Adequacy of Selected Lock Size Parameters for Expanded Panama Canal

Post-Panamax Lock Size Review Study

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1. Introduction

We are living in a time of dynamic global growth and development. No industry is so closely connected with the liberalisation and globalisation of world trade as the maritime industry. This includes not only shippers, vessel owners and ship operators but also ports and canals on the major trade routes. Particularly the shipping of containers, the fastest growing segment of the maritime industry, is directly related with major changes in world trade and the world economy.

With a consistently and rapidly growing container volume to be transported world-wide, the dimensions of containerships have increased steadily over the past 30 years. The 8,000 and 9,000 TEU vessels are here today and vessel size could increase even further.

The double digit growth of containerised trade over the last 5 years, and its expected continuation, has forced the container shipping industry to introduce fundamental changes. Therefore, to prepare for the future and remain commercially attractive, ports and vessels owners have realised the importance of planning well in advance to accommodate this growth. This applies also to the operators of canals on major routes, particularly the Suez Canal and the Panama Canal.

The Panama Canal with its geopolitical and economical role has been of enormous strategic importance to world shipping and world trade in the past. It has had such a significant influence, that the existing canal lock dimensions have led to a subdivision of the world fleet between ships which can pass through the Canal up to the Panamax-size and those that can not, the Post-Panamax vessels.

The existing Post-Panamax container fleet has clearly shown to vessel owners and operators the advantage of economies of scale. This segment of the world container fleet has, consequently, grown significantly in the past and will continue to grow most rapidly in the years to come. There is, however, concern amongst many key players in the industry, whether the role of the Panama Canal could be eroded in the future if modernisation, through the introduction of larger locks, is not undertaken. The *Autoridad del Canal de Panamá,* ACP, therefore has developed a Master Plan for an expanded Panama Canal with locks capable of accommodating Post-Panamax vessels.

The size of the locks and the new limiting parameters of the expanded Panama Canal should be critically reviewed in this study in light of what developments in the size and trade routes of ships - particularly containerships - may be expected in the future.

1.1 Purpose of this Study

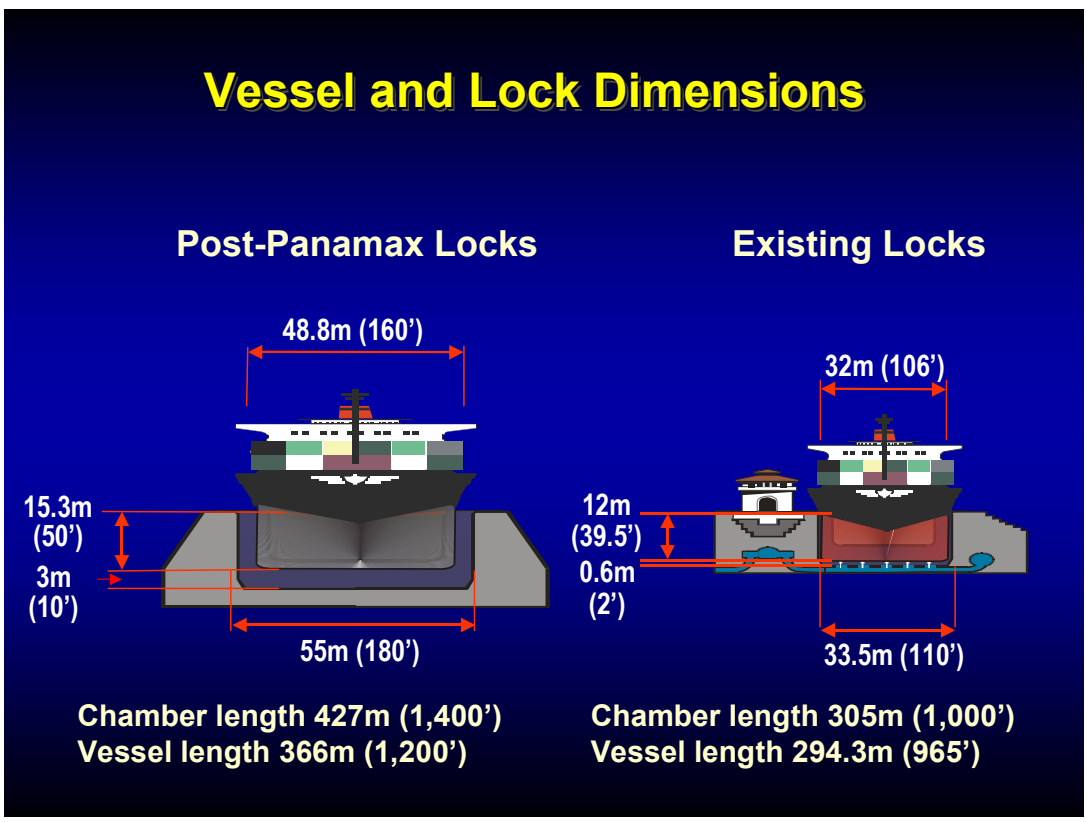
The purpose of the Post-Panamax Lock Size Review Study is defined in *Adequacy of Selected Lock Size Parameters for an Expanded Canal – Rev.4* received from ACP by e-mail dated 05-10- 05.

The task to be performed is defined in this paper as follows:

The Panama Canal is seeking an assessment on the adequacy of the selected Post-Panamax lock size parameters for the Expanded Canal. Included in the scope of adequacy is affirmation that the selected lock dimensions are of sufficient size and that they will effectively serve the workhorse ship of the trade segment and route that ACP seeks for the period that the locks will be active. Also included in the assessment of adequacy is documentation of any significant insufficiencies that affect the functionality, effectiveness or longevity of the selected Post-Panamax lock size parameters that are noted during the review. The trade segment must, as a minimum, include the container vessel trades and the route must include the Asia to/from United States East Coast (USEC).

The new Lock dimensions and corresponding maximum vessel dimensions are shown in the following figure taken from the ACP paper mentioned above. The old and new Panamax vessel dimensions are given as

Length_{oa}	295 m	**366 m**	**1,200'**
Beam	32.2 m	**48.8 m**	**160'**
Draft	12 .0 m	**15.3 m**	**50'**



1.2 Content of the Study

The study of the "*Adequacy of Lock Size Parameters Selected for an Expanded Canal*", reviews the vessel and lock dimensions considered in the ACP Master plan in light of present and future ship size and port developments. Considering the importance of the trade between Asia and the Eastern regions of the United States of America, particularly aspects of the development of US-East Coast (USEC) ports are considered and projections of these developments for the future are made. As containerships have become, and will continue to be, the fastest growing segment in world shipping, replacing traditional general cargo vessels, the main emphasis of this study is placed on container shipping but other ship types are also considered.

2. The Development of Containerships and their Dimensions

The most promising potential market of the new locks is that of full containerships. During the past ten years the average annual growth rate of container traffic through the Canal was about 11%. This strong growth, in spite of the restrictions to ships up to Panamax size has resulted from a greater use of the "All Water Route", connecting the East and West Coast of the Americas and of the growth in average vessel size. These factors are in turn driven mainly by the dramatic growth of the overall trade demand between Asia and the United States. With a large portion of the US population, and the more well-to –do, settled in the Eastern half of the US large retailers have set up distribution centres in these regions. This has further stimulated the trade to the East Coast. These distribution centres have the option of using the "All Water Route", through the Canal, or to take the land-route from the West Coast for their goods. The all "All Water Route" provides highly competitive economic advantages when compared with the other options.

In 1955, Malcolm McLean from Sea Land, one of Lloyds List's ***Three Men of the 20th Century***, totally transformed transportation and world trade with his notion of a standardised detachable container fit to be used on truck, rail and ship. Today, the commercial advantages of shipping cargo in locked containers have been widely recognized, resulting in uninterrupted growth. As a result, the success story of the containership is unparalleled in the history of shipping. Ever since their introduction containerships have consistently become bigger and more efficient.

Today, containers reach the most remote corners of the world and their success story continues. With the East - West container trade highly developed and continuing to grow, the North - South trades, as well as container trade between developing nations, are showing significant and accelerating growth. Today roughly 75% of general cargo is containerised. It is expected that this number will continue to grow to more than 90% by 2010.

From the very beginning, the development of containerships has been characterised by efforts towards the optimisation of ship design with respect to the number of containers to be carried and the efficiency of loading and unloading of containers. This has resulted in a steady increase in the size of the ships. Because of the special strength and stiffness problems of container ships all developments have been carried out in close co-operation of designers with classification societies.

With vigorously growing container volumes on most routes, the development and

introduction of larger ships has been a logical consequence. A prerequisite for the large ships to be successful, however, is that sufficiently large container volumes are available to consistently fill them. This applies to inter-continental long haul liner traffic as well as to feeder services. The 8,000 TEU mega container carriers, received with scepticism only a few years ago, are a reality today. Many Post-Panamax ships with a capacity of 8,000 TEU or more are on order and their maximum carrying capacity is approaching 10,000 TEU.

Since 2000, World-TEU capacity grew on average by 11% per year, whereas the number of containerships rose by only 6%. This underlines the continuing trend towards large vessels. The carrying capacity of the world container fleet of 3,490 ships (July 2005) has more than doubled during the past 10 years and has reached 7.5 million TEU. The average containership size today is 2,230 TEU compared to 1,535 TEU in 1995. The Post-Panamax fleet in operation has a share of more than 25% of the total TEU capacity today, and this is expected to grow to about 35% by 2008.

2.1 Post-Panamax Carriers

The development of Post-Panamax container vessels started in the mid eighties when the German shipyard HDW together with American President Lines, APL, pioneered the construction of these vessels.

Due to APL's success in the deployment of these vessels, the development of Post-Panamax containerships has progressed steadily, always close to the limits of the technically feasible. At the end of 1997, an extensive 8,000 TEU containership design project by a German consortium under the leadership of HDW and GL was completed. The results showed that it is indeed possible to cope with the structural and operational problems of a ship of that size or even beyond. On the basis of the strong interest in large ships of containership operators in Europe and in Asia, conceptual designs for 9,000 to 13,000 TEU containerships have been prepared by LR, GL and others, mostly in co-operation with shipyards. All of these designs are largely derived from the German 8,000 TEU feasibility study and design.

Looking at the economies of scale, it can be seen from Fig. 1 that the gain in economy or the additional savings in cost diminish as the ships get larger. Considering risks and investments Dr. M. Stopford from Clarkson Research believes that the economics "peter out" at ship size of about 6,500 TEU. This may be different for different operators. For a very large carrier operator like Maersk, with a dominant role in world container transportation, it will be easier to fill very large ships and operate them between their mostly designated terminals than it may be for smaller operators. Here also the hub and spoke model, which shippers generally do not seem to favour, can be better realised.

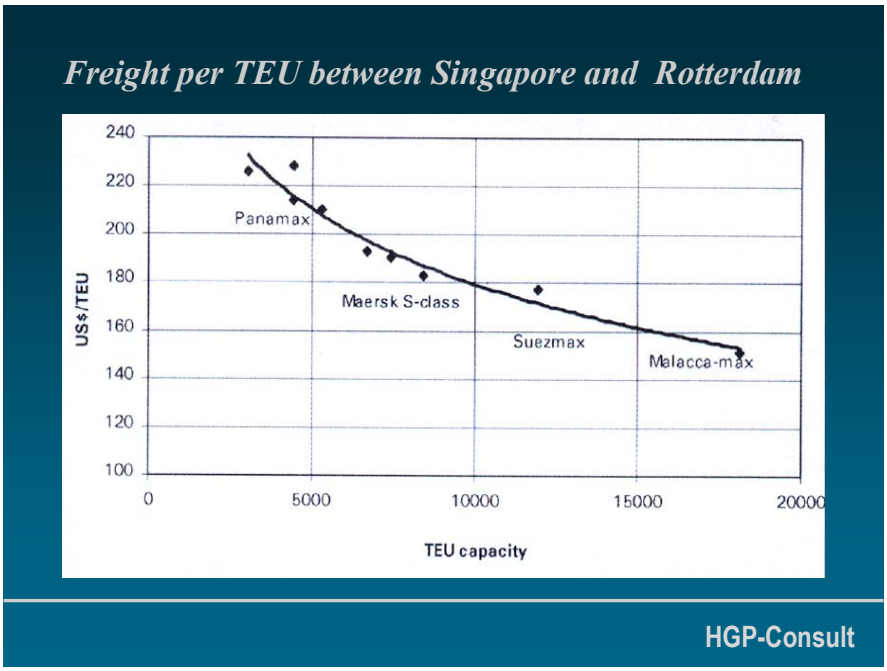


Fig. 1: Economies of Scale: Transportation cost per TEU as function of ship size (Wijnolst)

2.2 Present world container fleet

The world-fleet of fully cellular containerships consisted in July, 2005 of 3,490 vessels with a total deadweight of over 100 million tons and a carrying capacity of 7.5 million TEU. With an average age of about 10 years, containerships are much younger than the world-fleet or any other ship type. Only 18% of the fleet by TEU was built before 1990. Thus, the scrapping potential in the containership sector is very limited. Based on an average scrapping age of broken-up tonnage in 2004, which stood at 30.5 years, there were only 81 ships with about 60,000 TEU overall carrying capacity ready for scrapping at the beginning of 2005. This indicates that the composition of the world-container fleet will be effected mostly by additional tonnage entering operation.

In the period of 2001 to 2005 the capacity of the container fleet grew by nearly 70% to 7.5 million TEU (July 2005), with the following increases for the different size categories:

Up to 1,999 TEU	+ 4%
2,000 to 3,999 TEU	+ 5%
4,000 to 5,999 TEU	+ 12%
Above 6,000 TEU	+ 44%

A note on the size of containerships and TEU

Containerships are generally measured by their carrying capacity in TEU. This is a rather inaccurate measure, as the containers assumed to be fully loaded in reality usually include a number of empty containers or lightly loaded ones as well. Thus the

TEU numbers have become inflated. This is the reason why for some ships quite different TEU numbers are published.

The Axel Maersk Class of AP Moeller for instance is officially declared a 6,600 TEU vessel, corresponding to the number of fully loaded containers the ship can carry. On the other hand, the ship has space for about 9,000 TEU. This has to be taken into account when reading ship size in the tables below of ships in operation, under construction or planned. Like with regular freighters and multipurpose ships, dead weight tons, dwt, would be a more accurate measure for the carrying capacity of a container vessel. The combination of TEU and dwt gives the most objective measure for carrying capacity, indicating both container stowage space as well as total freight weight of a ship.

Size- TEU	6,800 to 7,500	7,200 to 7,800	7,800 to 8,400
Loa m	305	320	335
B m	42.8	42.8	42.8
d_{scant}	14.0 – 14.5	14.0 – 15.0	14.5 – 15.0
GT	88,000	90,000	94,724
dwt	97,500	100,000	105,000
Rows	17 / 15	17 / 15	17 / 15
40´bays	18 (4/14)	19 (4/15)	20 (5/15 or 4/16)

Table 1: Dimensions of typical Post-Panamax ships in the range up to 8,400 TEU with a beam of 42.8 m (17 rows on deck)

Considerable progress has been made in the development of Post-Panamax ships. At the beginning of this year 316 Post-Panamax container vessels were in operation, the largest containership officially being Hapag Lloyd's "Colombo Express" with 8,600 TEU. Un-officially, the above mentioned "Axel Maersk" from AP Moeller – generally rather secretive about their developments - has an even higher TEU count. The deadweight of the ship is given as 109,000 dwt. The "Colombo Express" with 103,800 dwt and the Savannah Express with 107,000 dwt have officially each been declared largest containerships on the oceans, albeit only for a few months. In July this year the "MSC Pamela" with a capacity of 9,200 TEU was put into service. By the end of this year at least four vessels of this class will have come into service. The ships have the following dimensions: L_{oa} 336.7 m, B 45.6 m, H 27.2 m, d 15 m; 16 rows of containers can be stacked in the holds up to10 high, 18 rows on deck, up to 7 high. The carrying capacity of these 107,849 GT vessels is 110,592 dwt.

2.3 Analysis of orders and projects

An amazing 1,233 containerships with a carrying capacity of 4.5 million TEU were on order world-wide in July of 2005. This corresponds to about 60% of the capacity of the world container fleet on that date. An analysis of the size of the vessels ordered shows that mostly large containerships will be built. Amongst the present orders, more than 200 vessels are in the range above 7,000 TEU.

A more detailed analysis shows that 930 containerships up to Panamax size and 303 Post-Panamax vessels were on order world wide in July of 2005. Interesting in the context of this study is that within the size range of ships on order up to Panamax size (< 5,000 TEU) with a total capacity of 2 million TEU, the Panamax vessels between 4,000 and 5,000 TEU had a share of 38%. This can be interpreted that the Panama Canal continues to have a strong influence on ship design and orders even now, when Post-Panamax vessels dominate the order book.

Size -TEU	5,500 – 6,750	6,800 – 8,400	9,200 – 10,250
Loa m	260 - 289	286 - 335	335 - 360
B m	40.0	42.8	46.0
H m	24.2	24.5	27.2
d_{scant}	14.0 m	14.0 - 15.0 m	14.5 - 15.0 m
GT	79,000	95,000	110,000
Rows	16 / 14	17 / 15	18 / 16

Table 2: Currently prevalent dimensions of Post-Panamax containerships

Currently prevalent Post-Panamax ship sizes in operation or on order today are listed in Table 2. Actual dimensions of some of the 9,000 to 10,000 TEU vessels being built are listed in Table 3.

175 of the vessels ordered are in the size range above 8,000 TEU. The average carrying capacity of these ships on order is in fact 8,250 TEU indicating that many 9,000 TEU and larger vessels are amongst them. All of the ships on order have a single engine and one propeller.

Main design parameters and the carrying capacity of large containerships

Adding a bay of 40' containers to a 9,000 TEU ship of the dimensions of the *MSC Pamela* given above would make the ship about 11 to 13 m longer and would add about 265 40' containers or 530 TEU to the carrying capacity. Increasing the beam of an 8,000 TEU ship from 42.8 m to 45.6 m, i.e. adding one row of containers under

deck and above deck each would add 15 containers of 40' to each bay amidships. In total this would add again about 260 40' containers or 520 TEU to the carrying capacity of the vessel leading to a vessel with a carrying capacity of 10,000 TEU.

Size	9,200	9,900	10,300	12,000	13,000
L_{oa}	336.7	349.0	347	366	382
L_{bp}	321	333.4	331	?*	366
B	45.6	45.6	46.0	49	54.2
H	27.2	27.2	27.2	27.2	27.2
T_{scant}	15.0	15.0	14.5	14.5	15
GT	107,590	116,000	?*	?*	?*
dwt	110,590	118,000	?*	?*	?*
Rows	18 / 16	18 / 16	18 / 16	19 / 17	21 / 19

* Exact numbers not known

Table 3: Containerships of more than 9,000 TEU on order or projects

Table 4 gives an overview of the dimensions of Post-Panamax containerships from 6,500 TEU up to 14,500 TEU. All ships, including the 9,500 TEU ships, would be able to pass through the new Panama Canal Locks. The 13,000 TEU and the 14,500 TEU designs are too long and too wide to pass through the new locks.

TEU	Panamax	6,500	8,500	9,500	12,000	13,000	14,500
GT	55,000	75,600	95,000	110,000	?	?	?
dwt	68,000	85,800	105,000	110,000	?	?	?
L_{oa}	298	304	335	335	366	382	410
L_{BP}	283	289	319	321	352	366	395
B	32.2	40.0	42.8	45.6	49	54.2	54.2
H	21.8	24.2	24.5	27.2		27.2	27.2
d_{scant}	13.5	14.5	14.5	15.0	14.5	15.0	15.0
Rows	13 / 11	16 / 14	17 / 15	18 / 16	19 / 17	21 / 19	21 / 19

Table 4: Overview of Post-Panamax containerships up to 14,500 TEU (ships in service and projects)

3. Where are the practical limitations to further size increases?

Limitations for the development of ULCC's – Ultra Large Container Carriers, say up to 12,000 TEU - and 'Mega Containerships' beyond that come from the following aspects:

- The maximum available size of the propulsion plant
- Structural limitations of the ship hull
- The water depth in port and port access
- Limiting dimensions of canals and straits on the major world routes
- The cargo handling facilities in and logistics requirements for the container terminals in ports
- Inland transport infrastructure requirements and existing availability.

3.1 Maximum available size of the propulsion plant

The largest slow-speed 12 cylinder Diesel engines installed in large containerships at present, have a maximum output of about 68,000 kW (95,000 BHP); this provides adequate propulsive power for a Post-Panamax ship of 9,000 TEU with a speed of about 25 knots.

Beyond this engine output, ships either have to go slower or even larger engines need to be built and installed. Alternatively, the design could be changed to a ship with two engine plants. It was generally expected at the end of the 20th century that large containerships would operate at sea with 25 to 27 knots. With the considerable increase in fuel oil prizes in the past couple of years, more attention is being given to fuel consumption and efficiency. All of the containerships with a carrying capacity beyond 8,000 TEU are powered by the same 12 cylinder engines as their smaller predecessors. This means that owners and operators accept a slightly slower ship with improved economic parameters.

Currently, both of the two designers and licensors for large slow-speed Diesel engines are offering engines of more than 12 cylinders. Sulzer offers a 14 cylinder, 960 mm bore engine in their new catalogue with a power output of 80,000 kW. MAN-B&W are going beyond 14 cylinders all the way to a 16 cylinder version of their 980 mm bore engine with about 92,000 kW and 31.5 m length. Such an engine will have a mass of more than 2,600 tons. Alternatively larger bore engines are being offered to the industry. Single screw containerships with a carrying capacity of more than 10,000 TEU operating at speeds of 25 to 27 knots will be possible with these engines.

It is clear today that ship-owners do not want to deviate yet from the well proven one engine / one propeller concept. However, the one engine / one propeller concept is reaching its limitations making a twin propulsion system the only viable alternative for even larger vessels than have been ordered so far.

One of the practical limitations for the largest engines is the overall length of the engine. This may cause problems with engine rigidity as well as possible interaction with the ship's hull. The ship's hull structure has to be strong enough to give active support to the engine.

Another serious limitation is the size of the propeller. With the draft of the large container vessels restricted to around 14 meters, the propeller diameter is limited to about 9.5 meters. Propeller manufacturers are reaching their technological limits regarding the diameter and weight of these large propellers. We have seen even larger propellers in the past for the very large tankers, but they were built for only a fraction of the power we are talking about today.

Propeller design problems are mainly connected with excessive cavitation of the propeller and rudder. Cases have been reported where severe cavitation problems on rudders of these high-powered ships have been observed after a short operation time of only months. Further improvements in the design of the propeller and new rudder designs are tried out on the latest deliveries or ships under construction. Manufacturers claim to be able to reduce these unacceptable conditions. There is no doubt, however, that as long as ships' drafts do not go beyond 14 meters, we are close to the power limits of propellers for these large vessels.

Twin propulsion systems, arranged as twin skegs, have several advantages such as redundancy, more flexibility regarding partial load, higher propulsive efficiency and no cavitation problems. Such a system will however drive up the new-building as well as the operating cost significantly. Ship-owners have not been prepared so far to opt for twin propulsion. The single engine/one propeller drive continues to be the standard.

Once the industry decides for a twin-screw design, the maximum overall efficiency will again be achieved with two of the larger engines available today. For a design speed of 25.5 knots with two of the presently largest twelve cylinder engines this could lead to a Mega Container Carrier of about 18,000 TEU with a total power of 103,000 kW. From a propulsion plant viewpoint, the 18,000 TEU Malacca-Max carriers proposed by Prof. Wijnolst could be feasible.

3.2 Structural limitations of the ship hull

Throughout the development of containerships, structural barriers regarding the strength and the stiffness of the ship's hull had to be taken. The open top ship hull poses fabrication challenges such as very thick plates for the deck structure and coamings which are highly loaded. Plates of up to 75 and 80 mm, i.e. more than 3 inches, have to be smoothly cut and welded in a way to reliably carry the high forces from the ship's cargo and the waves. Additionally, the structural deformations have to remain within certain limits, not to cause problems in the interaction of the hull with hatch covers and containers in the hold and on deck.

This calls for wider side structures of the ship-hull, reducing some of the economic advantages of the big ships. We are coming to practical limitations in this respect too.

3.3 Limiting Dimensions of Canals and Straits on the Major World Routes

The most important dimensional limitations on the world's major shipping routes around the world are given by the Panama Canal, the Suez Canal and ultimately the Malacca Straits.

The Suez Canal with a base of sand is continuously being dredged and expanded and thus adjusted to some degree to the bigger size of vessels. Today it handles

more than twice the tonnage of the Panama Canal and can accommodate without restriction the largest Post-Panamax containerships afloat, under construction or planned. In contrast, the Panama Canal with locks of fixed dimensions can accommodate a smaller percentage of the world container fleet every year. For the Panama Canal each expansion is a "quantum leap" compared to the gradual and steady expansion option available to the Suez Canal. The Suez Canal, like most ports, can be adjusted to vessel trends through excavation and dredging when it becomes economically desirable to do so. Because of the lock size restriction for the Panama Canal the vessel evolution must be anticipated; once the locks are built their limiting dimensions are fixed for a very long time.

In the Terms of Reference for this study (Rev.4, of 05.10.2005) it is stated:

"It is the "limiting nature" of the locks that requires that the next generation of locks be sized to be useful and affordable today and in the longer-term future. This is one of the most critical decisions of the expansion project because it sets the limit to which the Canal can aspire regarding future traffic. If the lock size is so large as to meet any expected future possibility then the project may become too costly under financial, environmental and social perspectives, which could prove to be a decisive obstacle. If the new locks are too small then the project will be obsolete before its time and the opportunity will be lost."

The present **Panamax** limits for vessel dimensions are

L_{oa} = 295 m B = 32 m d = 12 m

With the planned new lock size, these limiting dimensions will go up to

L_{oa} = 366 m (+24%) B = 48.8 m (+53%) d = 15.3 m (+28%)

The **Suez Canal** limitations for breadth and draft are changing with time, due to continuous dredging work by the Suez Canal Authority. Presently the shallowest cross-sections of the canal allow a maximum draft is 17.7 m (58') for a ship with a beam of 48 meters:

L_{oa} = unrestricted B = 48 m d = 17.7 m

It is expected that the draft limitation will be raised to about 21 meters by the year 2010.

The **Malacca straits** have a draft limitation of 21 meters. The VLCC fleet of oil tankers has this draft to allow them to pass the Straits on their way to East Asia. This is seen by many as the ultimate draft for large ships operating world-wide.

3.4 The Water Depth in Port and Port Access

Many of the regions where container ports are located, either close to the principal manufacturing districts or close to the main consumption areas, are limited by the depth of their waters. This applies, amongst many others, to ports in China, India and Northern Europe as well as to US ports, particularly the US East Coast ports.

The dredging of ship access canals to the ports and quay sides in port is cumbersome, expensive and not a once-only operation. Dredging has become an emotional and environmentally sensitive matter. This makes it very difficult and time consuming for port authorities, particularly in Europe and the US, to get the necessary approvals for port dredging projects. In the newly developing economies,

like China and India this is less of a problem yet.

Hydrodynamic shallow water effects for the large ships and feasible reductions in draught by reducing the ballast water quantities within these sheltered regions are being considered. Investigations show that de-ballasting for estuary trading in the case of reduced stability requirements may result in a draught reduction of approximately half a meter on fully loaded Panamax vessels. Dynamic trim, i.e. squat, on the other hand will reduce the permissible draught in pilotage waters at higher speeds. If speed reductions were to be introduced to reduce this effect, port call time could increase.

It must be anticipated that there will not be any major steps taken towards larger draft for containerships in the near future, as they would be too limited in their range of operation. There may be larger ships, like the Suez-max or Malacca-max vessels described by Prof. Wijnolst with a draft well beyond 14 meters which would operate between selected hub-ports with sufficient water depth. But they should become more the exception than the norm.

3.5 Cargo handling facilities and logistics requirements for the container terminals in ports

When expanding their cargo handling facilities, the main container ports are gearing up for ships with a beam of 50 m or more with drafts of up to 14.5 m. This enables them to handle ships beyond 8,000 TEU. Concepts for terminal designs are being considered today to cope efficiently with mega containerships some time in the future.

Together with the upgrading of ship to shore gantry cranes capacities, the increasing size of containerships requires an improvement of the container yard handling and intermodal distribution systems. An increase in the efficiency of these systems is mandatory to achieve further reduction of terminal operating costs and avoid congestion on the one hand, and to ensure sufficiently short lay times for the ships in port on the other. Current research and development projects are focusing on the aspects of efficient container stacking, terminal transportation and control technology. Automated transportation systems have been introduced successfully in several of the more innovative ports, such as Singapore, Rotterdam and Hamburg.

Loading or discharging a vessel simultaneously with more than one gantry crane is common practice today. The practical limit for a ship of around 300m in length is about 4 to 5 gantry cranes simultaneously. A further increase in handling capability requires increased speed for the crane movements, double trolley cranes and possibly servicing the biggest ships from both sides in a berth. All these possibilities are useful only if the port side facilities can accommodate the rapid movement of such large volumes of containers.

Outreach of Container Gantry Cranes

Most major container port terminals have crane facilities with an outreach of at least 50 meters. The following ports have cranes with an outreach of 60 m and more:

Bremerhaven
Dubai
Felixstowe

Hamburg
Hong Kong (65 m)
Long Beach
Rotterdam (65 m)
Shanghai (64 m)
Tanjung Priok

Important aspects when further increasing the capabilities and efficiency of large gantry cranes are structural strength and stiffness on the one hand and sophisticated control systems on the other. The control systems will decrease cycle time by actively minimising sway, skew and pending. A high degree of automation for the handling cycle of the spreader assures the accuracy of the movements.

Container stowage gets more difficult as ships get larger. The gantry cranes have to move deeper and wider and TEU distribution on the ship may become more complex. This contributes to a reduction of the efficiency of the very large ships. Their advantage is best realised with the ships travelling between designated hub ports where they are being fully loaded and unloaded, without intermediate port calls.

3.6 Transport infrastructure requirements and existing availability

Many ports registered a doubling of container volume within less than 10 years. Taking account of factors which are expected to slow down this growth, analysts predict an average annual growth rate of 6% over the next 20 years, (M. Stopford, Clarkson). This will still result in a doubling of container volume, on average, within 12 years, albeit from a much larger base.

As ships get larger and the crane capacity at the terminals increases, the container volume to be handled by the ports and the hinterland transport systems increases strongly. It is not always unproblematic for the inland logistics to keep pace with this development. The container trains servicing the ports of Los Angeles / Long Beach for example are reaching their capacity limits. This may cause waiting times and costly delays. It presses shipping lines to look for alternatives. In the case of the ports of Southern California, if the infrastructure can not keep pace with volume growth, ships may evade to other West Coast ports, most of which are being expanded. Also new container ports are planned all the way up to Canada. Here the infrastructure will have to be expanded or developed to meet the upcoming needs. Therefore there is no doubt that the interest to reach Gulf and US East Coast ports through the Panama Canal will continue to increase.

3.7 Conclusion on Limiting Factors for the Size of Containerships

Summing up, containerships could become larger than we see them today. Larger engines than the 12-cylinder slow-speed Diesel engines of today with about 68,500 kW are being offered and the way to twin engine / twin screw propulsion is open. Ports are rapidly following the development of the ships; cargo handling equipment in many ports can accommodate ships with a beam of 50 m and beyond.

There are however some serious limitations: Water depth of the port access channels and in port is a serious restriction in many ports. Dredging canals and ports

is becoming politically difficult, particularly in the developed nations. Therefore ships will have to become longer and wider. Long containerships have less resistance than beamy ones; their steel weight however is larger. The beamy ship in contrast tends to have too much stability, resulting in high accelerations in waves resulting in excessive forces for containers on deck. This may result in damage to the cargo or to the containers themselves.

Logistics requirements for the container terminals in ports and inland transport infrastructure requirements will be adjusted to the significantly growing container volumes in most terminals. With very large ships, the number of containers arriving or leaving at one time is becoming very big, resulting in considerable peaks and possible port congestions. This is not occurring with a steady number of arrivals of relatively smaller ships, which furnish a more regular supply, allowing a balanced distribution of cargo.

4. The Workhorse Ships – A Vision of the Future

Container transportation across the seas has matured during the past few years. There will not be one ideal ship size but we may expect to see ships of all sizes operating side by side. Looking into the future there is no doubt that we may see some very large containership. They will probably operate between designated ports with deep water access and sufficient water depth at the terminals, so-called hub-ports. But with their restrictions in operation and consequently limited flexibility, they may be expected to be more the exception than the rule.

For inter-continental transport there will be a range of ships from roughly 3,000 or 4,000 TEU all the way up to 10,000 and possibly 13,000 TEU. Some ship sizes have already or will become dominant and develop into work-horses of the intercontinental container trade. For some time to come the present Panamax ships of 4,000 to 5,000 TEU will continue to make up a workhorse group. Today we see a large number of Post-Panamax ships in the range between 5,000 and 6,000 TEU. This group has in fact grown by nearly 40% in 2004. It is a group of ships which have route deployment flexibility on the one hand and are large enough to be economical.

The ship at the present upper end between 8,000 and 10,000 TEU may also be expected to form a workhorse group.

The new Canal will have a strong influence and will probably dictate the maximum size of inter-continental work-horse ships. As a result a new Panamax size may certainly be expected to develop.

Ships listed in Table 5 were set up without regard for the extension of the Panama Canal. We may see them some time in the future, but they will not be able to go through the Panama Canal. It may be expected that the new Panamax dimensions, when published, will actually be decisive for whether ships of that size will be built or not.

L_{BP}	352 m	382 m	381 m	382 m
B	56.0 m	54.2 m	57.0 m	52.0 m
H	29.0 m	27.7 m	29.0 m	?
Draft	15.0 m	15.0 m	14.7 m	16.0 m
Rows	20/22	19/21	20/22	18/20
Prop No	2	2	1/2	1

Table 5: Dimensions of future container carrier projects of 12,000 TEU and above

5. The Development of Port and Inland-Transport Services

Containerisation is a tool that has helped promote multimodal door-to-door transport services world-wide. Reliable and efficient transportation has such an important influence on the economy of individual countries that the World Trade Organisation has set up a trade and transport facilitation program to assist particularly the less developed countries.

In many countries, ports and land transport service infrastructures have been modernized, expanded and privatised since the beginning of the 1990s. This has led to significantly improved port and logistics operations. However, the requirement for fast turnover of vessels or containers in ports, which is nowadays measured in hours or even minutes, is of little use if port congestion as well as insufficient inland transportation logistics causes severe delays. Container trade has increased so fast, particularly on the major trade routes that despite of massive port- investment and expansion programs, vessel waiting times have become a big problem. Much of the gain in port efficiency is lost due to inability of terminals to effectively connect with the hinterlands they serve. Port expansion programs are planned or are on the way everywhere and inland transport is being expanded. The development and efficiency of container shipping has however been so fast, that ports and land-transport have difficulties keeping up.

This may in fact have an influence on the future composition of the container fleet and container routes. Rather than concentrating the trans-continental traffic on very large ships serving the main hub ports of the world only, with feeder service to other ports, there will be advantages of direct services with small and medium sized containerships between medium sized and smaller ports. The hub and spoke system, proposed in the 90ies has not really materialized. Transhipment of containers is expensive and time consuming. Most shipping companies, except for the very largest, prefer to deliver

containers as close as possible to the final destination. Let us look at a few regions of interest to the Panama Canal.

North East Asia, with emphasis on China

China has become the third largest trading nation in the world. Clothing, furniture or consumer electronics manufactured in China and other Asian countries are transported to the US and Europe in containers. China's hunger for raw materials, components and luxury goods from the world, on the other hand, grows at a very fast rate and appears to be insatiable. This is to the benefit of shipping companies, ports and the main canals.

The development is reflected in extensive port building programs world-wide. Within their "Pacific Gateway Strategy", Canada for instance is planning to invest about € 500 Million in port development. The government expects that the container moves in the Pacific ports will rise by about 200% within the next 15 years. The same can be seen on the other end of the Pacific, where € 300 Million is being invested in the extension of Sydney's Port Botany, the second largest of Australia.

A particularly strong growth is predicted for the ports of China. Today's about 62 Million container moves will grow to 130 Million within no more than five years. Already today every fourth container being carried by the ships of the world's largest container fleet, Maersk, comes from China. Within a few years it will be every third container. This is supported by the strong growth numbers: In August this year export from China was 32% higher than a year ago, imports had grown by 23%.

The new deep water port of Shanghai, Yangshan, is presently starting trials. Within an investment program of about $ 1.8 billion for the first phase the port will have the capacity to handle about 20 million containers per year. Once completed, the $12 billion port will include the pier structure for 52 containerships and will be connected to the mainland and Shanghai via a 32 km bridge.

While Yangshan will become a leading port of the new century, the existing big ports are competing for the leadership places: This year Singapore, with a growth rate of 9.3%, is expected to surpass Hong Kong as the leading container port of the world. This in part is due to the large number of newly developed ports springing up everywhere in Southern China, which are draining cargo away from Hong Kong; it therefore has a growth rate of only 2%.

United States West Coast

With this determined and fast growth in Asia connected with continued strong growth of the container volume other regions in the world have difficulty keeping up with developments and are becoming bottle-necks in the container transportation chains. Waiting times in California ports have nearly doubled to an average of about seven days within the past few years. The US West-Coast ports have ambitious plans to expand. Ports of Los Angeles and Long Beech expect a doubling of container volume within a period of five to six years.

In the US as well as in Europe it is however considerably more difficult to extend ports than in China. Crowded cities bordering on the ports, like in Los Angeles and Long Beach, lead to extensive planning periods with sometimes insurmountable obstacles from environmentalists. Additionally the infrastructure for land transport of

containers to their final destinations is becoming an impasse in the US.

Man-made problems and crises can furthermore disrupt the container transportation chain and can be a threat to keeping a tight time schedule.

The US-West Coast strike at the end of 2002 involved some 29 ports on the US West Coast and caused enormous disruptions and confusion. It demonstrated how dependent today's industries and consumers are on the smooth operation of the container supply chain and what happens, when the container transport chain is being interrupted. Lloyds List estimated that US West coast ports handle about $300 billion of trade a year.

Loaded container vessels waited to be discharged off shore or were diverted to alternative ports, all the way to Canada or Mexico. The strike backed up to warehouses throughout Asia which were jammed full of containers waiting on shipment. The damage caused by the strike to the US economy became so extensive that President Bush finally intervened to end the lock-out with the Taft-Hartley Act in October 2002. Many inland factories depending on supplies and semi-products arriving in containers had to stop production after just one week already.

The sole dependence on West-Coast ports was recognized as a weakness of the supply chain. It was realised that there should be an alternative. Although the strike or lock-out was settled after an intervention from the administration, the vulnerability of the West Coast ports to the power of the longshoreman's union became obvious. Prudent owners and shippers, although they may not want to say so, must have contingency plans in place to use the All-Water Route from East Coast US ports to Asia and back in case of future labour problems, or to mitigate the risk by using the West Coast ports as well as the All-Water Route.

The **All-Water Route** was given a boost by the lock-out. This route, particularly with the new Lock dimensions, which would enable Post-Panamax vessels to transit through the Panama Canal, reduces the need to send containers between US West Coast ports and the East Coast region via the so called Land Bridge. Seemingly the economics of doing so are favourable. This possibility will bring an alternative for owners and ship operators to solely using the West Coast ports for their Post-Panamax vessels.

United States East Coast

The East Coast ports of the US have been slower in adapting to the larger ships than the ports of most other regions along the main trade routes in the world. Today the importance of investing in modernisation and preparing for the future has been realised. Several East Coast ports are preparing for the larger ships. This includes the ports of New York and New Jersey, Maryland and Hampton Roads ports, Charleston, Savannah and Jasper County Services as well as Jacksonville, Florida.

The port of New York and New Jersey manages the most important USEC terminals as they provide access to more than 100 million of North America's most affluent consumers. Today, their container terminals move more than 4.4 million TEU annually – by far the largest volume of container traffic on the East and Gulf coasts of North America.

To meet the increasing market demand for international goods, the Port Authority of New York and New Jersey is in the process of an extensive port development project

to increase handling capacity. Container terminals will be reconfigured for maximum productivity and efficiency. On-dock rail capabilities are being expanded to improve inland access, and channels and berths are deepened to eventually accommodate ships with a draft of up to 15 meters.

These development plans are typical also for other US East Coast ports. Most envisage a draft limitation for port access and pier side of between 14 and 15 meters. This draft limitation is also assumed for other big ports in the world, like the port of Hamburg, presently with an annual container volume of 6 million TEU. Ships with larger draft may be expected to be unable to call at US East Coast ports in fully loaded condition.

Round-the-world services

Shipping lines with a regular round-the world service have been successful in the past. They operate with a large enough series of similar vessels so that they can offer weekly calls at each of the ports of call along their round-the world-route according to a fixed weekly schedule. These services with ships passing through the Panama and Suez Canal will benefit from the possibility of using larger vessels through the new Panama Canal.

6. Evaluation of the Post-Panamax Lock and Vessel Dimensions

A comparison is made between the new “Post-Panamax Lock” dimensions and the maximum vessel dimensions derived from them, and the dimensions of the large present-day Post-Panamax vessels, 8,000 and 9,000 + TEU.

The old and the new (in bold letters) Panamax dimensions are shown here again:

Length_{oa}	295 m	**366 m**	**1,200’**
Beam	32.2 m	**48.8 m**	**160’**
Draft	12.0 m	**15.3 m**	**50’**

With the new lock dimensions all containerships up to and including the 8,000, the 9,000 TEU in service or under construction today would be able to pass through the new Panama Canal locks. The new locks will be large enough to accommodate even a 12,000 TEU vessel, as listed in Table 3.

This is a big step or a “quantum leap” for the Canal as well as for world shipping. The new lock dimensions appear to be well chosen. The workhorse container vessels described above would all be able to transit the Canal.

6.1 Impact of the Post-Panamax Lock dimensions on world shipping

The new lock dimensions are large enough for 10,000 to 12,000 TEU vessels to pass through. All containerships presently operating on the seas would be able to go through the Panama Canal. The uncoupling from the Canal as seen in the development of the Post-Panamax container vessels will be reversed by the extension of the Canal to the new dimensions.

As in the past, the Panama Canal will have a decisive influence on shipping also in the future. There will be a very significant step from the present Panamax size ship to the new Panamax limitation.

The new Panamax container carrier could have the following dimensions:

L_{oa}	366 m	1,200’
B	48.8 m	160’
Draft	15.3 m	50’

A container vessel with a length of 366 m could carry two more bays of 40’ containers than the 10,000 TEU ship. The new Panamax container carrier would also have a beam of 48.8 m and carry one more row of containers in the holds and on deck. This would bring the total carrying capacity close to 12,000 TEU.

Even if the new Canal dimensions will have the most significant influence on containerships, also the trade with other ship types will adjust to the new dimensions. New shipping volume will be attracted to the Canal. Particularly the bulker trade could be affected, with the new Panama Canal attracting larger ships. The influence on tankers probably will not be as significant, as draft will be a limitation. Nevertheless, the opportunity may create additional business for the Canal. The future of LNG transport is hard to predict, however even here additives do not have to be excluded.

7. Final evaluation of adequacy of selected Post-Panamax locks size parameters

The new lock sizes and limiting dimensions will be a very significant step for world shipping, as they will be able to accommodate many of the large Post-Panamax ships, including bulkers and tankers of today. Containerships up to the largest size of vessels in service today and most of those coming into service in the foreseeable future will also be able to pass. Even though there may be larger containerships in the future than the new Post-Panamax size, they may be expected to be the exception, considering the pros and cons. They will not form workhorse ships on a large scale.

The new Canal dimensions will have a strong influence on the design of future ships. It is to be expected that ship owners and operators will be interested in the flexibility of staying within the new Panamax dimensions. This is expected to give new impulses to slow down or even stop the development towards larger ships in the future.

8. Any Insufficiencies found and Recommendations

Length of the Canal Locks: The new lock dimensions were analysed and their effect was scrutinized and discussed with knowledgeable persons from the shipping industry and with Dr. Stopford from Clarkson. No obvious insufficiencies were detected considering, without going into detail, the efficiency of the locks, the economics as well as the water consumption. In all discussions it was agreed that the selection of the lock dimensions appears to be well taken. The length and beam appear to have a strong effect on the efficiency. The discussions went from a shorter

length, limiting the ship size to 350m, to a further extended length of the locks, allowing two 200 m ships into the locks at the same time. This is mentioned here for discussion purposes; it can not be answered within this study.

Breadth of the Canal Locks: The ACP plan is for the old and the new locks to operate alongside each other. There may be a time in the future where, for reasons of maintenance cost, lack of water or other motives only the new locks would be kept operating. The following discussion is given here for that case:

- Could the breadth of the new Canal be increased to 69 or 70 meters instead of the proposed 55 m? This would allow two present day Panamax vessels to enter the locks next to each other. The combined vessel beam including a gap of about 0.6 to 1 m would be 65 m.
- The world fleet today is strongly formed by the present Panamax dimensions. Panamax ships are strongly represented in most big ship types, tankers, bulkers and containerships. Between 15 and 30% of all 3,490 containerships have a Panamax beam. Or looked at in another way, about 1,000 of the 2,300 containerships, which are larger than 1,000 TEU and are expected to operate internationally, have a Panamax beam. Many smaller tankers and bulkers also have a Panamax beam or slightly less. There are for instance many bulkers with 30m beam.
- With the lock dimensions presently proposed, only one Panamax vessel could enter the locks, perhaps together with smaller ships with a beam of up to about 16 m. This could lead to some inefficiency of the new locks or to relatively high canal rates for Panamax vessels.
- It will take many years for the new Panamax dimensions to become widely spread amongst the world fleet; therefore the efficiency of the new locks would increase only very slowly. With the possibility of bringing two present Panamax ships through the Canal, the efficiency would be high right from the beginning.

Executive Summary

The Panama Canal is seeking an assessment on the *Adequacy of the Selected Post-Panamax Lock Size Parameters for the Expanded Canal*. The aim of the study is to analyse the main dimensions of present and possible future ships in light of the dimensions of the Expanded Canal. All ship types are basically considered, but the emphasis is given to containerships, the shipping sector with the most extensive long term growth. An analysis of the development of containerships up to the largest ships in service, under construction or on order today is followed by a systematic consideration of possible future further developments and extensions of containership design. The geo-political and geo-economic role of the Panama Canal is considered. Limiting factors for the further growth of containerships are discussed regarding the maximum available size of the propulsion plant and ship propulsion, structural strength and stiffness of the ship's hull, beam and depth limitations of world canals and straits, the water depth of port access and in port, and finally port facilities and inland transport infrastructure requirements and availability.

On the basis of these considerations, it is concluded that even larger ships than the 10,000 TEU vessels coming into service today are possible. Ports have generally responded to the developments of the containerships quickly, even if at a high cost. Gantry cranes in most major ports can service ships with a beam of up to 42.8 meters. New cranes in some ports have an outreach of 60 m and 65 m already today. Regarding the water depth it is however concluded that it can be expected to remain limited to about 14.5 to 15 m in the majority of world ports.

The container volume shipped to and from the USA has an exceptionally high growth rate. The further growth of the port capacity to stay ahead of or in line with the development of the container volume is however seen critical, particularly for the US West Coast ports. This also applies to the infrastructure; the trains of the land-link connecting the US West coast to the Mid-West and the most populous East have reached their capacity limits. As an alternative, there is a strong industry-interest in the All-Water-Route to the Us East Coast.

The economies of scale effectively become less significant as the ships go beyond about 12,000 TEU. Considering the economic and operational risks and the reduction in flexibility of very large ships, it is believed by many maritime economists that the most economical containership size is and will be around 6,000TEU.

Container shipping operations will continue to become more diverse as the world container fleet continues to grow. Different types of services, hub and spoke services, one-level transcontinental and feeder services as well as direct services to medium sized and minor ports close to the final destination of the containers exist already today. This development is expected to intensify as the container volume on most routes continues to grow. Based on these particulars it is expected that several workhorse groups of intercontinental container carriers will evolve. There will be the group around 3,000 to 4,000 TEU, the present Panamax group, a group around 6,000 TEU and finally a large ship group with a carrying capacity of between 7,000 and 10,000 TEU.

It is found that the new lock dimensions are a big step regarding the transit possibility for larger ships. The dimensions are well selected. All containerships presently in operation, including today's largest 9,000 and 10,000 TEU vessels will be able to pass the Canal. Even larger ships such as a 12,000 TEU vessel could be designed to

be able to transit the new Canal. It is concluded that the locks are of sufficient size and that they will effectively be able to serve for a long time to come the workhorse ships of the main trade segments and routes.

It can not be excluded that even larger containerships will be put into service; it may, however, be expected that they will operate on special routes only and that they will be the exception rather than the new norm. It would appear uneconomical to prepare the Canal for the largest ships possible.

As in the past, the Canal will have a decisive influence on the design of ships in the future. New Panamax ship types will be developed. For this reason it is recommended that the new Panamax dimensions and limitations should be published as soon as possible. It is possible that some of the design-projects presently considered, with overall dimensions beyond the new Panamax parameters, will be modified to fit the new Canal.

During the assessment of the adequacy of the new locks attention was given to find any significant insufficiencies that may affect the functionality, effectiveness or longevity of the selected Post-Panamax lock size parameters. No such inadequacies were found.

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