

# Container System Design Developments Over Two Decades

L. A. Harlander<sup>1</sup>

This paper reviews the progress made over the past 20 years in the design and handling of containers. Factors influencing present container dimensions and strength criteria are discussed, as well as the crucial activity to establish container standardization. The container itself—"the common denominator"—is addressed from the viewpoint of its fittings, design loads and construction materials; and the containership from the viewpoint of arrangements, size, speed, stability, stowage and economics. The author offers several conclusions following the last two sections of the paper, which cover the remaining components of the system, namely, the shoreside gantry cranes and terminal facilities.

## Introduction

APPROXIMATELY 20 years ago, the author presented two papers covering the basic engineering development of the container system employed by Matson Navigation Company. The first paper, entitled "Engineering Development of a Container System for the West Coast/Hawaiian Trade," was presented before the Northern California Section of the Society in June 1959, and later published in the 1960 *Transactions*. The second paper, entitled "Further Developments of a Container System for the West Coast/Hawaiian Trade," was presented at the Spring Meeting, San Francisco, California, in April 1961, and published in the 1961 *Transactions*.

The purpose of the present paper is to describe some of the further design developments, including their background and justification, which have been applied to the equipment and facilities treated in the previous papers.

The container system addressed herein is of the lift-on/lift-off type, employing shoreside gantry cranes as the principal means of effecting the transfer of containers between ship and terminal. Included in this discussion are some of the factors which have influenced the current design of containers, containerships, cranes and terminal handling facilities. In view of the crucial role container standardization has played in container system development, the background of the standardization effort and the criteria used to develop the standards are emphasized.

## Containers

**The common denominator.** The common denominator of an integrated container system is the container itself. Its size, payload capacity, strength characteristics, and special features relating to transport and handling set forth the vital design criteria for ships, terminal facilities, highway chassis, and container railcars. However, these basic container characteristics cannot be intelligently evaluated and selected until there is a clear understanding of the modes of handling and transport required for an efficient container system. It takes very little in way of extra strength or additional features to increase the cost of a container; which, when multiplied by tens of thousands of containers, can result in additional investment which may be difficult to justify. This presents us with a paradox: the container cannot be designed without full knowledge of the modes of transport and transfer, while, on the other hand, the transport and transfer systems cannot be designed without full knowledge of the container. Thus,

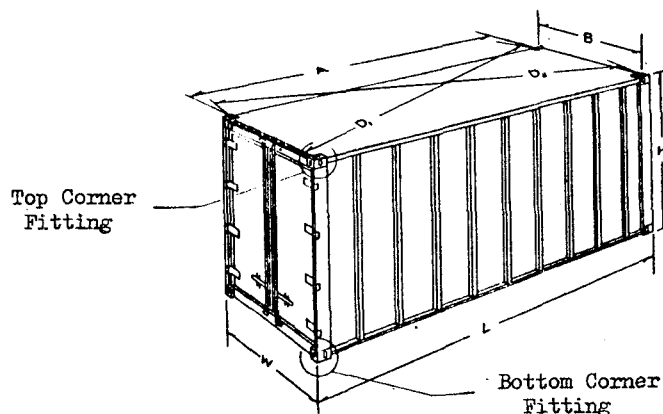


Fig. 1 The common denominator

an iterative procedure is required to develop a container system. Both the American National Standards Institute (ANSI) and the International Organization for Standardization (ISO) container standards, which were coordinated to a high degree, evolved from such a procedure. These standards, therefore, not only form the basic criteria for the design of containers which are to be interchanged between carriers, but establish certain fundamental characteristics for the design of all facilities and equipment used to transport and handle containers. The common denominator is shown in Fig. 1.

**Background of container standards development.** In June 1958, two Maritime Administration (MarAd)/Industry Committees were formed: one on container dimensions and one on container construction and fittings. The purpose of these committees was to implement the recommendation of the Federal Maritime Board, which was as follows:

1. Endorse the principle of standardization of container sizes for United States Merchant Marine use.
2. Direct the Office of Ship Construction to request the current applicants for construction subsidy and/or mortgage insurance involving containerships, to cooperate in a joint study of the possibility of standardizing container sizes for interchangeable use between their vessels, and report thereon to the Board/Administrator.

In July 1958, the American National Standards Institute (then called the American Standards Association [ASA]) held a general conference of the transportation industry. It was agreed that standards were needed if the objective of container interchange was to be achieved. Project MH5 was established under ASA procedures and the MH5 Standards Committee was created,

<sup>1</sup> President, L. A. Harlander & Associates, Richmond, California.

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composed of industry representatives.

From the very beginning, there was heated debate over sizes, strength criteria, and the appropriate scope for a standard. A consensus on any area of standardization was difficult to achieve, due largely to the following:

1. There were those who already had made sizable investments in container systems designed to meet their own requirements. Each wanted the unique characteristics of their own systems to be included in the standards, even though these systems varied considerably as to container size and design features.

2. There were those who believed that only a modular series of container sizes would enhance the interchange and carriage of containers.

3. There were those involved in the manufacture of containers, fittings and equipment who wished to introduce their proprietary features into the standard.

4. Some of those who were representing safety interests felt that containers should be able to meet string strength standards, including the ability to encounter the full force of green seas when stowed on a ship's deck. (requiring the use of scantlings, such as found in ship construction)

5. Manufacturers and users of handling equipment wanted the container to be equipped so that it could be handled, conveyed, or secured by each of their own favorite schemes. If provisions for all such techniques were incorporated, perhaps the container could of been handled by most devices known to man—but at a heavy price.

6. Ships, railcars, highway vehicles, and various types of handling equipment presented different criteria for container design. These automatically created a conflict of interest among the various groups involved. Each group could easily "justify" container features to meet its own requirements, but felt that characteristics advocated by other groups were excessive.

On April 16, 1959, the MarAd/Industry Committee on Dimensions recommended container lengths of 12, 17, 20, 24, 35, and 40 ft and a height of 8 ft. On June 25, 1959, the MarAd/Industry Committee on Construction and Fittings set forth its final recommendations to the Office of Ship Construction. Those recommendations in abbreviated form, were as follows:

1. Maximum gross weight: 12-ft length 28 000 lb; 17- and 20-ft lengths 44 800 lb; 24-ft length 56 000 lb; and 35- and 40-ft lengths 67 200 lb.

2. Containers shall be designed for carrying stacking loads on corner posts (in lieu of sidewalls).

3. For design purposes, there shall not be mixed stowage within the same cell.

4. Containers shall be designed for six-high stacking.

5. The dynamic loading criteria shall be:

- (a) The container ends should be designed of equivalent strength to standard trailer construction (for rail interchange, this may require shock-absorbing mounts).

- (b) Two *g* for lowering and landing by cranes during ship loading/discharge operations.

- (c) Six-tenths (0.6)*g* for the sides in ship handling.

- (d) One and a half (1.5)*g* on the bottom due to rolling and pitching of a ship.

- (e) One and a half (1.5)*g* on the bottom container due to the weight of five above (*G* = 5*g*) in stacking. The foregoing are based on a maximum design roll of 30 deg to each side.

6. Containers need not be designed to be lifted without spreader bars.

Concurrent with the efforts of the MarAd/Industry Committee, the Van Container Subcommittee of the MH5 Sectional Committee was working on standard specifications for containers. On February 25, 1959, the Van Container Subcommittee unanimously approved the outside length dimensions of 12, 17, 20, 24, 35, and 40 ft.

From that point onward, some very interesting meetings took place within the MH5 effort. On September 16, 1959, the Size Task Force under the Van Container Subcommittee met without direction from its parent committee and voted out the 12, 24, 17, and 35-ft lengths and added as proposed regional standards the lengths of 13¼ and 26½ ft. The Size Task Force recommendations were adopted by the Van Container Subcommittee on October 1 and 2, 1959, and the MH5 Sectional Committee agreed on October 28, 1959, to submit these recommendations to letter ballot. Due to poor communications, lack of understanding of the procedures, and the role of the Maritime Administration, West Coast steamship companies were in a state of confusion. The results of the ballot were so varied that the MH5 Sectional Committee reballoted the issue on June 29, 1960, covering only the 10, 20, 30, and 40-ft nominal lengths and the 8-ft height and width. On April 14, 1961, ASA gave its approval to the standard and, thus originated the current standard sizes.

Meanwhile, on the international scene, it was evident that if containers were to move in worldwide transportation systems, it would be necessary to provide an international forum, where impediments to the international interchange of equipment could be discussed and resolved. An international project for equipment standardization under the auspices of the International Organization for Standardization was formed by a number of nations, and in September 1961 the first meeting of the Technical Committee ISO/TC 104, Freight Containers, was held.

The first standard, which included a family of sizes (lengths of 10, 20, 30, and 40 ft; height and width of 8 ft), dimensional tolerances, basic strength requirements, and the key ingredient of corner fittings, was approved by the ASA Review Board in September 1965. During the same month, the corner fitting design, which was incorporated in the ASA Standard, was submitted as a Draft ISO Recommendation at an ISO meeting in The Hague, where it received considerable support.

These two events greatly accelerated the containerization movement. Standardization of the corner fittings, a vital requirement for the interchange of containers between carriers, enabled investors and lending institutions to make the necessary commitments for the development of intermodal containerization without the high risk of obsolescence before their investments could be amortized. Container leasing companies could invest in large fleets of containers, knowing that there would be a broad market for their equipment.

However, the process for design development of the ASA corner fittings included an element of "political expediency" necessary for its approval and lacked certain technical merit. Also, the 1965 Standard was lacking in scope as regards to geometry of understructure, racking loads, and lashing loads.

Following the establishment of the 1965 Standard, the introduction of refinements for additional features became more difficult because: (1) as the growth of containerization "snowballed," there were many additional special-interest groups, including regulatory bodies, who wanted to "help" steer the effort; and (2) the owners of the thousands of containers which were being built under the 1965 ASA Standard were concerned about changes which might make their equipment obsolete.

To make matters more complex, air-mode interests wanted the standard container to be compatible with both fixed-wing and rotary-wing aircraft. This demanded a new set of very high strength requirements, together with a special securement system to be used within the aircraft, and a bottom structure to be compatible with a conveyor system for handling the containers. Due to the cost and excessive weight associated with a container that would be compatible with truck, rail, ship and aircraft, it was elected to separate the strength and handling features for each mode and leave it to the user of the equipment to determine the two or more modes in which his container was to be transported. This approach was attractive to those who were interested principally in interchange between the air-and-highway or the

rail-and-highway modes. Obviously, the strength capability to stack 30-ton containers six-high for the marine mode, with the attendant additional weight, presented no interest to those using the air mode, who could foresee limited interchange between ship and aircraft.

After another six years of debate, nationally and internationally, sufficient consensus was achieved to permit the publishing of the ANSI 1971 Standard. This standard included the revised corner fitting design introduced by the U.S. Delegation at the 1967 ISO Meeting in Moscow, and was augmented to provide for the following:

1. Design load criteria for each mode, that is, marine, railroad highway, air and terminal handling.
2. Container lengths of 24 and 35 ft and an additional height of 8½ ft.
3. Container base configuration.
4. Racking and lashing loads.
5. Optional features for: (a) forklift pockets, (b) straddle lift handling, (c) conveyor handling (air mode), (d) container tunnel and gooseneck chassis, and (e) specifications for electrical power.

The current ANSI Standards, published in 1979/1980, essentially incorporate the 1971 Standard, but were reformed, refined and augmented in scope to include additional container types. Container heights of 9 and 9½ ft were also added.

**Basic criteria for standards. Size lengths**—When Sea-Land started its container operation in 1956 as the Pan Atlantic Steamship Company, the 35-ft container was the largest size which could be transported over the highway in all states and was highly suitable for motor carrier freight densities. The Matson 24-ft container was an economical size for the West Coast, since it could move over Western highways in doubles, was suitable for city delivery and provided a good cube/payload relationship for the trade. The 24-ft container could carry approximately the same payload as that of a 40-footer when being transported over the road on a tandem-axle chassis.

Based on a census taken under the auspices of the ASA-MH5 Committee in June 1965, the population of containers owned by marine companies totalled 20 815, with the following breakdown by lengths:

| LENGTH               | NUMBER | PERCENT |
|----------------------|--------|---------|
| 40                   | 551    | 0.2     |
| 35                   | 9582   | 46      |
| 30                   | ...    | ...     |
| 24½                  | 1148   | 5½      |
| 24                   | 4425   | 21      |
| 20                   | 2377   | 11      |
| 17                   | 1598   | 8       |
| 10                   | 353    | 1½      |
| 12 }<br>27 }<br>36 } | 745    | 3½      |

It is interesting to note that the Sea-Land and Matson fleets comprised 67 percent of the container population, in contrast to ASA standard lengths, which comprised 16 percent. Because Matson was operating a nonstandard container fleet, they were concerned about discrimination: (1) in the carriage of government cargoes, (2) in shipbuilding subsidies, (3) in Title XI financing, and (4) by regulatory bodies. They were also concerned about the ability to compete on even ground in intermodal transportation. Sea-Land had similar concerns. After years of effort and the passage of legislation barring government agencies from discriminating against nonstandard container operators, both Matson and Sea-Land were able to get their sizes included in the 1971 ANSI Standard.

The proponents of the modular concept who succeeded in processing the 10, 20, 30, and 40-ft lengths through the ASA standards procedures in 1961 believed that the physical inter-

change and intermodal carriage of containerized freight would be enhanced by the modular series, and that additional lengths would open the door to the proliferation of sizes.

The 40-ft container, which was generally accepted by all, was chosen because it was the maximum size which could be transported by highway throughout most of the United States, and there were indications that those states which did not permit 40-ft semitrailers were considering the liberalization of their length restrictions.

Over the years, the marketplace ruled out the 10- and 30-ft sizes, leaving the 20- and 40-ft lengths. Due to its high cubic capacity and the fact that it requires little or no additional cost to handle a large container, compared with a smaller one, the 40-footer is by far the most popular size for the transport of manufactured goods in high-volume operations. The 20-ft container is advantageous both for moving high-density cargo and for handling of smaller shipments without necessitating cargo consolidation. However, because the handling of more than one container size in terminals and ship operations represents a significant cost penalty due to operational inefficiencies, the 20-footer is not attractive in certain large-volume operations. Unfortunately, the decision to ship cargo in a particular-size container is based on a tariff which, in many cases, has no relationship to the relative cost of moving cargo door-to-door.

**Heights**—The marketplace, as it turns out, has had more influence over container heights than have the standards. Since the height standard was not vital for the interchange of containers between carriers, more containers in the United States were built to heights of 8½ ft or more, rather than the 8-ft height stipulated in the 1961 and 1965 standards. As of 1965, 70 percent of containers in service had a height of 8½ ft. Even after the 8½-ft height was included in the 1971 ANSI Standard, tens of thousands of containers were placed in service with heights of 9 or 9½ ft in order to obtain additional cubic capacity.

In 1979, however, the ANSI Standards effort, involving approximately 50 member organizations, was able to catch up to the "real world" and provided for the 9- and 9½-ft container heights.

**Future sizes**—Because of the economic attraction for more and more cubic capacity, together with certain liberalization of highway size limits, dimensions of 45-ft length and of 8½-ft width are currently being considered seriously. Obviously, such additional size dimensions cannot be considered in the unrestricted interchange of containers. With the appropriate equipment, however, in a controlled particular service, the additional sizes certainly present economic incentives.

**Maximum gross weight ratings.** The gross weight ratings which apply to containers today were originally proposed in 1958 by a special committee on container standardization formed by the Maritime Administration. Bagged flour and canned goods, each having a stowage factor of 50 to 52 ft³ per ton, were used as approximate payload weight criteria. Since there was a spectrum of container lengths under consideration at that time, gross weight ratings were assigned to size groups; that is, 20 long tons was originally assigned to containers ranging in length from 16 to 20 ft and 30 long tons to 32 to 40-ft containers. It was recognized at the onset that the gross weight for a 40-ft container exceeded that allowed on most highways. There was, however, and still is, an interest in loading the containers to the full 30 long tons at, or near, the marine terminal to enhance both ship and container utilization. The gross weights set forth in the standard for the 20, 30, and 40-ft containers are 20, 25, and 30 long tons, respectively. The maximum gross weight of 30 long tons, therefore, automatically sets the minimum load rating criterion used for container cranes, terminal handling equipment, and ship structures. These weight ratings were never controversial during the period of container standards development and, to date, have proven to be reasonable. However, there is a movement to increase the gross weight of the 20-ft container.

**Corner fittings.** Container corner fittings probably presented the largest hurdle in container standardization. Various corner fittings that were proprietary in nature were introduced as proposed standards. In view of the many demands imposed upon the container relative to its handling and securement, there was no design available which would meet all the criteria introduced for container corner fittings. Factors considered in the design were simplicity, weight, cost, load encroachment, strength, gathering for spreader locks, ease for attachment to each of the three faces, compatibility for lifting with shackles, and the very questionable requirement of compatibility with a No. 32 hook. In addition, it was felt desirable to avoid a proprietary fitting which could restrict the free use of the design or incur royalties. To make matters more complex, there was considerable interest at that time in providing for various types of container coupling systems which were in use or in the process of development.

A significant contribution to the standardization effort was made by Sea-Land in January 1963 when it released its Patent #3,042,227, covering a box-type corner fitting with a mating rotatable engaging lug, on a royalty-free basis for the furthering of standardization. The basic concept of the fitting and its engaging lug was offered even though it would be modified dimensionally to make it more acceptable as a standard.

Even after the twist-lock box fitting was developed, there was heavy debate over its relative merits, compared with those of the Speedloader fitting manufactured by National Castings, which was in use in a few container systems.

At the time the corner fitting became part of the ASA Standard in 1965, there was no agreement on the loads which a corner fitting would have to withstand, except for stacking and lifting with a twist-lock. Although artwork published in support of container standards showed containers being lifted by bridles from the side apertures of the bottom corner fittings, there was insufficient bearing area in the corner fittings to withstand such loads.

In addition, the bottom face of the lower corner fitting was too thin to permit landing of a fully loaded container without upsetting the bottom face when the aperture missed the cone or twist-lock. Also, when containers were to be stowed on the deck of a ship with some type of a lashing system, there was no way of knowing what type of loads could be imposed on the containers without failure. Another concern with the bottom corner fitting design at that time was the use of a round hole on the end face of the bottom corner fitting, which was a carryover from a proposal using this particular aperture for coupling two 20-ft containers. Since the container coupling feature had lost some interest by this time, it was elected to make this aperture oval to take advantage of the twist-lock concept in designing of attachment devices for this aperture.

After extensive oratory, volumes of correspondence, some development and a lot of testing, a new modified fitting was established and introduced as a draft recommendation at the ISO meeting in Moscow in June 1967, where it was approved by Technical Committee 104 and subsequently processed under the procedures of ISO.

**Design loads.** The design loads used for strength criteria in the standards are based on static loads which have been established to take into account the dynamic loads likely to be encountered in container operations. Many proposals have been introduced into the standardization effort involving elaborate, dynamic testing facilities and procedures aimed at duplicating loads found during actual operations. Fortunately, static loads prevailed over dynamic loads for the assessment of actual container strength. Static loads provide for simplicity, convenience, and economy in testing and enhance the repeatability of test results.

The design load has been defined as the minimum statically applied load which the container shall be designed to withstand; upon application of the design load during testing, the container shall show neither permanent deformation nor abnormality

**Table 1 Design load factors**

| Basic—For Each Mode                     |                     |                  |         |      |
|-----------------------------------------|---------------------|------------------|---------|------|
| Direction of Load Relative to Container | Terminal Operations | Marine           | Highway | Rail |
| Downward                                | 2.0                 | 1.8              | 1.7     | 1.5  |
| Lateral                                 | 0.2                 | 0.6              | 0.2     | 0.3  |
| Longitudinal                            | 0.7                 | 0.4 <sup>a</sup> | 0.7     | 2.0  |

| Closed Van Cargo Containers<br>Marine-Highway-Rail |                                                                                                   |                    |
|----------------------------------------------------|---------------------------------------------------------------------------------------------------|--------------------|
| Structure                                          | Load                                                                                              | Design Load Factor |
| Floor (cargo)                                      | 25 000 lb over any 10 linear feet; balance of payload uniformly distributed over remaining length | 2.0                |
| Floor (wheeled vehicles)                           | 12 000-lb total (6 000 lb maximum per wheel)                                                      | ...                |
| End wall                                           | payload                                                                                           | 0.4                |
| Sidewall                                           | payload                                                                                           | 0.6                |
| Roof                                               | 440 lb over 12 in. × 24 in.                                                                       | 1.5                |
| Corner structure                                   | 5 × maximum gross weight (each corner post 1/4 load)                                              | 1.8                |

<sup>a</sup> AUTHOR'S NOTE: A load factor of 0.6 was used in the 1971 Standard to provide for transverse stowage. The basis for 0.4 is not known.

which will render it unsuitable for use.

In other words, the strength criterion used is essentially a safety factor having a value of 1, based upon yield. The author considers this philosophy regarding strength to be one of the most important factors leading to economical containerization. If, for instance, a safety factor of 2 were required, the weight of a dry freight container would be increased by approximately 60 percent, with a corresponding cost penalty. However, there were, and still are, many who advocate safety factors similar to those used in the building codes. The justification for an apparent low strength margin on closed van containers is:

1. The container is designed to transport cargo, not people.
2. In most operations, the design loads are seldom exceeded, especially when containers are not loaded to maximum gross weight.
3. The load required to cause container rupture, which would result in the discharge of cargo, is considerably higher than the design loads.
4. Common sense, when working around containers during operations, usually precludes injury to personnel if there should be a failure due to rough handling. The same rationale applies to ships carrying deck containers in heavy weather.

**Design load factors.** Design loads are derived by multiplying the design load factor by either the payload or maximum gross weight depending on the particular structure being loaded. Although the various design load factors have been established for marine, highway, rail and air modes, only the controlling factors for the marine-highway-rail container are treated herein. The loads which a marine intermodal freight container must withstand are shown in abbreviated form in Table 1. The criteria for selected loads are as follows:

- *Floor structure*—A load factor of 2 provides for impact when the container is landed on its four corners. Because an allowance must be made for cargo which is not uniformly distributed within the container, the design load is considered to be 50 000 lb distributed over 10 ft of the container, with the balance of the design load (2 × maximum payload) spread over the remaining area of the floor. The floor structure must also be capable of accommodating a forklift truck axle loading of 12 000 lb. These

floor strength criteria were agreed upon in the early stages of standards development.

- *End walls*—The inertial force, due to rapid deceleration, is considerably less for the end panel than that developed at the base of the container, due to cargo characteristics, the friction between the cargo and the container floor, and the friction between cargo packages.

Over the years, there has been much controversy regarding the appropriate end-wall load factor. Both the Sea-Land and Matson container fleets had end-wall strengths comparable to highway trailer construction and equivalent to a 0.2 design load factor. This corresponds to approximately 0.7g experienced at the base of the container during brake application. Although data have been introduced to show that the 0.2 and 0.7 load factors should be modified one way or another, they generally have been accepted for the highway mode.

The end-wall forces experienced in the marine mode have never been agreed upon. Since a variety of assumptions has been made concerning possible pitch amplitudes and frequencies, in conjunction with vessel length, sea states, and other factors, estimated values—excluding cargo friction—have ranged from 0.05g to 0.4g for containers stowed longitudinally. Based on studies with which the author has been involved that take into account sea states and vessel size, the true value appears to be on the low end of the scale except for the case of very small vessels. To complicate matters, some operators were stowing containers transversely aboard ship and were advocating an end-wall load factor of 0.6 in order to keep the cargo from bursting the doors open during heavy rolling. To resolve this dispute, a compromise of 0.4g was agreed upon for the marine mode. The rationale to justify the 0.4g as being reasonable was that cargo friction would diminish end wall loads, and there was already successful experience in the transport of containers stowed transversely having an end-wall strength corresponding to 0.4.

The standards call for a load factor of 0.4 for the rail mode. This requirement was challenged on numerous occasions in the late 60's. Depending on cargo characteristics, coupling speed, and the cushioning system in the railcar, a wide variation of loads can result. Railcar impact tests conducted by Trailer Train Company<sup>2</sup> showed that containers stowed with cartoned goods, and mounted on a modern railcar with currently used cushioning systems, experienced an end-wall load of 0.4g at an impact speed of approximately 7½ mph; at a speed of 9 mph, the end-wall load was about 0.7g. These test results, along with many others, have

trains of container cars that were not subject to impact loads sustained in classification yards.

- (e) At some nominal cost, coupling impact speed could be controlled to, say, 6 mph, and adequate cushioning systems could be provided. (Cargo would also enjoy a lower impact speed.)

- (f) It was estimated that the cost penalty at that time was in excess of \$100 per container, which would equate to over \$3 million for a container fleet of 30 000. In addition, door strength is usually achieved by use of an additional set of door latch hardware which must be operated every time the doors are opened and closed. This added hardware must also be maintained.

- (g) As regards transverse stowage aboard ship, there is simply no justification to add strength to all containers just because a limited few ship operators find it advantageous to stow transversely. In these cases, stronger containers or special restraint systems should be employed.

- *Sidewalls*—The design load factor for the sidewall of a container is principally controlled by ship's roll. The value of 0.6 was recommended by the MarAd/Industry Committee and confirmed during the early ASA standardization effort by assuming a roll amplitude of 30 deg and a rolling period of 13 sec, with the container center of gravity 45 ft above the ship's rolling axis. Although proposals have been made for a higher design load factor, the 0.6 value has never been particularly controversial and certainly has been proven to be of reasonable magnitude.

- *Corner structures*—Six-high stacking and a 0.8g dynamic force to cover pitch and heave were introduced at the early stages of the standardization effort and generally have been accepted. Also, the clearances of 1½ in. between the container and the ship's cells in the longitudinal direction and 1 in. in the transverse direction have proven to be practical. These clearances control the amount of eccentricities in the column loading of the container corner posts when stacked in a ship's cell, and approximate the practical limit that can be accommodated without getting into cost and weight penalties. Also, sufficient bearing area between the corner fittings of stacked containers is difficult to achieve with excessive offset between fittings.

The six-high stacking criterion corresponded to the size of ships which were considered for container transport in the late 50's and early 60's. This requirement, together with the gravitational and 0.8g dynamic forces for the case of the 40-ft container, equates to a load of 151 200 lb imposed on each of the top corner fittings of the bottom container in the stack. There is

tainer tiers on deck. This system did not require containers to have any particular racking strength. Other operators were employing various combinations of diagonal and vertical lashing, as well as the use of interbox connectors. Since it was not possible to start with an agreed-upon securement system, and therefore establish the appropriate loads for the containers, it was elected to determine the maximum loads which could be imposed on typical container structures without adding significantly to the cost and weight. One reason the standardization of lashing loads proved to be extremely difficult was that there were already many thousands of containers built to the previous ASA Standard which had no provision for lashing loads. There was also concern over liabilities which might be assumed by manufacturers and owners if earlier-built containers were to fail under newly established lashing load criteria. The loads which eventually were agreed upon for lashing are shown in Fig. 2 and originally were based on negotiations with manufacturers with little test data available and no particular lashing system in mind. However, these loads were confirmed by testing to be easily accommodated by typical structures found in early the containers.

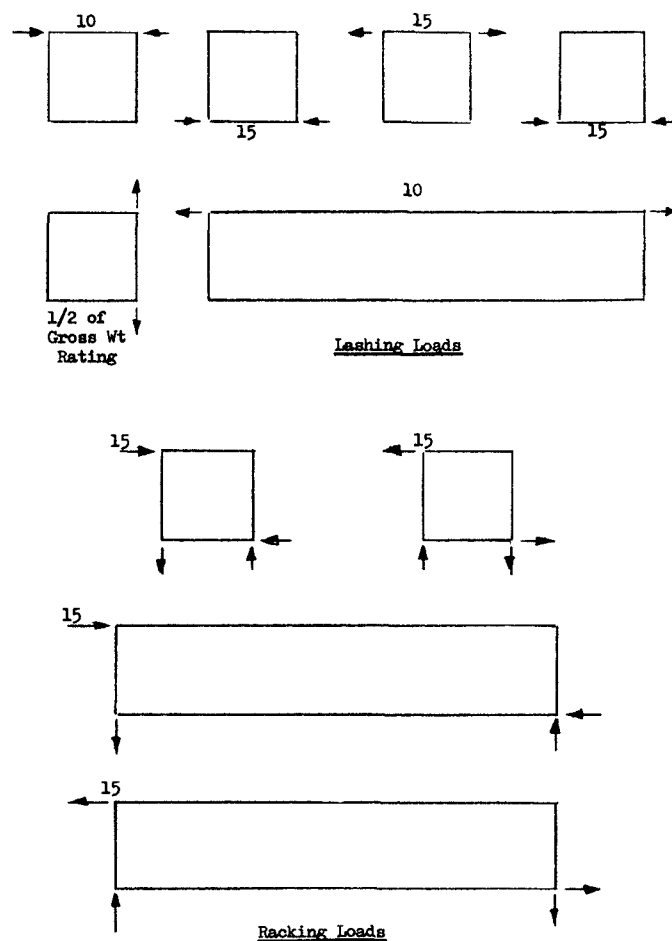
It is interesting to note that Fig. 2 shows a vertical tensile load of 15 long tons. That same assembly for the case of a 40-ft container is required to withstand  $67\frac{1}{2}$  tons in compression. One would expect the corner post capability to be of the same magnitude in tension. In this particular case, however, there was considerable concern over the adequacy of the welds between the corner posts and the corner fittings of existing containers, in addition to the bearing area and eccentricity involved with an unknown attachment device. It should be noted that Fig. 2 does not provide for a longitudinal compression load applied to the upper fittings. The reason for this is that the compression strength of the roof rails already is dedicated to the "beam" loading of the container when loaded with cargo and supported by its four corners.

It is the author's opinion that although the loads prescribed in Fig. 2 are quite substantial when considering the normal scantlings found in container construction, they could be increased significantly if there were control over the particular corner fitting aperture to be used and if the attachment devices were properly designed. For example, in 1969, Trailmobile carried out tests to determine the capability of the headers and sills of a typical container to withstand the lashing loads proposed. Eight tests were conducted so as to impose both tension and compression on each of the headers sills. Six of these tests reached 100 000 lb, the limit of the hydraulic test fixture. A compression load of 65 000 lb on the forward header and 85 000 lb on the forward sill initiated buckling on unsupported flanges. However, it must be borne in mind that thousands of containers have been built with forward headers made from aluminum extrusions which were only rivetted to "ears" on the corner fittings.

- **Racking loads**—As for the case of the lashing loads, the racking strength of the container, both transversely and longitudinally, had little support until the late 60's. Various values were proposed depending on the deck stowage configuration envisioned. The magnitude of 30 000 to 35 000 lb appeared to represent a strength which could be achieved without too much penalty. The actual requirement of 15 long tons, which was negotiated, had support because it equaled a value obtained by rounding out tons in multiples of five.

**Construction materials.**—The primary construction materials used today for containers are: (1) aluminum with steel end frames; (2) all steel; and (3) fiberglass-reinforced plywood (FRP). Wood flooring is commonly used for all closed van containers.

With regard to the major operators, the aluminum/steel combination is still the most popular type of construction in the United States for the 40-ft container, with all-steel in second place. Leasing companies prefer steel due to lower acquisition and maintenance costs. Although earlier steel containers exhibited heavy corrosion problems, the current use of Corten steel



- Notes: 1) 1979 ANSI Loads for Closed Van Cargo Containers  
 2) Loads shown in long tons

Fig. 2 Lashing and racking loads

with modern coatings has proven successful in service. The main criterion for selection between aluminum/steel and all-steel containers relates to the value placed on weight reduction. Typical 40-ft container weights for aluminum and steel containers in the APL fleet are 6100 and 8400 lb, respectively.

FRP containers appear to have lost popularity in the United States. One reason for this is the dry rot problem. Earlier containers with which the author was familiar lost their moisture seal at the plywood boundaries and in way of floor structure fastenings. Also, minor damage to the gel coat permitted moisture to migrate through the fiberglass laminate. The weight of an FRP container approximates that of an all-steel container. At the present time, however, the FRP container has considerable popularity in Europe.

**Experience.** Deterioration, caused by galvanic action between dissimilar metals and steel corrosion, is the primary factor which sets the life of a container. When trailer manufacturers first started to build containers, many of them ignored the galvanic action problem. One group of containers was sent to sea with dissimilar aluminum alloys between the sheets and the rivets, and, after one voyage, many containers had to be removed from service. Brass identification plates riveted to aluminum containers also provided an "instant" education. Early light-gage steel containers, with no steel preparation prior to painting, turned into sieves within a year.

Most of the M&R dollar spent on containers goes to the repair of damage caused by abuse, rough handling, and accidents, rather

than to preventive maintenance. By carefully monitoring repair costs, container design can be gradually improved by adding additional strength judiciously to reduce certain types of repair. Because of the abuse floors receive in dry freight containers due to forklift trucks and an array of floor-damaging cargoes, floor strength is often increased over that required by the standards. Careful detail design based on the economic tradeoffs between initial cost, weight, and M&R cost experience is absolutely necessary for the production of an economical container.

A question often asked is: "What is the life of a container?" Surveys have indicated 8 to 14 years.<sup>3</sup> However, one specific example is the case of the first 600 aluminum/steel containers built for Matson Navigation Company, which were introduced into service in 1958. These containers had 6061-T6 side skins and 6062-T6 aluminum posts with steel end frames which received only an enamel paint coating. In 1981, approximately 23 years later, 85 percent of these containers are reported to be in service. The containers which have been removed from service suffered from excessive damage rather than excessive deterioration.

### Refrigerated containers

The 1961 paper set forth the design of the first Matson refrigerated container and provides a good reference for identifying certain developments which have since taken place. Probably the most important development in refrigerated container design has been the introduction of polyurethane foam insulation in lieu of fiberglass insulation.

In the early 60's, Matson invited bids for refrigerated containers having a nominal wall thickness of 2 in. with polyurethane foam insulation. At that particular time, some of the leading trailer manufacturers were attempting to develop production methods which would make use of the foam-in-place technique. The problems which had to be overcome included the bulging aluminum side panels or linings due to excessive pressure buildup, the variation in the in-place density of the material, void spots, and an application rate which was not fast enough to achieve economic production. At the time of bidding, only one trailer manufacturer was in a position to bid on the units. These units proved successful, and, almost overnight, the use of thin walls with polyurethane foam became a standard for both containers and refrigerated highway trailer vans.

Also in the early 60's, Matson experimented with side posts made up of aluminum flanges with sandwiched foam to take the shear load and to reduce the heat bridge. Such post construction appeared to be attractive from the heat-transfer standpoint and was adequate from the stiffness and static bending aspects; however, these containers were unable to survive fatigue tests with alternating bending loads. The adhesive between the core material and the aluminum proved satisfactory; however, there was failure in the foam adjacent to the adhesive. At the present time, refrigerated containers with foam sandwich wall construction are being manufactured in Europe. Based on current technology in the field of plastics, it is predicted that this type of construction will become popular.

The original Matson refrigeration units utilized space approximately 12½ in. deep at the forward end wall of the container. The refrigeration unit was made up in two sections: the evaporator section, including coil and fans, was mounted from the inside; and the unit housing the compressor, condenser, and electrical control box was mounted from the outside. The container itself had a jog in the forward wall to accommodate these two units with insulation between them. The container wall also had to accommodate the racking strength requirements of the container.

The most popular arrangement used today is a one-piece re-

<sup>3</sup> Cushing, C. R., Higgins, M. L., and Kimball, P. B., "A Study of Intermodel Container Safety," Report No. CG-D-22-76, prepared for the Department of Transportation, U.S. Coast Guard, Dec. 1975.

frigeration unit which is completely connected and tested prior to installation into the front recess of the container. This requires the container to have an insulated wall capable of withstanding the required racking load located aft of the end frame where the racking loads are imposed. Another approach has been to use the "picture frame" concept, where the refrigeration unit itself provides the necessary strength and insulation for the forward wall of the container. In either case, there has been no apparent improvement made in the space requirements for a given refrigeration capacity.

### Containerships

**Size and speed.** The two most important characteristics of a ship which must be established by the owner in order to assure the highest possible return on investment are size and speed. For the purpose of this paper, it is assumed that the type of ship has been established and is the lift-on/lift-off containership where containers are vertically stacked in cells below deck as well as stowed on deck.

For a given annual cargo throughput in a trade, various combinations of size, speed and number of ships are available. It can be demonstrated that if we were interested solely in the cost per ton-mile of moving cargo by ship, we would want the ship as large as possible with a rather low speed. However, when we give proper consideration to the time value of cargo, the need to provide a frequency of service which is competitive, and capability of the ports being served to handle large vessels, and the potential market share of the cargo available to the owner, we place limits on the size of the vessel which can be justified economically. Time has proven, however, that these limiting factors are constantly changing and ships therefore become obsolete because of the economic forces dictating higher capacities.

For the case of large containerships built to date, all have been designed to transit the Panama Canal; therefore, the beam is limited to approximately 106 ft. The draft is automatically limited by certain ports which must be served which are still under 35 ft. The length of the vessel can be limited by the available container terminal berths or harbor maneuvering considerations.

The largest containership in terms of capacity, the *Frankfurt Express*, was recently placed by Hapag-Lloyd in the Europe-Far East TRIO Service. This vessel, which measures 941½ ft length overall, 889 ft between perpendiculars, 105½ ft in beam, with a 42 ft maximum draft, has a 3045-TEU container capacity with a service speed of 23 knots. Before we see the next generation of containerships significantly larger than this, there must be sufficient economic justification also to build a new generation of terminals with deep water and larger container-handling facilities.

Just over the past 10 years, fuel oil prices have risen tenfold. This has had a direct impact on speed trends, which had previously entered the 25 to 30-knot range, but which are now back in the 20 to 25-knot range. Figure 3 shows the influence fuel costs have on optimum speed for achieving a minimum at-sea unit transportation cost. It must be noted that other factors, including scheduling and competition, often dictate a higher speed.

**Propulsion.** A typical all-purpose fuel rate for a steam turbine containership with refrigerated containers has been 0.53 lb/shp hr. Using this fuel rate for a plant developing 36 000 hp, on a ship spending 75 percent of her time at sea with fuel at \$25 per barrel, results in an annual fuel bill of \$9 250 000. In contrast, the fuel for a low-speed diesel engine, with diesel auxiliaries capable of burning heavy oil, would cost approximately \$6 400 000, or a savings of \$2 850 000 per year. This simple arithmetic provides the only necessary incentive to take a hard look at diesel propulsion in today's marketplace. It has been over only the past two or three years, however, that diesel propulsion has become attractive for large U.S.-built containerships, due to high initial

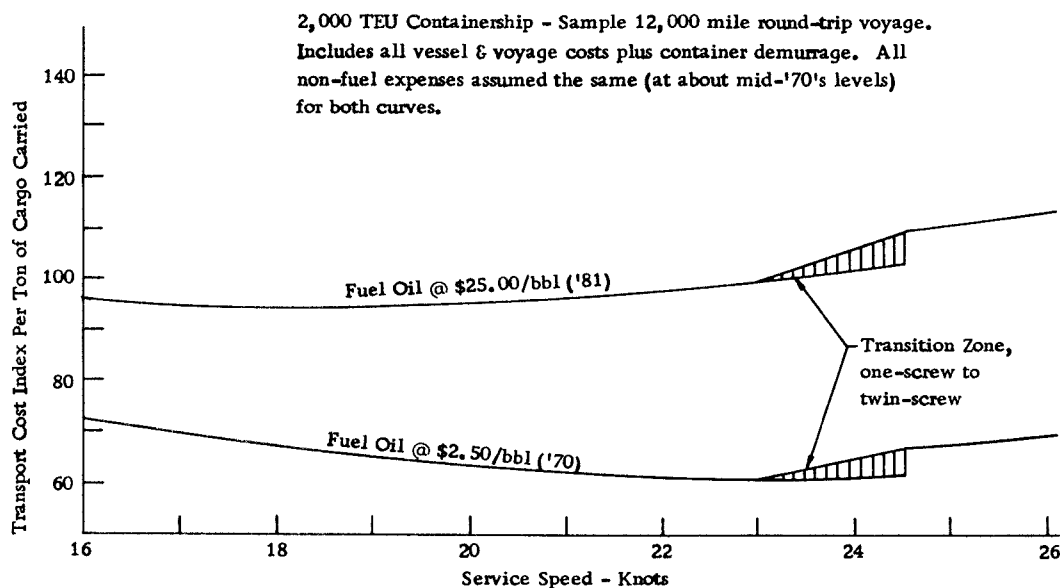


Fig. 3 Sensitivity of optimum service speed to fuel oil cost

cost, lack of manufacturing facilities and lack of sufficient horsepower.

For the case of the American President Lines C-9's, the equipment cost for the 43 200-hp diesel plant over that of a steam plant was approximately \$6 000 000. In foreign shipyards, where the engine is manufactured, erected only once, and placed in the ship for testing, the cost of a diesel plant is actually lower than that of a steam plant.

Diesel propulsion has little impact on containership design. Some additional space is required for the engine room; however, the additional weight is more than offset by the savings in bunker capacity.

**Basic arrangements.** Another fundamental decision relates to the basic arrangement of the ship. Figure 4 not only shows some of the containerships which have been built over the past 20 years for West Coast operators, but sets forth certain key basic arrangements. The *Hawaiian Citizen*, a converted C-3, with its house and engine room amidships, was typical for cargo ships built before the container era. However, this type of arrangement must be avoided today since good vessel utilization dictates that the midlength area be dedicated to container stowage.

For the case of the Matson 071 ships, the main engine was placed as far aft as possible with a house directly over it. The intent, here, was to avoid stowing containers aft of the house,

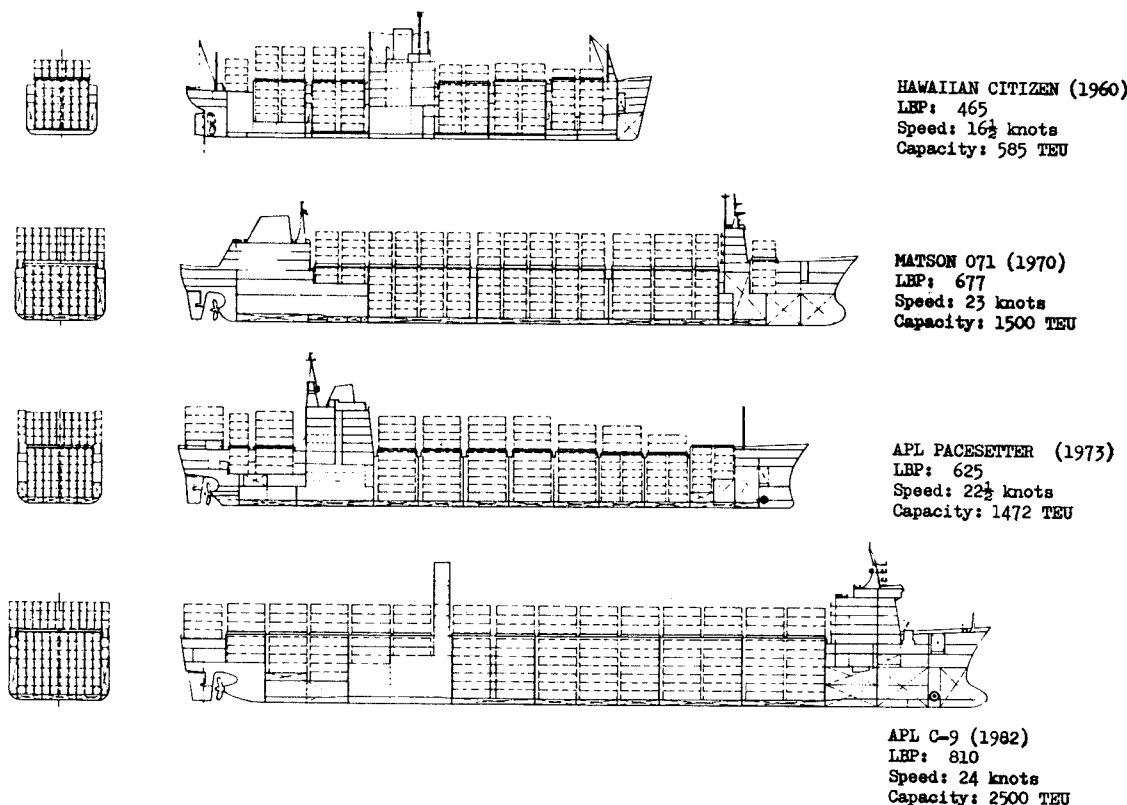


Fig. 4 Comparison of West Coast containerships

which would reduce container handling productivity due to split operations and the need for the container crane to boom-up to pass the house. Also, the ship's crew enjoys separation from longshoremen activity. The forward house, with navigation bridge and accommodations for the deck officers, was kept "thin" for the sake of ship utilization. The author advocates the placement of the navigation bridge forward in large containerships for the following reasons:

1. It enhances the lookout function and provides the master with a "front-row seat" when navigating in congested waters with poor visibility.
2. When attempting to maintain maximum sea speed in rough seas without sustaining container damage, a watch officer, near the bow where the action is, is likely to make a speed reduction in a timely manner compared with a watch officer who is, say, 600 ft from the bow and cannot see what's going on.
3. The forward house, itself, protects containers.
4. Additional containers can be stowed on deck without concern for visibility from the bridge.

The *Pacesetter*, shown in Fig. 4, reflects the arrangement used most in recent years. The engine room is aft of midships to provide for good container utilization. All of the quarters are placed over the engine room, which reduces the initial cost of the vessel, both by saving on house structure and by avoiding redundancies in heating, hot water, air-conditioning and other hotel systems. One drawback in this arrangement, which is apparent in the sketch, is the loss of container deck stowage forward because of visibility considerations.

It might be worth mentioning here that at the present time there are no published regulatory requirements setting standards for visibility from the bridge. Criteria for line-of-sight range from sighting the ship's bow to that of looking over containers stacked four-high on the No. 1 covers. Currently, for the case of U.S. ships, this matter is left with the local U.S. Coast Guard for assessment and is quite controversial.

The C-9, with all of the quarters placed forward, has the advantages cited for the 071's without the additional costs associated with dividing the accommodations. However, the engineers must take a walk when going on and off watch in the engine room. Engine room emergencies, with the engineers' staterooms at a distance from the engine room, were carefully considered but not deemed significant in view of the safety features involved in a modern machinery plant. The engine room on the C-9 is probably as small as it could possibly be, considering the size of the main engine and the three 2500-kW generators driven by medium-speed Enterprise diesels. The stowage space for containers on deck was maximized by keeping the area allocated for the smoke stacks, engine room ventilation, and the waste-heat boiler to a minimum.

**Below-deck stowage.** The basic concept for below-deck stowage has not changed over the past 20 years. The cell guide clearances used for the *Hawaiian Citizen* are essentially the same as those used today, which are controlled by container strength standards. The gathering at the top of the cell guides for the case of the C-9's is  $\pm 6$  in. in the longitudinal direction and  $\pm 4$  in. in the transverse direction. This compares with 8 and 4 in. used for the case of the *Hawaiian Citizen*. Additional gathering, of course, improves productivity in container handling by removing the precision required for spotting containers. However, it does have an impact on container utilization within the ship. If one thing has been learned about the design of cell guides and their attachment to the hull structures, it is to design them strong and stiff. If the vertical span of the cell guides between anchorage points becomes excessive, a container being hoisted or lowered which is not in trim with the ship tends to distort the cell guides, which in turn allows the container to become more skewed, ultimately jamming. The cell guide structure in the *Hawaiian Citizen* was not adequate and had to be modified completely to stiffen the guides. One reason for the cell guide problem in this

case was the use of a revolver crane with bridles from a single fall which provided no control over container trim.

Due to the difference in the maximum gross weight rating of a container, compared with the average weight of containers handling a variety of commodities, there is no particular problem in going to seven-high container stacks in the hold. The weight, of course, must be controlled in each stack so as not to exceed the strength capability of the bottom container. Containerships with eight-high and nine-high stacking have been built; these ships have either provided intermediate container support or the bottom containers have been built with the corner post structure to withstand nine-high stacking.

**On-deck container stowage.** On-deck container stowage probably has received more attention than any other basic feature of containership design. Hundreds of container-lashing schemes and container restraint systems have been advocated and new refinements are constantly taking place. Deck containers are extremely attractive from cost and ship utilization standpoints; they can be stowed in tight block configurations from side to side of the ship and stowed three, four, or five high, depending on cargo density and ship stability. One approach to provide good fore and aft access on deck, and yet obtain good vessel utilization, is to control the height relationship between the top of the cover and the ship's deck so as to provide good headroom under the outboard containers. This arrangement, which was first used for the *Hawaiian Monarch* and *Hawaiian Queen*, can be seen in Fig. 4.

It has been argued many times that containerships should be designed with sufficient depth to permit all containers to be protected below deck and eliminate the many problems associated with lashing deck containers. Such schemes obviously would increase construction costs, increase light ship weight, raise the center of gravity, and reduce utilization. Probably more importantly, such configuration would decrease crane productivity in port—essentially every container would have to be hoisted and lowered a greater distance due to the additional freeboard. In addition, deck containers present an advantage to the crane operator when spotting and landing a container. The adjacent container which already has been landed can be used to stop the swing and provide the necessary guidance in the transverse direction. This important feature was overlooked by many designers in the past, who provided too much transverse clearance between containers to permit this time-saving technique.

In all probability, the "best" on-deck container securement system has yet to be designed. The two basic approaches which have been used are: (1) a lashing system, using wire rope, rod and interbox connectors or stacking fittings; and, (2) a structural restraint system involving buttresses and stacking frames located between container tiers or on-deck cell-type structures. Another restraint system which has been designed uses vertical structures at the end of each container row with facilities for attachment to the ends of the container at each tier.

Lashing systems have the following advantages over existing structural restraint systems:

1. Less expensive.
2. Usually provide for better space utilization on deck.
3. Weigh less and therefore improve both deadweight and stability.
4. Better crane productivity.
5. Better flexibility in handling various container heights.

The improved crane productivity just cited would be dependent upon the specific systems. In a lashing system, container handling and the lashing function can, for the most part, be carried out simultaneously. A structural restraint system which requires the additional hoisting and lowering of containers or requires the crane to handle frames or structural components would reduce crane productivity.

The main advantages of a structural restraint system are: (1) It reduces or eliminates the need for substantial racking strength

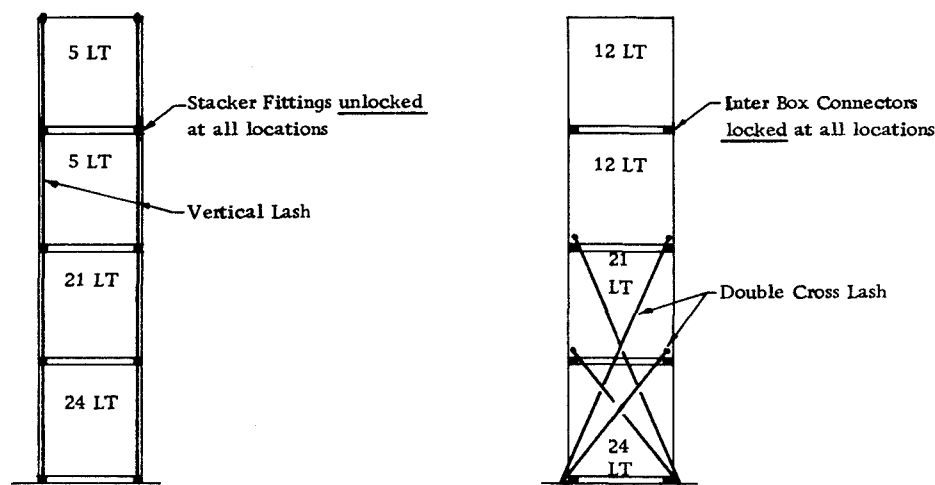


Fig. 5 On-deck container securing systems

in the containers, and (2), it eliminates the multiplicity of lashing components which must be maintained, inspected and installed properly to ensure integrity of the system. In a lashing system, the failure of one component (or one container) can cause a “domino” effect, resulting in a loss of an entire block of deck containers.

Two typical lashing systems which have evolved on the West Coast are shown in Fig. 5. The one on the left uses only vertical lashing with stacking fittings between containers; containers must take all the racking or shear load. The configuration on the right requires diagonal wire rope or rod lashings and augments the shear strength of the stack. In addition, this configuration employs interbox connectors between containers which not only locates the containers, but, with a twist-lock feature, connects the container with the capability of absorbing high tensile loads. Since maximum container weights are limited by the container and lashing system strength, strict control must be exercised over the weights of each container in a stack. The container weights shown for each configuration represent one example of the many weight combinations which can be achieved in each case. For example, the fourth tier weight can be increased, provided the third tier weight is decreased. For all practical purposes, fifth tier containers in these lashing configurations must be kept virtually empty.

**Hatch covers.** The basic design criterion for pontoon-type lift-on/lift-off hatch covers for containerships is simply to make them sufficiently large so as to keep the number of covers to a minimum and, hence, reduce handling time. The size of the cover is restricted by the weight which can be lifted by the container crane. In many cases, this has held to 30 long tons—the maximum gross weight of the container.

For the case of the C-9's, the hatch covers span five 40-ft container cells and weigh close to 23½ long tons. If hatch covers spanning 40-ft cells are to be capable of also handling 20-ft containers with their concentrated corner weight at midspan, additional structure, and, hence, weight, is required. The number of hatch cover dogs is kept to a minimum to reduce operating costs. Four dogs per cover, two on each end, are now considered sufficient. The author has often wondered what would really happen if these large covers had no dogs, assuming, of course, the ship stays upright.

There have been many covers in the past which have developed cracks in high-stress areas. It is believed that most of such problems can be traced simply to detail design, which was not adequate for the loads actually encountered. For example, a 13-wide deck container configuration over two hatch covers might result in a total load of over 450 tons for a single cover. Obviously, care must be taken not only to transmit this load properly into

the coaming, but to provide for proper location and reinforcement of shear chocks so as not to buckle skirt plates during heavy rolling.

To provide for productivity, a “gathering” system should be installed on the coaming to reduce spotting time when landing covers on their respective coamings. Provision should be made for stacking covers over each other and when practical, on top of adjacent deck containers. Lifting of covers directly by the crane's lifting beam saves time over a special bridle arrangement between the lifting beam and the cover. At the present time, there is considerable interest in the use of pontoon covers without gaskets. For the case of large containerships with ample freeboard, there is no need to make the covers weathertight under all sea conditions. Gasketless covers which have been designed employ a small clearance between the hatch cover skirt plates and the coaming, with a bar located on the coaming inside the skirt plate to keep rain and spray from entering the hold. It makes little difference in a containership if some water does enter the hold.

**Stability.** The one characteristic that many containerships seem to have in common is the lack of stability. One reason for this is the ability to stow more and more containers on the deck of a ship which was originally designed with less container capacity in mind. The capacity of a containership is often determined by its stability rather than its deadweight capacity. Stability in large containerships has become difficult since the Panama Canal places a limit on beam and certain harbors restrict draft, which in turn places limits on ballast that can be carried. It appears that, in the future, one should consider carefully the economics of reducing topside weight by making use of aluminum or fiberglass structures. Perhaps more attention should be given to the moment of inertia of the waterplane (at the expense of hydrodynamic efficiency), free surface in tanks, and damage stability characteristics, in an attempt to improve stability.

To complicate matters, information concerning container weights may not be available for all of the containers until the ship has been actually loaded. In an attempt to keep container bookings coordinated with the stability and deadweight limitations of the vessel, computer calculations are performed by shoreside personnel throughout the loading operations. Methods have been developed to estimate container weights prior to receiving them at the terminals, based on statistics from previous voyages. If stability is not calculated in a timely manner, containers must be discharged if it is later found that the metacentric height (*GM*) is not adequate.

The U.S. Coast Guard requires sufficient stability to meet its weather criterion, which is simply that of having sufficient *GM* to limit a vessel's heel to 14 deg or angle of heel to one half of the

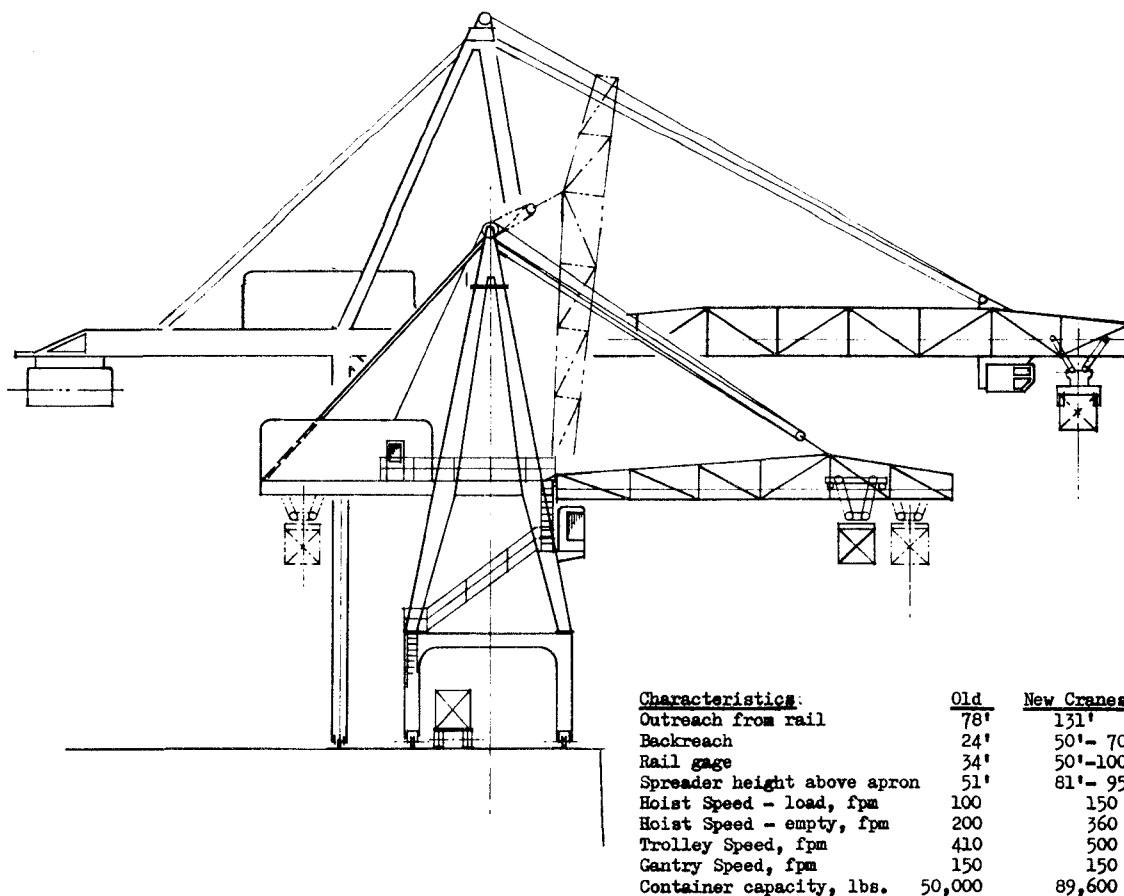


Fig. 6 Shipperside container gantry crane comparison: 1959 crane versus current Portainer

freeboard when applying the wind load on the projected lateral area of the ship and its containers. The wind load formula used is a function of length, and results, for example, in a  $15\frac{1}{2}$ -lb/ft<sup>2</sup> wind load for a 625-ft vessel. Depending on drag coefficient, this equates to a wind velocity of 60 to 70 knots. This stability criterion appears to result in reasonable *GM*. Ships built under subsidy or Title XI financing, however, are also required to meet MarAd's one-compartment standards, which can impose a considerable penalty depending on compartmentation. It is the present author's opinion that much of this penalty could be eliminated if the existing criteria for damage stability calculations were revised to reflect a more probable extent of damage and the actual survival conditions of the vessel.

Another important factor concerning containership stability regards measures to prevent excessive stability. Ships carrying containers with a high *GM*, especially break-bulk ships with heavy cargo in the holds and containers on deck, subject the containers and their lashings to heavy loads. High *GM* has contributed to container casualties at sea; or, perhaps the high *GM* has taken container and container lashing components to their rated capacity and has located certain deficiencies elsewhere in the system.

### Shoreside gantry cranes

The author's 1959 paper showed a clearance diagram for the first shoreside container gantry crane designed and constructed for the handling of containers. Hundreds of cranes of this type now have been built and can be seen in virtually every major port in the world. Paceco, builder of the first crane, and its licensees alone have built 285 such cranes. The main difference between the first crane and the current generation of cranes is the relative

### Metric Conversion Table

Original data herein were measured in U.S. customary units. Following is a list of standard factors for conversion to metric (SI) values:

|                                      |
|--------------------------------------|
| 1 long ton = 1.016 047 metric tonnes |
| 1 lb = 0.45 kg                       |
| 1 ft = 0.3048 m                      |
| 1 in. = 25.4 mm                      |
| 1 hp = 0.7457 kW                     |

size. The offshore outreach for the first crane was 78 ft measured from the offshore rail. Today, a typical outreach is 115 ft. This would be based on a ship with Panamax beam with deck containers stowed from side to side on the ship.

Container crane heights also have increased markedly over the years, with many of the older cranes being raised by means of spacer sections inserted above the vertical legs. The first crane was designed for a lifting beam height of 51 ft over the pier apron. A typical height at present is 81 ft. Figure 6 shows a comparison in size between the first crane and a new crane built by Paceco for Dutch Harbor, Alaska. Hoist and travel speeds have changed to match the longer distances which must be traveled; typical values are shown in Fig. 6.

Motor-generator sets, with dc drive motors and variable voltage control, are still being used on most cranes in order to achieve reliability and good speed control. However, static silicon controlled rectifier (SCR) systems are gaining popularity due to energy saving. The wire-rope-driven trolley has been used on the vast majority of the cranes built to eliminate the overturning moment caused by placing the hoist machinery in the trolley.

## Terminal facilities

The marine terminal, which performs a vital role in the expeditious door-to-door movement of containers, probably has been the focal point of container system development over the past 20 years. Various types of equipment and operating modes have been introduced in an effort to reduce handling costs, reduce ship time in port, reduce land requirements, and still provide a competitive service in the receipt and delivery of containers. Since transit time of shipment, from a shipper's standpoint, extends from the receipt of a container by the carrier to its delivery, it makes no difference to him whether a delay is brought about by a slow voyage or by having his container buried in the terminal.

The marine terminal operating mode addressed in the author's 1959 paper was the all-chassis system in which all containers in the terminal are on wheels. In this operation, the drayman enters the terminal and proceeds to a designated parking slot to deliver or pick up a container. During vessel operations, longshoremen on yard tractors serve the cranes directly from these same slots. Thus, containers have random access and can be received and delivered simultaneously with stevedoring operations with little or no interaction between draymen and longshoremen.

In the early 1960's, Matson introduced the straddle carrier mode of operation. In this mode, the straddle carrier serves the shipside crane and moves the containers between the crane and the rows of stacked containers in the container yard. Since containers must be received and delivered on chassis, the straddle carrier must also load containers on the chassis prior to delivery.

The straddle carrier mode has two basic advantages over an all-chassis mode in a high-volume operation; that is, less investment in equipment and less required land. It requires less investment in equipment because the savings achieved by the elimination of hundreds of chassis required to maintain an all-chassis operation at the terminal is greater than the investment required for the straddle carriers. The stacking of containers two or three high in rows permits savings in land and it also keeps the distance between the container yard (CY) containers and the ship shorter. Upon discharge from the ship, the container is landed directly on the pier apron and, hence, time is saved by not having to accurately spot the container. In addition, since numerous containers can be placed within the reach of the crane, and since straddle carriers need not be at the crane during load or discharge, delays are less likely due to queuing. However, these advantages are obtained at a price because of the following factors:

1. Due to high wheel loading, paving must be more substantial.
2. Flexibility is lost in responding to container delivery demands and rehandling is required to retrieve a box buried in a stack.
3. More skill is required for a straddle carrier operator.
4. The labor content is higher due to additional rehandling.
5. Maintenance and repair costs to straddle carriers have proven to be substantial.
6. Due to the small clearances between container rows, the incidence of container damage when driving down rows of containers is appreciable.

In 1960, Paceco built its first mobile container yard gantry crane for Matson, to be used in a low-volume operation for loading containers to and from rail cars. To date, Paceco and its licensees have built 351 yard gantry cranes which bear the trade name "Transtainer." This name has "caught on" worldwide to such an extent that it is applied to cranes of this type regardless of who the manufacturer might be. (The author will take the same license in his discussion.)

Following are typical characteristics for today's rubber-tired transtainer (built by Paceco):

|                    |                           |
|--------------------|---------------------------|
| Span               | 80 ft                     |
| Clear height       | 49 ft (4-high + passover) |
| Hoist speed, full  | 82 fpm                    |
| Hoist speed, empty | 160 fpm                   |
| Trolley speed      | 180 fpm                   |
| Gantry speed       | 440 fpm                   |

It should be noted that spans vary considerably—rail-mounted transtainers have been built with spans over twice that just indicated.

In large-volume operations, the transtainer has the same advantage over the all-chassis system as the straddle carrier, namely, reduced equipment investment and less required land. However, it has considerable advantage over the straddle carrier mode as regards land utilization. The transtainer mode usually involves yard tractors with special yard chassis to serve the shipside crane from the transtainer. The transtainer also loads and discharges containers on and off highway chassis.

Matson Navigation Company has recently introduced an automated terminal system in the ports of Richmond and Los Angeles.<sup>4</sup> This system, which is named "Matson Overhead System," embodies high-speed, automated, rail-mounted yard gantry cranes. These cranes, with spans of 180 to 200 ft, are capable of stacking containers four high. Containers are fed between the shipside cranes and the yard gantry cranes by special container transfer conveyors which permit container handling rate improvement by over 20 percent and, thus, enhance ship turnaround time. Matson has estimated that container handling rates have increased from 25/30 to 30/40 containers per hour. Smaller, rubber-tired yard gantry cranes are used in conjunction with large rail-mounted gantries.

## Conclusions

1. Based on current worldwide road systems, the 40-ft container, with the available heights of 8½, 9, and 9½ ft, is an excellent standard for achieving maximum cubic capacity. A smaller container, which can efficiently carry high-density cargo and which is more suitable for delivery in many cities, is also attractive. Although the 20-ft container meets these requirements, the author believes this container is too small for optimum container system economics. Since it is one half the length of a 40-footer it does have advantages for railcar utilization and the carriage of empties over-the-road. However, if the smaller container were, say, between 25 and 26 ft and had a gross weight rating of 30 long tons, it could handle high-density cargo, be used in doubles by truckers, and carry more freight. When accommodating these smaller containers aboard ship, three slots would replace two 40-ft slots, which would provide space between containers for lashing on deck and room for cell guide structure when stowed below deck. Nevertheless, the 20-footers are with us in high numbers and no doubt will remain as the standard well into the future.

2. Container strength standards at the present time are excellent. However, provisions should be made for optional nine-high stacking and consideration given to increasing certain lashing loads, including that of bringing the corner post tension of the 20-ft container to the same value as that of a 40-footer. For the sake of the cargo, end-wall loads should be held to 0.2g. Let us hope container operations in the future will be tempered with common sense and adequate safety practices so as to preclude the imposition of unnecessary additional strength requirements.

3. The state of the art for below-deck container stowage is such that there appears to be little likelihood for a new breakthrough; on-deck stowage, however, requires further effort for improvement.

4. No doubt, we will see more efforts on the part of regulatory

<sup>4</sup> Montgomery, M., "A New Container Terminal Design at the Port of Richmond, California," SNAME, Northern California Section, 1980.

bodies to control visibility from the bridge of a containership, even though television cameras are and can be employed. As often the case, one serious casualty involving poor visibility will result in instant regulations.

5. If a shipowner knew, before applying for Title XI financing, the "bottom line" price he would have to pay to comply with the MarAd one-compartment standard he would perhaps give more consideration to other financing options (if available) at a higher interest rate. For the sake of economical ship construction and operations, the present criteria for a one-compartment subdivision standard should be thoroughly reexamined (especially the 15-deg maximum heel after flooding).

6. The marine terminal will continue to receive much attention due to larger ships and higher annual throughput coupled with land shortage and the need to provide timely service to shippers and consignees. High-density stacking with improved

systems for serving the shipside crane and setting up container/chassis combinations for expeditious delivery will be the area of challenge and perhaps additional breakthroughs. The "Matson Overhead System," with its innovative features, has already made significant contribution in some of the problem areas.

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