Development of a foldable Maritime Container

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Abstract—*Foldable containers are attractive for logistical and commercial reasons. Attempts to develop and introduce foldable containers failed until now and technical complications were partly the reason for this. The paper describes these technical problems and introduces a newly invented concept of a foldable container that can fulfil all requirements of a standard maritime container. Explanation is given why the new concept has better potential compared to the traditional "shopping crate" concept. Discussions on relevant aspects are presented, like the construction of the corner posts (buckling), the stiffness of the single panels during (un)folding, static balancing with springs, safety for the personnel, the reduction of the door width and the increase of total weight. The follow-up to build and test a prototype is described and attention is given to other initiatives in the world to develop a foldable container.*

Keywords: collapsible container, stacking, static balance, torsion spring, shaky mechanism, green solution

I Introduction

For transportation of goods all over the world frequently maritime containers are used, see fig. 1. Due to imbalance of container flows between continents, it is sometimes inevitable to return empty containers to the sender, or to reposition them to storage yards. Measurements show that, on the average, about 20% of all containers transported by vessels are empty.

Fig. 1. Standard 20 ft maritime container

In 1999 the Port of Rotterdam Authority started, together with TU Delft, a project to study the feasibility of foldable (maritime) containers to reduce the space occupation of the empties depots in the harbour. At that time several initiatives, at other places in the world, to build and use foldable containers, had already been taken, but none of them had proven to be successful. The Dutch study group concluded that these unfortunate results were mainly due to problems with the technical concept and the operational flexibility of container shippers. The cost saving potential of a foldable container is high, especially when also the hinterland transport, which takes about 50% of all transportation costs, is considered. The effect of the foldable container at the total costs of the logistic chain is however limited, since the exploitation of a container takes about 3% and the storage takes about 1% of these total costs – for the usual logistic concepts. As a result of the study [1], involving literature search (patents), interviews with specialists from shipping companies, brain storm activities and preliminary design calculations, some guidelines for the design of a foldable container were formulated.

These guidelines are the basis of the functional requirements described in the next chapter. A new folding concept is presented in chapter III and it will be compared with the traditional concept. Preliminary calculations regarding main dimensions are presented in chapter IV. The follow-up of the design study since 2001, the development of a full scale prototype, will be described in chapter V. The development of other concepts will be given attention in chapter VI.

II. Functional requirements

Maritime containers for general cargo must confirm the standard ISO 1496 [2]. Significant topics are:

- External dimensions: the width must always be 8ft, while the length is based on 20 ft (40 ft is the most widely used size), and the height is maximally 8½ ft (high cube 9½ ft).
- Rated weight, dependent on the container length.
- Corner fittings for handling, stacking and securing (see fig. 1).
- Test loads for strength (see fig. 2).
- Test methods for water tightness.

Regarding the strength requirements: a maritime container must resist a normal force in each corner post of 848 kN, due to the requirement that nine containers at maximum load could be stacked. This involves certainly a problem of buckling. Slender corner posts are preferred because of a wide door opening. The current design of containers has been evolved towards an optimized result.

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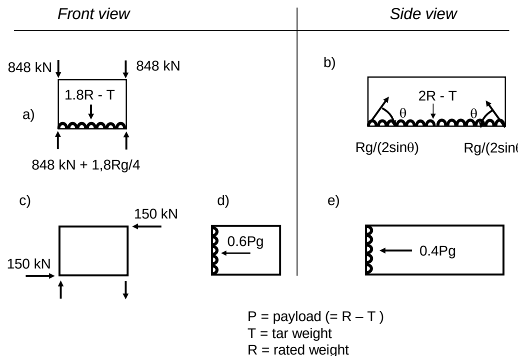

Fig.2 Typical test loads of a maritime container (ISO 1496)

The standard [2] recognizes several sub-types of containers, but only the flat-rack can be considered as foldable. The flat-rack consists of a base and short walls that are hinged to the base and can be laid down. Two or more flat-racks stacked and fastened, within the height limit, can be considered as one container.

For foldable containers the study group has formulated additional demands and wishes [3].

- The kinematic structure should be simple and contain no loose parts.
- Only minimal reduction of internal dimensions and door width are allowed, compared to what is used in practice.
- To save production and repair costs, the material to be used is steel, while mass produced container parts should be used as much as possible.
- The tar weight, which is about 3900 kg for a 40 ft container, should not increase much. Extra tar weight of 10% is assumed to be acceptable (the rated weight is 30.400 kg, while the average cargo weight is about half the rated weight).
- The whole (un)folding procedure must be performed using standard handling equipment, with no more than two persons and within ten minutes.
- The (un)folding method must be safe in various situations.
- The collapsed container must satisfy the requirements of a container with reduced height. A stack must function as one normal container.

These additional demands should distinguish to select a favourable kinematic concept. Further demands, for instance regarding securing and locking of moving parts, sealing of connections, good cleaning options etc. can be considered in a later stage of the design.

III. Kinematic concepts

From [4] a certain type of folding concept is known (“shopping crate”), see fig. 3. This has been the reference concept of the brain storm of the Delft study group.

As a result of the brain storm a second concept has been developed [5], which has suspension bars between the roof and the short walls of the container, see fig. 4. In this concept the long walls, which are disconnected from the roof and hinged to the bottom part, are laid down first. Then the roof is lifted off, causing the short walls to rotate via the suspension bars, until they reach the position where the bar and its short wall are in-line. By gravity force the short walls will pass this shaky position and, when the roof is lowered, the folding will continue. The pin joint between each short wall and the bottom part has been placed intentionally eccentric at the wall for two reasons:

- To create space for the long sidewalls already lying down (folded position).
- To create a corner post without hinges, such that it can better resist the required normal force and buckling effect (erected position).

During the unfolding, external forces are required to pass the in-line position in the reversed way. These external forces can be applied manually or by additional devices (see later the example in chapter V).

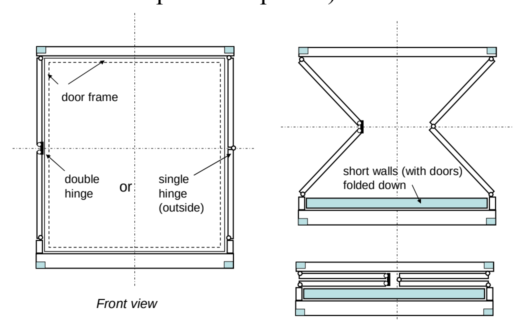

Fig.3 Foldable container, type “shopping crate”

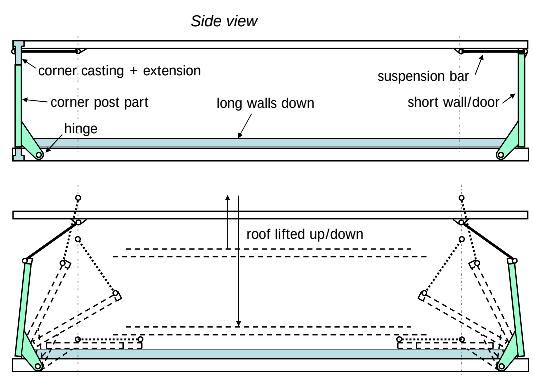

Fig. 4 Foldable container, type “suspension bar”

The two concepts can be compared with each other to obtain their advantages and disadvantages. Main issues are described below.

A. *Dealing with the corner post construction (buckling)*

The suspension bar concept has a clear corner post that can be dimensioned well for buckling. Each corner post is split up into three parts; the contact areas are far away from the middle cross section, where the buckling risk is high. Separation of the parts occurs in longitudinal direction, which avoids friction and jamming effects. Each corner post needs a lock with the roof part.

The shopping crate concept needs a further decision: which wall will resist the normal force. In case that it concerns the long wall with single joint in the middle: the corner post consists of four parts and contains a contact area right in the middle, which is less favourable because of buckling risk. Separation occurs also in longitudinal direction. Locks are required at the middle separation along the full length of each long wall. In case that the corner post concerns the short wall: this corner post has three parts and no contact area in the middle. The separation between wall and roof occurs in the traverse direction. This corner post needs to be released, e.g. by lifting the roof a little, before the short wall can be folded down. A lock is required between each corner post and the roof part. In this case there can be a double hinge in the middle of the long wall, allowing easier folding but also requiring extra locks.

B. Dealing with the internal width and the door width

In the suspension bar concept the thickness of the long walls and the dimensions of the corner posts, and thereby the internal width and the door width, can be the same as in normal containers. However, the door frame consists only partially of the corner posts. Adjacent to the upper part of the corner post (the corner casting extension of the roof) the door frame needs to be made narrower. It means that the upper ≈ 30 cm of the door opening will be about 8 cm less wide.

In the shopping crate concept the door frame needs to be always between the long side walls. That will reduce the door width along the full height. Another point is that the thickness of the long walls will be increased by the protruding hinges. Anyhow the door width will be reduced by (estimated) 8 to 12 cm when compared to a normal container.

C. Dealing with bending of the long sidewalls

The shopping crate concept has a (single or double) hinge in the middle of the long wall. This may needs attention when considering the requirement d) in fig. 2. The variant with the double hinge needs extra parts that take over the missing bending stiffness. These extra parts must be removed before folding. The variant with a single hinge can be made with sufficient resistance against bending outwards. It is however unlikely that a slender wall can be constructed.

The suspension bar concept can use the same wall construction for the long sidewalls as the normal container: corrugated steel sheet.

D. Dealing with the safety of the folding procedure

All parts that can be disconnected, must occasionally be (un)locked and secured. Assuming that these are manual operations, already here the safety of the personnel must be regarded.

In the suspension bar concept, all connections can be unlocked and the resulting structure is still stable (exception: the long sidewalls, see next chapter). The personnel does not have to do any operation while the lifting equipment is active. The folding procedure of this concept is intrinsic safe, also for the locking aspect.

In the shopping crate concept the configuration is unstable after unlocking the long sidewalls. Before unlocking, the lifting equipment must already be in its position where it holds the roof strained upwards, e.g. with taut ropes. The personnel always need to do this job under the lifting equipment. Also for initial unfolding of the long walls external (manual) force will be required.

Considering the properties of both concepts it will be clear that many technical issues need careful attention. Underestimation of the technical problems is one good reason that concepts of foldable containers have not yet been developed such that they are appreciated in practice. The suspension bar concept seems to be potentially better when a maritime container is envisaged. Because it is a new concept, further calculations are required to show that this concept is viable. Some results of the investigations are presented in the next chapter. Anyhow the new concept has been patented [6].

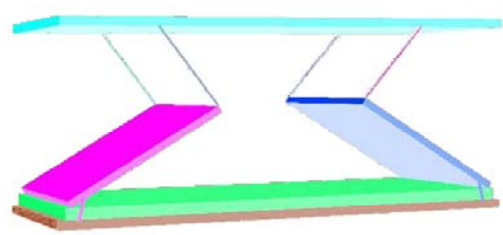

Fig. 5 Multi-body model for simulation with ADAMS

IV. Preliminary calculations

Prior to making strength calculations and designing parts in detail, dynamic simulation of the folding process has been performed. A multi-body model (ADAMS) with masses, obtained from a standard 20 ft container, was used, see fig. 5. Asymmetric short walls - to express that the door part is different from the other short wall - and various load cases have been applied, including wind forces. A typical result is depicted in fig. 6, showing the normal force in the suspension bars during the folding process. Naturally a clear dynamic effect occurs during passage of the shaky position, but all forces are still reasonable and the folding is performed correctly. For unfolding the model was extended with a certain spring-and-band application (not described further), which was a favourite solution for unfolding at that time. The simulation made clear that the main idea of the folding concept works satisfactory. Movies of various simulation runs are available for demonstration.

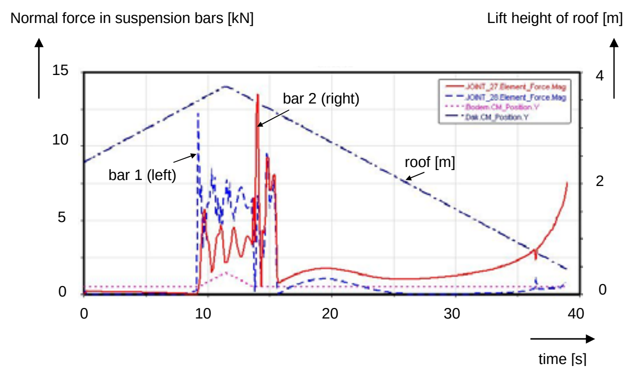

Fig.6 Typical result of simulation

For appreciation of the concept in practice the folding of the long walls – a side problem – needs to be solved in the same convincing way as done for the short walls. A long wall of a standard 20 ft foldable container has a mass of about 300 kg. When this wall lies down and must be erected, the required lifting force is about 1500 N. For manual unfolding at least 5 persons are thus needed.

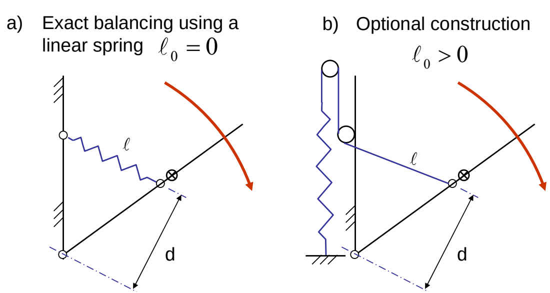

Fig.7 Balancing a sidewall with a spring (exact)

Compensation of the gravity force by springs would be a great improvement. Exact compensation [7] by a linear spring is theoretically possible (see fig. 7 left) but requires a spring with released length zero, which seems to be technically impossible, or a combination with a band or rope, as drawn in fig. 7 right.

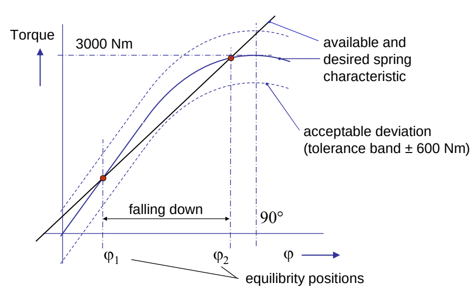

Fig. 8 Balancing a sidewall with a torsion spring (approximated)

Alternative gravity compensation can be obtained with torsion bars, preferably integrated with the hinges between the long wall and the bottom part. A torsion spring with constant stiffness has however a sinusoidal characteristic for the vertical force component, so only approximated compensation is possible, see fig. 8. The figure shows that the remaining lifting force, assuming a lift arm of 2m (the wall height), could be less than 300 N. This lifting force can be delivered by one person. The preliminary calculations of the torsion spring [5] have lead to a typical solution like:

"Two torsion bars for each wall with a diameter of 25 mm and a length of 3.15 m, in parallel arrangement."

It is likely that such torsion bars can be applied in-line, integrated in the hinges, assuming that the mass of the long wall can be reduced a little.

From the preliminary calculations it can be concluded that the new folding concept is very promising.

V. Follow-up and prototype design

To develop a prototype of the foldable container, various companies have been contacted from the year 2002 on. However, despite enthusiastic initial reactions, no commercial partner could be found to make the necessary developments and investments. Mainly this is due to the facts that the container production industry is concentrated almost completely in one country (China) and that container development is no longer core business.

Chances to move away from this deadlock came with the world-wide climate discussion and the attention (and available grants) for so-called green solutions. In 2006 a group of students investigated the marketing concept of the foldable container during their MSc-thesis at TU Delft. They decided to continue as young entrepreneurs[1] to develop the prototype. They succeeded to obtain financial and technical support from a shipping company, who convinced them that a 40 ft foldable container would be the most interesting container type to develop. Main issues of further development, in which the author participated as senior advisor, are described below.

Dealing with the height of the bottom- and the roof part.

During (un)folding several parts are disconnected and in that situation each panel must be strong and stiff enough to carry at least its own weight. For the 40 ft container the bottom and the roof need to be considered as disconnected parts, subject to bending due to their own mass. Considering that a beam (I-profile, steel) needs a height of about 30 cm to satisfy the deflection that is usually adopted for constructions (max. 1/500 of the length), the height of the folded container will be at least 60 cm. Finally it succeeded to construct all parts such that four collapsed containers fit in one high-cube

[1] HCI (Holland Container Innovations), www.hcinnovations.nl

container (height 9½ ft or 2.896 m), using standard twist-locks for their interconnection to build the stack.

Dealing with spring compensation of the long walls.

The torsion springs that had been calculated for the 20 ft container can be used here as well: four springs need to be applied for each wall. They will reduce the maximum lifting force to about 600 N. The folding of the long walls can be done with two persons. Further reduction is theoretically possible [8].

Dealing with the locks of the long walls.

Human operated locks are assumed. Both longs walls need to be (dis)connected to the roof part with locks. A discussion point is where to place such locks: inside or outside the container? Inside locks have the advantage that the long walls cannot be opened by unauthorized persons from the outside. Drawback is that, when the last inside lock is opened, that person is in a dangerous situation, no matter the side wall is spring-balanced. The best solution seems to be that locks will be applied both inside and outside the container. Operating the locks inside can be done then always while the locks outside are closed.

Dealing with deflection of the roof during (un)folding of the long walls.

In the ideal situation the roof has no deflection and there is a small clearance between the horizontal contact areas of the long walls and the roof, when the container is in erected position. In practice the roof tends to deflection that will be resisted by the long walls and that causes friction when the long wall starts to rotate for folding. When the long wall will be erected again, the deflection needs to be eliminated before the long wall can rotate to its upright position. For this problem two ways of thinking are recognized: (1) Construct a curved roof such that deflection due to gravity results in a flat shape; (2) Lift the roof part a little at the side to connect.

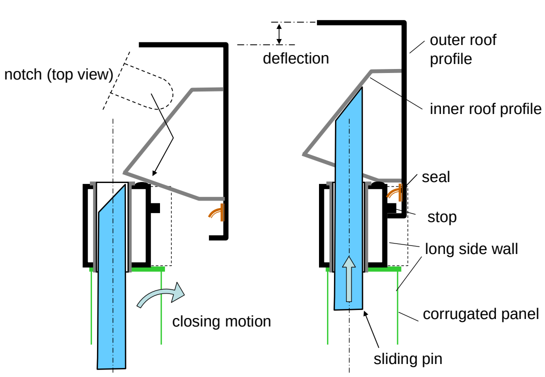

Fig. 9 Wedge mechanism to lock a long side wall

For the latter option a special lock mechanism has been developed that takes care of both the lifting and the closing motion. For a drawing of the principle see fig. 9. By lifting the pin against the sloped inner roof profile, the roof is moved upward while the wall moves sideward, until the stop. The pin can be the output part of a crank-and-slider mechanism, the “dead points” as the open and closed position. This mechanism can be hidden in the corrugated wall profile. In the closed position the roof and the wall have form closure in all directions.

Dealing with the unfolding (passing the shaky position).

By lifting the roof, the structure unfolds until the situation has been reached as drawn in fig. 10. Continuation of the upward motion results in lifting off the whole structure, including the bottom, from the ground. Gravity of the short walls prevents that the short walls pass the shaky position, which would be required for further unfolding. Additional devices can help to complete the unfolding. Various solutions have been proposed and discussed. Probably the simplest solution is to add push bars at the outside of the short walls, as a pendulum, such that they project below the bottom. When replacing the structure at the ground, the mass of the bottom part has enough potential energy to push the sidewalls beyond the shaky position. During the last lowering phase, the roof - by its suspension bars - takes over the motion of the walls, until they reach their vertical position. This unfolding method has been tested with the prototype and it has been proved to work very satisfactory. However, there is still the practical problem of dealing with the push bars as unwanted loose parts.

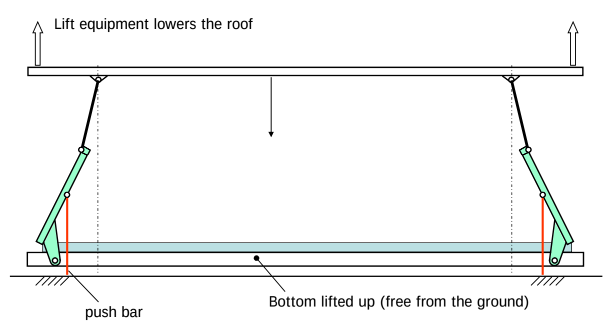

Fig. 10 Unfolding: passing the shaky position using push bars

Fig. 11 HCI foldable container (40 ft)

The first prototype of the foldable container (fig. 11) has been built and tested with good result.

The presentation was on June 10, 2009. Since then several modifications have been implemented, mainly to reduce the weight, which is now less than 5000 kg. HCI won the Shell LiveWire Young business award (Netherlands 2010) and the foldable container was selected as one of the five finalists for the Postcode Lottery Green Challenge 2010. Certification of the HCI foldable container is expected before the end of 2010.

VI. Other initiatives of foldable containers

The initiative of Geoffrey Richter [2], also known as "foltainer" (fig. 12) has been suspended in 2002, probably due to technical and financial problems. Recently an investment group has taken up again the activities.

Independent from the Dutch development (the HCI-40 ft container), another Dutch inventor[2] recently created a prototype of a foldable container, see fig. 13. This "shopping crate" concept is made of composite material and has the advantage of a low weight. Both short walls have been constructed as lattice doors that can be opened vertically, like a garage door, and hide in the roof part. This solution may avoid the disadvantage that the door frame reduces the door opening. The roof is lifted at a central connection point (non-standard), which avoids problems with deflection of the roof panel during (un)folding. At this moment it is unknown whether or not this prototype can be certified as a maritime container.

VII. Conclusions

Foldable containers are attractive for logistical, commercial and environmental reasons. They are however technically complicated and the shipping companies are sceptic regarding their use in practice.

A new concept for a foldable maritime container has been proposed that can fulfil all requirements of the ISO-standard. The prototype of such a container, as developed by a group of enthusiastic master technicians in the Netherlands, has been tested successfully and is now ready for certification. As this container is fully compatible with a standard container, introduction in practice may occur without major problems. A field test with a series of containers is under preparation. Appreciation of this container can be improved by further development, in the first place to reduce the total mass of the empty container.

Comparable developments elsewhere in the world may lead to a competition in foldable containers, as "green solutions" in transportation.

[2] Rene Giesbers

Fig. 12 Foltainer –Foldable container

Fig. 13 Cargoshell foldable container

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