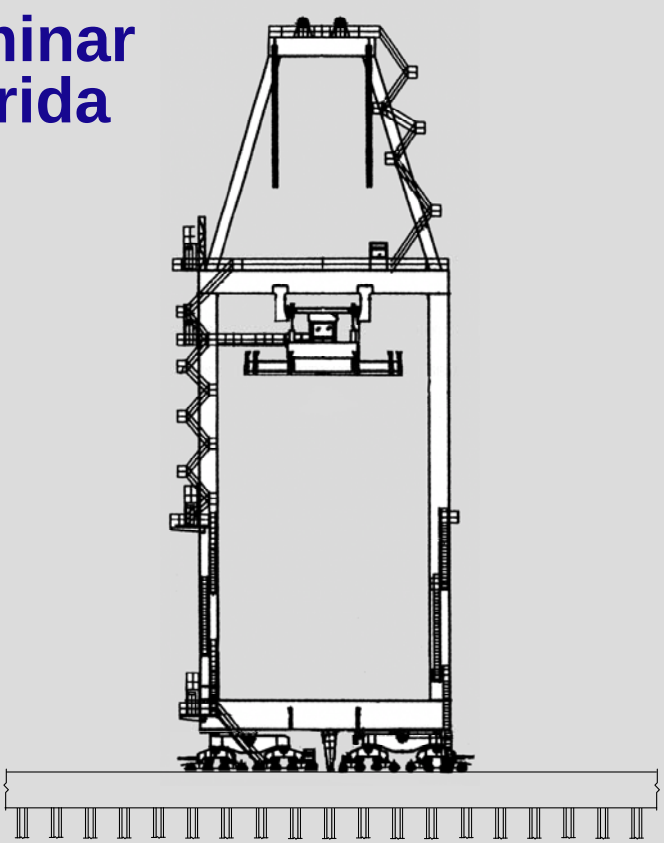
Crane Loads & Wharf Structure Design: Putting the Two Together

AAPA Facilities Engineering Seminar
January 2006 – Jacksonville, Florida



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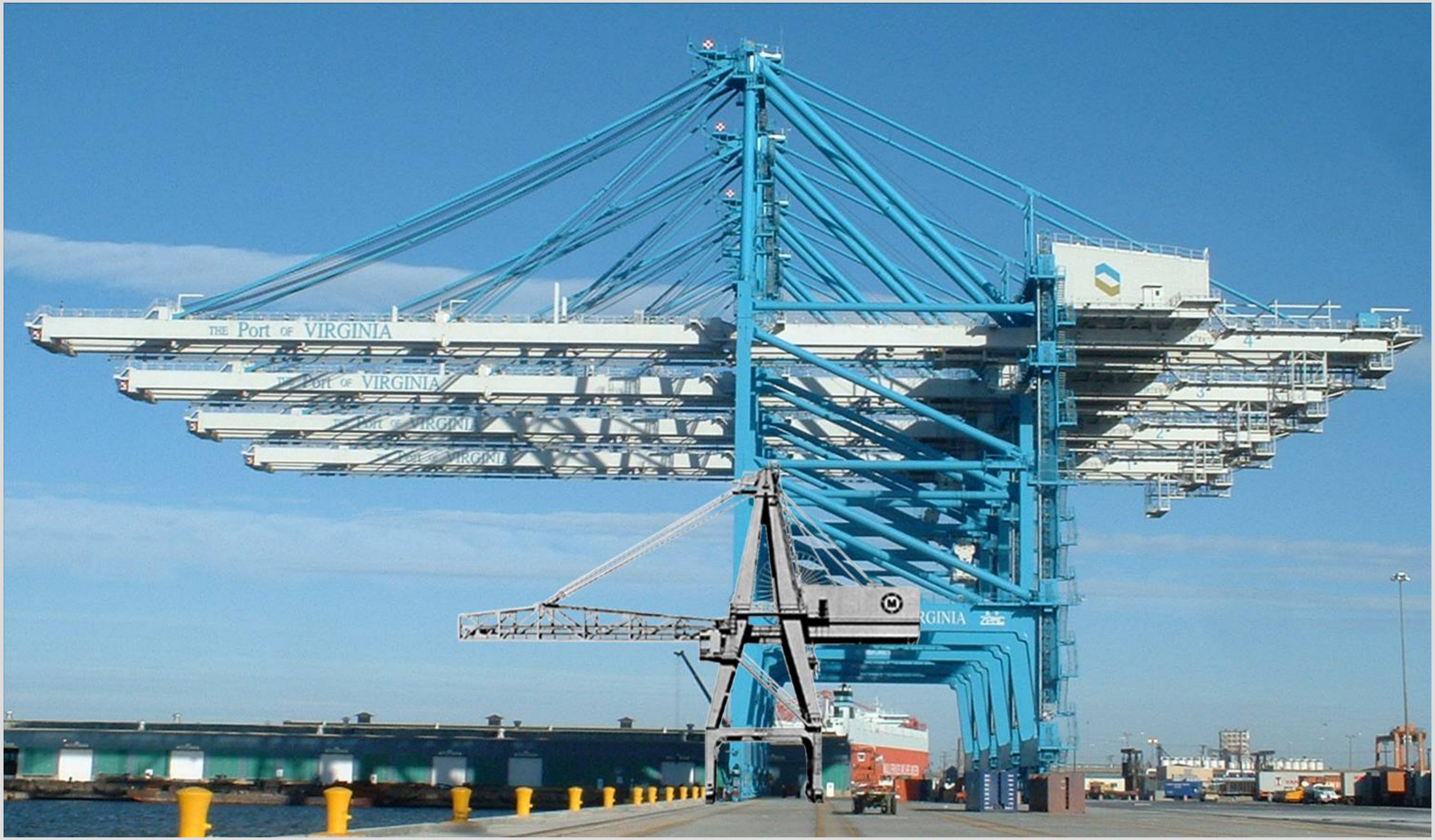
Crane Size Growth:
1st Container Crane & Jumbo Crane



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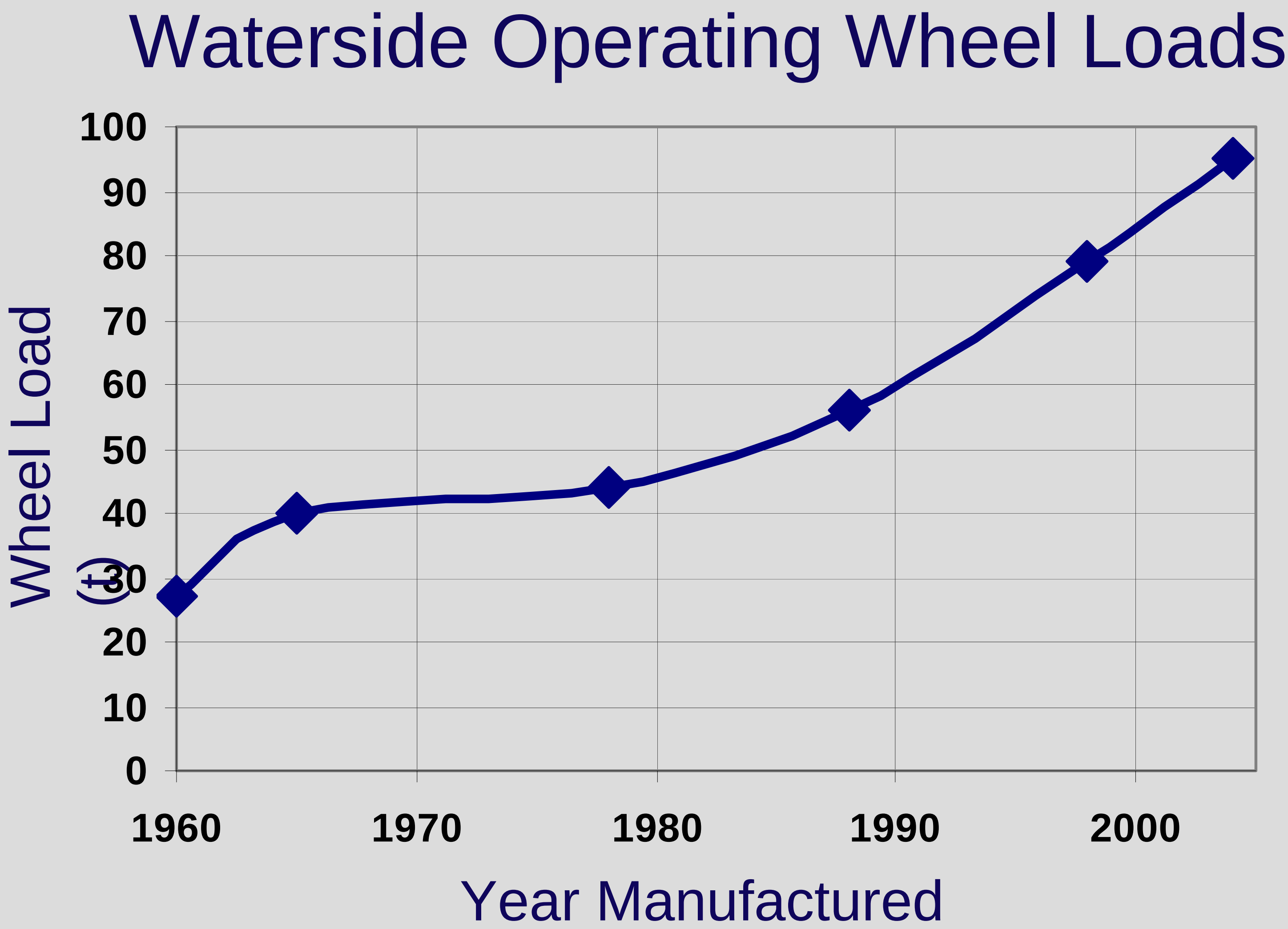
Crane Service Wheel Loads



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Crane Loads

Crane loads increasing

Codes becoming more complex

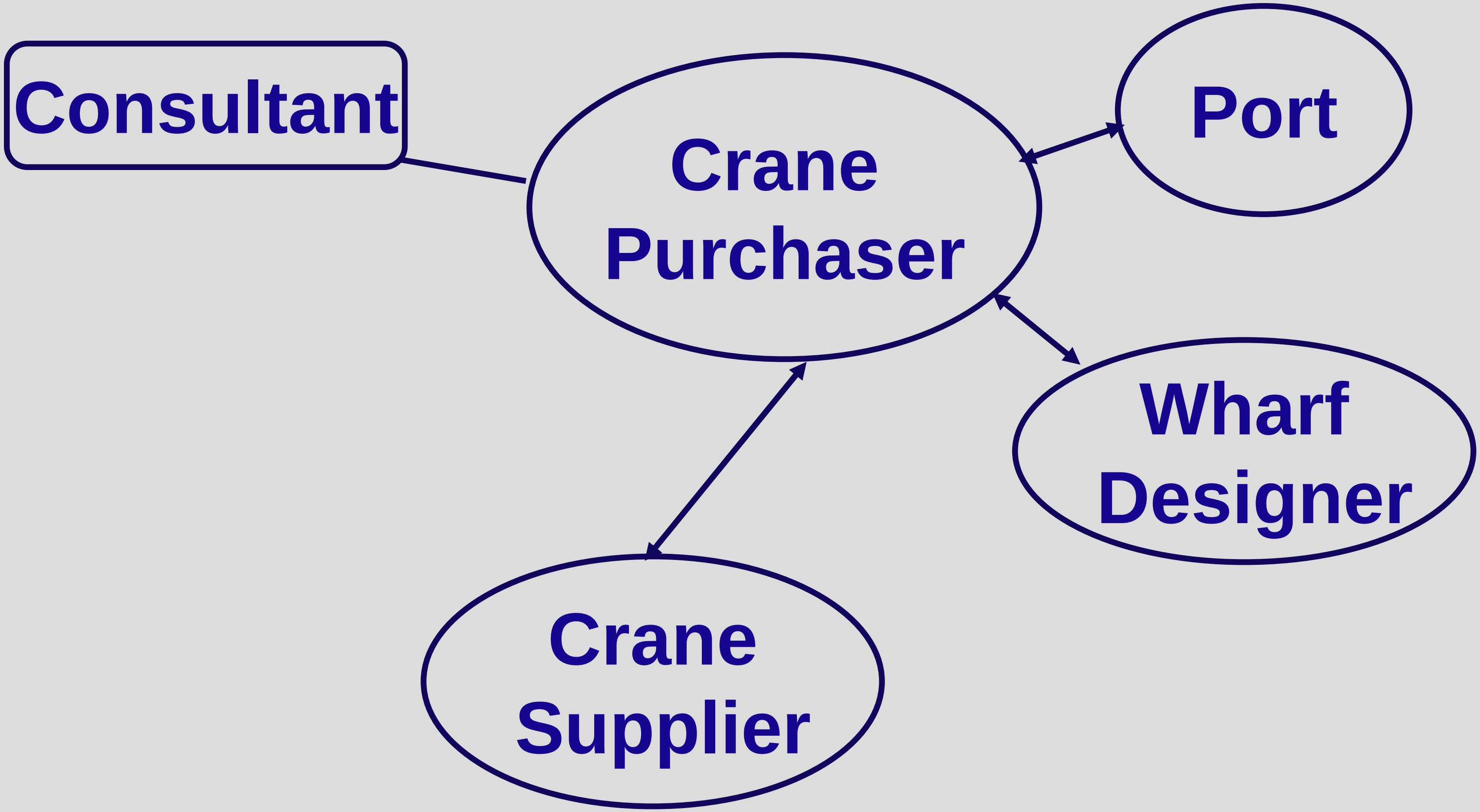
Consequences of misapplication more severe

Chance of engineering errors increasing

Presentation Outline

- The Problem – Overview
- Wharf Designer's Perspective
- Crane Designer's Perspective
- Putting the Two Together
- Q&A and Feedback

The Problem – Overview



Crane Purchaser Difficulties

Purchaser specified

“Allowable wheel load: 200 kips/wheel”

Suppliers submit

Supplier A	180 k/wheel
Supplier B	200 k/wheel
Supplier C	220 k/wheel

Which suppliers are compliant?

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Crane Supplier Difficulty

Purchaser specified

- Allowable wheel load: 200 kips/wheel
- In some cases, linear load (kips/ft)

Not defined

- Operating or out-of-service?
- Unfactored or factored?
- Wind profile?
- Increase for storm condition?

Wharf Designer Difficulty

Client provides limited crane load data

No loading pattern

No basis given – Unfactored or factored?

Same loads given for landside and waterside

No details of wind or seismic criteria

Wharf Designer Perspective

Wharf Designer Perspective

Codes and Design Principle

Crane Girder Design

Design for Tie-down Loads

Crane Stop Design

Seismic Design Considerations

Codes and Design Principle

Design Codes & Standards

Crane

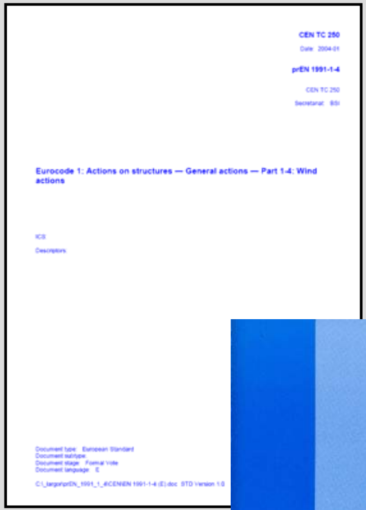
FEM, DIN, BS, AISC …, Liftech

Wharf Structures

ACI 318 Building Code and Commentary

ASCE 7-05 Minimum Design Loads for Buildings and Other Structures

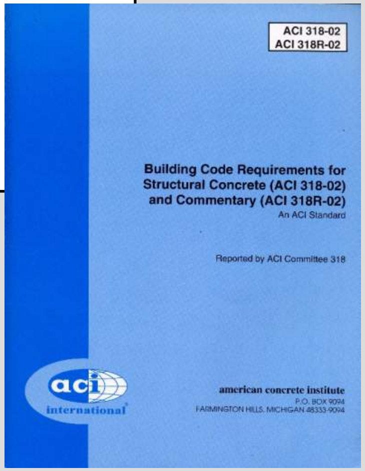
AISC Steel Construction Manual



CEN TC 250

prEN 1991-1-4

Eurocode 1: Actions on structures — General actions — Part 1-4: Wind actions



ACI 318-02
ACI 318R-02

Building Code Requirements for Structural Concrete (ACI 318-02) and Commentary (ACI 318R-02)
An ACI Standard

Reported by ACI Committee 318

american concrete institute
P.O. BOX 9094
FARMINGTON HILLS, MICHIGAN 48333-9094

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Design Principle - Wharf Structure Design

Load Resistance Factored Design (LRFD)

Required Strength $\leq$ Design Strength

Required Strength = $\sum$ Service Loads * Load Factors

Design Strength = Material Strength * Strength Reduction Factor Φ

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Load Factors & Φ Factors

ACI 318	Load Factors			Concrete Φ Factors		
	D	L	W	Ten	Comp	Shear
to 2002	1.4	1.7	1.3	0.90	0.75/.70	0.85
2002+	1.2	1.6	1.6*	0.90	0.70/.65	0.75

* 1.3 if directionality factor is not included

Design Principle – Soil Capacity

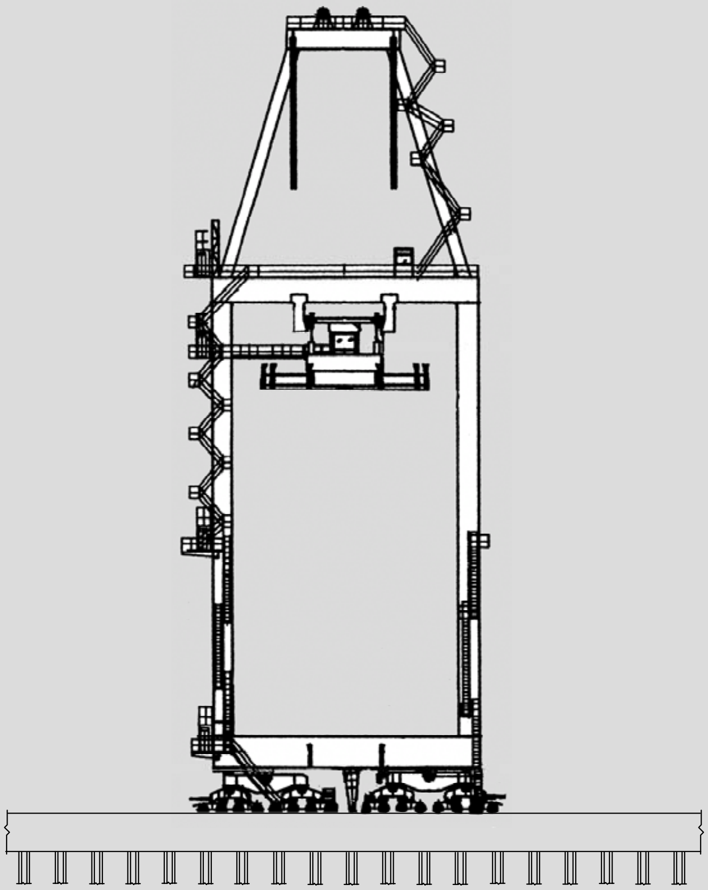
Allowable Stress Design

Generally use service loads

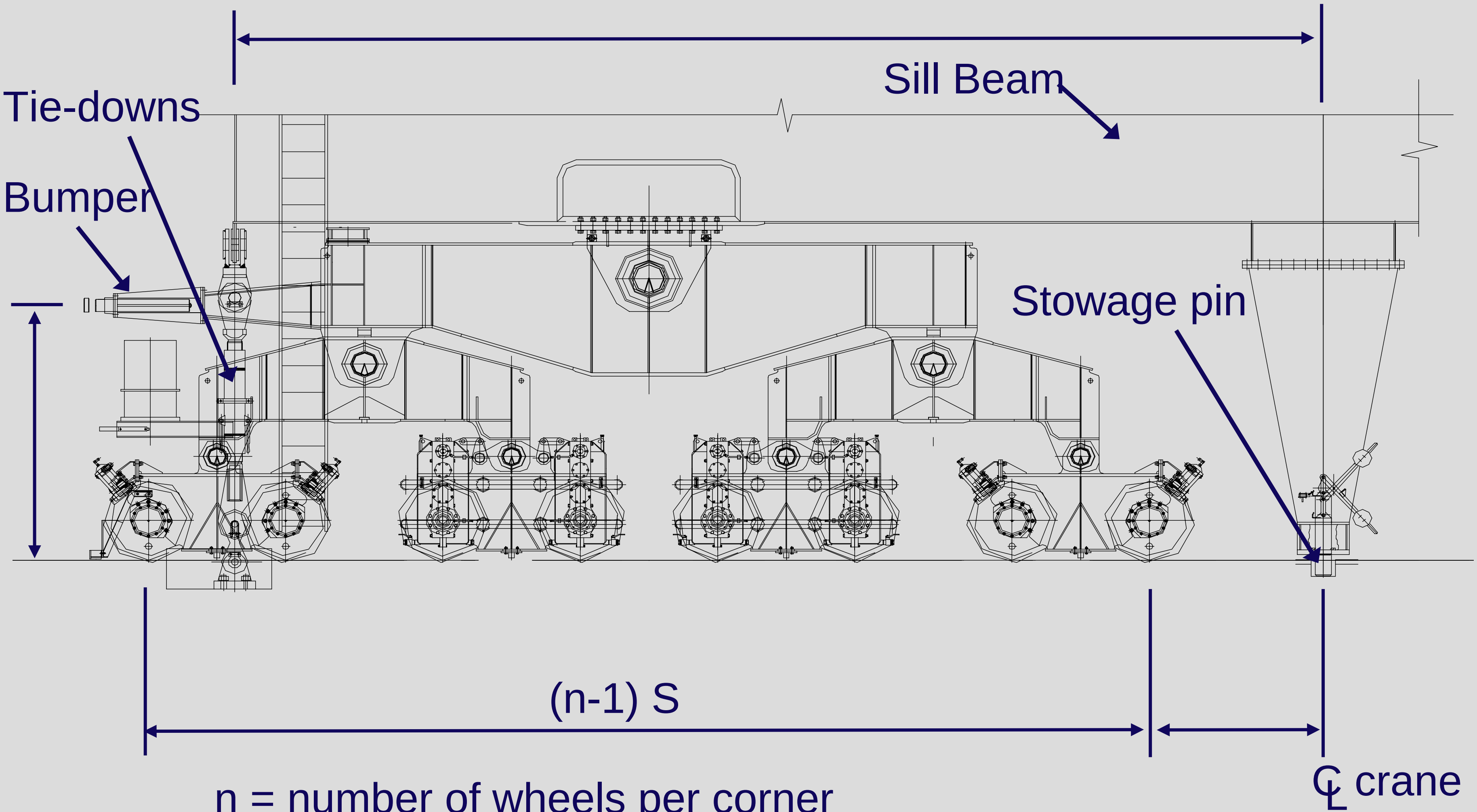
Factor of safety typically 2.0 for operating

1/3 increase for storm wind or overload

Crane Girder Design



Required Crane Geometry Data

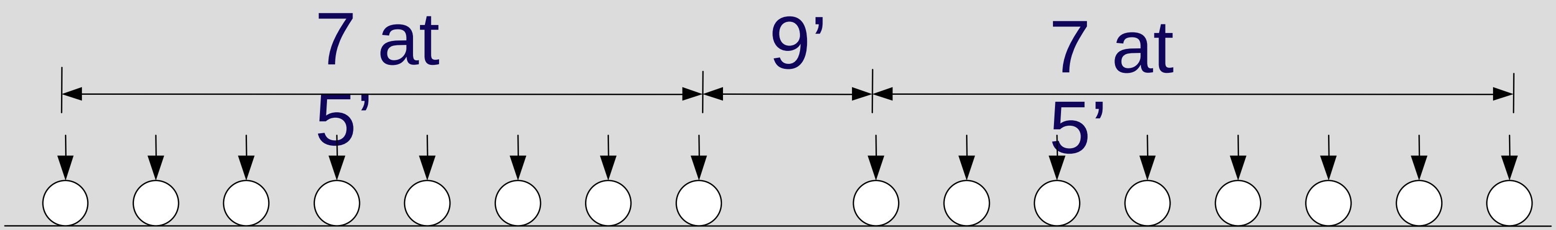


n = number of wheels per corner

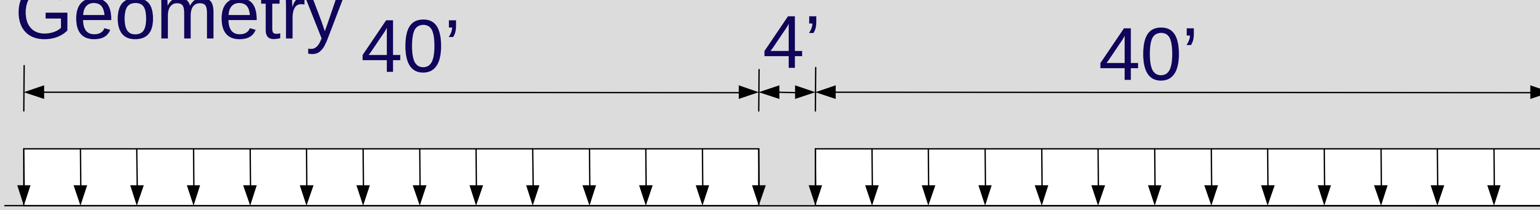
S = average wheel spacing

Typical Wheel Loading Geometry

Typical Wheel Spacing



Recommended Wheel Design Load Geometry



Dead Loads and Live Loads

Wharf Loads

D – Wharf structure self weight

L – Wharf live load, includes containers and yard equipment (does not control)

Crane Loads (ASCE 7-05)

D – Weight of crane excluding lifted load

L – Lifted load or rated capacity

ACI Load Factors – Crane Loading

ACI 318	Load Factors		
Year	D	L	Composite
to 2002	1.4	1.7	1.45
2002+	1.2	1.6	1.30

Some designers treat crane dead load as live load and use the 1.6 factor. This results in 23% overdesign;

1.6 / 1.3 = 1.23.

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Example Combination Table: Service Wheel Loads

Mode		Operating				Stowed
		WOP1	WOP2	WOP3	WOP4	WS1
Dead Load	DL	1.0	1.0	1.0	1.0	1.0
Trolley Load	TL	1.0	1.0	1.0	1.0	1.0
Lift System	LS	1.0	1.0		1.0	1.0
Lifted Load	LL	1.0	1.0		1.0	
Impact	IMP		0.5			
Gantry Lateral	LATG	1.0				
Op. Wind Load	WLO		1.0	1.0		
Stall Torque Load	STL			1.0		
Collision Load	COLL				1.0	
Storm Wind Load	WLS					1.0
Earthquake Load	EQ					
Allowable Wheel Loads (tons/wheel)	LS	50 x S				70 x S
	WS	65 x S				90 x S

S = Average spacing, in meters, between the wheels at each corner.

Example:

*S = 1.5 m, Allowable LS Operating = 50 t/m * 1.5 m = 75 t/wheel*

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Example Combination Table: Factored Wheel Loads

Mode		Operating				Stowed
		WOP1	WOP2	WOP3	WOP4	WS1
Dead Load	DL	1.2	1.2	1.0	1.0	1.2
Trolley Load	TL	1.2	1.2	1.0	1.0	1.2
Lift System	LS	1.2	1.2		1.0	1.2
Lifted Load	LL	1.6	1.6		1.0	
Impact	IMP		0.8			
Gantry Lateral	LATG	0.8				
Stall Torque Load	STL			1.0		
Collision Load	COLL				1.0	
Storm Wind Load	WLS					1.6
Earthquake Load	EQ					
Allowable Wheel	LS	60 x S				80 x S
Loads (tons/wheel)	WS	75 x S				100 x S

S = Average spacing, in meters, between the wheels at each corner.

Example:

*S = 1.5 m, Allowable WS Storm = 100 t/m * 1.5 m = 150 t/wheel*

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Tie-down Design

Multiple Tie-downs at a Corner

Uneven tie-down forces

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Causes of Uneven Distribution

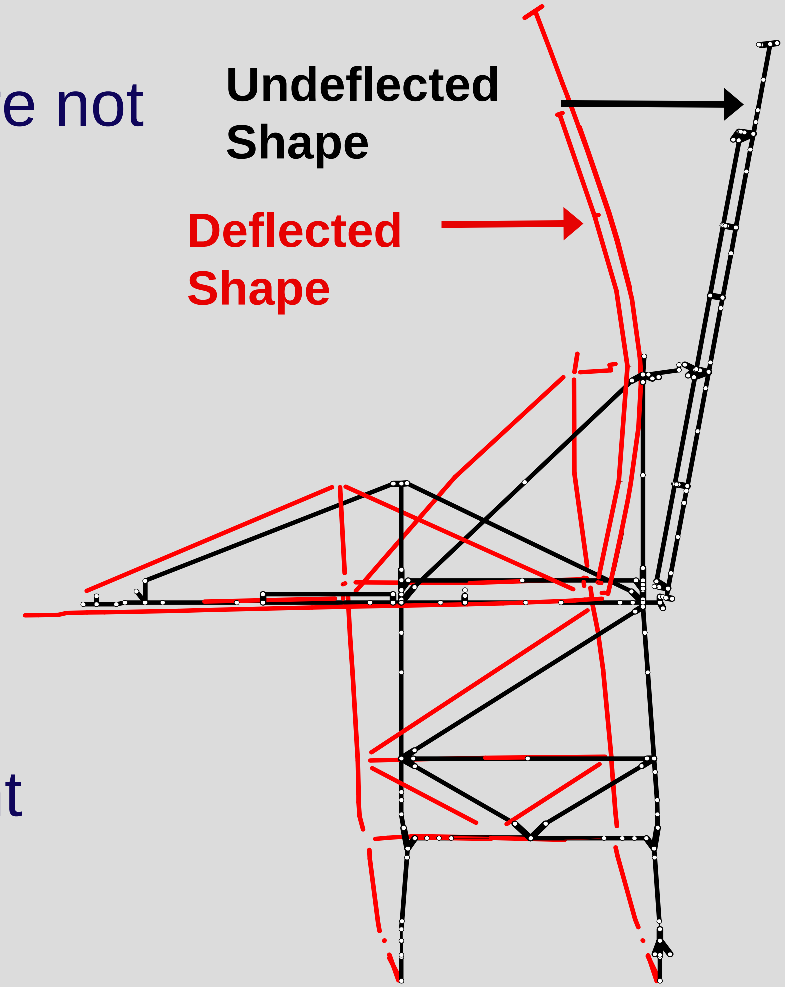
Some reasons why forces are not evenly distributed:

Crane deflection

Contruction tolerances

Wharf pins not centered

Links not perfectly straight due to friction

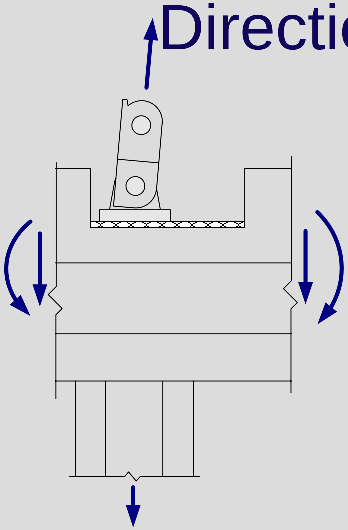


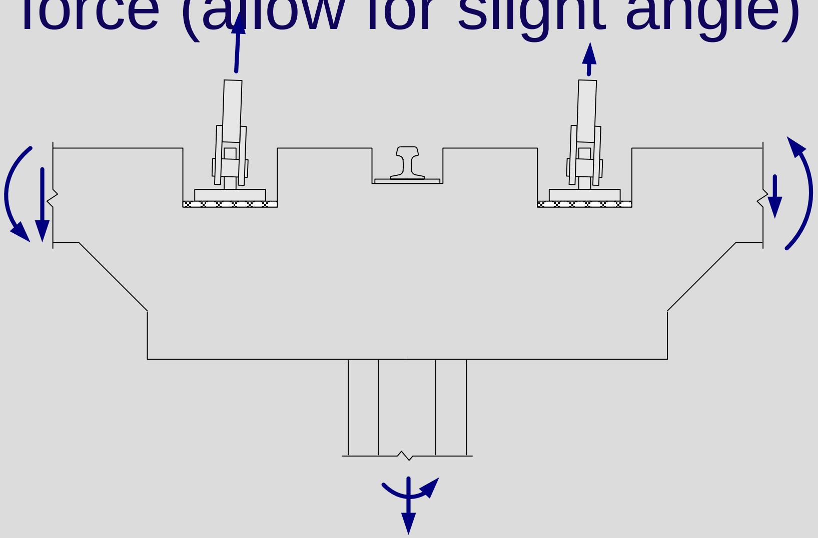
Tie-down Loads

Manufacturers typically provide the service corner uplift force

Needed data:

- Factored corner uplift force
- Distribution between tie-downs
- Direction of force (allow for slight angle)





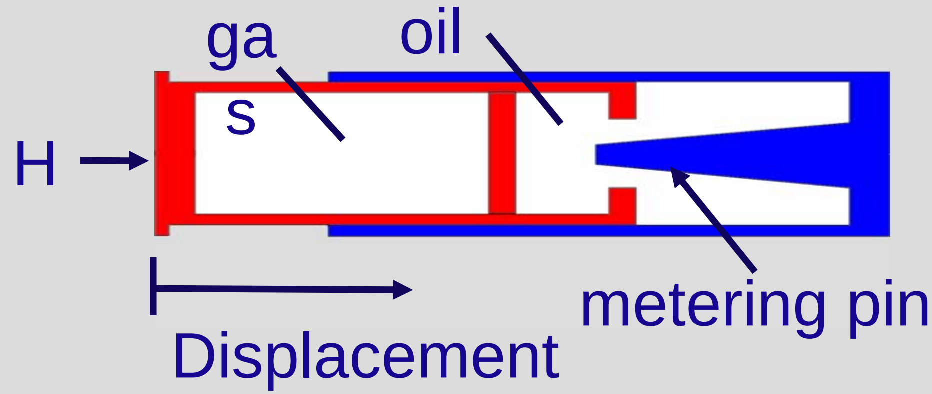
Crane Stop Design

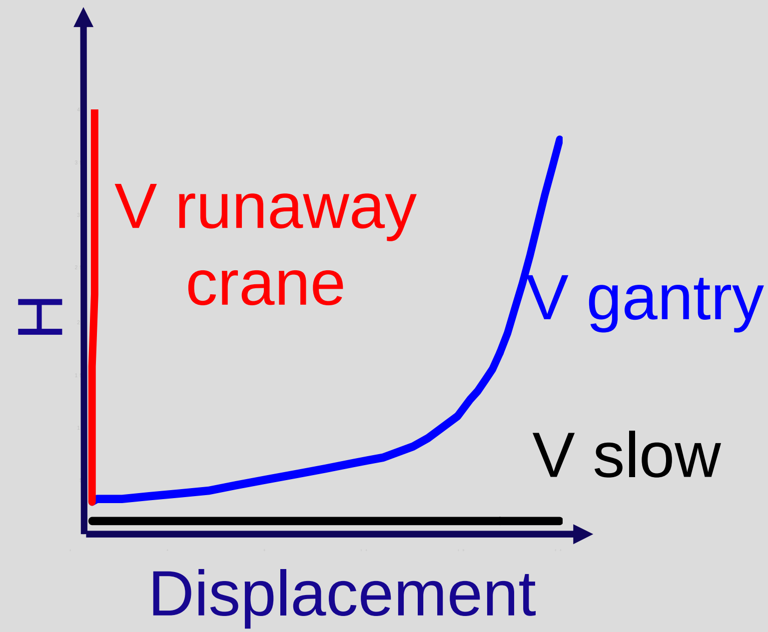
Bumper Load Provided by Manufacturer

Rated Bumper Reaction

Bumpers sized for collision at maximum gantry speed

Does not address runaway crane





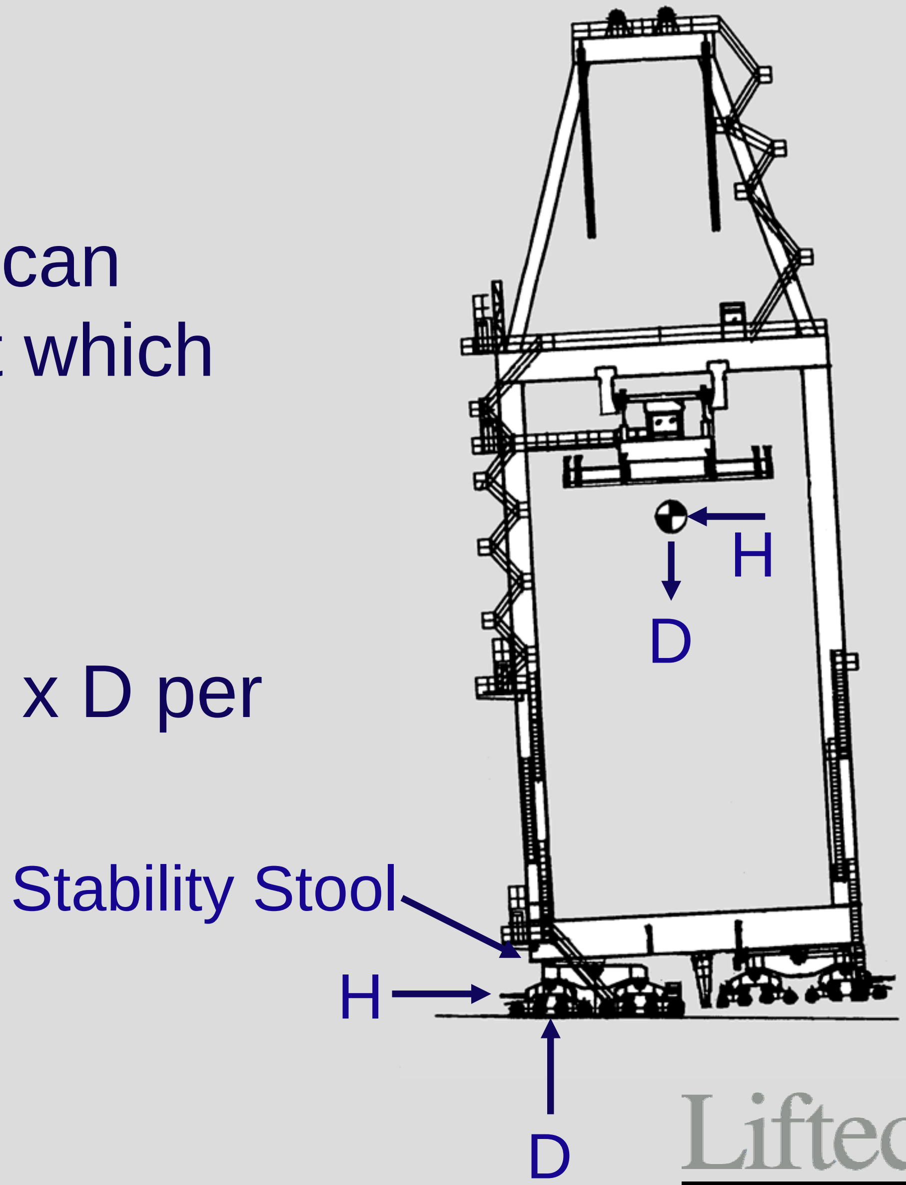
Recommended Crane Stop Design Load

Tipping Force

H= maximum load that can develop, i.e. the load at which the crane tips.

D = crane weight

H = approximately 0.25 x D per stop



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Wharf Seismic Design – Crane Loading

The mass of typical jumbo A-frame cranes can be ignored

For certain wharves and cranes, a time-history analysis may be necessary

Large, short duration wheel loads can be ignored

Localized rail damage may occur

The crane may derail

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Crane Designer Perspective

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Crane Designer Perspective

Basic Loads

Storm Wind Load

Load Combinations and Factors

Tie-down Loads

Basic Loads

Dead and Live Loads

Dead Loads

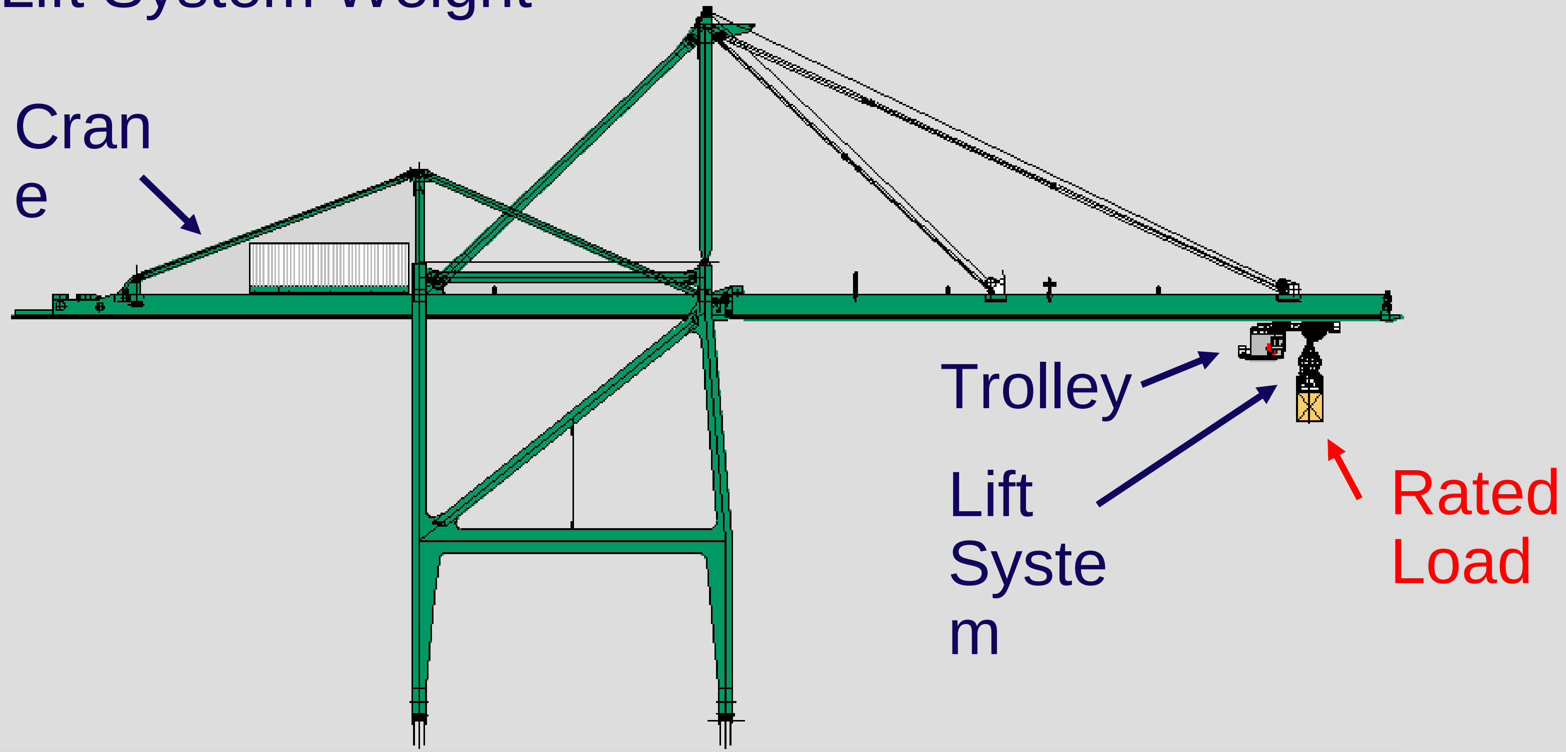
DL: Crane structure weight

TL: Trolley structure weight

LS: Lift System Weight

Live Loads

LL: Rated container load



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Inertial Loads

IMP: Vertical impact due to hoist acceleration

LATT: Lateral due to trolley acceleration

LATG: Lateral due to gantry acceleration

Overload

COLL: Collision

SNAG: Snagging headblock

STALL: Stalling hoist motors

Normally do not control

Environmental Loads

WLO: Wind load operating (In-Service)

WLS* : Wind load storm (Out-of-Service)

EQ: Earthquake load

Often a major source of discrepancies

Wind Load, Out-of-Service

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WLS: Out-of-Service Wind

Wind Force = $\sum A \times C_f \times q_z$

- A = Area of crane element
- C_f = Shape coefficient (including shielding) } From wind tunnel testing
- q_z = Dynamic pressure, function of:
  - Mean recurrence interval (MRI)
  - Gust duration
  - V_{ref}^2, where V_{ref} is a location-specific, code-specified reference wind speed
  - Exposure (surface roughness)

} Need to clearly specify

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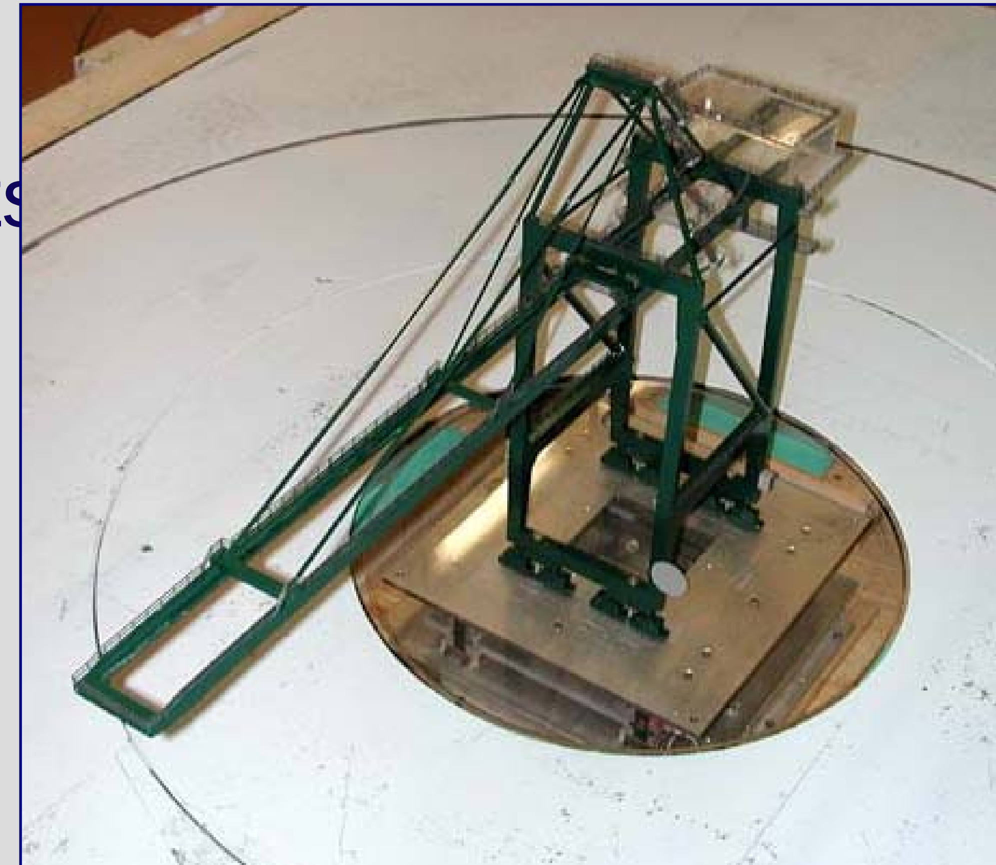
Shape Coefficient, C_f

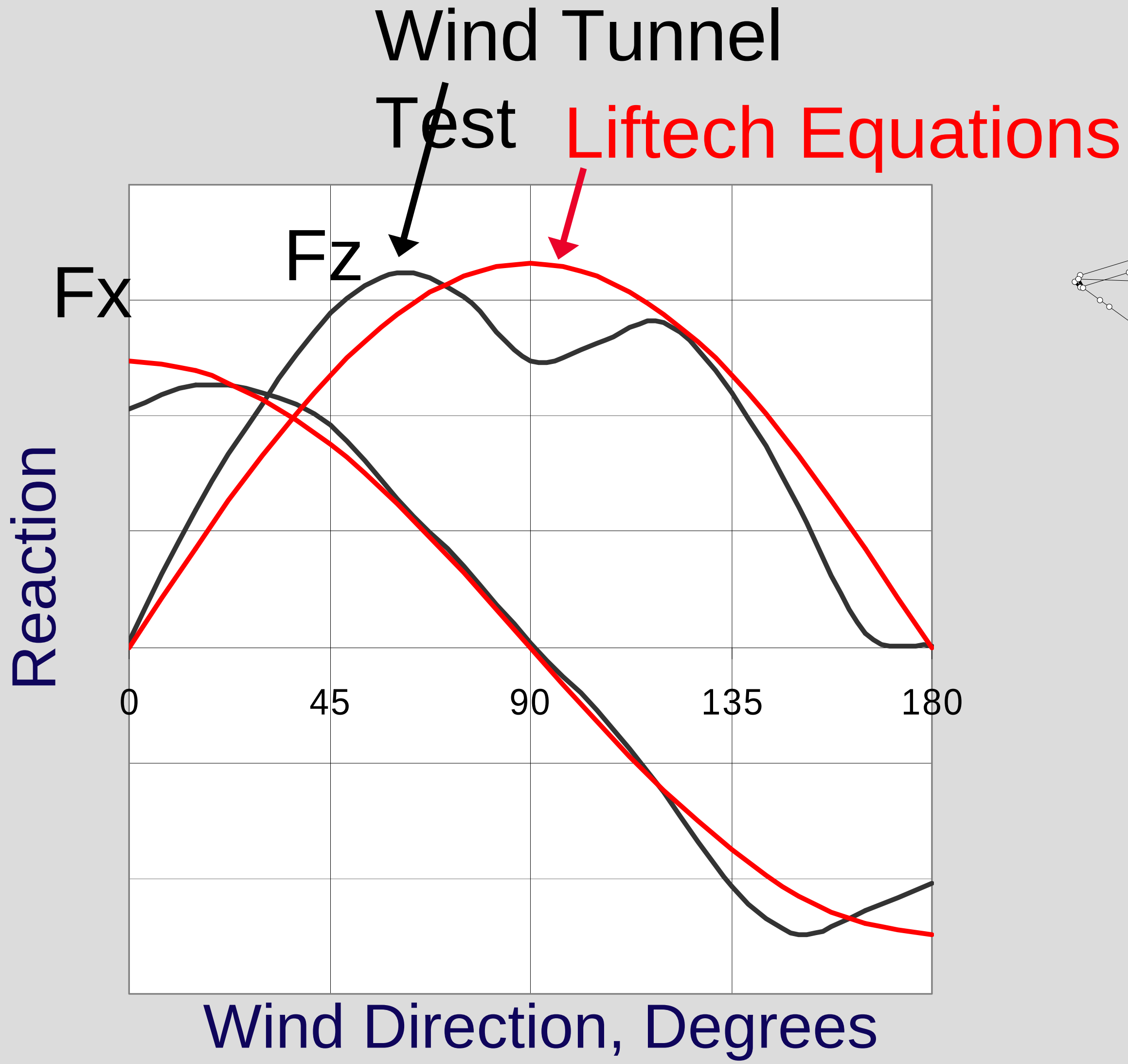
Empirical values: FEM, BSI, etc.

Wind tunnel tests are more accurate

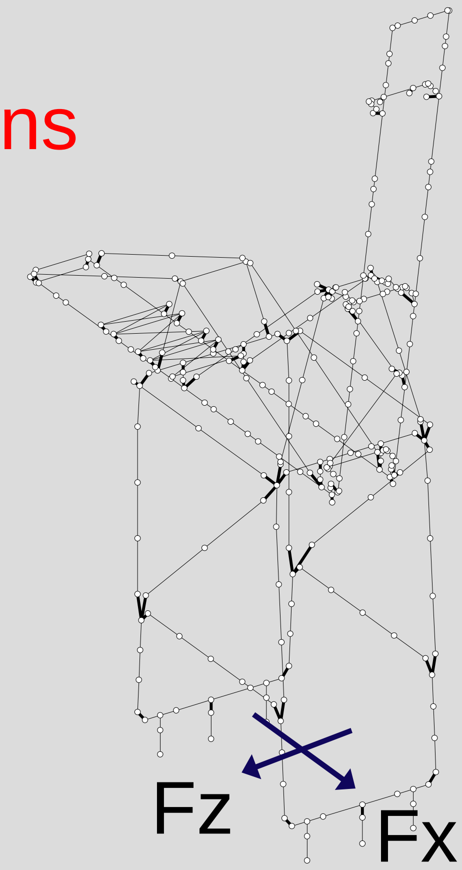
- Boundary layer
- Angled wind effects
- Shielding effects



Angled Wind



Wind Tunnel
Test
Liftech Equations
Fz
Fx
Reaction
0
45
90
135
180
Wind Direction, Degrees



Fz
Fx

WLS: Mean recurrence interval (MRI)

Wind Force = $\sum A \times C_f \times q_z$

A = Area of element

C_f = Shape coefficient (including shielding) } From wind tunnel testing

q_z = Dynamic pressure, function of:

- **Mean recurrence interval (MRI)**
- Gust duration
- V_{ref}^2, where V_{ref} is a location-specific, code-specified reference wind speed
- Exposure (surface roughness)

} Need to clearly specify

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Mean Recurrence Interval

Probability of Speed Being Exceeded

	Years in Operation				
MRI	1	10	**25**	50	100
10 yrs	.10	.64	.93	.99	.99997
25 yrs	.04	.34	.64	.87	.98
50 yrs	.02	.18	**.40**	.64	.87
100 yrs	.01	.10	.22	.39	.64

Example:

Chance of 50-yr wind being exceeded in 25 years: 40%

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WLS: Gust duration

Wind Force = $\sum A \times C_f \times q_z$

A = Area of crane element

C_f = Shape coefficient (including shielding) } From wind tunnel testing

q_z = Dynamic pressure, function of:

- Mean recurrence interval (MRI)
- Gust duration
- V_{ref}^2, where V_{ref} is a location-specific, code-specified reference wind speed
- Exposure (surface roughness)

} Need to clearly specify

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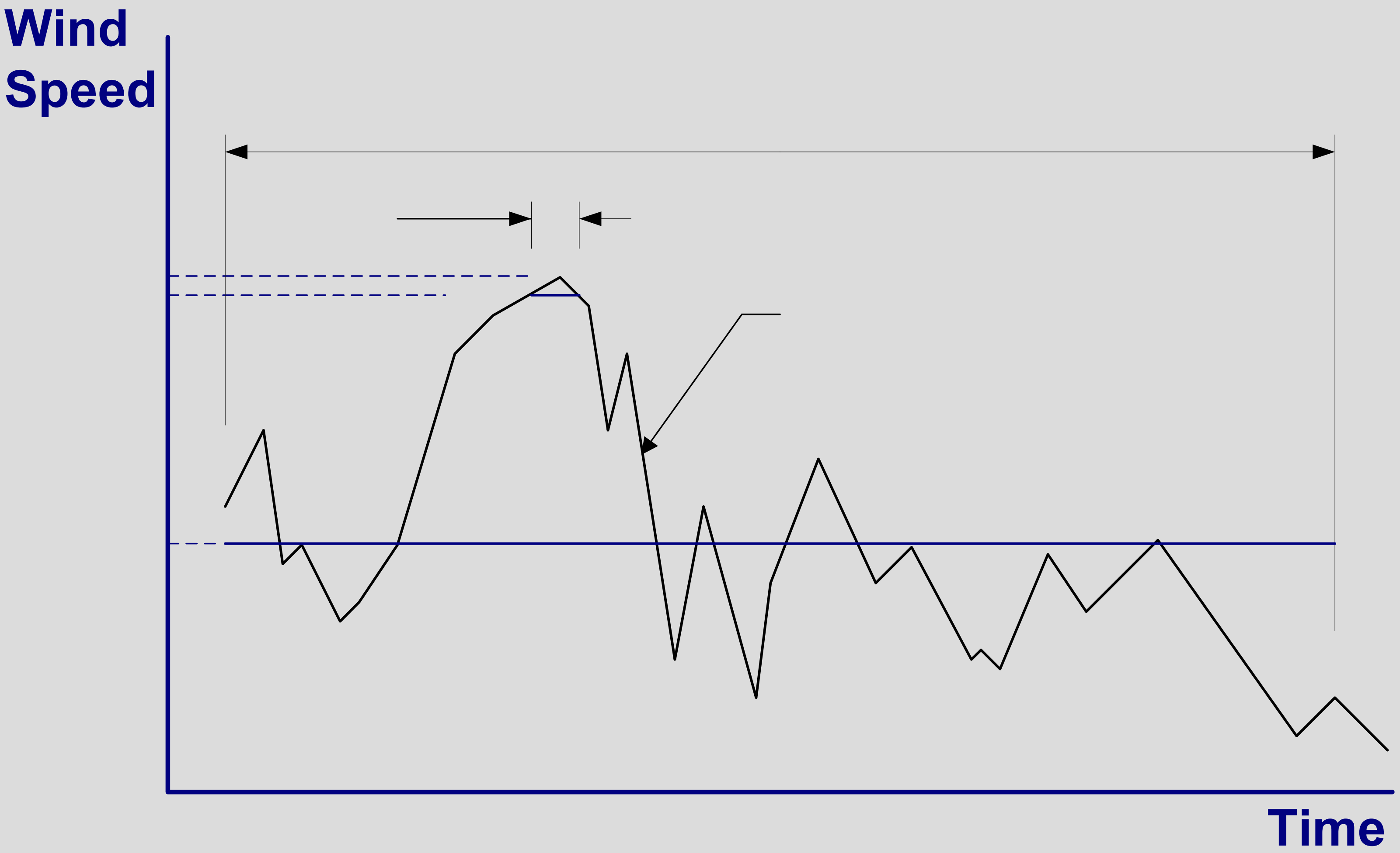
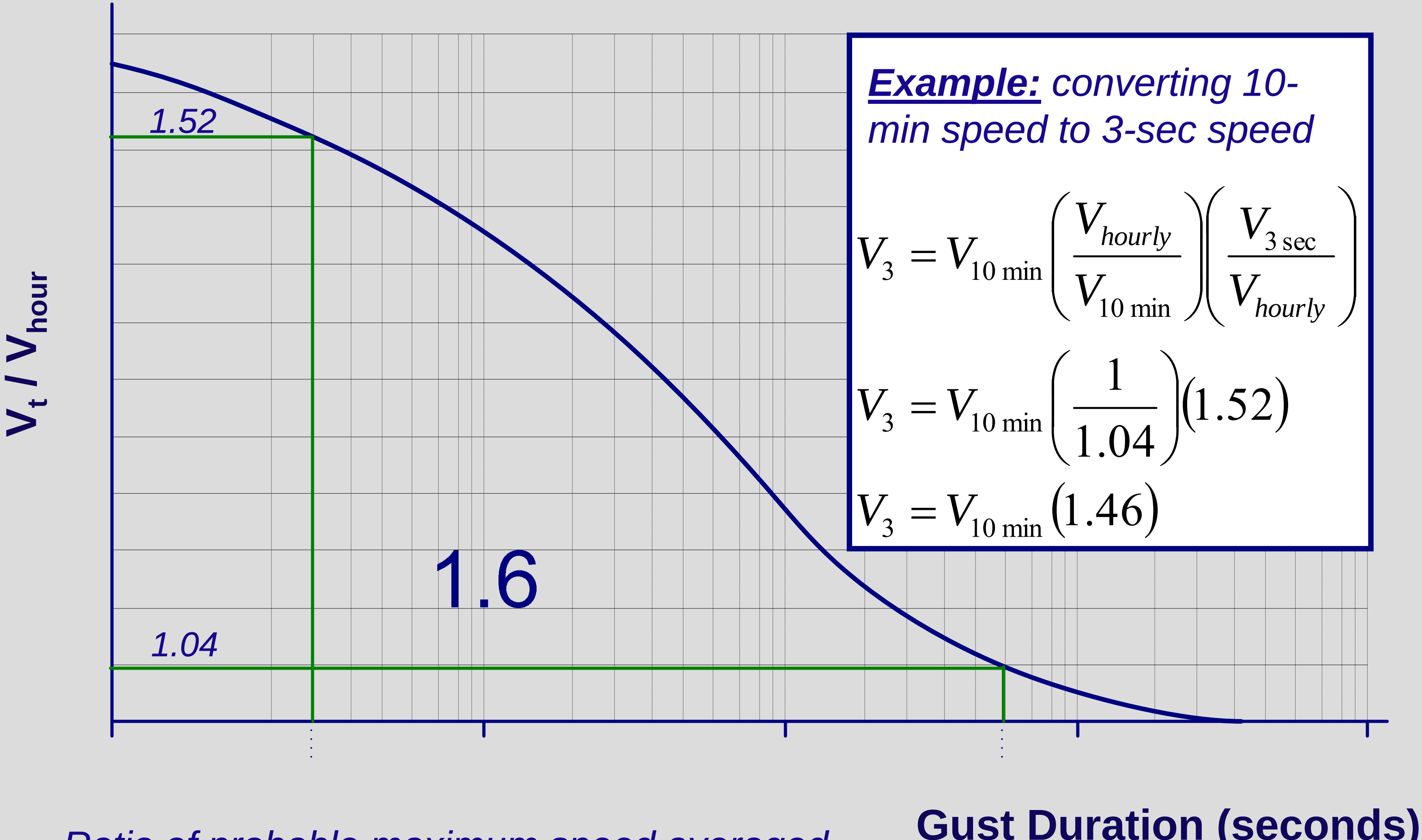
Gust Duration



Wind Speed vs. Gust Duration



Example: *converting 10-min speed to 3-sec speed*

$$V_3 = V_{10\text{ min}} \left(\frac{V_{hourly}}{V_{10\text{ min}}} \right) \left(\frac{V_{3\text{ sec}}}{V_{hourly}} \right)$$

$$V_3 = V_{10\text{ min}} \left(\frac{1}{1.04} \right) (1.52)$$

$$V_3 = V_{10\text{ min}} (1.46)$$

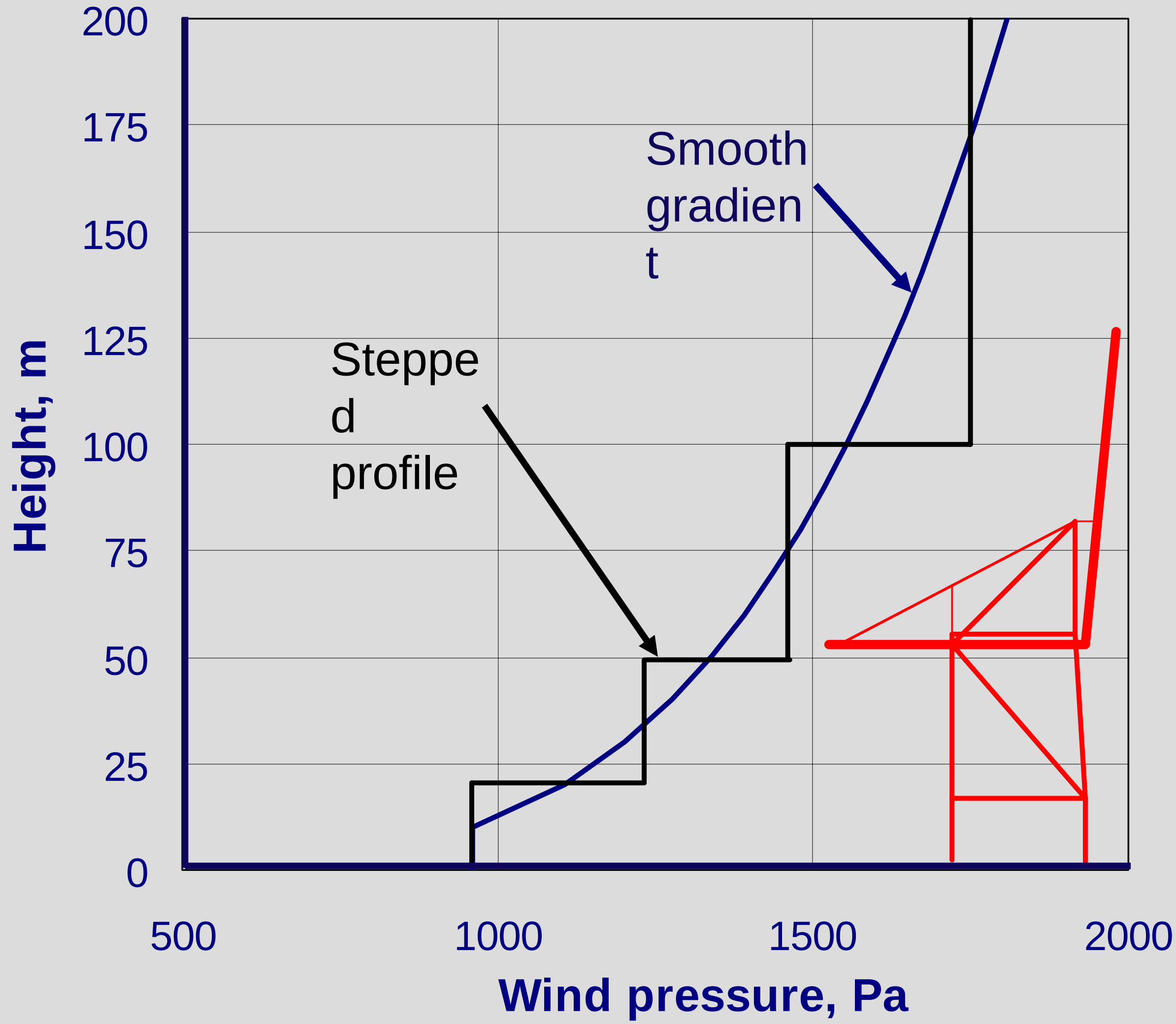
Ratio of probable maximum speed averaged over "t" seconds to hourly mean speed. Reference, ASCE 7-05.

Code Gust Durations

Code definitions of basic wind speed

Code	Gust Duration	MRI
EN 1991-1-4	10 min	50 yrs
FEM 1.004	10 min	50 yrs
ASCE 7-02	3 sec	50 yrs
HK 2004	3 sec	50 yrs

Typical Pressure Profiles



Shape of profile depends on surrounding surface roughness

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Variation in WLS

Variable	Variation	Effect on V	Effect on F *
MRI	25 to 50 yrs	7.5%	15.6%
Gust duration	3 sec to 10 min	46%	113%
Profile	Open terrain to ocean exposure	5-10%	10-20%

See later slides for effect on calculated tie-down load!

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Recommendations for Specifying WLS

Return Period	Use 50-yr MRI
Basic wind speed Gust duration Profile Other factors	Use local civil code
Shape coefficients	Wind tunnel tests

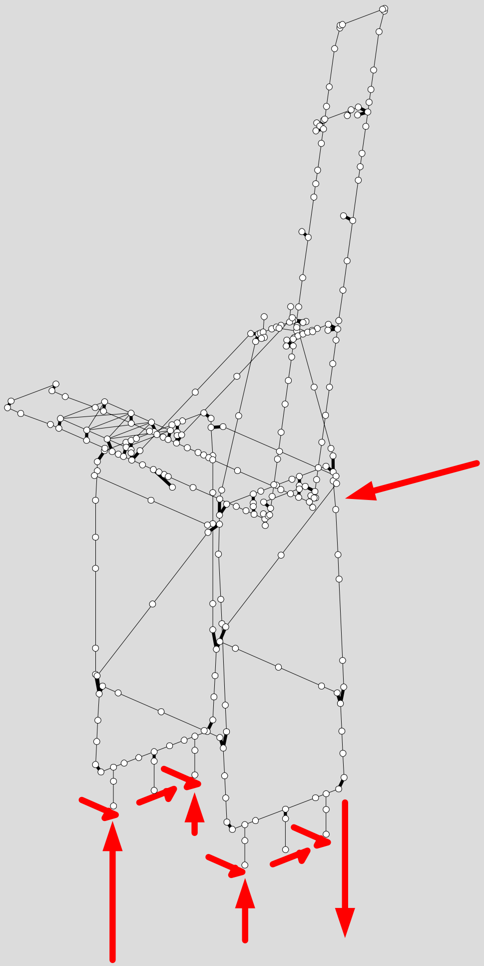
Do not mix and match between codes for pressure and load factors !

Corner Reactions – Angled Wind

Do not use spreadsheet !

Use frame analysis program

Frame stiffness is significant to reactions



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Load Combinations
Crane Design

Load Combinations

Load combinations

- Operating
- Overload
- Storm wind (out-of-service)

Design approaches

- Generally Allowable Stress Design (ASD)

Operating Condition Loads

DL:	Crane weight*
LL:	Rated container load
IMP & LAT:	Inertial loads
WLO:	Wind load, in service

Excluding Rated Load

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Out-of-Service & Overload

DL: Crane weight*

WLS: Wind load storm (out-of-service)

Overload Conditions (in and out-of-service)

Including trolley and lift system

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Recommendations

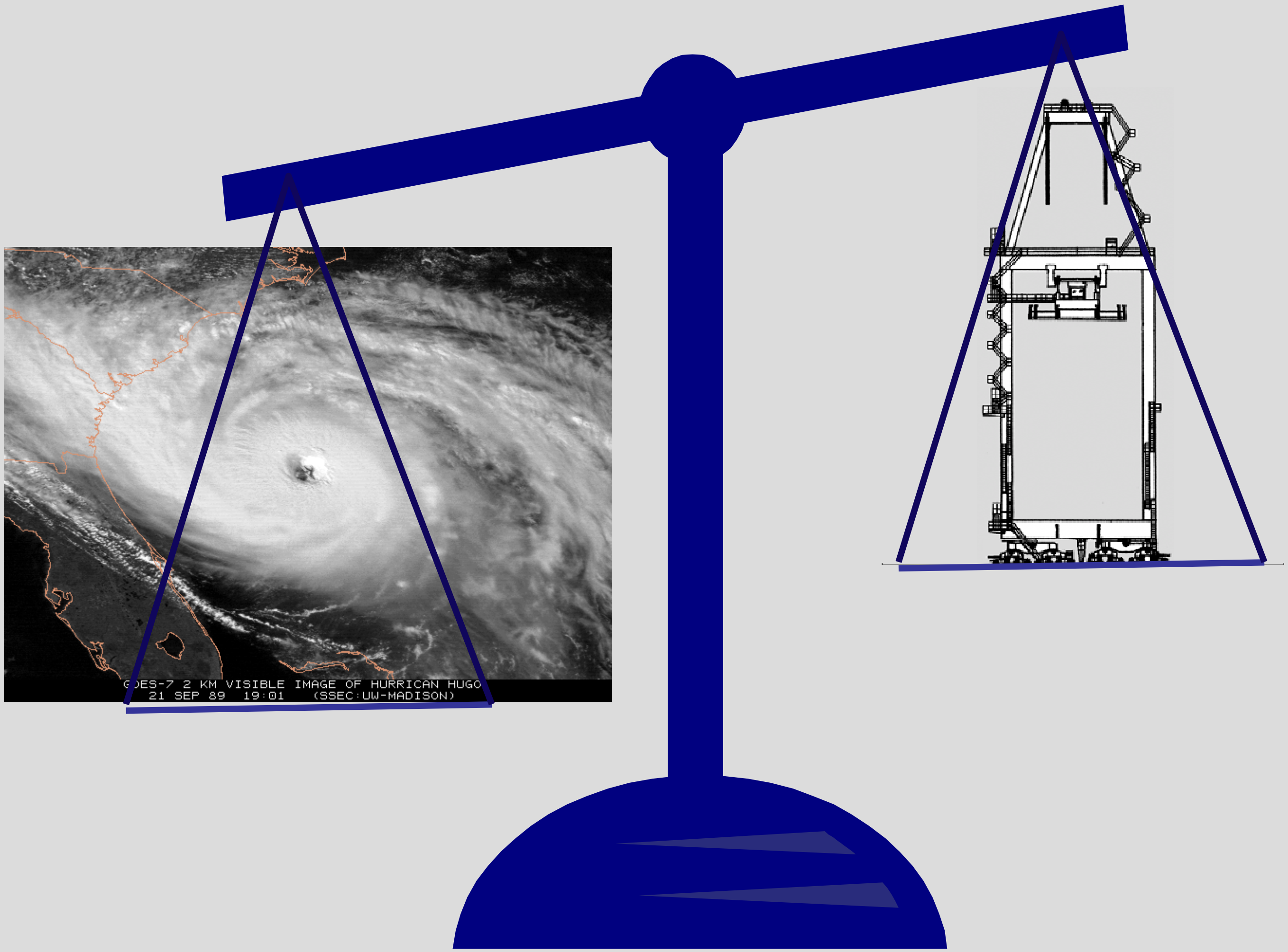
Requesting crane wheel load data

- Specify wind criteria
- Ask for basic loads
- Combine per ACI load factors

Requesting crane bids

- Provide factored load tables
- Ask to fill in tables
- Specify allowable factored loads

Tie-down Loads



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Tie-Down Failures

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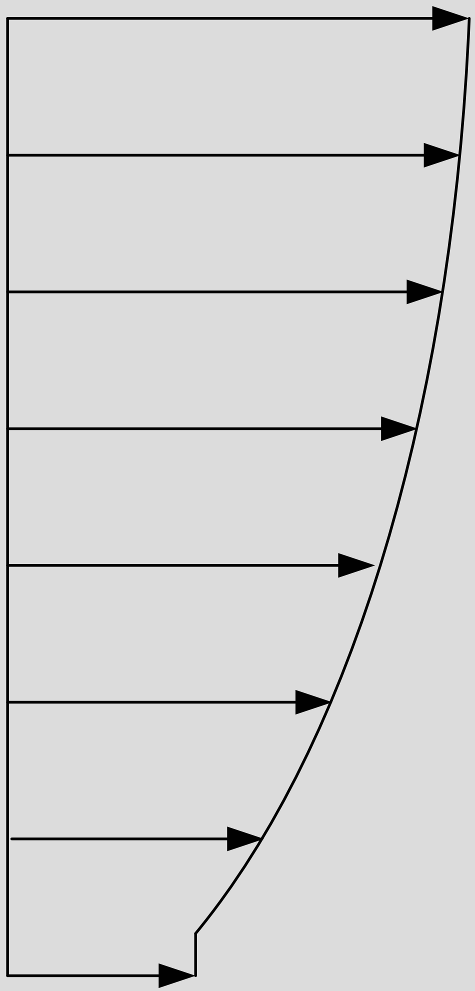
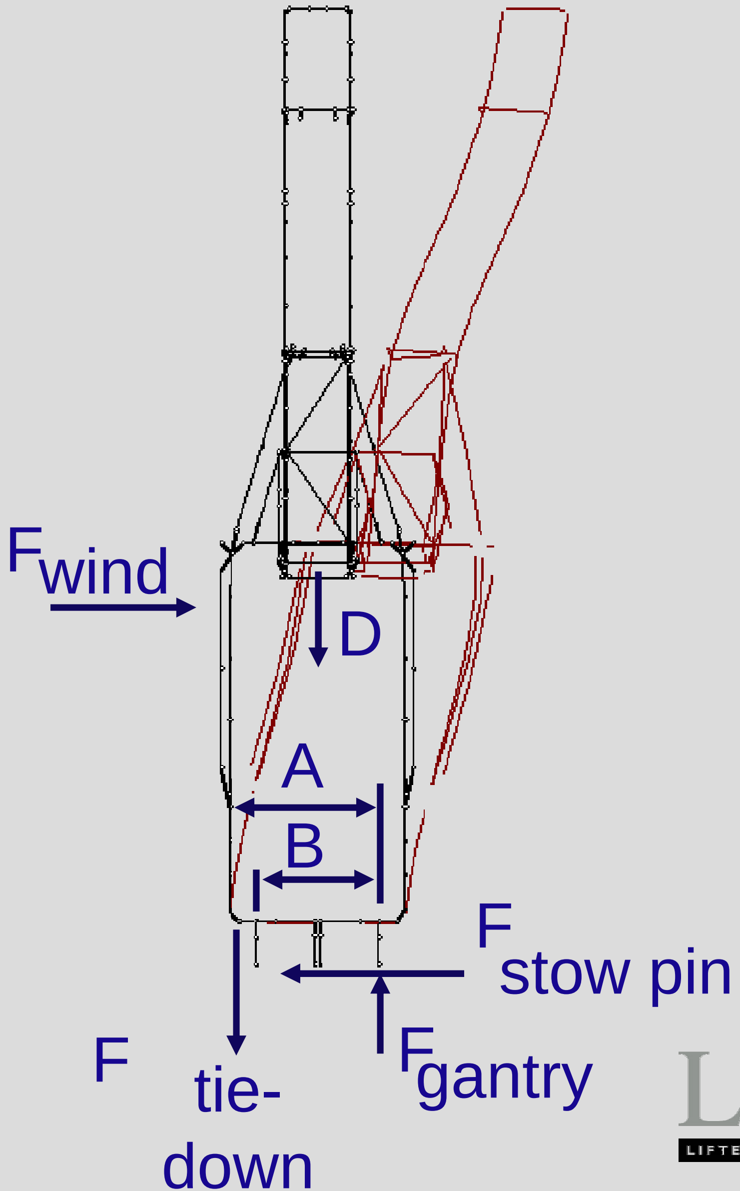
Wind Load & Crane Reactions

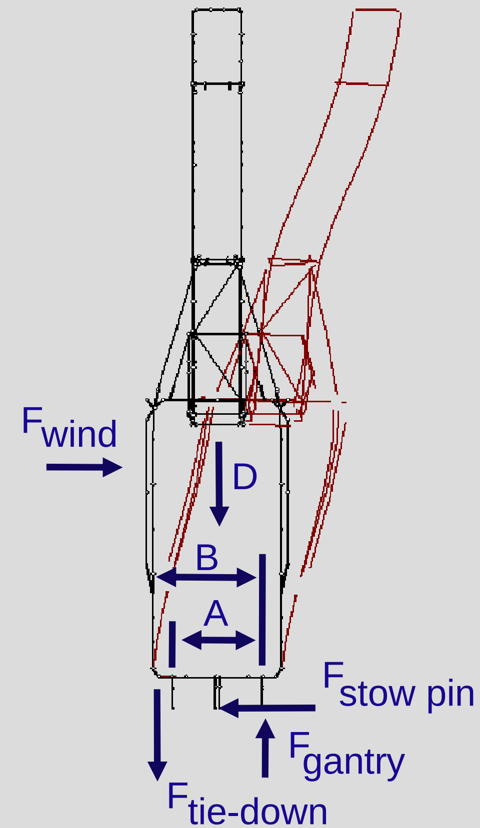




Error in Calculated Tie-down Force

Ratio of moments:

$$\gamma = \frac{F_{wind}h}{D\frac{B}{2}} = \frac{Overturning\ Moment}{Righting\ Moment}$$

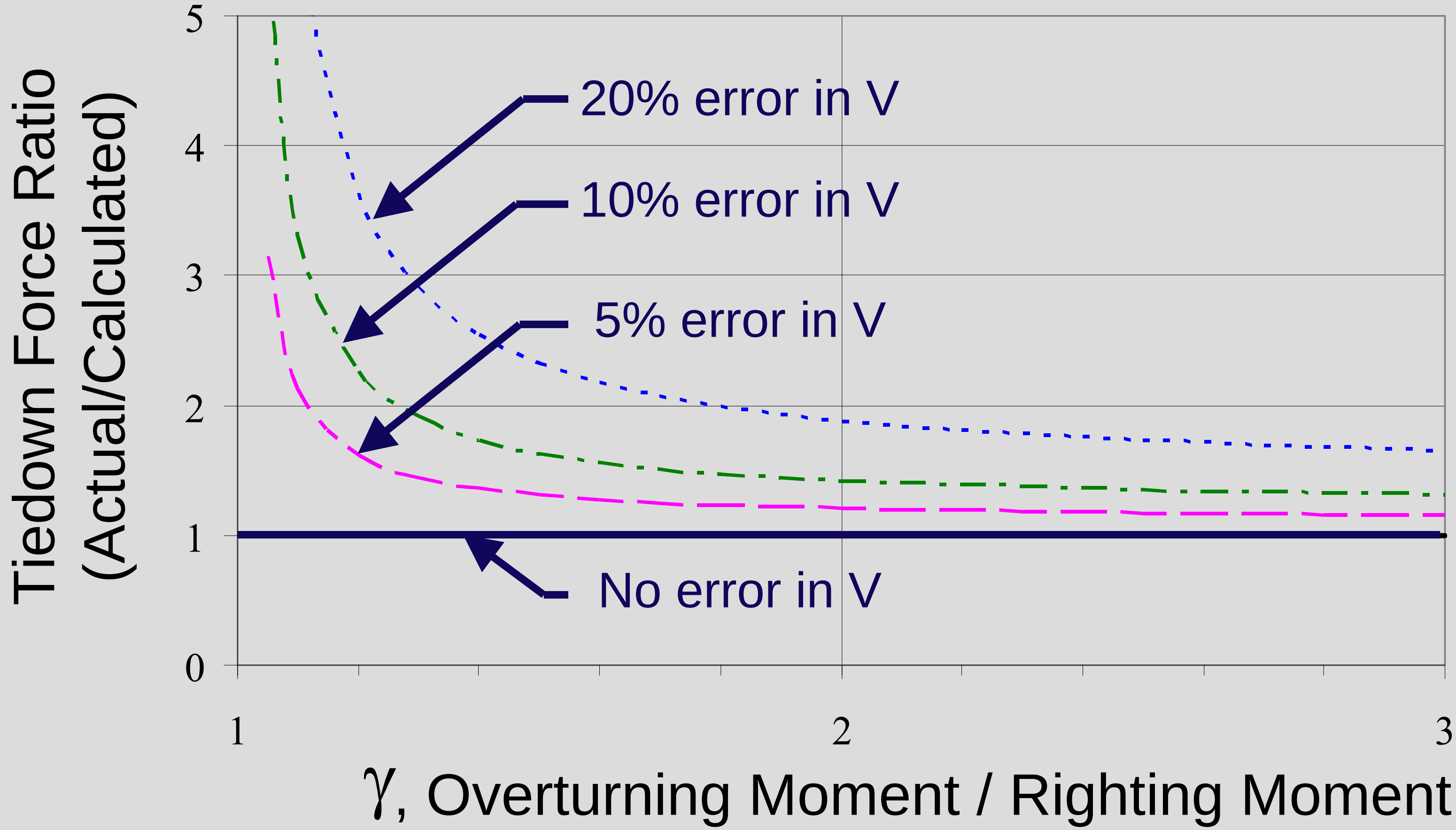


Error in calculated tie-down force:

If e = error in wind force,

$$\frac{F_{Tiedown,Actual}}{F_{Tiedown,Calculated}} = \frac{\frac{1}{A}\left[(1+e)F_{Wind}h - D\frac{B}{2}\right]}{\frac{1}{A}\left[F_{Wind}h - D\frac{B}{2}\right]} = \frac{(1+e)\gamma - 1}{\gamma - 1}$$

Error in Tie-down Force



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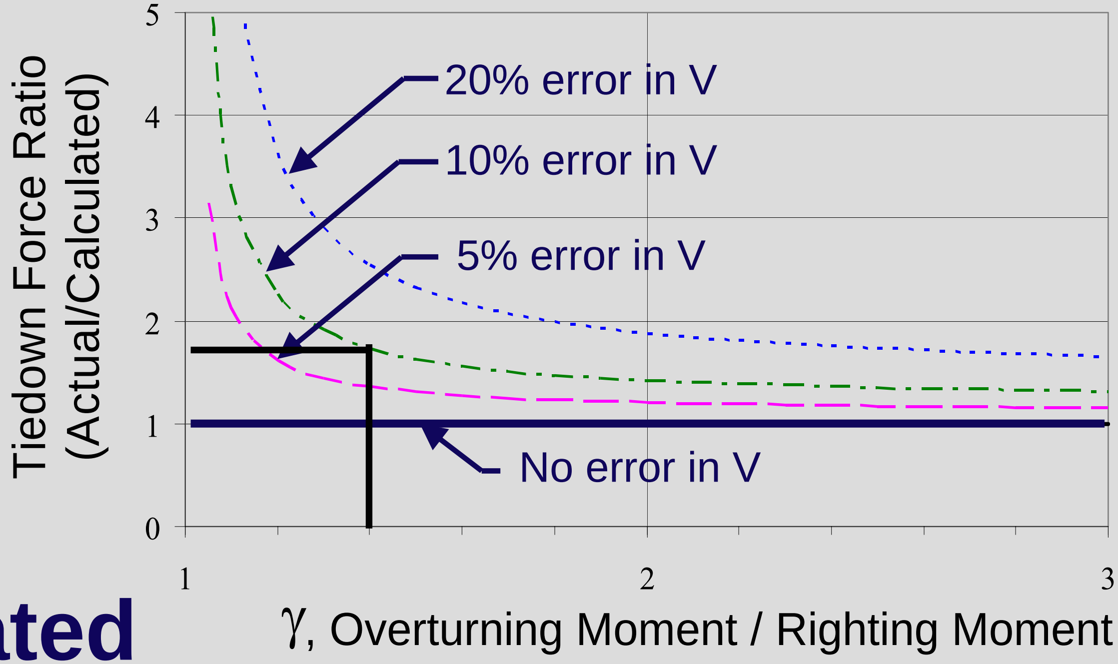
Example:

Error in wind speed = 10%; γ = 1.4

Error in wind pressure = 21%



Error in calculated tie-down force = 74% !

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Stability Load Factors

Load	Factor		
	BSI	ACI	FEM
Dead Load	1.0	0.9	1.0
TL + LS	1.0	0.9	1.0
Wind Load, 50-year MRI	1.2	1.3*	1.2

** 1.6 with ASCE 7-02 “directionality factor”*

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Uplift: Factored vs. Service

Load	Service	Factored: Load Factor	Factored
Dead Load	-500	x 0.9 =	-450
Wind Load	+450	x 1.3 =	+585
Calculated Uplift	-50		+135
	“No Uplift”		**“Uplift”**

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Putting the Two Together

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Problem Recap

Crane supplier and wharf designer work with incomplete and inconsistent data

Reasons:

- Crane supplier generally uses Service Load approach
- Wharf designer generally uses Factored Load approach
- Neither knows what basis the other uses

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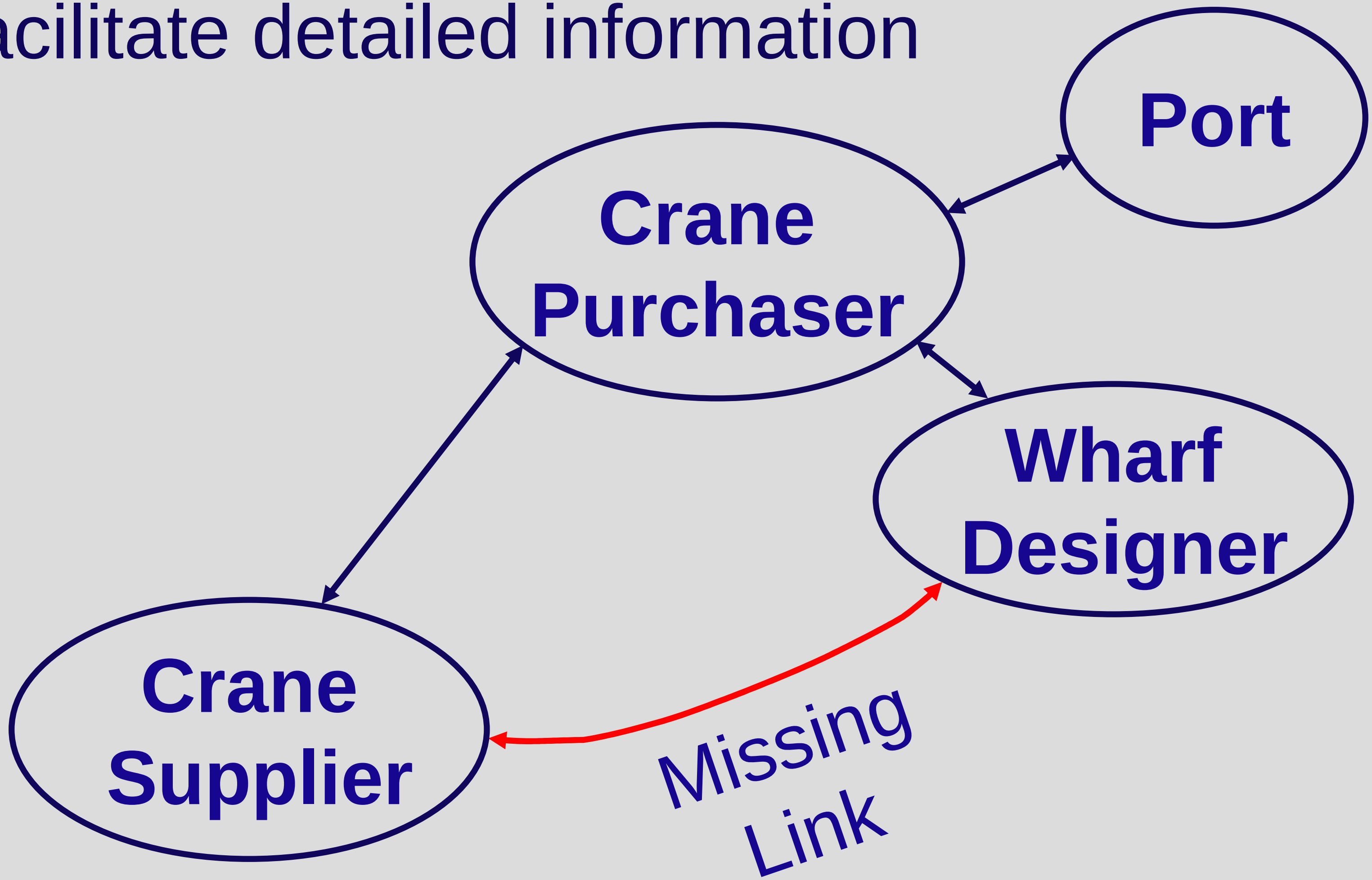
Solution

Crane purchaser provide or facilitate detailed information



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Obtain From Wharf Designer

Assumed wheel arrangement

Service or factored

Load factors

Load combinations for operating, overload, and out-of-service conditions

Complete wind criteria

Allowable wheel loads, kips/ft*

** Crane supplier tends to provide kips/wheel*

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Example Combination Table: Service Wheel Loads

Mode		Operating				Stowed
		WOP1	WOP2	WOP3	WOP4	WS1
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Lifted Load	LL	1.0	1.0		1.0	
Impact	IMP		0.5			
Gantry Lateral	LATG	1.0				
Op. Wind Load	WLO		1.0	1.0		
Stall Torque Load	STL			1.0		
Collision Load	COLL				1.0	
Storm Wind Load	WLS					1.0
Earthquake Load	EQ					
Allowable Wheel Loads (tons/wheel)	LS	50 x S				70 x S
	WS	65 x S				90 x S

S = Average spacing, in meters, between the wheels at each corner.

Example:

*S = 1.5 m, Allowable LS Operating = 50 t/m * 1.5 m = 75 t/wheel*

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Example Combination Table: Factored Wheel Loads

Mode		Operating				Stowed
		WOP1	WOP2	WOP3	WOP4	WS1
Dead Load	DL	1.2	1.2	1.0	1.0	1.2
Trolley Load	TL	1.2	1.2	1.0	1.0	1.2
Lift System	LS	1.2	1.2		1.0	1.2
Lifted Load	LL	1.6	1.6		1.0	
Impact	IMP		0.8			
Gantry Lateral	LATG	0.8				
Stall Torque Load	STL			1.0		
Collision Load	COLL				1.0	
Storm Wind Load	WLS					1.6
Earthquake Load	EQ					
Allowable Wheel	LS	60 x S				80 x S
Loads (tons/wheel)	WS	75 x S				100 x S

S = Average spacing, in meters, between the wheels at each corner.

Example:

*S = 1.5 m, Allowable WS Storm = 100 t/m * 1.5 m = 150 t/wheel*

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Ask Crane Supplier For

Wheel arrangement

Wheel loads for individual loads

Combined wheel loads for operating, overload, and out-of-service conditions

Complete wind criteria used and basis for shape factors

Individual and corner factored loads for tie-downs including direction of loading

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Example Design Basic Load Table

Wharf Designer needs from Crane Supplie

		Wheel Load			
		Seaside		Landside	
		LHS	RHS	LHS	RHS
Dead load	boom down				
	boom up				
TL + LS	outreach				
	backreach				
	parked				
LL	outreach				
	backreach				
IMP	outreach				
	backreach				
LATT					
LATG	outreach				
	backreach				
OWLx					
OWLz					
OWL< (Angled Max)					
Stall					
COLL	boom down				
	boom up				
EQx					
EQz					
SWLx					
SWLz					
SWL< (Angled Max)					

Recap

Obtain detailed crane and wharf design data

Stick to one crane design code

Stick to one wharf design code

Use consistent design basis

Facilitate communication

Q & A

Crane Loads & Wharf Structure Design: Putting the Two Together

Thank you

This presentation will be available for download on Liftech's website:

www.liftech.net

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