Operating Jumbo Cranes on Existing Wharves

TOC Asia 2004

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Purpose

Many ports have older, existing wharves, but need newer/larger cranes to operate the larger ships

Wharf modification is expensive

Ports should investigate using new technology to re-rate the wharf prior to committing money to upgrade

Overview:

Section 1: Operator's Perspective

Section 2: History of Crane Loads on Wharves

Section 3: Wharf Load Factors

Section 4: History of Wharf Rated Capacities

Section 5: Reassessing the Rated Capacity of Existing Wharves

Section 6: Other Considerations

Section One:
Owner's Perspective

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The Port of Virginia

The Virginia Port Authority (VPA)

- An Agency of the Commonwealth of Virginia

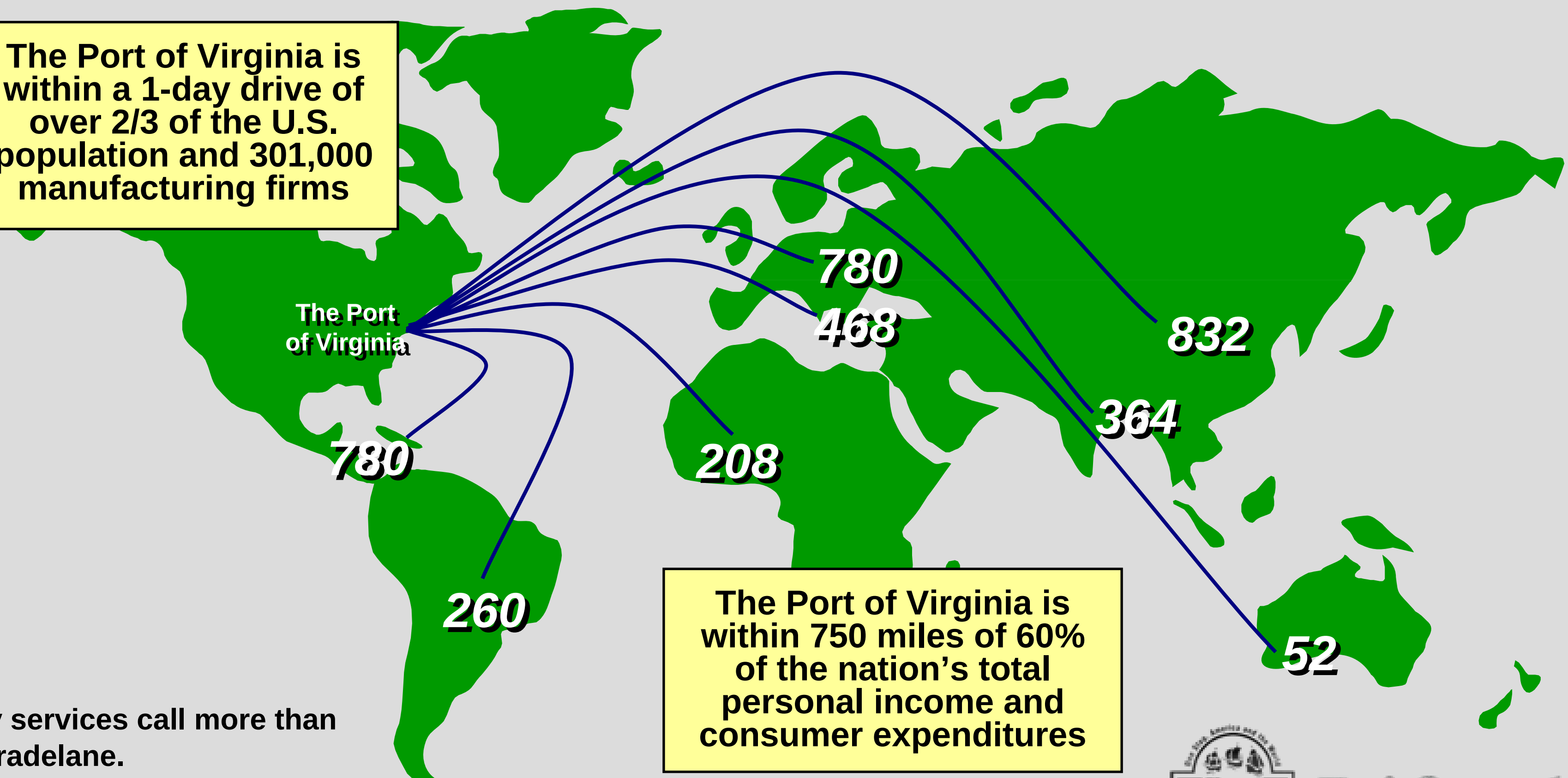
Virginia International Terminals (VIT)

- A Virginia Non-Stock, Non-Profit Operating Affiliate of the Virginia Port Authority
- Operates the Terminals Owned by the Commonwealth

The Port of Virginia

The Port of Virginia offers world-class shipping facilities and is served by more than 75 steamship lines with sailings to over 250 ports in 100 overseas locations.

The Port of Virginia is within a 1-day drive of over 2/3 of the U.S. population and 301,000 manufacturing firms



The Port of Virginia is within 750 miles of 60% of the nation's total personal income and consumer expenditures

***Many services call more than one tradelane.**

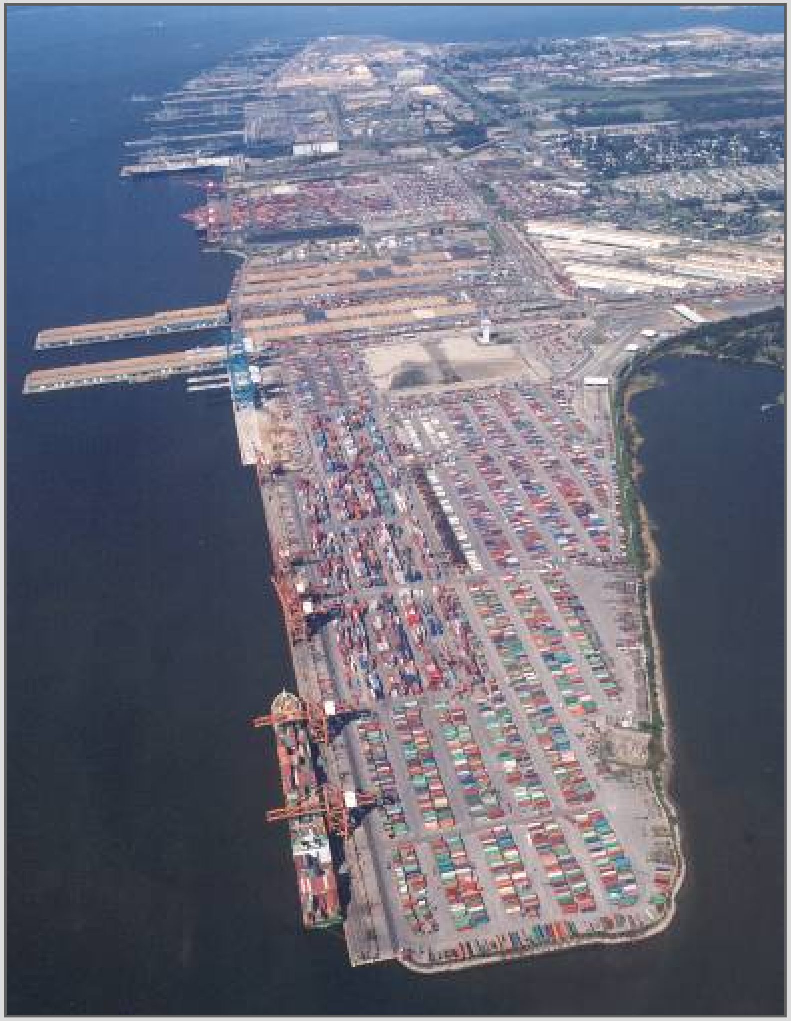
The Port of Virginia

The Port of Virginia is Currently Ranked:

- 8th Largest Container Port in the U.S.
- 3rd Largest Container Port on the East Coast

In the Year 2003 The Port of Virginia Handled:

- 1.65 Million TEUs of Containerized Cargo
- Combined Value of $28 Billion



The Port of Virginia

Virginia Inland Port (VIP)
Front Royal, VA

Norfolk International Terminals (NIT)
Norfolk, VA

Newport News
Marine Terminal (NNMT)
Newport News, VA

Portsmouth Marine Terminal (PMT)
Portsmouth, VA

The Port of Virginia

- Three Marine Terminals Constructed Over Time
- Terminals Were Constructed by Various Agencies
- Some Structures Date Back to 1918
- Many of the Existing Container Cranes are First and Second Generation (13 Containers Wide)

THE Port OF VIRGINIA 1607 2007

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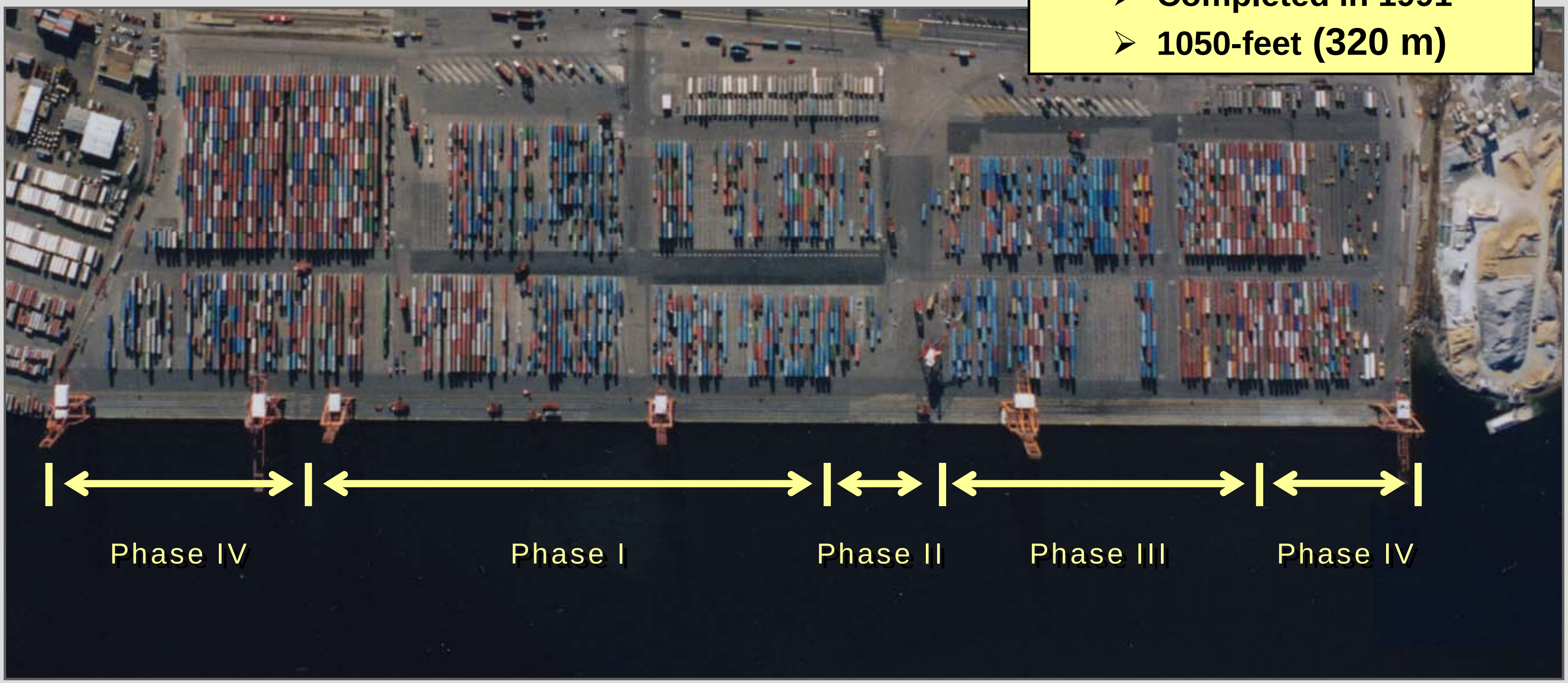
Portsmouth Marine Terminal

Wharf Structure

Phase IV

- **Completed in 1991**
- **1050-feet (320 m)**



Portsmouth Marine Terminal

PMT Cranes are all 50-ft (15.2-m) Gage

Crane #1
- Purchased in 1967
- 16 Containers Wide
- Operating Wheel Loads (kips/ft)
  - LS: 21
  - WS: 21

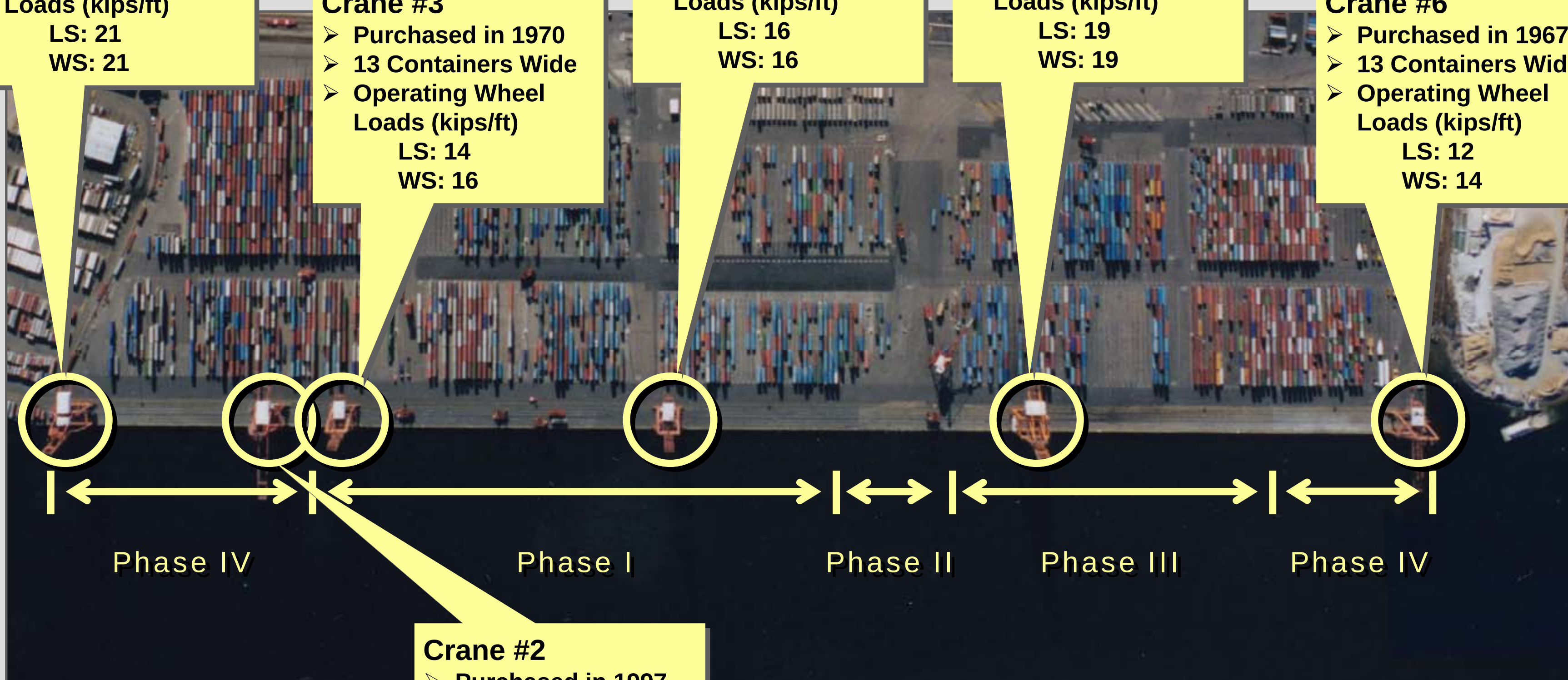
Crane #2
- Purchased in 1997
- 16 Containers Wide
- Operating Wheel Loads (kips/ft)
  - LS: 17
  - WS: 21

Crane #3
- Purchased in 1970
- 13 Containers Wide
- Operating Wheel Loads (kips/ft)
  - LS: 14
  - WS: 16

Crane #4
- Purchased in 1971
- 13 Containers Wide
- Operating Wheel Loads (kips/ft)
  - LS: 16
  - WS: 16

Crane #5
- Purchased in 1987
- 15 Containers Wide
- Operating Wheel Loads (kips/ft)
  - LS: 19
  - WS: 19

Crane #6
- Purchased in 1967
- 13 Containers Wide
- Operating Wheel Loads (kips/ft)
  - LS: 12
  - WS: 14



Note:
20 kips/ft ≅ 30 t/m

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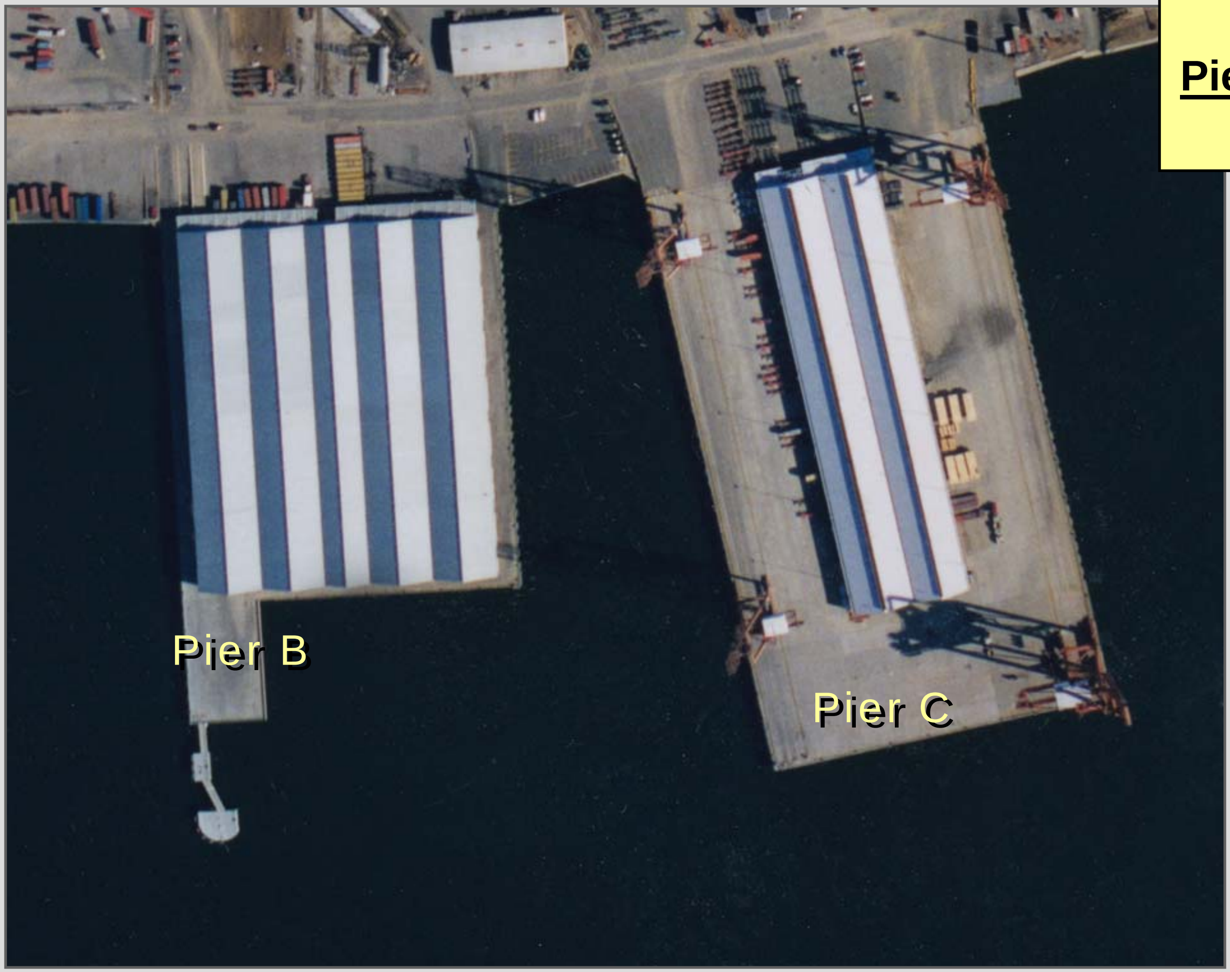
Newport News Marine Terminal

VPA Acquired NNMT in 1971.



Pier B

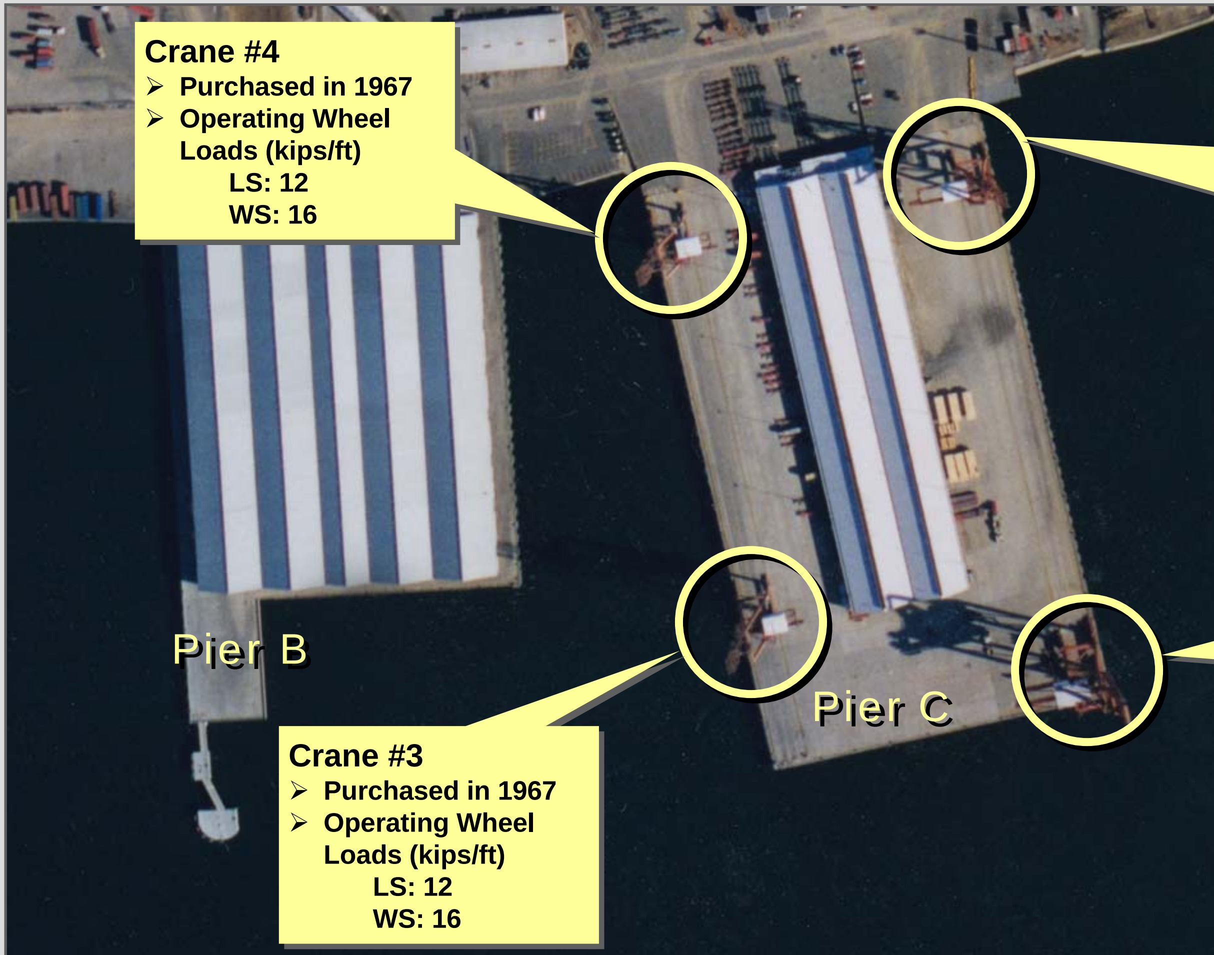
- Completed in 1967

Pier C

- Completed in 1982

Newport News Marine Terminal

NNMT Cranes are All 50-ft Gage, 13 Container Outreach



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Norfolk International Terminals

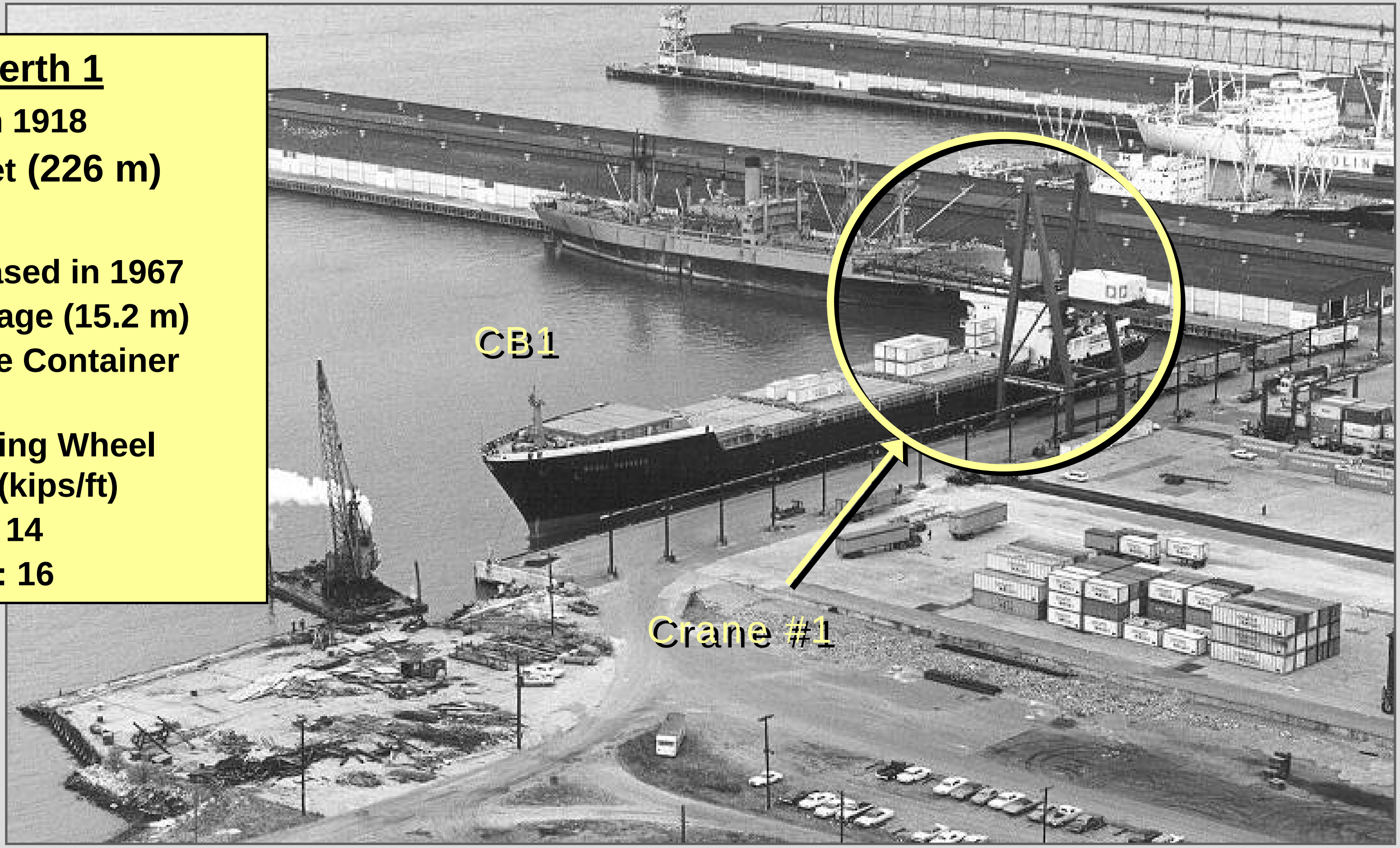
NIT Container Terminal Opened in 1967

Container Berth 1

- Built in 1918
- 740-feet (226 m)

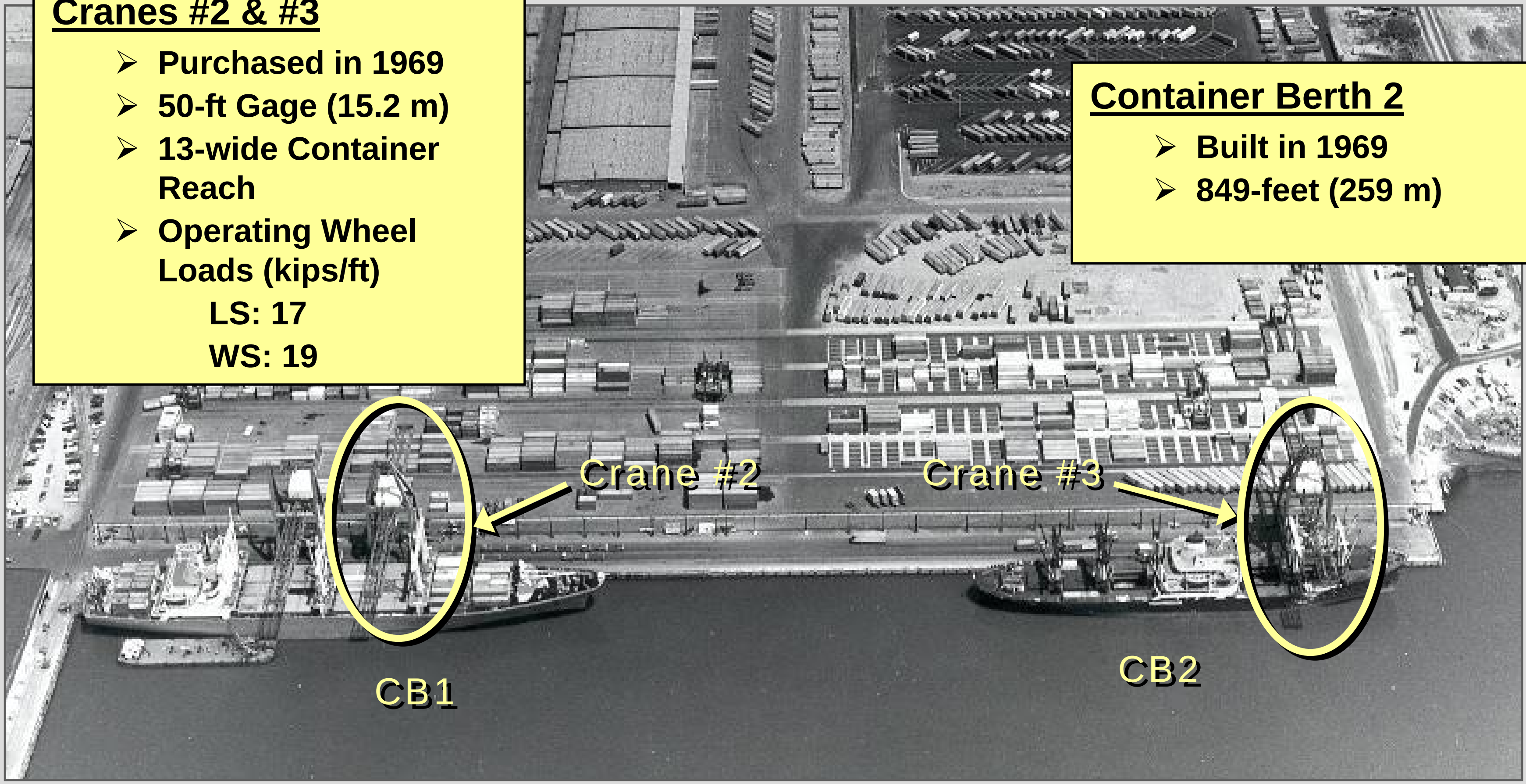
Crane #1

- Purchased in 1967
- 50-ft Gage (15.2 m)
- 13-wide Container Reach
- Operating Wheel Loads (kips/ft)
  - LS: 14
  - WS: 16



Norfolk International Terminals

Terminal & Wharf Expansion in 1969



Cranes #2 & #3

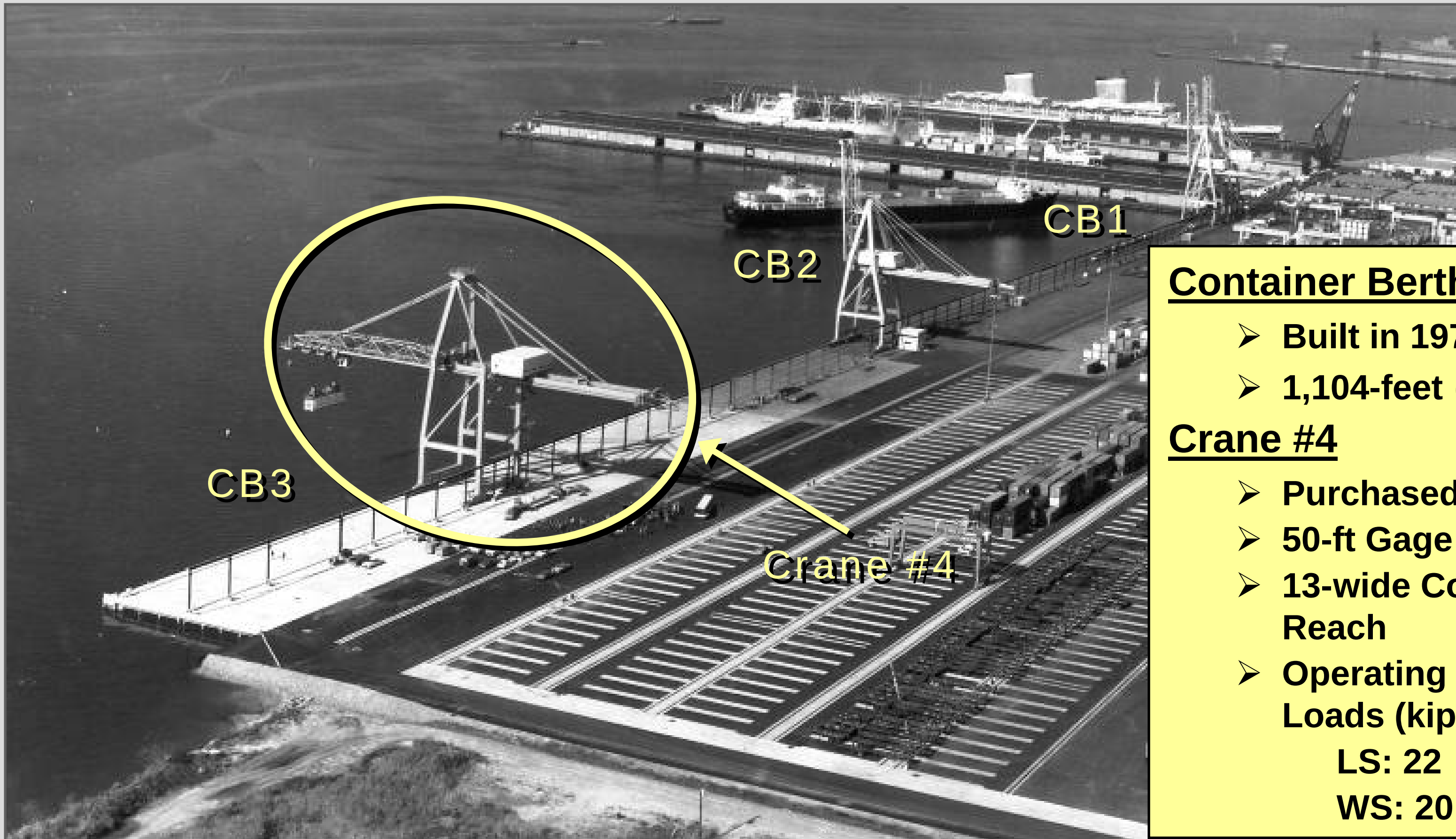
- Purchased in 1969
- 50-ft Gage (15.2 m)
- 13-wide Container Reach
- Operating Wheel Loads (kips/ft)
  - LS: 17
  - WS: 19

Container Berth 2

- Built in 1969
- 849-feet (259 m)

Norfolk International Terminals

Terminal & Wharf Expansion in 1975 & 1978



<u>Container Berth 3</u>

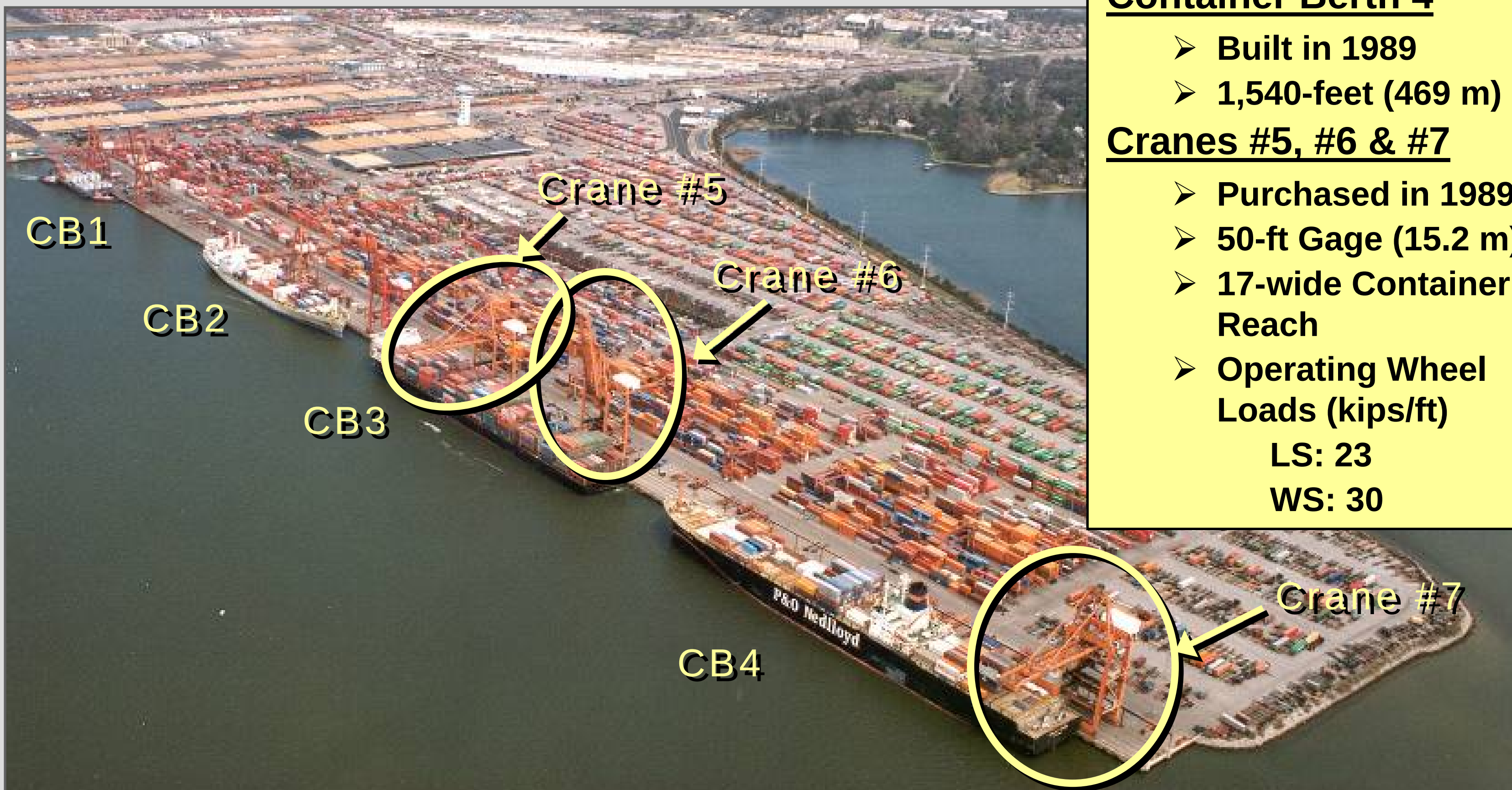
- Built in 1978
- 1,104-feet (336 m)

<u>Crane #4</u>

- Purchased in 1978
- 50-ft Gage (15.2 m)
- 13-wide Container Reach
- Operating Wheel Loads (kips/ft)
  - LS: 22
  - WS: 20

Norfolk International Terminals

Terminal & Wharf Expansion in 1989



Container Berth 4

- Built in 1989
- 1,540-feet (469 m)

Cranes #5, #6 & #7

- Purchased in 1989
- 50-ft Gage (15.2 m)
- 17-wide Container Reach
- Operating Wheel Loads (kips/ft)
  - LS: 23
  - WS: 30

Norfolk International Terminals

South Terminal Renovations

- Significant Portions of the Existing Wharf Are Structurally Obsolete & Require Replacement

- All Existing Berths Are Functionally Obsolete and Require Renovation
  - Wharf Cannot Support Higher Loads of Modern Container Handling Equipment
  - Wharf Cannot Support Modern Container Cranes, 100-ft (30.5 m) Gage
  - Wharf Cannot Provide Deep Water Berths Required for Modern Container Ships

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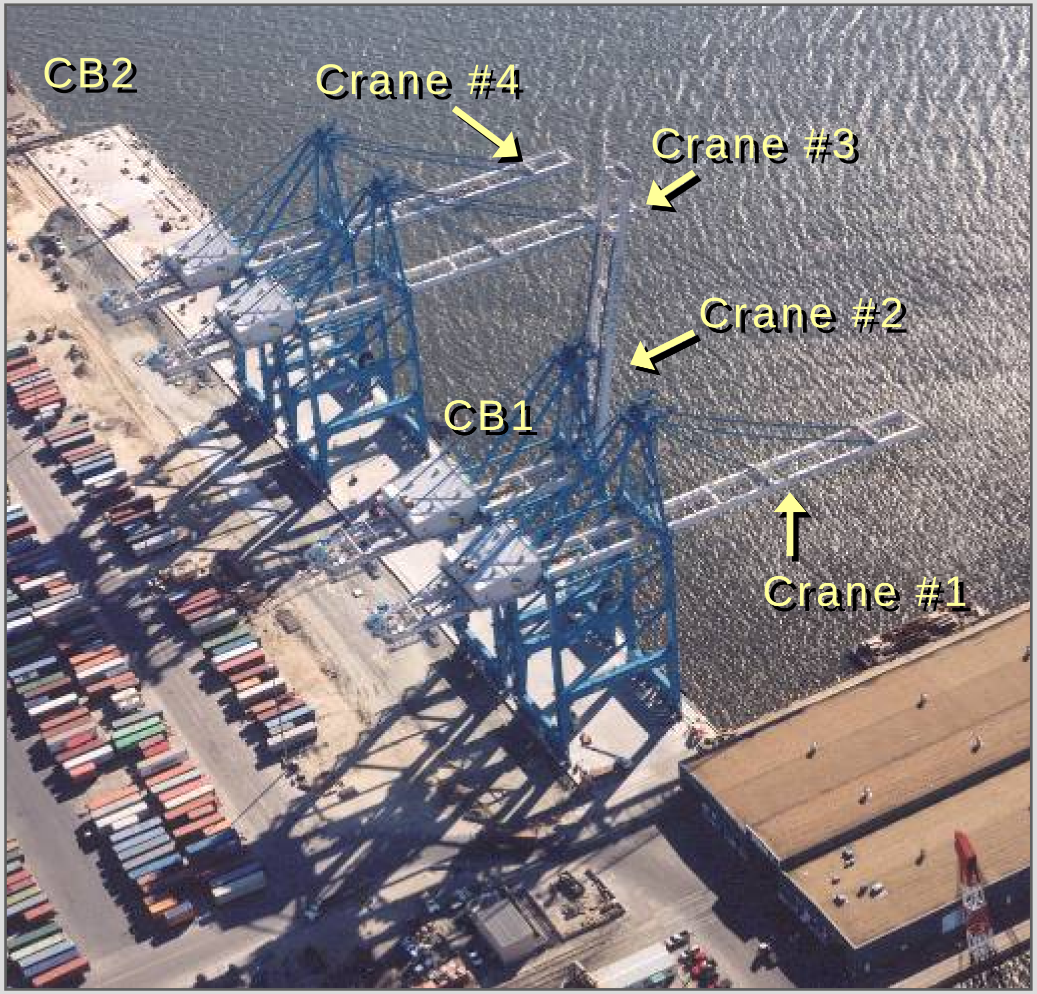
Norfolk International Terminals

Terminal & Wharf Renovation in 2003



New Container Berth 1

- **Built in 2003**
- **1,308-feet (399 m)**

New Cranes #1, #2, #3 & #4

- **Purchased in 2003**
- **100-ft Gage (30.5 m)**
- **26-wide Container Reach**
- **Operating Wheel Loads (kips/ft)**
  LS: 50
  WS: 50

Norfolk International Terminals

Continuing Wharf Reconstruction 2004

The Port of Virginia

- Wharf and Cranes at NIT South Required Complete Replacement
- PMT and NNMT Require Modern Cranes
  - Greater Outreach
  - Faster Speeds
  - Higher Loads
- Older Cranes Have Wheel Loads of 12 to 30 kips/ft
- Newer Cranes Have Wheel Loads of 25 to 50 kips/ft
- Need to Accommodate Modern Cranes on Existing Structures

Section Two:

History of Crane Loads on Wharves

Ship Evolution

Ship	Containers Rows	Minimum Crane Outreach* (m)
Panamax	13	38
Post-Panamax	16	46
Maersk Standard	17	48.5
Suez-max	19	54
Malacca-max	24	66

*Based on:

6-m, setback

1-degree list

Crane Evolution
(1960 to Present)

Paceco-First Container Crane (1960)

Europeans (Early 1960’s)

Japanese (Late 1960’s)

Repeated with:

- Koreans (1970’s)
- Others
- Chinese (1990’s)

Service Wheel Loads

Operating Condition (OP)

Dead Load + Trolley Load + Lift System + Rated Load + 0.5*Impact + Operating Wind Load

Storm Condition (ST)

Dead Load + Trolley Load + Lift System + Storm Wind Load

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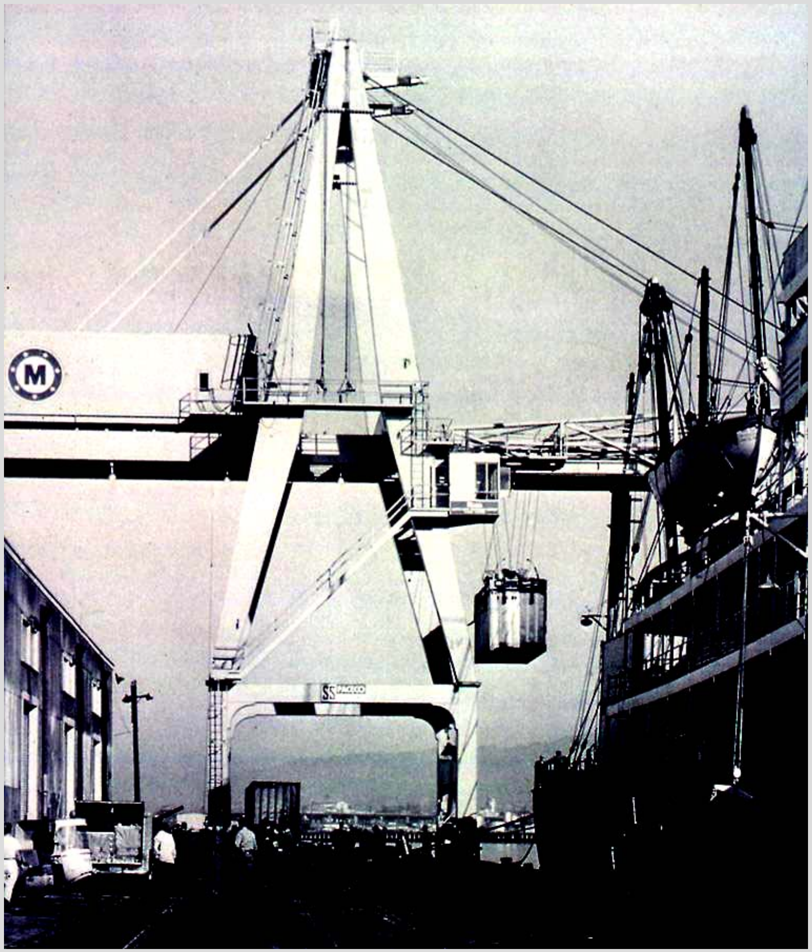
First Container Crane

(1960) Paceco Cranes for Matson Navigation



* Note: 6 wheels / corner

Gage	10.4 m
Outreach	23.8 m
Lift Height	17.8 m
Capacity	22.7 t
Weight	290 t

Service Wheel Loads* (t/wheel)

	OP	ST
Landside:	11	14
Waterside:	12	11

Paceco SL7
(1964)

Gage	15.24 m
Outreach	33 m
Lift Height	24 m
Capacity	30.5 t
Weight	490 t

Service Wheel Loads*
(t/wheel)

	OP	ST
Landside:	30	38
Waterside:	40	31

* Note: 6 wheels / corner

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Paceco Panamax Modified A-Frame
(1970)

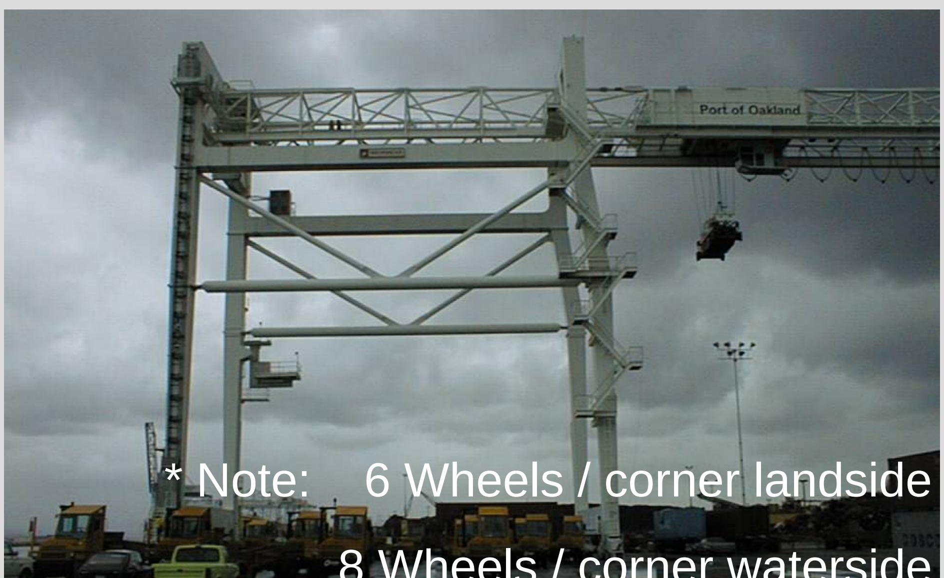
* Note: 6 wheels / corner

Gage	30.48 m
Outreach	35 m
Lift Height	25 m
Capacity	40.6 t
Weight	580 t

Service Wheel Loads (t/wheel)

	OP	ST
Landside:	34	43
Waterside:	41	46

Low Profile Cranes
(1970s)



* Note: 6 Wheels / corner landside

8 Wheels / corner waterside

Gage	30.48 m
Outreach	35.2 m
Lift Height	2730 m
Capacity	40.6 t
Weight	550 t

Service Wheel Loads*
(t/wheel)

	OP	ST
Landside:	49	39
Waterside:	43	17

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Post-Panamax Series
(mid-1980s to early 1990s)

* Note: 8 Wheels / corner

Gage	30.48 m
Outreach	44.2 m
Lift Height	29 m
Capacity	40.6 t
Weight	910 t

Service Wheel Loads* (t/wheel)

	OP	ST
Landside:	45	54
Waterside:	47	45

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Post-Panamax Low Profile Crane
Port Everglades (1991)

* Note: 8 Wheels / corner

Gage	30.48 m
Outreach	44.4 m
Lift Height	32.3 m
Capacity	40.6 t
Weight	1270 t

Service Wheel Loads* (t/wheel)

	OP	ST
Landside:	61	121
Waterside:	111	83

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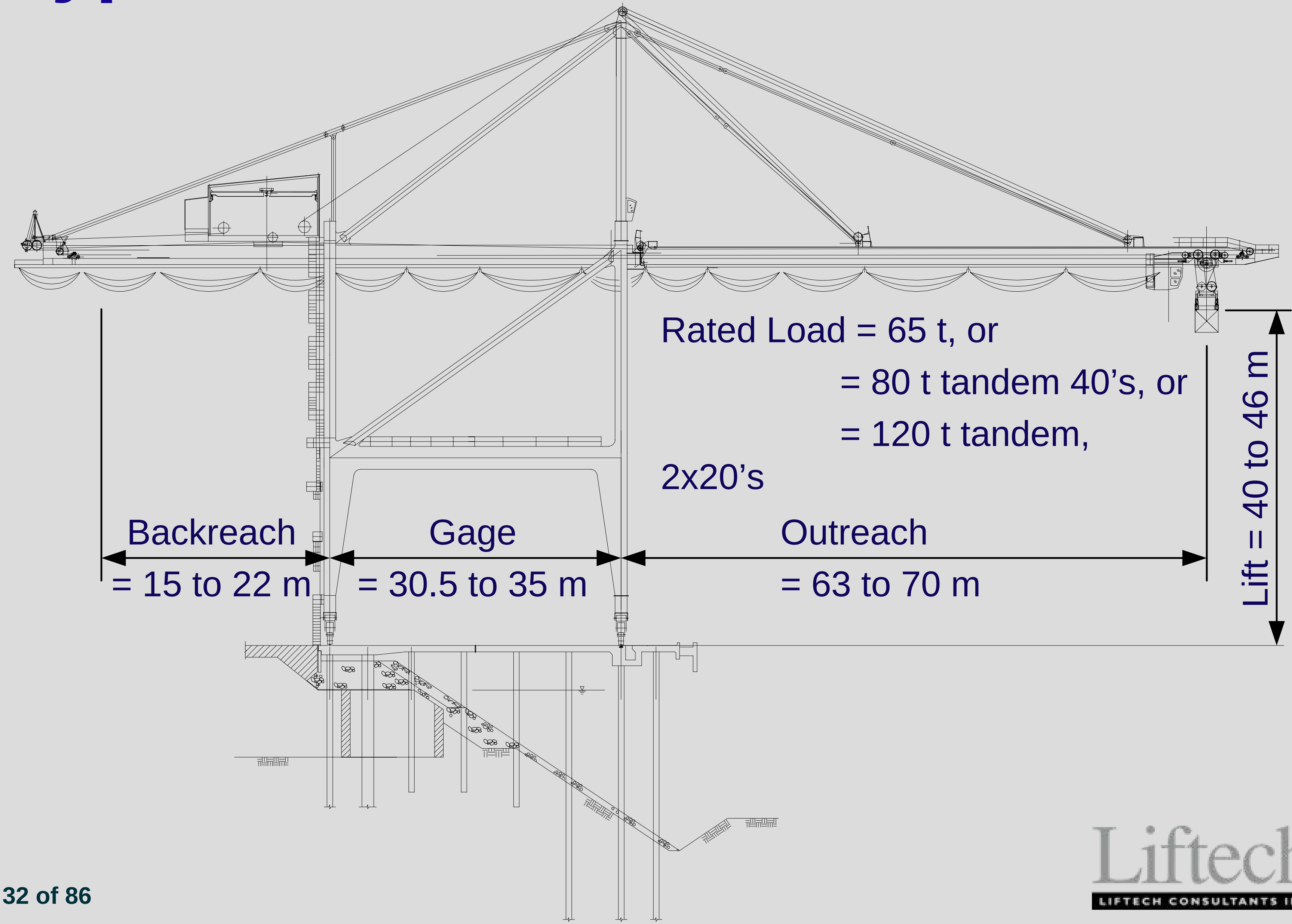
Typical Jumbo Crane



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Suezmax Cranes
Virginia Port Authority North (1998)

Gage	30.48 m
Outreach	61.3 m
Lift Height	36.6 m
Capacity	50.8 t
Weight	1110 t

Service Wheel Loads* (t/wheel)

	OP	ST**
Landside:	42	79
Waterside:	79	110

Notes:

* 8 Wheels / corner

** Boom stows at 19 deg

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Malaccamax Cranes
Virginia International Terminals South (2003)

* Note: 8 Wheels / corner

Gage		30.48 m
Outreach		70.5 m
Capacity	50.8 t	@ 70.5 m
	66.0 t	@ 63.5 m
Lift Height		40 m
Weight		1590 t

Service Wheel Loads* (t/wheel)

	OP	ST
LS:	73	120
WS:	95	124

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Future Jumbo Cranes?

Gage	30 to 40 m
Outreach	73 to 75 m
Lift Height	46+ m
Capacity	80 to 120 t
Weight	2,000+ t

Service Wheel Loads (t/wheel)

	OP	ST
Landside:	90	140
Waterside:	110	150

Malaccamax Crane & Statue of Liberty

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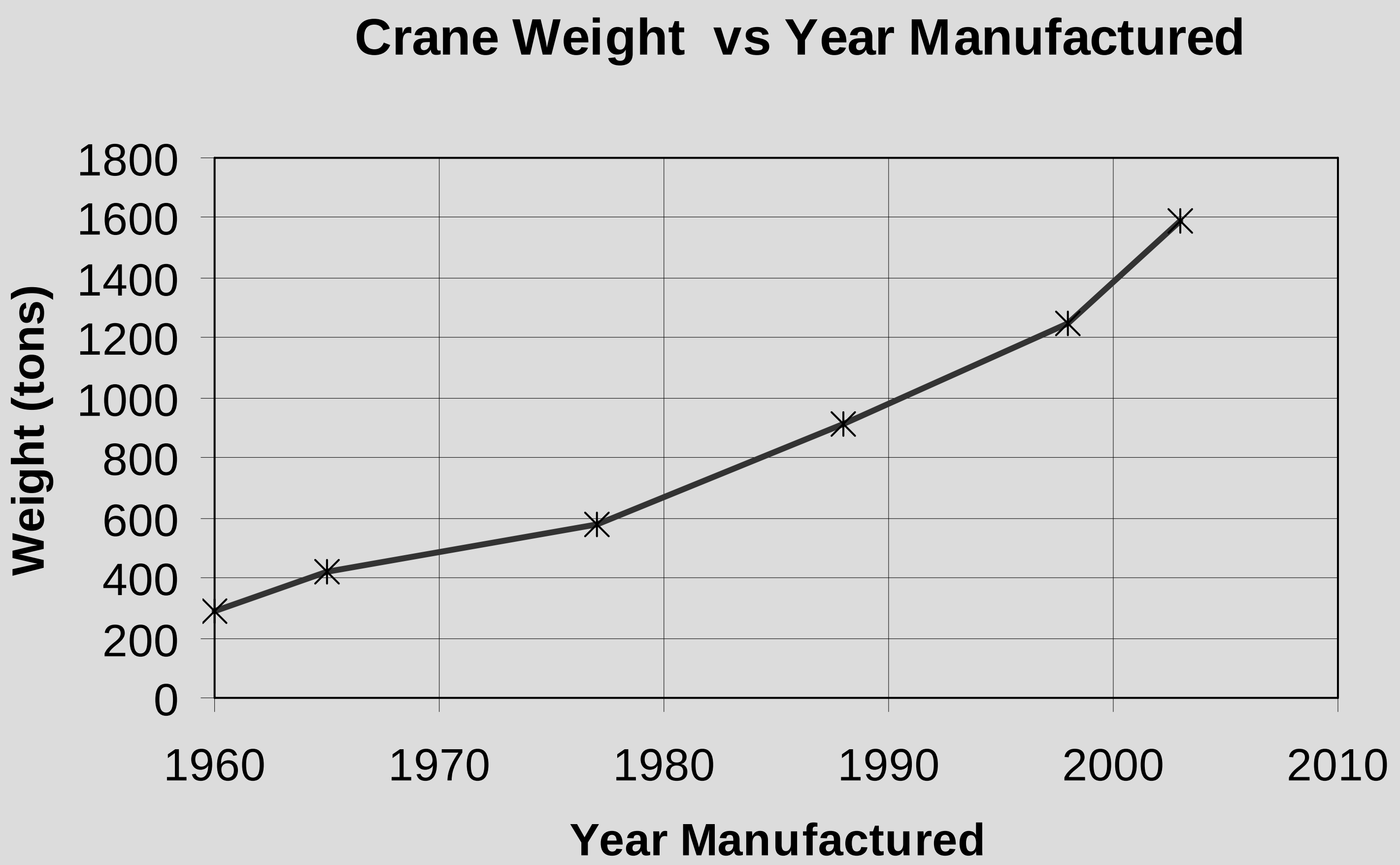
Crane Comparison:
1st Container Crane & Malaccamax Crane

Crane Comparison:
1st Container Crane & Malaccamax Crane

Crane Weight Evolution



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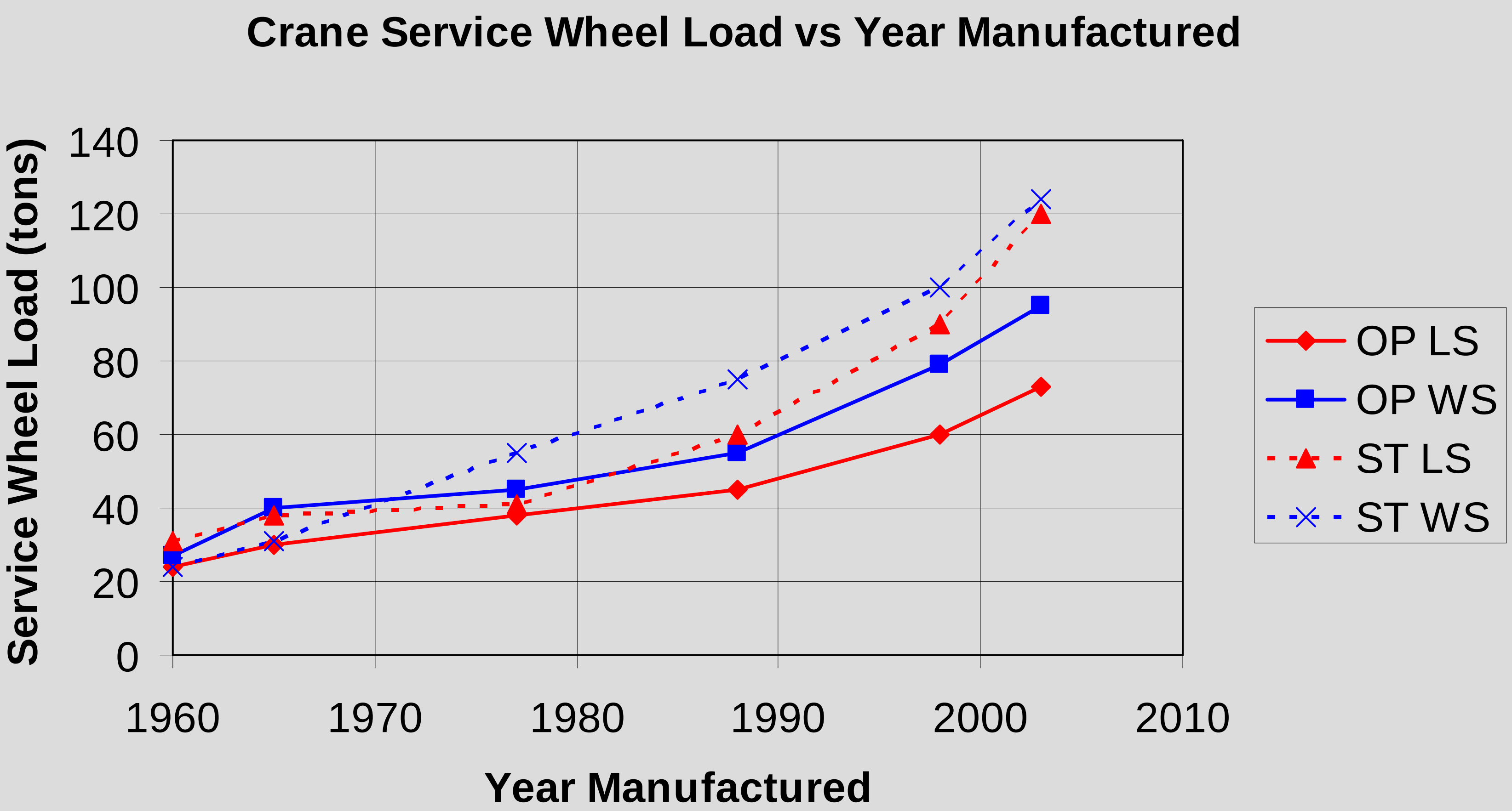
Crane Service Wheel Loads



Other Reasons for Wheel Load Increases

Crane modifications

Twin and tandem lifts

Dual hoist

Wind loads

Crane Modifications

Modifications can increase weight & wheel loads

Typical modifications:

- Increase lift height
- Increase outreach
- Change gage
- Increase lifted load

Modification Options
Geometry Changes

Increasing lift height, Port of Long Beach

Increased wind-induced wheel loads

Increased tie-down loads

Slightly increased dead load

No significant increases in operating loads

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Modification Options
Geometry Changes

Increased outreach

Boom addition

Increased operating wheel loads

Slightly increased wind-induced wheel loads

Slightly increased tie-down loads

Slightly increased dead load

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Modification Options
Geometry Changes

Rail gage change

Redistribution of dead load (from WS to LS)

Redistribution of moving loads

Increased tie-down loads

Note: Modified from wider gage, shown in red

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Twin …

… & Tandem Lifts

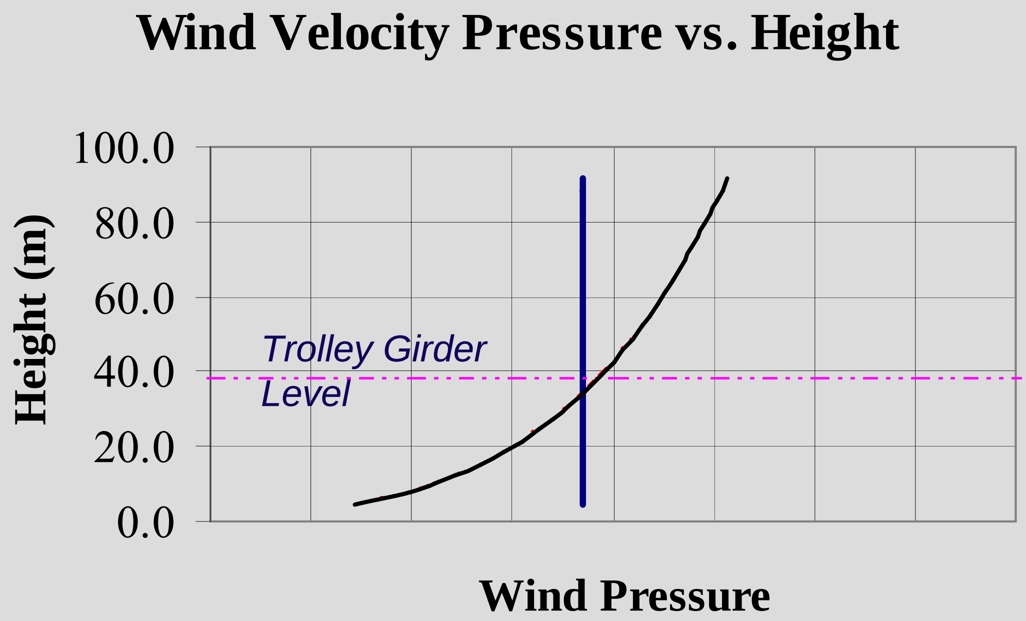
Dual Hoist

Storm Wind Loads

Older cranes designed to a constant wind pressure for the full height of the crane

Actual wind pressure varies with height

Wind speed mean recurrence interval (MRI) should be considered for structure and tiedowns



Storm Wind Speed:
MRI & Probability of Exceeding

May want to reassess stowage hardware for older cranes, based on recent knowledge

Recommend:

- 50-yr MRI for crane structure
- 200-yr MRI for tiedowns

MRI (yrs)	Probability of Excedence (%): 1 yr	25 yrs	50 yrs
25	4	64	87
50	2	40	64
200	0.5	12	22

Section Three:

Wharf Load Factors: One Perspective

Factors Influencing Probability of Collapse

Taken from “Ultimate Load Analysis of Reinforced and Prestressed Concrete Structures,” by L. L. Jones:

Applied Load Factor = X * Y, where

X = factors influencing probability of collapse

Y = factors influencing seriousness of the results of collapse

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Factors Influencing Probability of Collapse

Group X:

A. Workmanship (inspection, maintenance, materials)

B. Loading (control of use)

C. Accuracy of analysis (type of structure)

Note: Group X factors vary from 1.1 to 3.95

Source: "Ultimate Load Analysis of Reinforced and Prestressed Concrete Structures" by L. L. Jones

Factors Influencing Seriousness of the Results of Collapse

Group Y:

D. Danger to personnel

E. Economic considerations

Note: Group Y factors vary from 1.0 to 1.6

Source: "Ultimate Load Analysis of Reinforced and Prestressed Concrete Structures" by L. L. Jones

Example: Combining Factors

Ultimate Load Factor = X * Y

A. Good workmanship
B. Very good loading definition
C. Very good analysis

X = 1.3

D. Not serious danger to personnel
E. Very serious economic loss

Y = 1.2

Ultimate Load Factor = 1.3 * 1.2 = 1.56

Source: “Ultimate Load Analysis of Reinforced and Prestressed Concrete Structures” by L. L. Jones

Assessment of Factors

Depending on Engineer’s assessment of the A to E factors, the Load Factor can vary.

Load factors can vary from:

low of 1.1 (= 1.0 x 1.1)

high of 6.31 (= 3.95 x 1.6)

typically $\leq$ 1.6

Source: “Ultimate Load Analysis of Reinforced and Prestressed Concrete Structures” by L. L. Jones

Section Four:

History of Wharf Rated Capacities

Working Stress Design

Service Loads Before 1963

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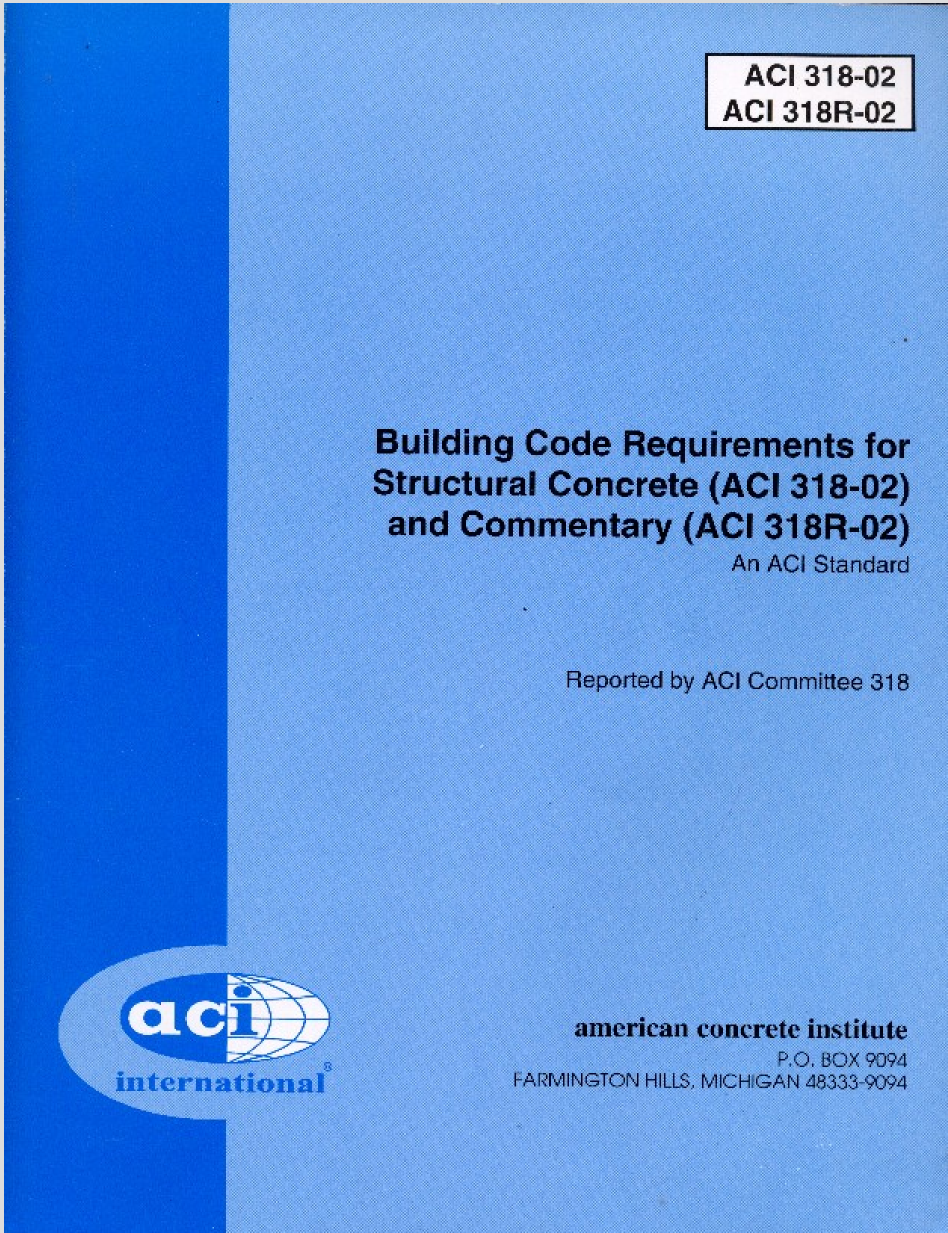
Ultimate Load Design

ACI 318

U.S. Standard for Concrete Design



Ultimate Load Design
1963 – 1970

$U = 1.5\ DL + 1.8\ LL$

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Ultimate Load Design
1971 – 2001

$$U = 1.4\ DL + 1.7\ LL$$

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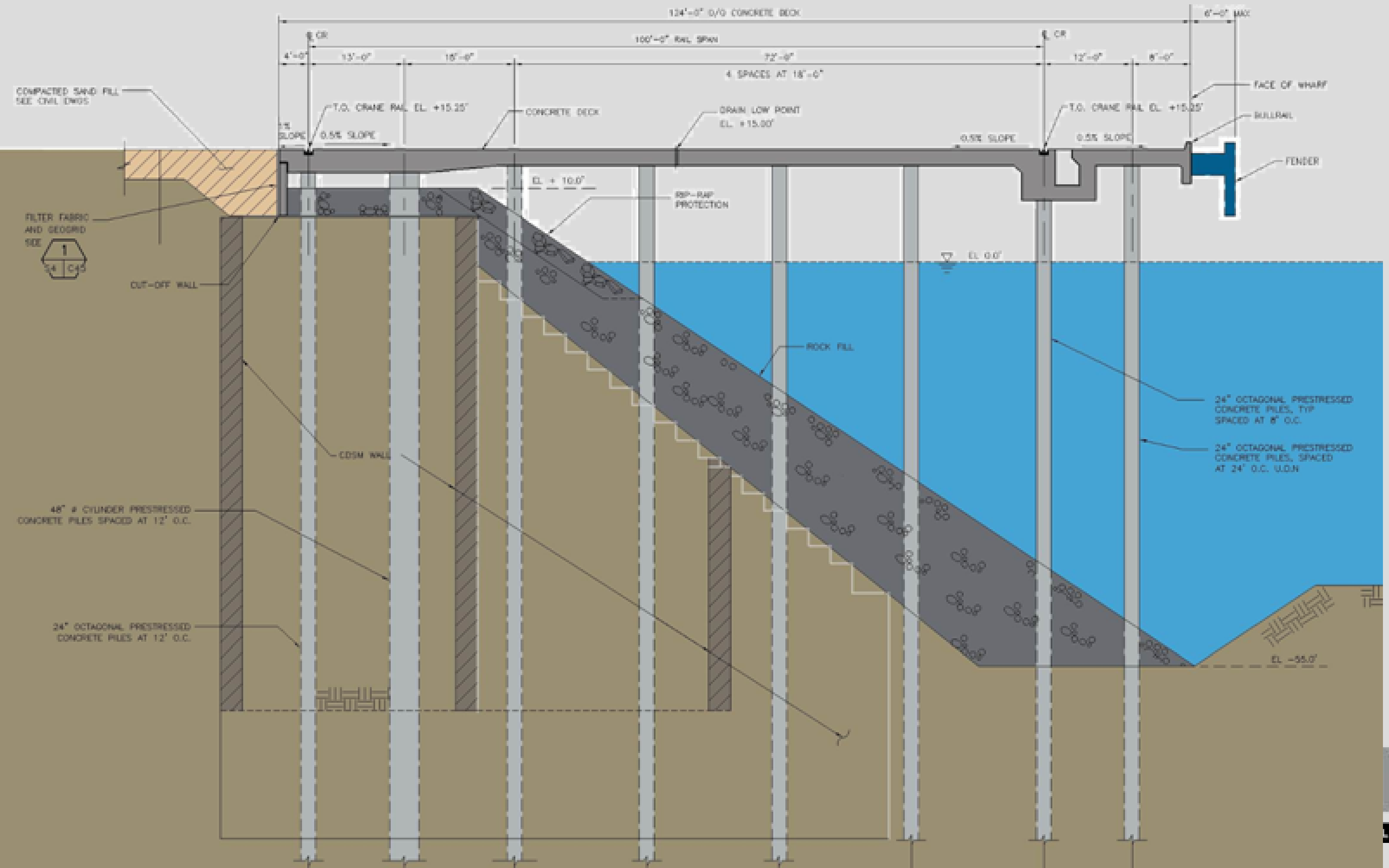
Ultimate Load Design

2002 – Present

$$U = 1.2\ DL + 1.6\ LL$$



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Design Methodology Summary

Working Stress Design:

Before 1963	Service Load Factors

Ultimate Load Design:

1963-1970	U = 1.5 DL + 1.8 LL
1971-2001	U = 1.4 DL + 1.7 LL
2002-Present	U = 1.2 DL + 1.6 LL

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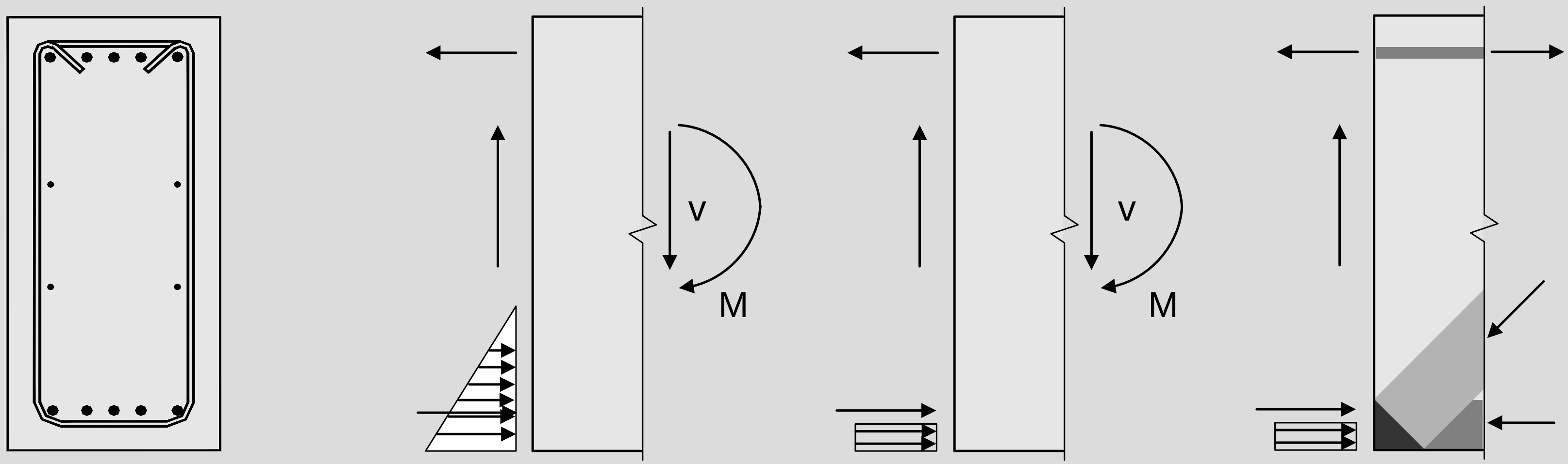
History of Design Capacity



	Isolated Beam	1960 Elastic *	1990 Plastic	2002 Strut & Tie
Relative "Service" Strength				
Moment M		1.00	1.50	1.70
Shear V		1.00	1.00	1.35

* Considering Calculated Strength and Load Factors

Section Five:
Reassessing the Rated Capacity of Existing Wharves

Reassessing the Rated Capacity of Existing Wharves for Higher Loads

Control group X factors, A to C

Reassessing the Rated Capacity of Existing Wharves for Higher Loads

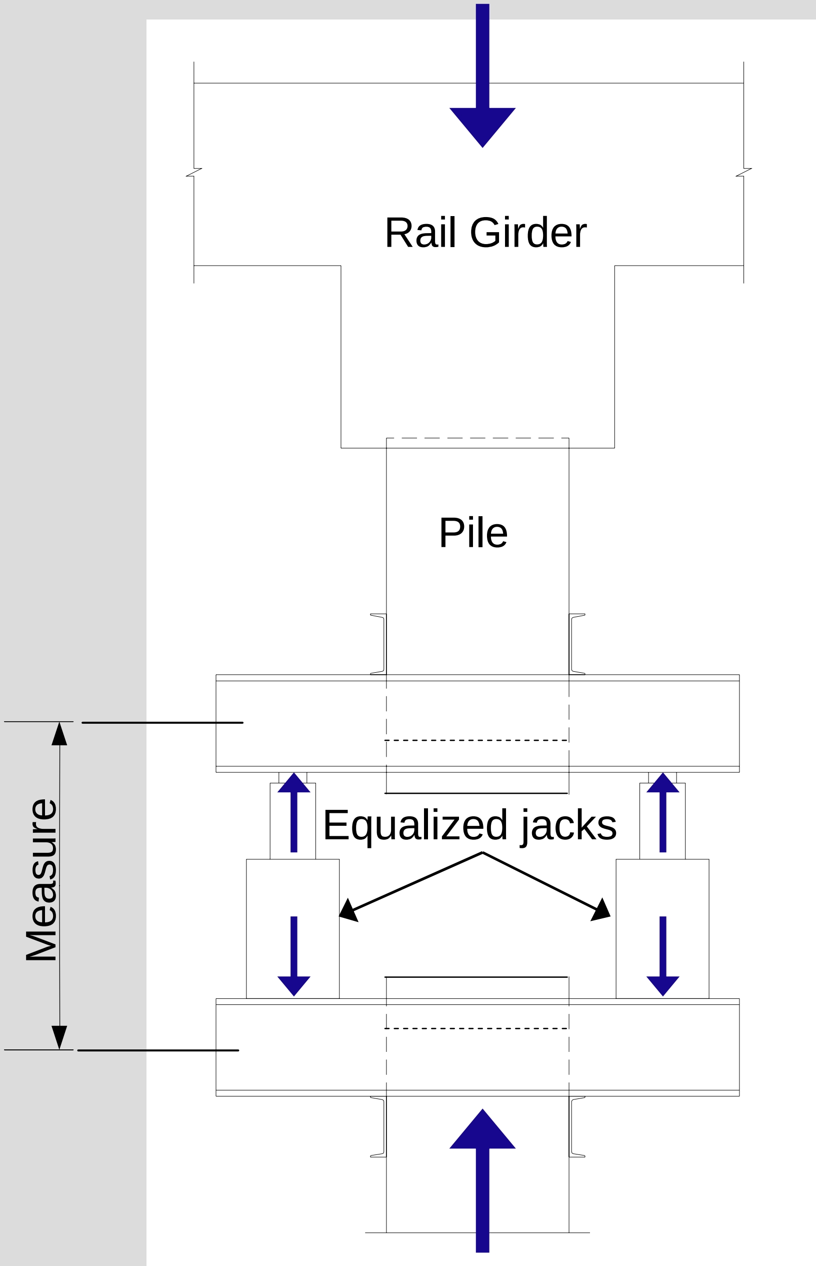
A. Workmanship:

- Materials—Concrete strength testing
- Piles—Capacity based on load tests
- Inspection of wharf for cracking, deterioration
- Proper maintenance and repairs

Pile Load Testing

Destructive Testing:

- Cut pile
- Jack
- Measure resulting deflection
  - When jacked
  - When released
- For elastic movement:
  - Jack deflection = released deflection



Reassessing the Rated Capacity of Existing Wharves for Higher Loads

B. Loading: Controlling the Load

Weighing crane

Using limiting devices for rated load

Providing overload fuses in cranes

Reassessing the Rated Capacity of Existing Wharves for Higher Loads

C. Accuracy of Analysis: Use state-of-the-art modeling and analysis tools:

Limit state design

Beam on elastic foundation—accurately modeling piles as springs, better understanding of loads and distribution of wharf

3D models—Analyze the entire wharf, not just the crane girders

Strut & tie model (STM) for concrete beam and column design

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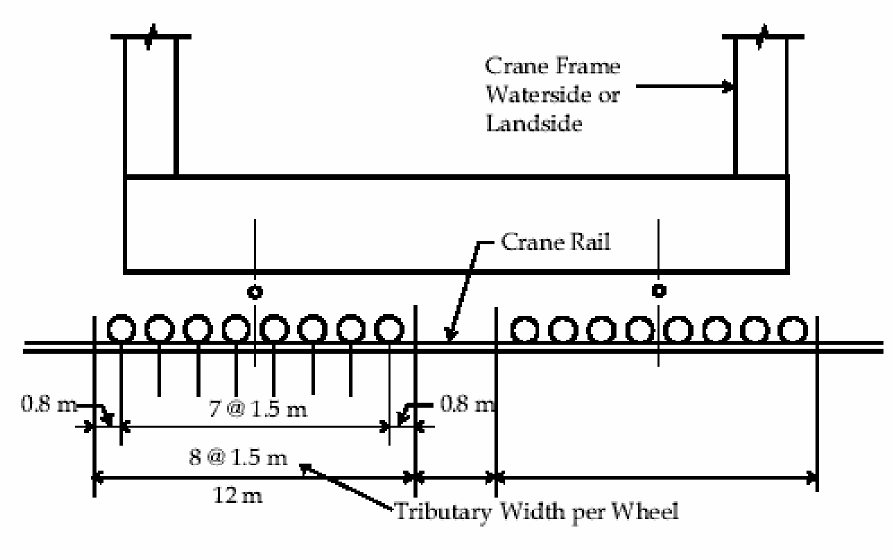
Beam on Elastic Foundation

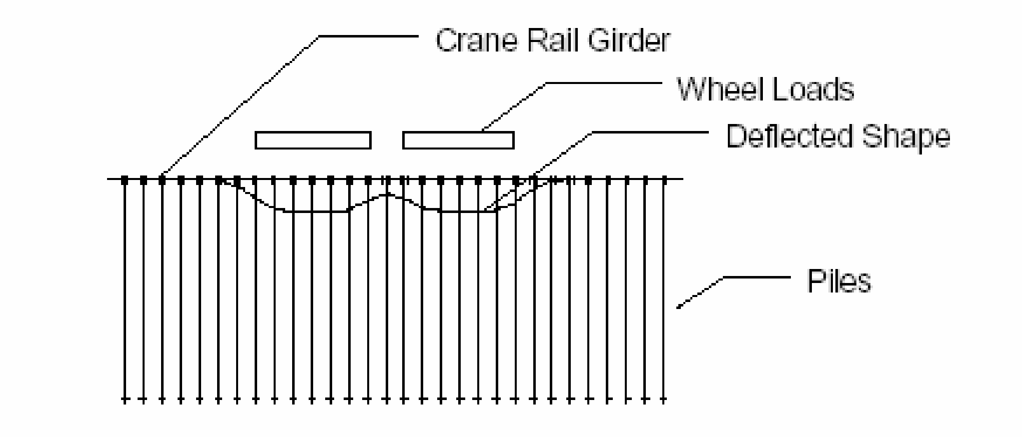
Elastic deflection of piles included

Girder may be modeled with cracked section properties.

Pile stiffness may be modeled with un-cracked section properties

2-D Analysis





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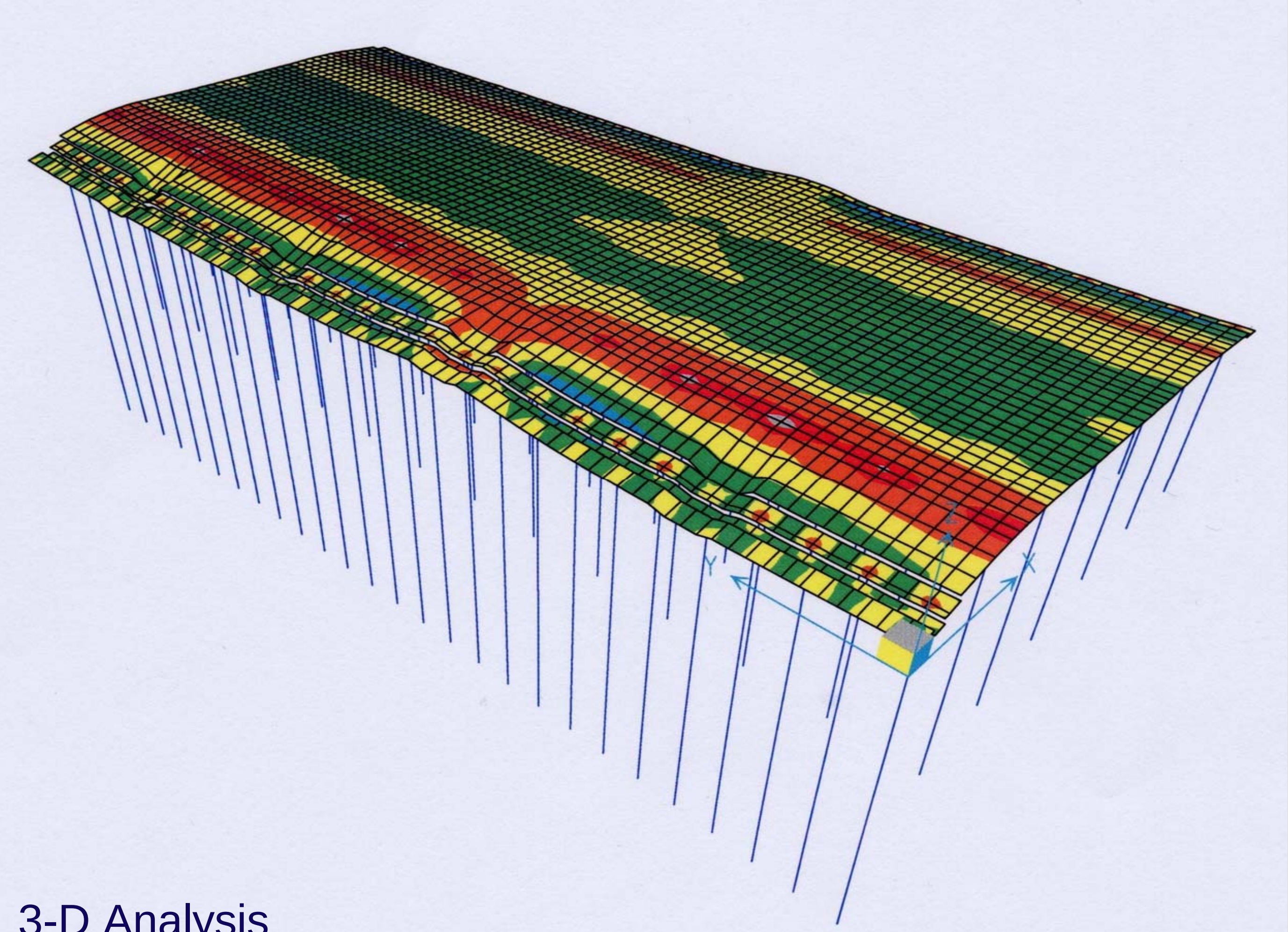
Analyzing the Entire Wharf



3-D Analysis

Strut and Tie Model

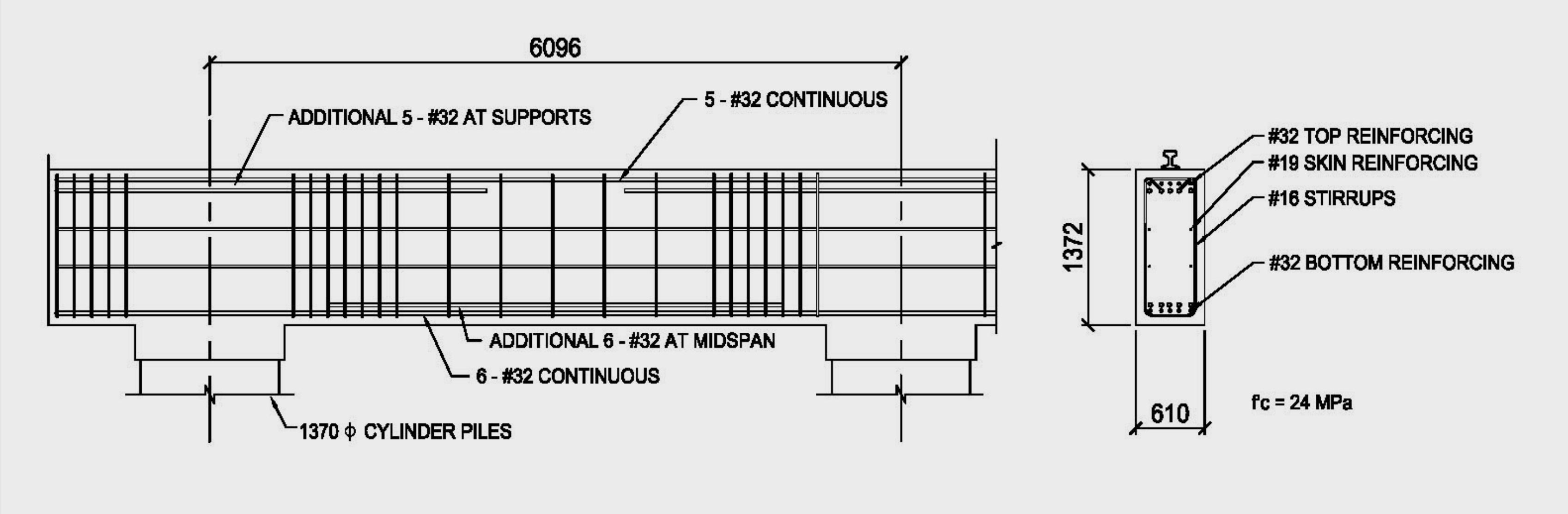
More accurately calculates capacities of structures having significant in-plane stresses or discontinuities.

Ultimate design uses empirical formulae to calculate strength

Strut and tie model converts the ultimate design model into compression and tension elements and provides more realistic results

Strut and Tie: Case Study

Virginia Port Authority, Portsmouth Marine Terminal, Phase 3 LS Girder

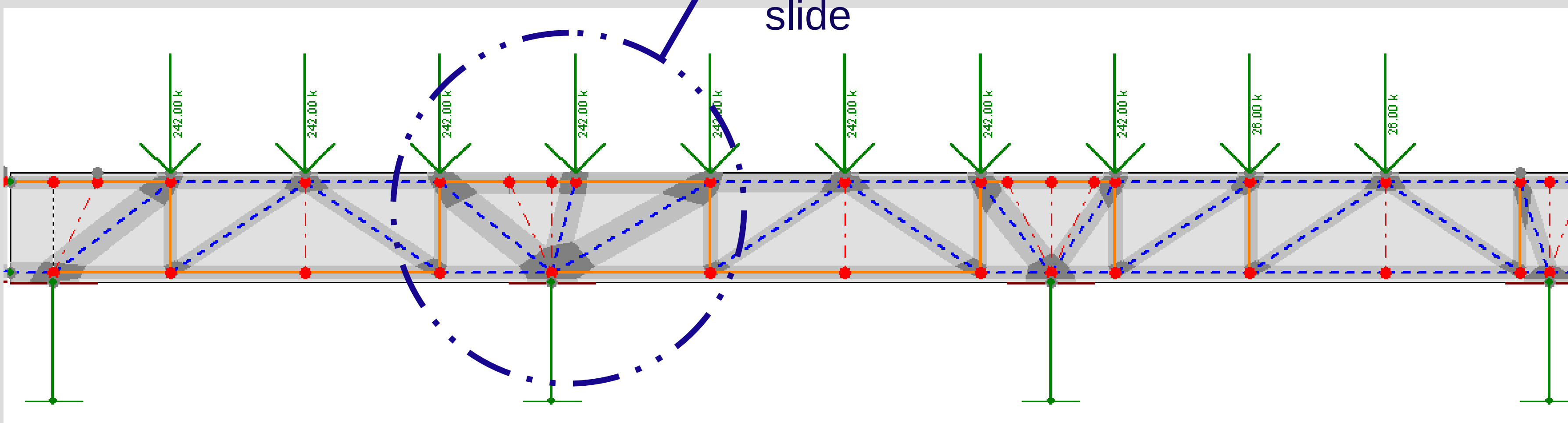


Details at Landside Crane Rail Girder

Strut and Tie: Case Study

Virginia Port Authority, Portsmouth Marine Terminal, Phase 3 LS Girder

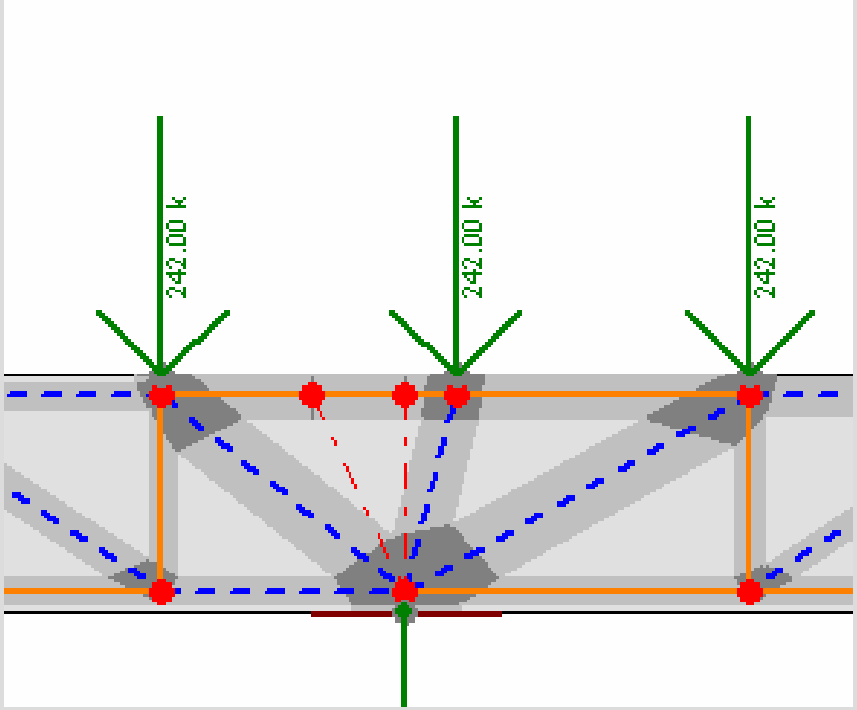
See next slide



Strut-and-Tie Model

Strut and Tie

Virginia Port Authority, Portsmouth Marine Terminal, Phase 3 LS Girder



Strut-and-Tie Model

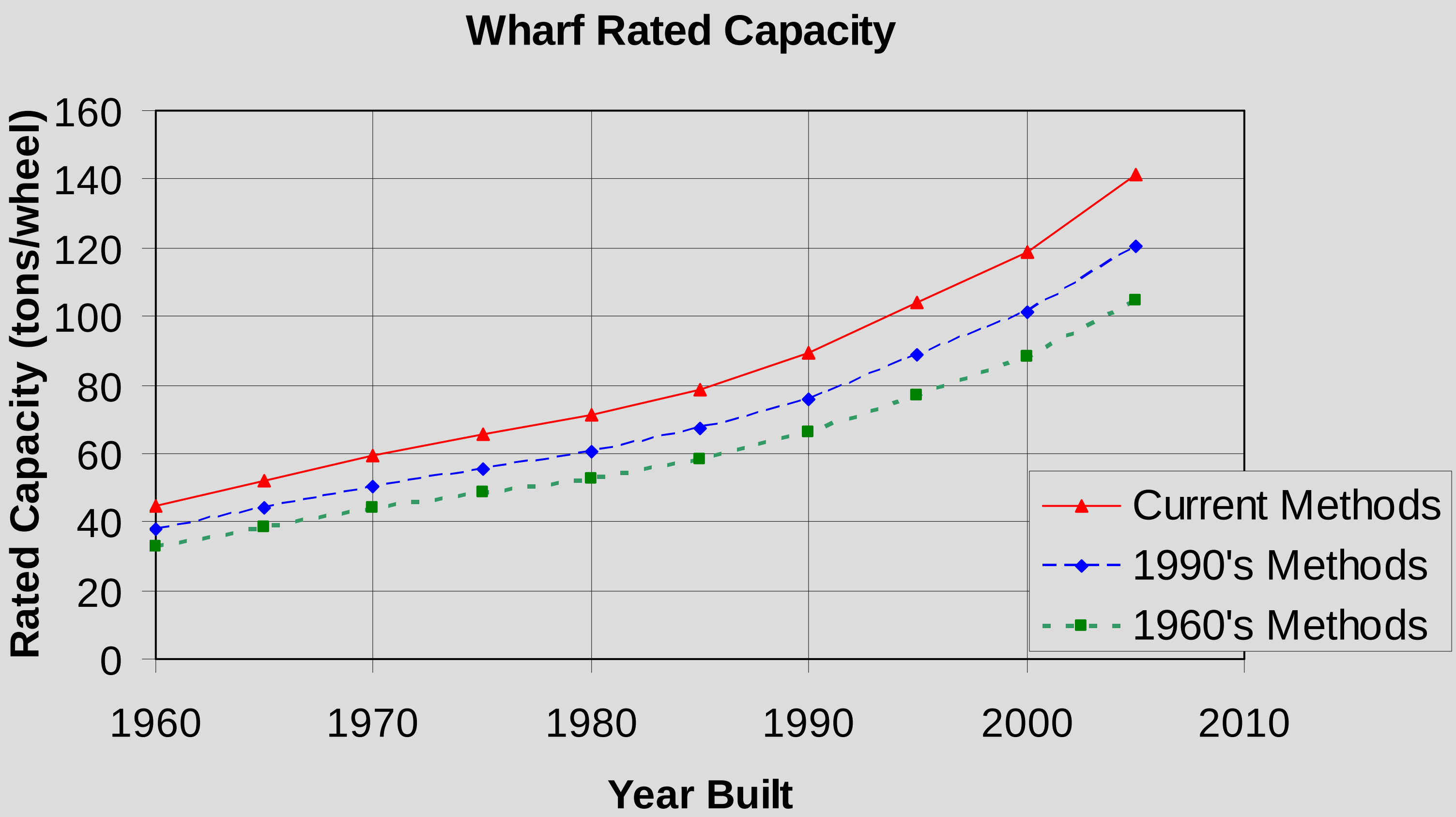
Strut and Tie: Case Study

Virginia Port Authority, PMT Case Study

Results:

- Increased allowable wheel load in center bays by 35%
- No increase in end bay allowable wheel loads
- No reinforcement for operating condition required
- Minimal modification required for stowed locations

Theoretical Wharf Rated Capacity vs. Year Built: Design



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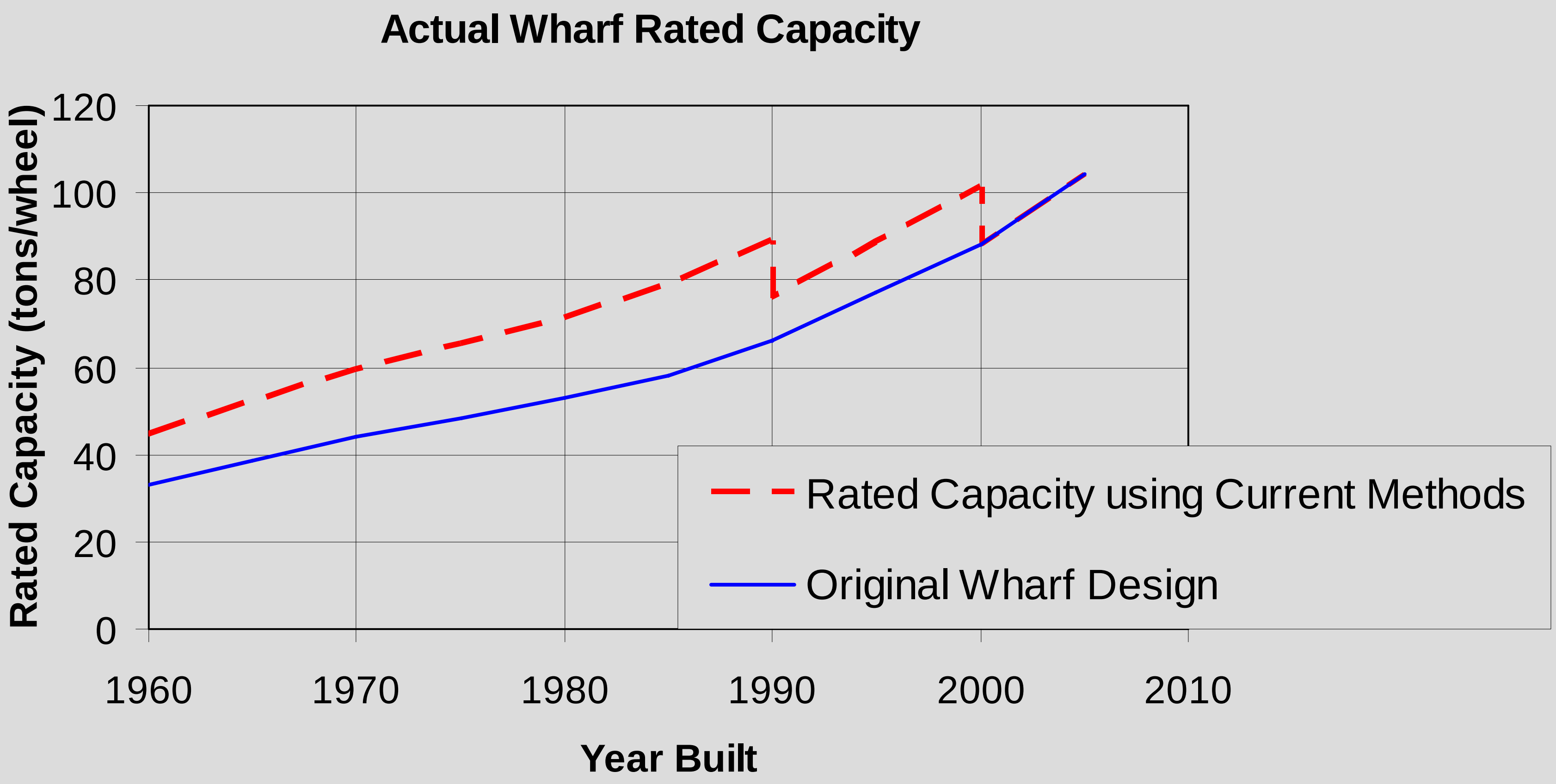
Actual Wharf Rated Capacity vs. Year Built: Design



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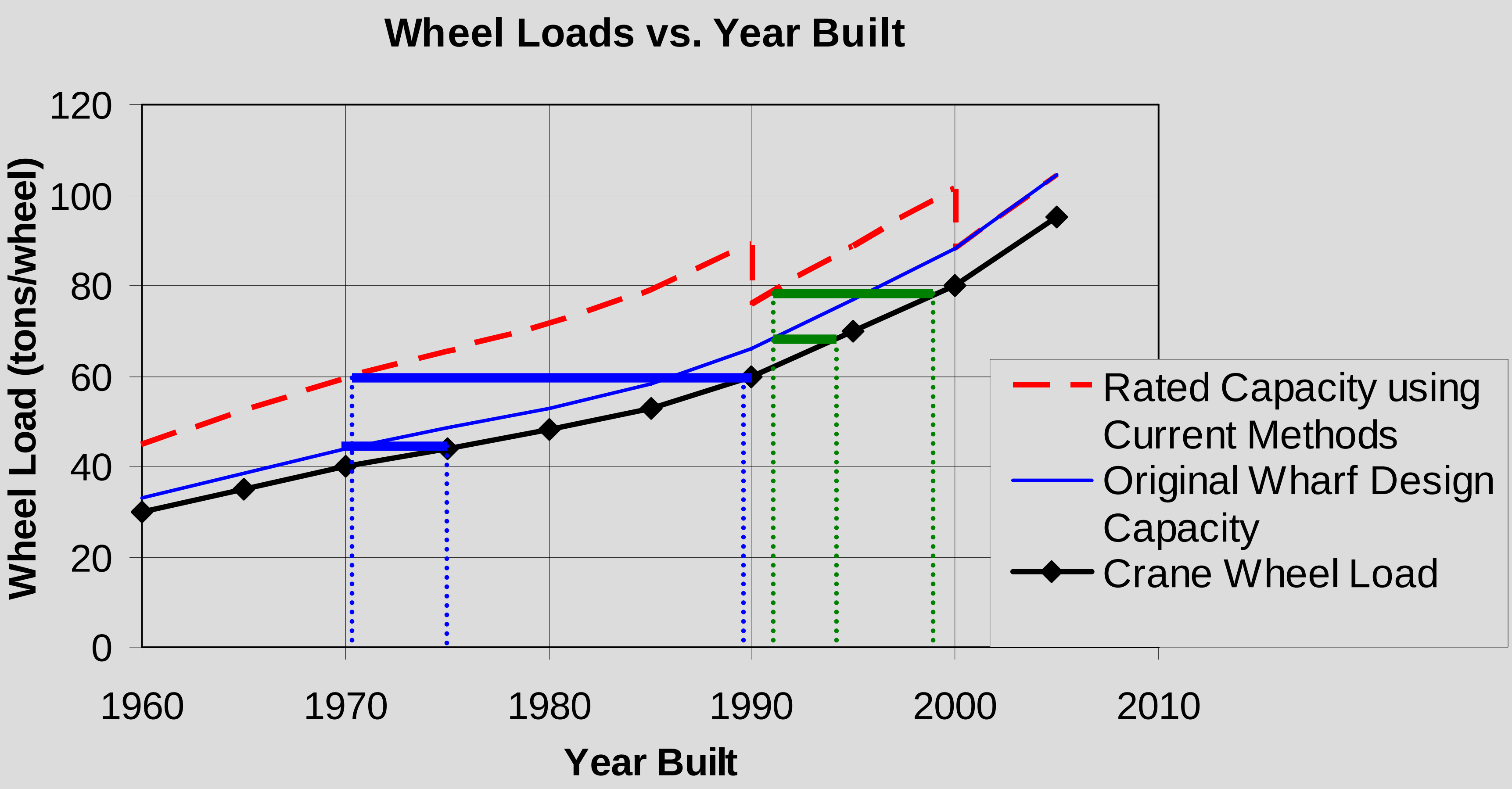
Wharf Rated Capacity and Applied Crane Loads



Section Six:
Other Considerations

Crane/Wharf Interface

Stowage Brackets

Collision Bumpers

Tie-downs

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Tie-downs: Pusan Hurricane, 2003

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Tie-downs

Rational stability combinations to calculate tie-down forces

Establish load path from crane to wharf … using the same loading and criteria

Often, the original design is not satisfactory

Most storm-related collapses are from tiedown system failure

Tie-downs

More Information?

This presentation is available for download on our website:

www.liftech.net

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Operating Jumbo Cranes on Existing Wharves

TOC Asia 2004

Thank You

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WESTWOOD RAINIER
NASSAU

Values of X Factors

vg—very good g—good f—fair p—poor

Characteristic			(Loading) B = vg	g	f	p
Very Good Workmanship	C = (Analysis)	vg	1.1	1.3	1.5	1.7
		g	1.2	1.45	1.7	1.95
		f	1.3	1.6	1.9	2.2
		p	1.4	1.75	2.1	2.45
Good Workmanship	C = (Analysis)	vg	1.3	1.55	1.8	2.05
		g	1.45	1.75	2.05	2.35
		f	1.6	1.95	2.3	2.65
		p	1.75	2.15	2.55	2.95
Fair Workmanship	C = (Analysis)	vg	1.5	1.8	2.1	2.4
		g	1.7	2.05	2.4	2.75
		f	1.9	2.3	2.7	3.1
		p	2.1	2.55	3.0	3.45
Poor Workmanship	C = (Analysis)	vg	1.7	2.15	2.4	2.75
		g	1.95	2.35	2.75	3.15
		f	2.2	2.65	3.1	3.55
		p	2.45	2.95	3.45	3.95

Source: "Ultimate Load Analysis of Reinforced and Prestressed Concrete Structures" by L. L. Jones

Values of Y Factors

Characteristic		D = (Personnel)		
		Not serious	Serious	Very serious
E = (Economic Considerations)	Not serious	1.0	1.2	1.4
	Serious	1.1	1.3	1.5
	Very serious	1.2	1.4	1.6

Source: "Ultimate Load Analysis of Reinforced and Prestressed Concrete Structures" by L. L. Jones

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