was used to complete finite element analysis of parts of the design which are unique to the collapsible container. Parts and materials currently used on 1AA containers were considered to be properly engineered to withstand the loading conditions on a container. The maximum loading conditions which the container would be exposed to were considered and the forces which the individual parts would need to withstand were determined through static force analyses of the container. None of the components tested exceeded the material yield strength.

**End Lever**
A 3625lb bearing load was applied at the hydraulic cross member attachment point. This load accounts for a factor of safety of two. The loading scenario simulates the forces this member will see during the erecting process. The force is directly related to the weight of the end panels and the geometry of the j-hinge attachment.

**Corner Post**
A 32200lb compressive load was applied to the top face of the post, which simulates a stack of nine empty containers with this post being part of the bottom container. The load is simply the weight of eight...
containers distributed through the four posts of the bottom container.

![Fig. 12 Corner Post Stress Analysis](image)

**Hydraulic Cylinder Linkage**

A 385lb bearing load was applied at the hydraulic cylinder mounting point. This member provides the direct transmission of the force from one of the hydraulic cylinders to two end levers. This test was performed to simulate the erecting and collapsing operations of the end panels.

![Fig. 13 Hydraulic Cylinder Linkage – Collapsing](image)

**Hydraulic Cylinder Cross-Member**

A 3625lb bearing load was applied at the hydraulic cylinder mounting point. These two parts are the stationary mounting points for the hydraulic cylinders so they receive the same force that is distributed through the end lever parts also analyzed.

![Fig. 14 Hydraulic Cylinder Cross-member](image)

J-hinge

A 16800lb load was applied at the end post attachment point and a 1500lb end linkage force was applied at a 45° angle to the hinge to simulate the forces applied to the hinge during top lifting of the container in a maximum load condition. The linkage force is generated from the moment the ends receive due to the geometry of the j-hinge.

![Fig. 15 J-hinge - Container Top Lift](image)

**SUBSYSTEM STRENGTH ANALYSIS**

Many calculations were completed throughout concept development for the purpose of dynamic motion feasibility and also basic structural integrity. The calculations required the use of engineering principles to develop the proper formulas to represent the problem at hand. This section describes some of the critical calculations completed.

**Strength Calculations for the Connecting Link**

The link will experience its greatest load at the onset of the erecting phase because the geometry causes a large portion of the force placed on the link to be directed horizontally instead of vertically. Due to this, the likelihood of buckling will be greatest at this point. The part is constrained on both ends by connecting pins and is free to rotate about them. Material selection is common steel bar stock with cross section of .25in (6.35mm) x 4in (101.6mm).

\[
P_{cr} = \frac{C \pi^2 EI}{l^2} \quad (1)
\]

C: End condition constant
E: Modulus of Elasticity
I: Moment of Inertia
l: Length

With an estimated load of 3250lbf on the link, the results show a factor of safety of approximately 36.
The link can be viewed conservatively as being an eccentrically loaded column by virtue of its offset (one-sided) mount locations where it is joined to the ends and hydraulic subsystem (through the slotted side rails). Its degree of eccentricity is approximately equal to half of the thickness of the link.

\[
P_{cr} = \frac{S_{yc}}{A \cdot E} \left( 1 + \left( \begin{array}{c} e \cdot c \\ k^2 \end{array} \right) \cdot \sec \left( \frac{l}{2k} \right) \right) \cdot \sqrt{\frac{P_{cr}}{A \cdot E}}
\]

(2)

\[
P_{cr} = 56,589\text{lbf}
\]

\[
S_{yc}: \text{compressive yield strength}
\]

\[
e/c/k^2: \text{eccentricity ratio}
\]

\[
l/k: \text{slenderness ratio}
\]

\[
A: \text{cross-sectional area}
\]

**Strength Calculations for the Locking Mechanism**

The transverse bar of the locking mechanism is to be made of steel bar stock with cross sectional dimensions of 1in (25.4mm) x 2in (50.8mm). The loads imparted upon it by the forklift, end panels, and internal connections will be of very low magnitude, however, a buckling calculation is valuable to prove the robustness of the safety mechanism.

\[
P_{cr} = \frac{C \pi^2 EI}{l^2}
\]

\[
P_{cr} = 6871.6\text{lbf}
\]

With an estimated load on the bar of well less than 50lbf, it would have a factor of safety of 137.4. Buckling of this bar will not be a concern.

**SCALE MODEL**

For the purpose of demonstrating the design and for dynamic validation of the subsystems integrated into the final design, a 1:20th scale model was created. Much time was spent scaling the 3D model to appropriate sizes so that the pieces of the scale model could be manufactured. The scale model components were created using rapid prototyping and assembled by the team. The model clearly shows the process of collapsing and erecting the container and demonstrates how each subsystem interacts.

**CONCLUSIONS**

The design presented in this paper represents a great innovation in the intermodal shipping industry and has the potential to greatly affect the industry. This container design satisfies the design specifications set at the onset of the project. It would not be surprising to see this design in wide use in the intermodal shipping industry in the near future.

**FUTURE WORK**

Now that a design is in place for an automated collapsible container, future work should focus on optimizing the design. Optimization of materials could result in reduced weight and increased performance characteristics. Cost analysis could be performed to reduce the cost of materials and manufacturing to make the container design more competitive based on its purchasing cost in addition to its cost saving potential.

**ACKNOWLEDGMENTS**

The project team would like to thank our sponsor, Sam-Son, for the opportunity they provided by developing this project. Thanks also go out to the many RIT faculty and staff who have assisted along the road to completing the project. A special thanks also goes out to Josh Gannon for his help with rapid prototyping.

**REFERENCES**