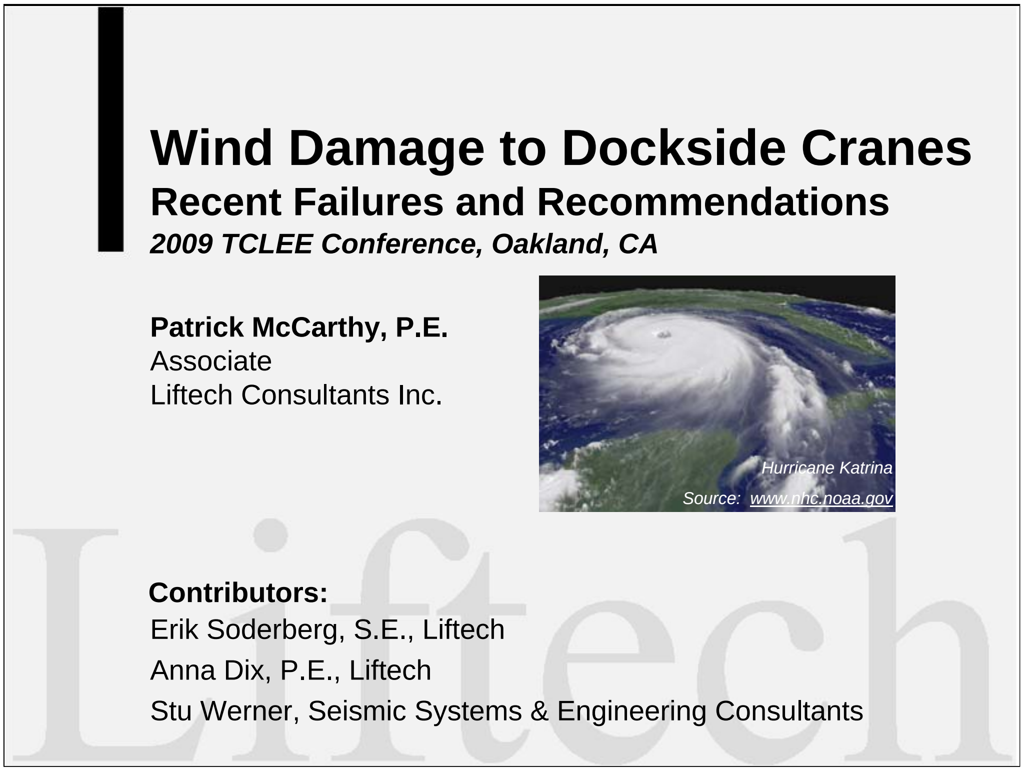


Good morning. My name is Patrick McCarthy. I have BS and MS degrees from UC Berkeley. I worked for Paceco Corp from ’95-’99 and Liftech Consultants Inc. for the last ten years.

I want to thank my other contributors. Mr. Soderberg also presented on Monday regarding Seismic Guidelines for Container Cranes.

Cranes are a vital part of the transportation lifeline. I will discuss wind-related damage to dockside cranes and present ways to reduce the likelihood of such damage.

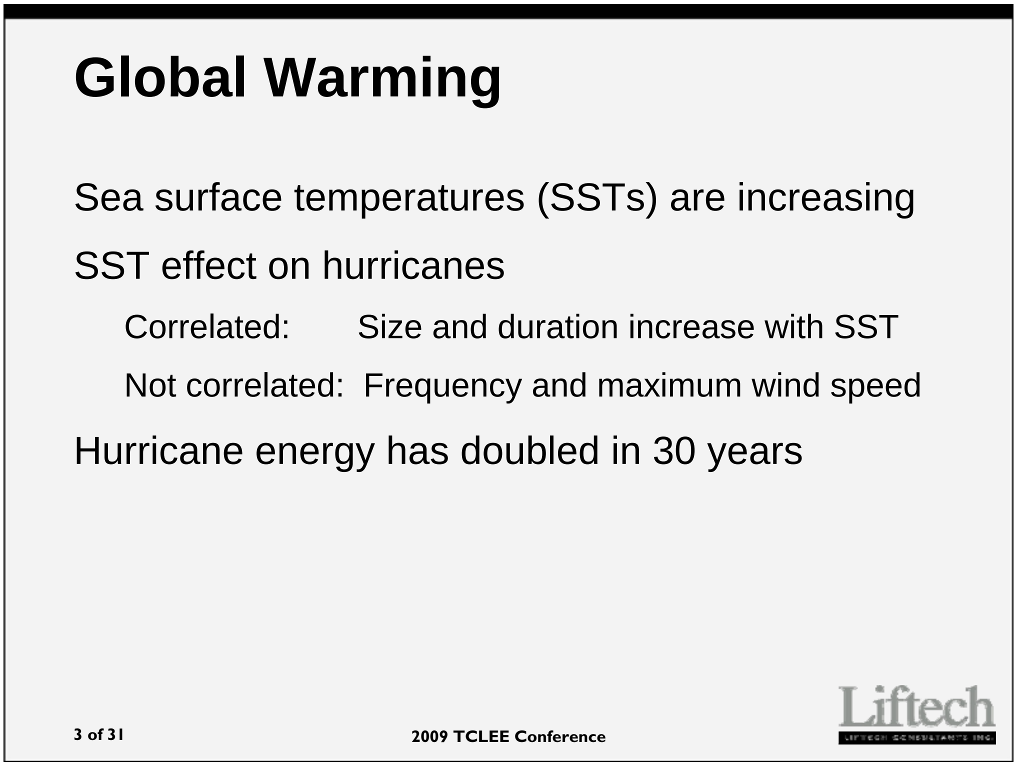
This image is Katrina. From the National Oceanic and Atmospheric Administration website.

Cranes in New Orleans fared well, with only some local damage to operator’s cabs, etc.

I want you to remember this image later on. Notice the size of the storm.

> “Lifelines are the systems and facilities that provide services vital to the function of an industrialized society and important to the emergency response and recovery after a natural disaster. These systems and facilities include communication, electric power, liquid fuel, natural gas, transportation (airports, highways, ports, rail and transit), water, and wastewater.”

I’m going to start by discussing hurricane winds. Are they increasing?



SSTs are increasing. This affects hurricanes.

Studies by Emanuel (Nature) and Hoyos (Science Express) indicate that hurricane **intensity, size, and duration** are increasing, and are **correlated** to increasing **sea surface temperatures** (SSTs).

SSTs have increased approximately **0.5 C in the tropics**.

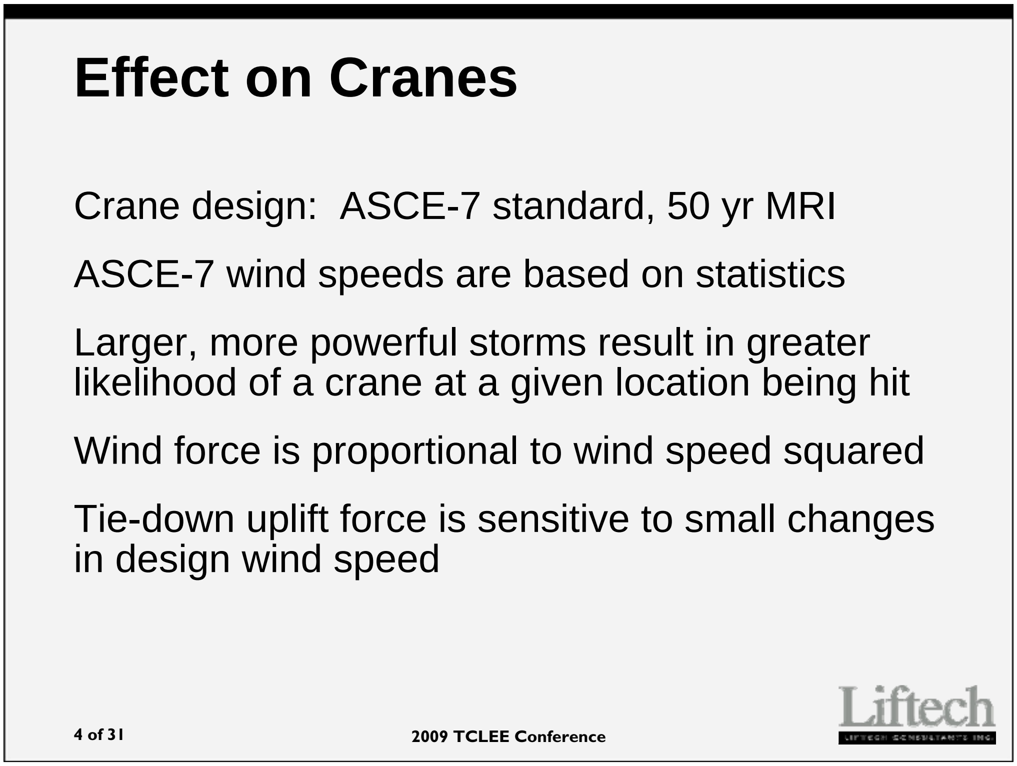
Storm **duration increased approximately 60**%.

Total North Atlantic plus Western North Pacific power dissipation index (PDI) (basically the **total energy released**) **has approximately doubled over the last 30 yrs**.

> (There is no apparent correlation between the number of hurricanes formed each year and the SST.)

> (There is only a small correlation between increasing hurricane maximum wind speeds and SSTs.)

In effect, the theoretical maximum wind speed may not be increasing, but the “winds” are and that effects cranes …



Crane designs are typically based on the ASCE-7 standard, *Minimum Design Loads for Buildings and Other Structures*, with a 50-year mean recurrence interval (MRI), 3-second gust wind speed, at 10 m elevation.

Certain-year MRI wind speeds are based on statistics. For instance, statistically, there is a 64% chance of exceeding a 50-year MRI wind speed in 50 years, or 1/50 in any given year.

Remember the size of Katrina in the first slide. The area hit hard by that storm was tremendous.

Also remember Emily, which traveled across Florida. Emily struck the West coast of Florida and went all the way through the state, and regained Category 2 status on the other side, damaging cranes on the East Coast. Normally, we would expect Hurricanes to “fizzle” out before hitting land, or shortly after hitting land.

If the likelihood of a hurricane hitting a location increases due to storms lasting longer (and being bigger), I would expect the ASCE-7 wind standard to gradually increase their statistical MRI wind speeds in hurricane regions.

In other words, hurricanes are more likely to hit a certain location, so instead of hitting every 75 years with a certain storm, it might hit every 50 years.

The same wind speed will occur more often, decreasing the recurrence interval for the same wind speed. (Maybe a current 75-year wind will become a 50-year wind?)

Overturning moments are proportional to the wind speed squared. Refer to Port’s 2003 paper for how a small change in wind speed can have an amplified affect on tie-down forces.

Note: Cranes here on the West Coast typically do not have tie-downs and are not likely to be affected by changing wind effects any time soon.

Hurricanes cause damage. The risks are real.

Typhoon Maemi struck Pusan, Korea in September of 2002.

Two cranes are shown (see underside of crane boom).

Initial failure of tie-down attachment to wharf.

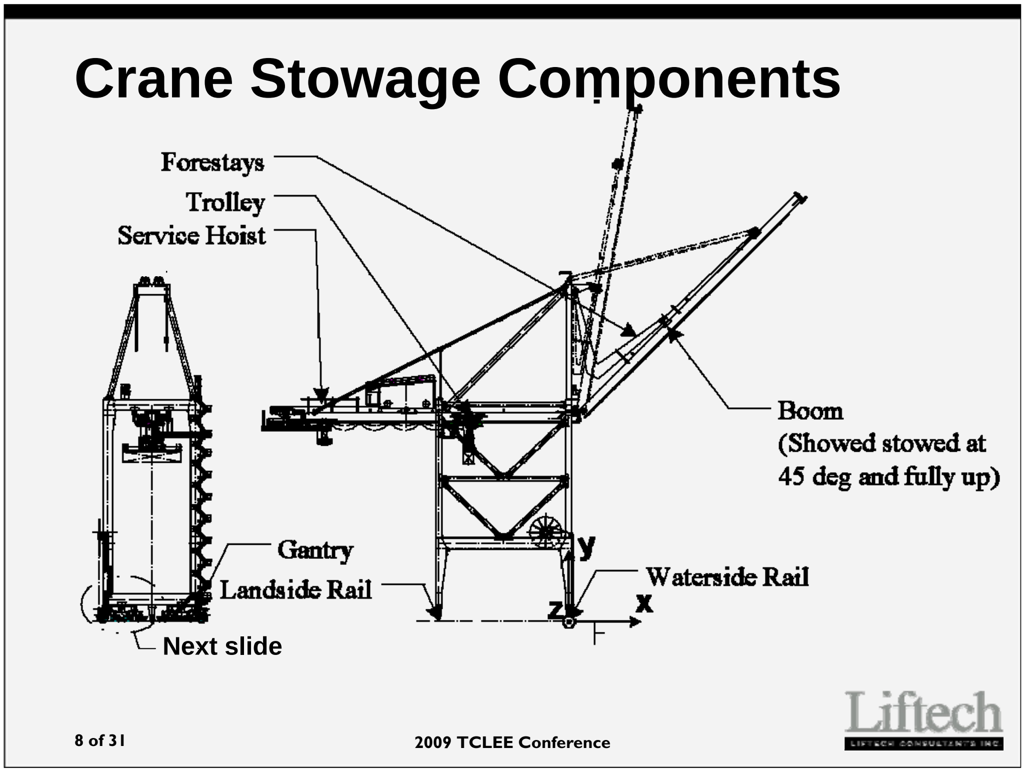
Consequential damage.

Six other cranes were also lost due to a single, initial tie-down failure and subsequent domino-effect collisions.

We have not experienced a case where the crane has failed before the stowage system.

3 pairs of 2 cranes (red & white booms)

Now that I have your attention, I will talk about traditional tie-down design and some associated problems.

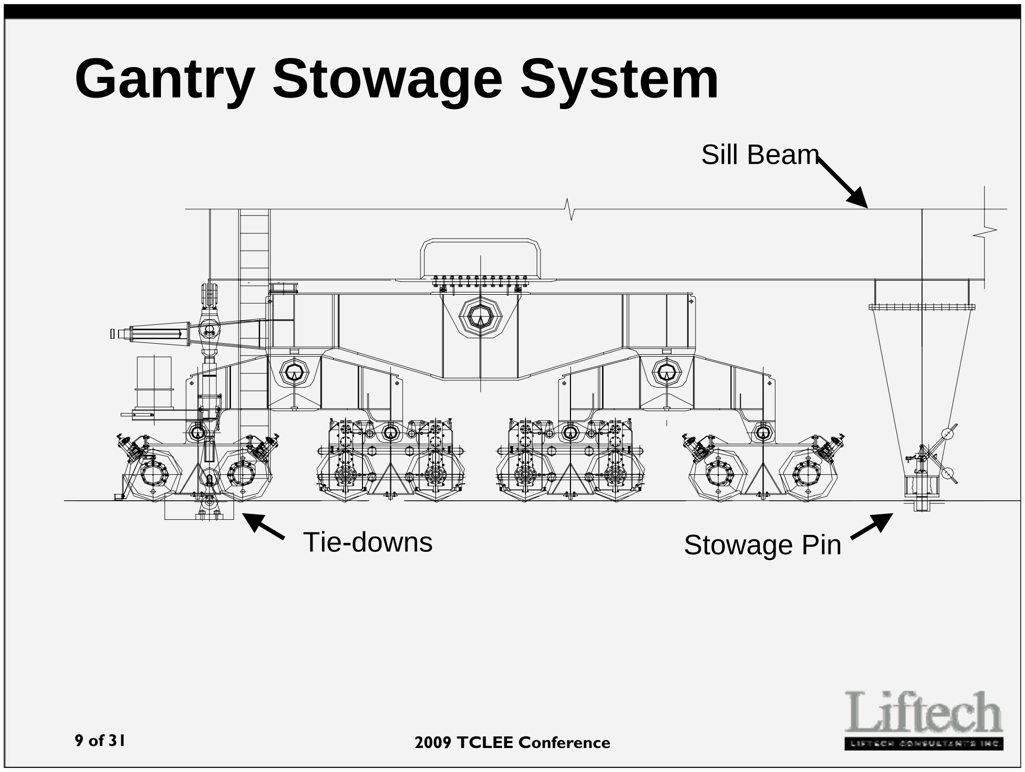


For those of you who are unfamiliar with crane stowage components, they are shown here.

Most failures are uplift-related, so we will focus on the tie-downs.

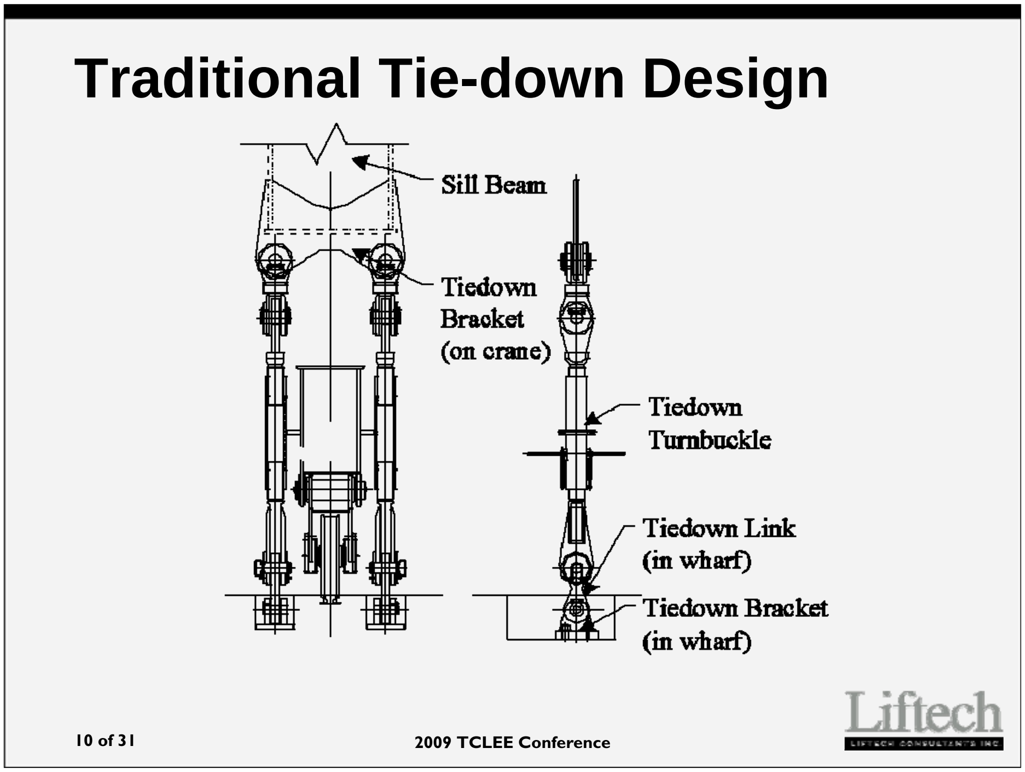
- Tie-downs take uplift (Y-dir)
- Stowage pins take gantry travel direction forces (Z-dir)
- Gantry wheels transmit trolley direction forces to rails (X-dir)

Next slide shows the stowage system in more detail.



Tie-downs are most effective toward the end of the sill beam.

See next slide for tie-down details.



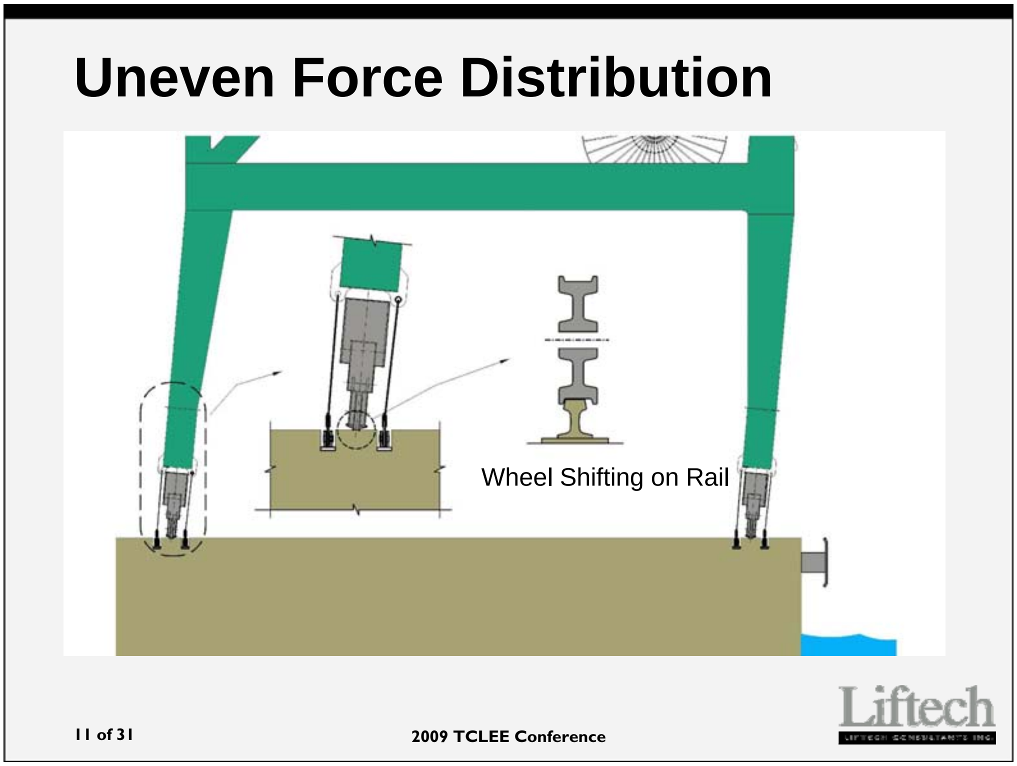
(See slide for typical tie-down components.)

Ideally, we would prefer only **one tie-down per corner**.

For hurricane wind regions, uplift force is typically too large with today's jumbo cranes to practically have only one tie-down per corner.

Cannot test turnbuckles

Size makes securing difficult



Cranes are flexible and Hurricane forces cause cranes to deflect and move.

The forces in the tie-downs are **not evenly distributed**.

Why?

Crane structure deforms, translating and rotating.

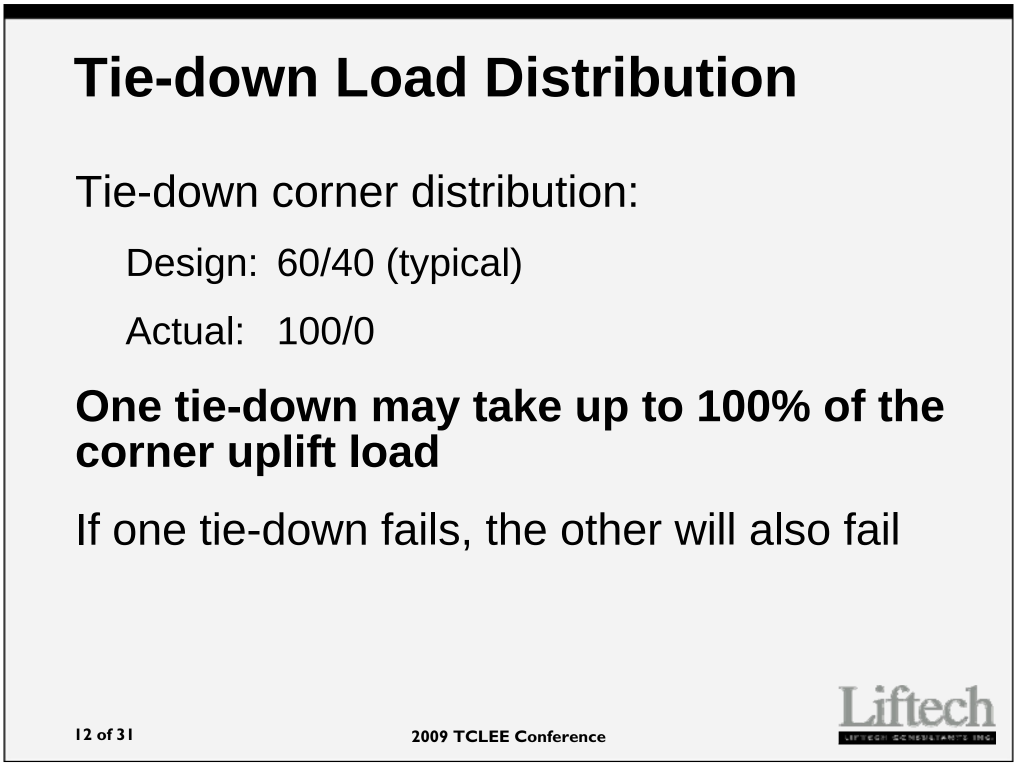
Gantry wheels can shift.

Gap in stowage pin socket allows gantry wheels to roll (or slide) along the rail.

Links are not perfectly straight.

Wharf pins are not symmetric

(**See enlargement with tie-downs**)



For years, designers have used a 60/40 or 70/30 load distribution per corner. We thought this was conservative.

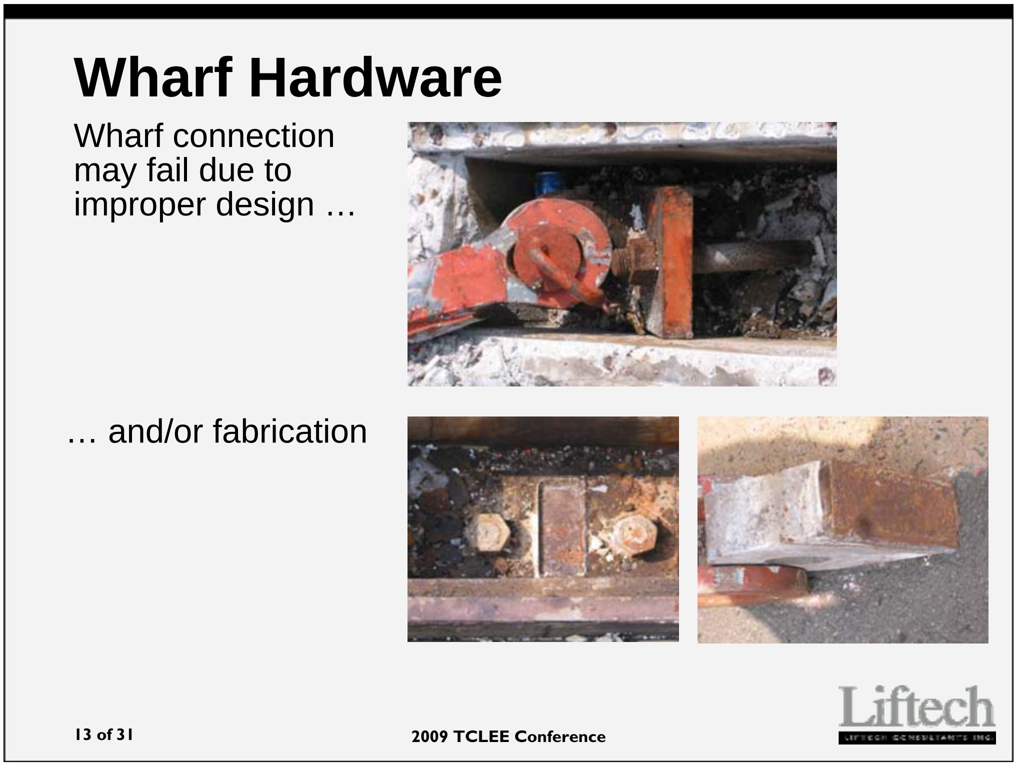
Recent analyses indicate that the actual distribution may be as much as 100/0%.

If a single tie-down was designed to 60% of the total uplift, the actual uplift would be 100/60 = 1.67 times the design uplift.

The tie-down may survive due to factors of safety—or it may not survive.

Many older cranes have seen their design wind speed. Others have not.

The tie-downs are typically not the weakest element …



… usually, the wharf hardware to crane tie-down interface is the first to fail.

Wharf connection design may not be consistent with crane design.

The tie-down wharf hardware is often designed to a lower standard, compared to the tie-down design (ASD vs. LRFD). The unequal load distribution may cause the wharf hardware to give way.

Upper image is a tie-down **pullout failure with smooth anchor bolts**.

Lower image is a tie-down wharf bracket failure due to improper fabrication--**4 mm** (3/16 in) fillet weld between **base plate** and **60 mm** (2.5 in.) lug.

The fabricator also used a **filler plate** between the lug and base plate!

Onsite inspection may have prevented this terrible workmanship.

How to Design?

If possible, use one tie-down per corner

Otherwise, two equalization approaches:

- Mechanical equalizer
- Ductile link

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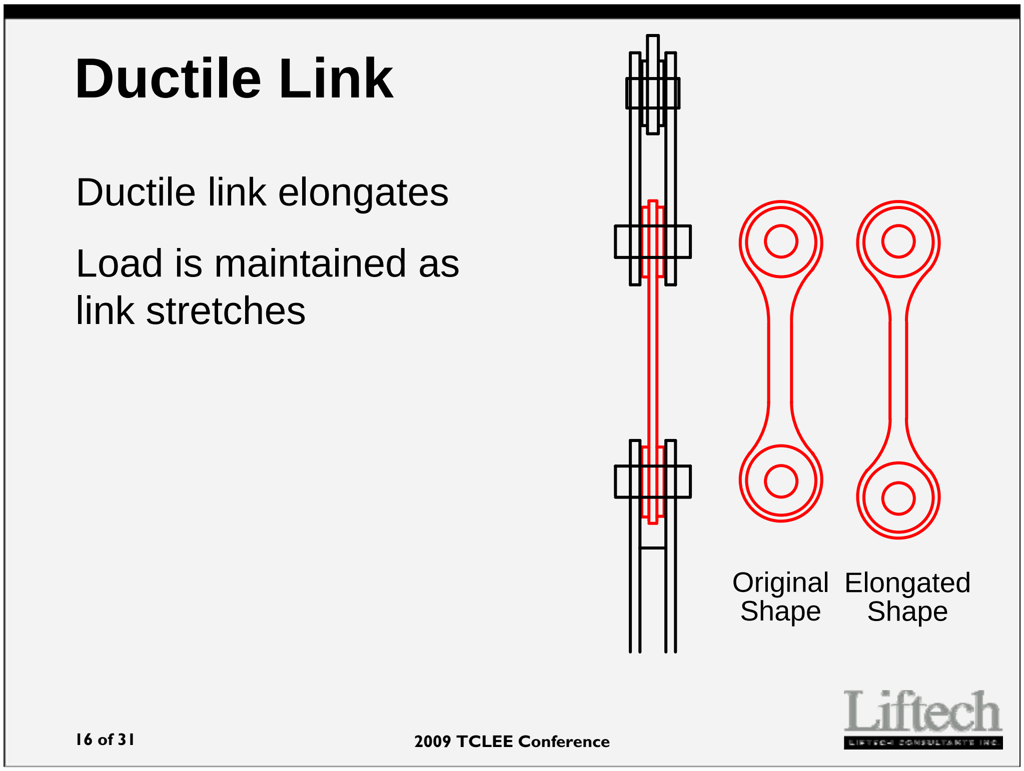
As mentioned, the best method is to use a single tie-down per corner, but this is often impractical.

The mechanical equalizer beam system is not presented—as it is heavy and difficult to implement.

Another choice is to use a “ductile link.”

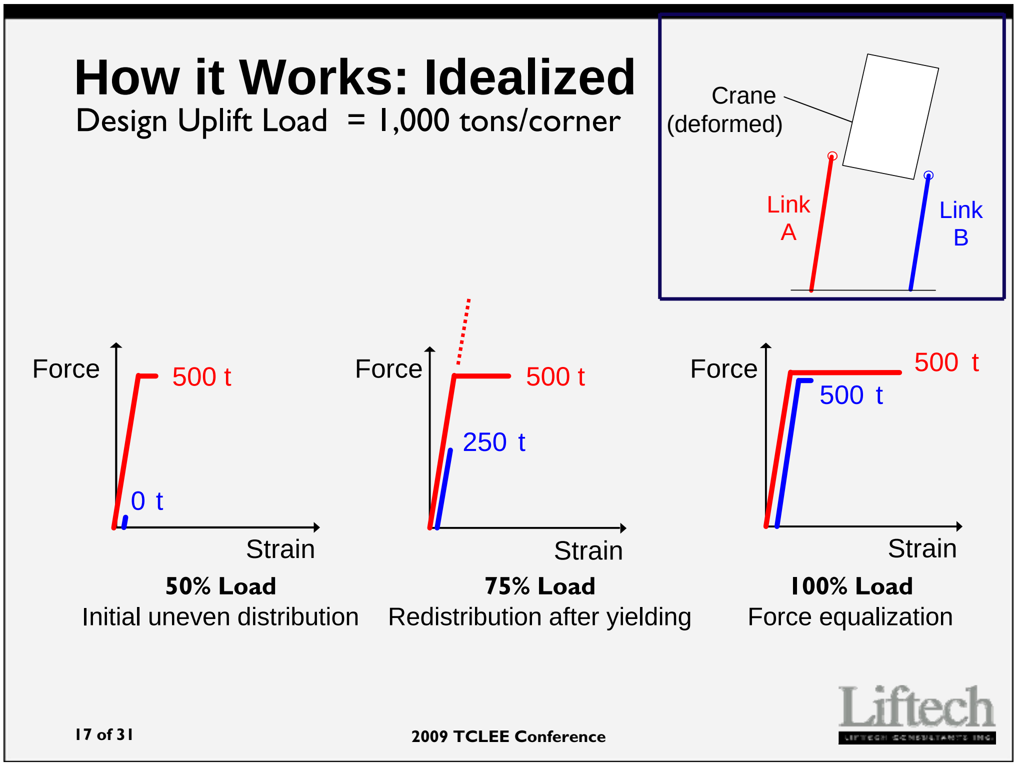
I will present equalization through ductile yielding of a structural element.



If one link in the tie-down system is capable of deforming **plastically without loss of strength** until the other link engages, the tie-down loads will eventually equalize.

(*Refer to original and elongated shapes.*)

Plastic elements acting as fuses have been used for decades to protect structures from severe damage during earthquakes.



How does it work?

Initially the loads in multiple tie-downs are not equal. In some cases, the entire corner upload force is carried to one tie-down. In this example, with a 1,000 ton corner load, the initial distribution is uneven. The desired distribution at the design uplift load is 50/50.

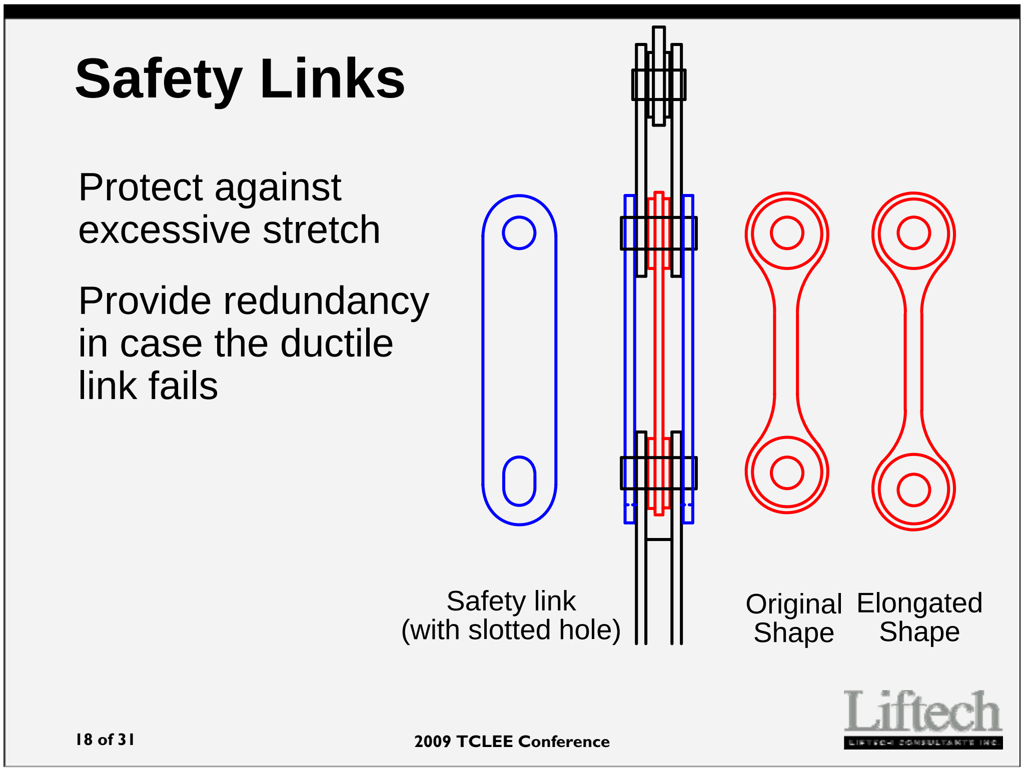
With the ductile link, the heavily loaded tie-down yields at half of the design uplift load, allowing load to transfer to the lightly loaded tie-down.

As the uplift force increases, the ductile link stretches plastically. The load remains (relatively) constant in the heavily loaded tie-down and increases in the lightly loaded tie-down. Normally, the load might follow the dotted line shown in the middle graph.

Eventually the load is shared equally, and the full strength of the multiple tie-downs is utilized, as intended.

(Note that the force/strain graphs are **idealized**.)

This protects the wharf hardware from overload.

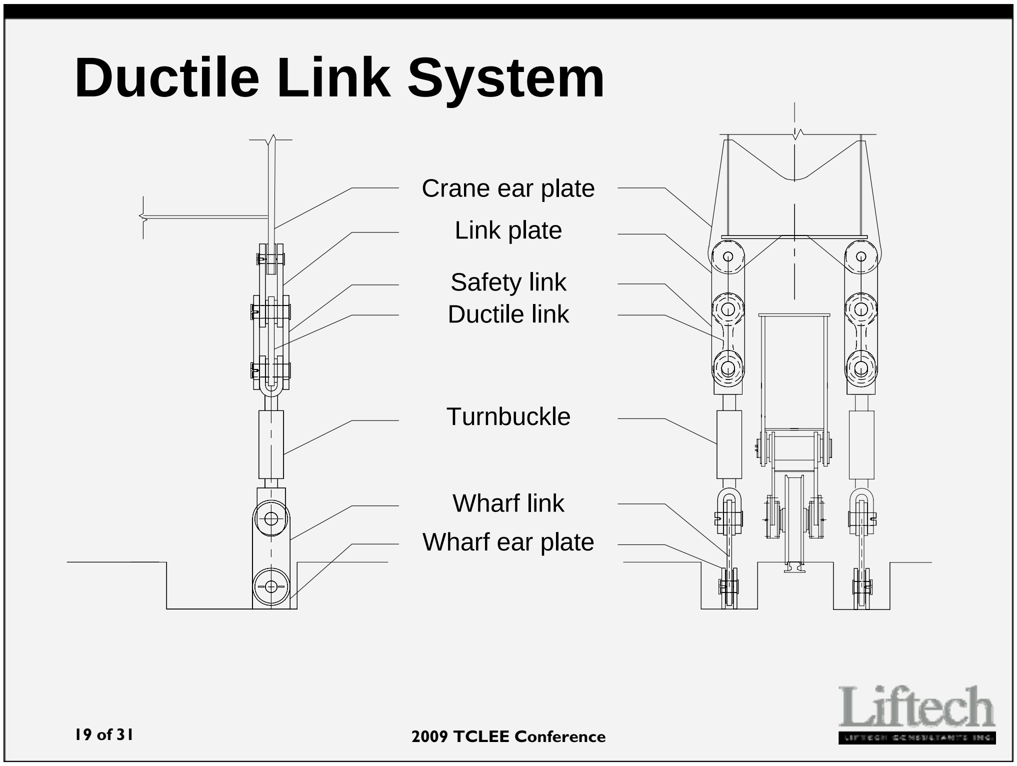


What if both links are loaded to their failure deformation? Their strength is insufficient to continue carrying the load. How can we keep failure from occurring?

It is likely that the elements in the rest of the system have some reserve strength. This strength can be utilized with the use of safety links connected in parallel with the ductile link.

The ductile link has done its job and distributed the load. Now the failure should be controlled by the remaining weakest element.

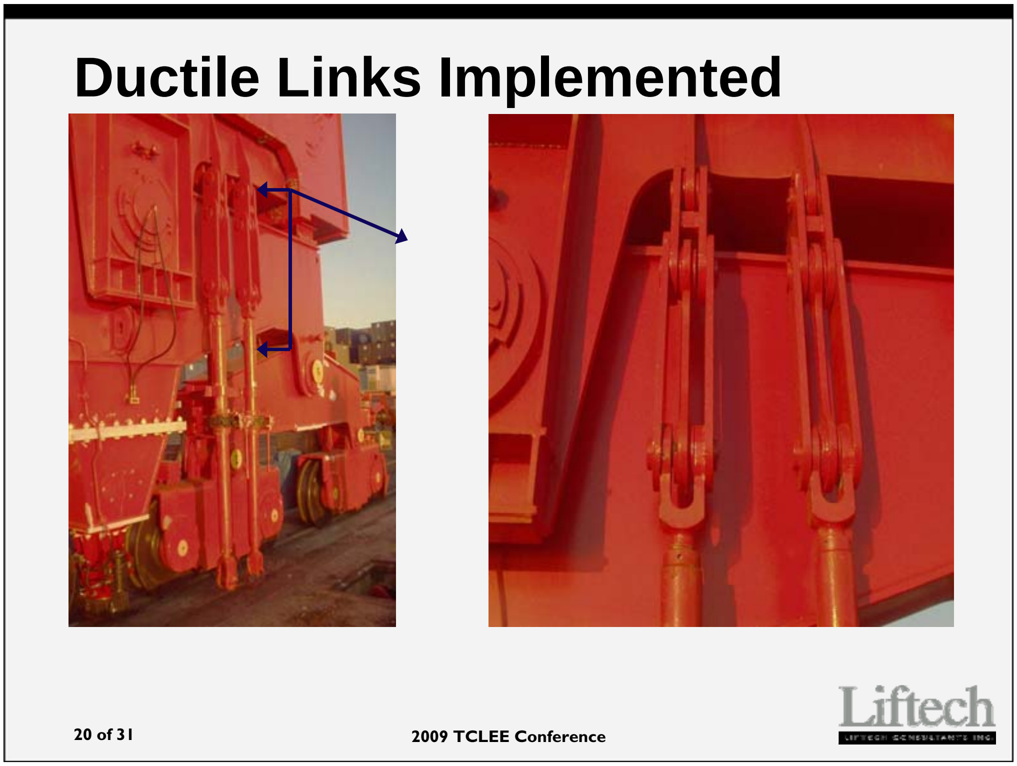
The safety link also provides some redundancy.



Notice how the ductile link fits in to a typical tie-down system.

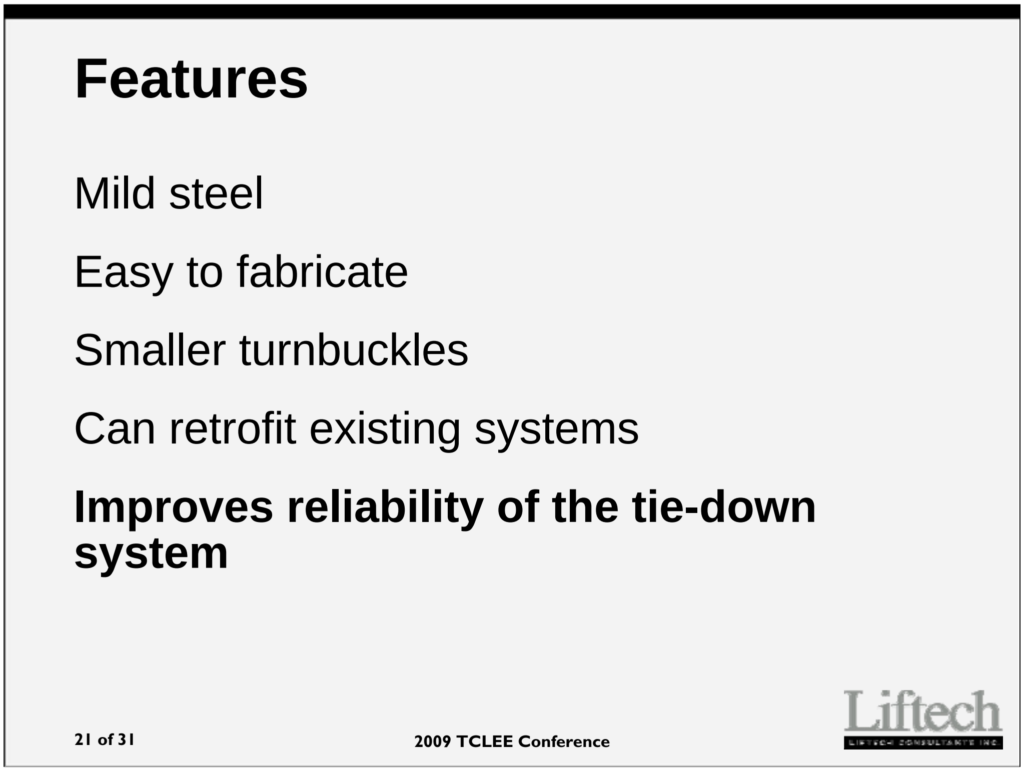
The ductile link-safety link system is typically larger than a traditional tie-down.

There may be some interference with the gantry.



Here is a ductile link system with four tie-downs per corner.

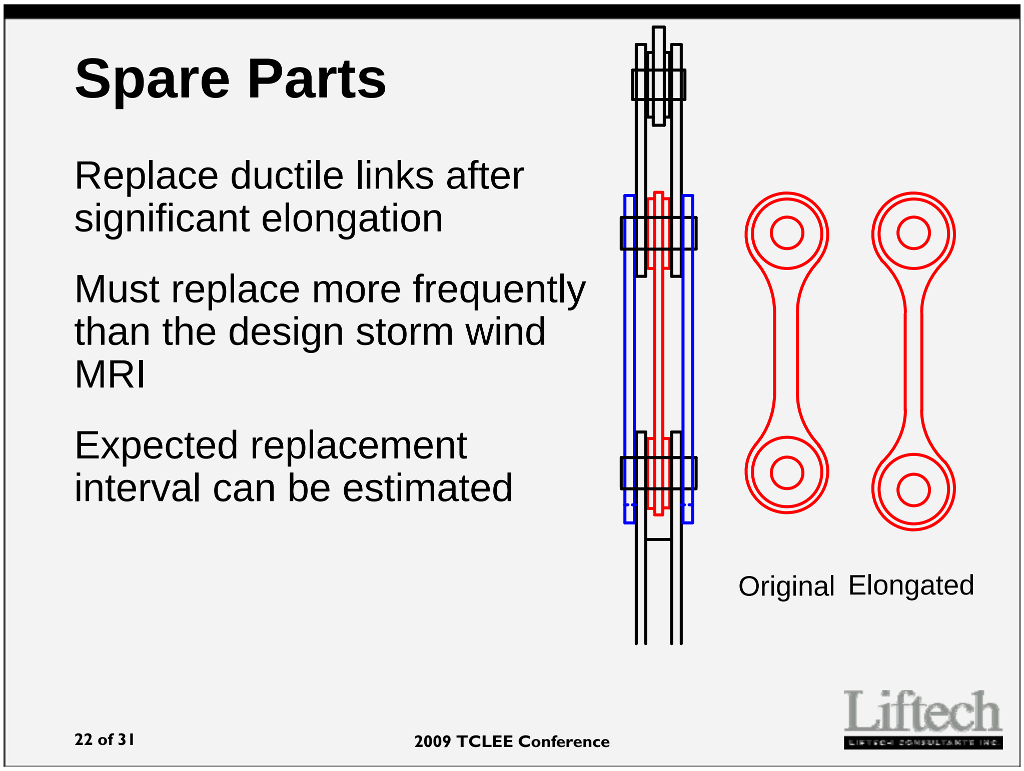
(Implemented in New Jersey)



Ductile links improve reliability. ←This is the main feature

Ductile links can be added to existing cranes, although it is not cheap and sometimes it is difficult to fit.

On new cranes with multiple tie-downs, using ductile links is relatively easy and should not increase the crane price.

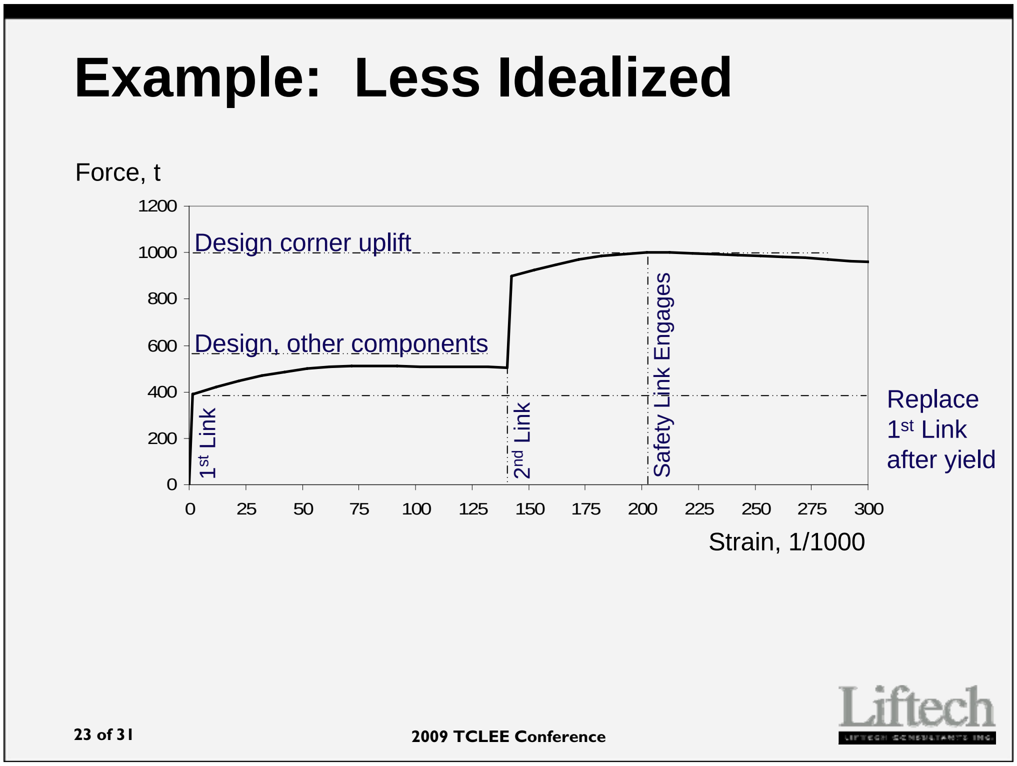


To ensure that adequate ductility exists and that the ductile link will equalize the loads in the next typhoon, the link should be replaced if significant stretch has occurred.

More frequently than design storm MRI because first link yields prior to developing full design corner uplift.

We expect a typical replacement design interval to be a decade.

Refer to the paper for a method of estimating the replacement interval.



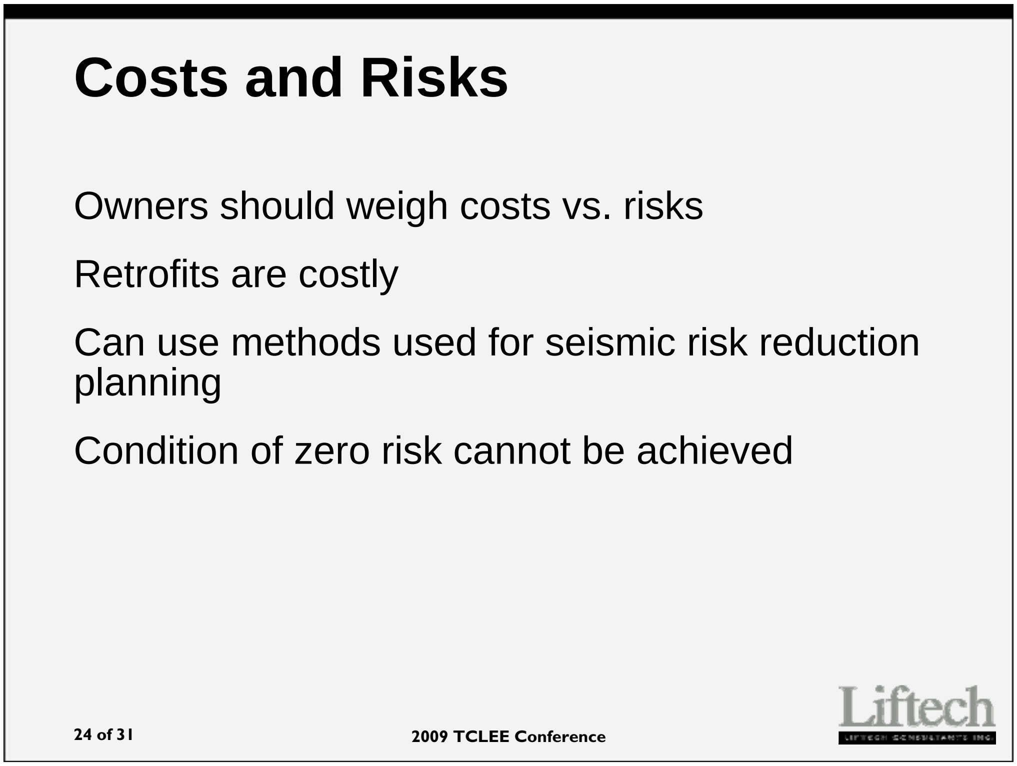
In reality, the link force at ultimate is greater than at yield, as shown.

The design steps provided are only guidelines and only mention a few of the design issues.

Salient features:

1st link

1. 2nd link
2. Safety link
3. Design uplift
4. Design other components in one link
5. Replacement



Retrofit cost is not cheap, but is not expensive compared to the crane costs.

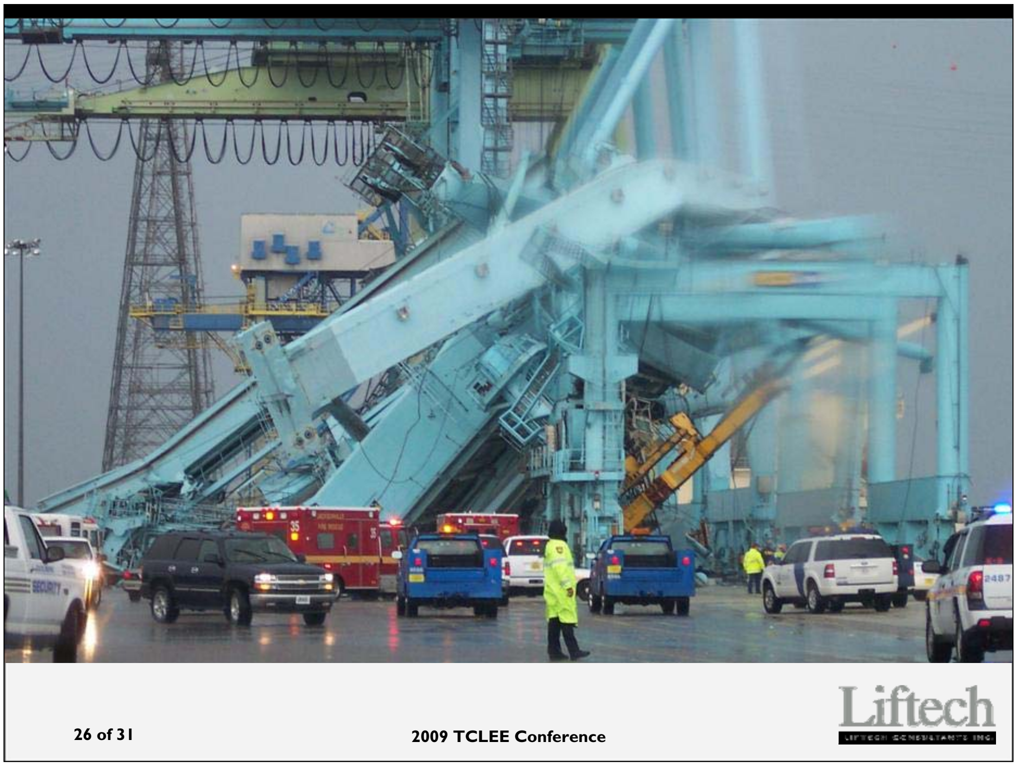
(Around $50-100 K as a really rough estimate.)

See Stu Werner's *Seismic Guidelines for Ports* (TCLEE, ASCE, March 1998) for information regarding seismic risk reduction planning at major ports.

Unacceptable crane **damage risk must be weighed against costs of retrofit**.

Risk of economic, life safety, political, legal, and administrative losses must be considered. These are **owner-specific**.

What about securing cranes for non-hurricane winds?



Cranes in Jacksonville collapsed due to reported downburst.

One crane ran away and collided with an adjacent crane—both cranes collapsed.

(Haven't heard confirmed reason for run-away crane or wind speeds.)

Gantry Braking Systems

Component	Use	Design
Motor	Operations (dynamic)	Rated speed, WLO (25 m/s wind)
Motor brakes (disc or caliper)	Static hold	150% WLO (30 m/s)
Wheel or rail brakes	Static hold	200% WLO (35 m/s) combined with motor brakes
Anemometer	Wind speed	35-40 mph operating warning 45-55 mph high wind alarm

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The following discussion represents typical minimum specified braking system capabilities and operating parameters.

The motor stops the crane during operations (dynamic).

The motor brakes hold the crane statically. When control power is lost, motors will not work, but the motor brakes set.

The wheel (or rail) brakes are also static. Also set during an E-stop--if dynamic, some damage will occur. Recommend wheel brakes instead of rail brakes (less damage and more vertical reaction at wheels).

Anemometers at highest fixed structure.

Audible alarms set at wind speeds decided depending on location, etc. 16-18 m/s (35-40 mph), 20-25 m/s (45-55 mph)

Motor brakes engage at operating warning alarm.

At high wind alarm, usually a bypass is needed to attempt to move a crane.

Procedures in High Winds

Acceptable procedures vary

- Braking system components and capabilities
- Crane manufacturer recommendations
- Local wind characteristics and forecasting
- Time required to stow a crane
- Personnel
- Acceptable risk
- Details

Maintenance

Emergency Plan

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Stowage plans will vary depending on many factors.

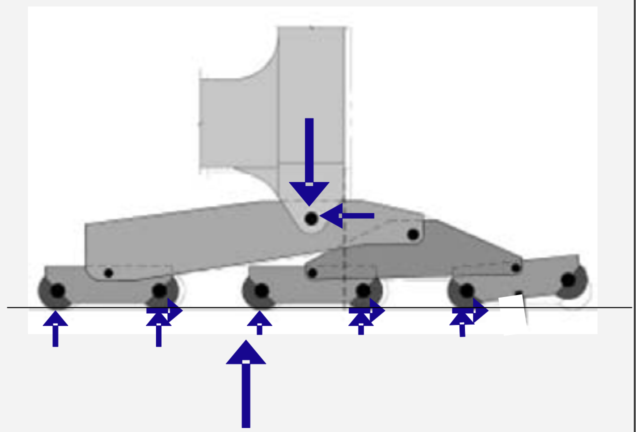
Each port or terminal should develop their own stowage plan.

The TT Club has a reasonable publication, “Windstorm,” which describes common considerations and provides many recommendations.

Braking Design Considerations

Effect of “light” corner(s)

“Prying” effect



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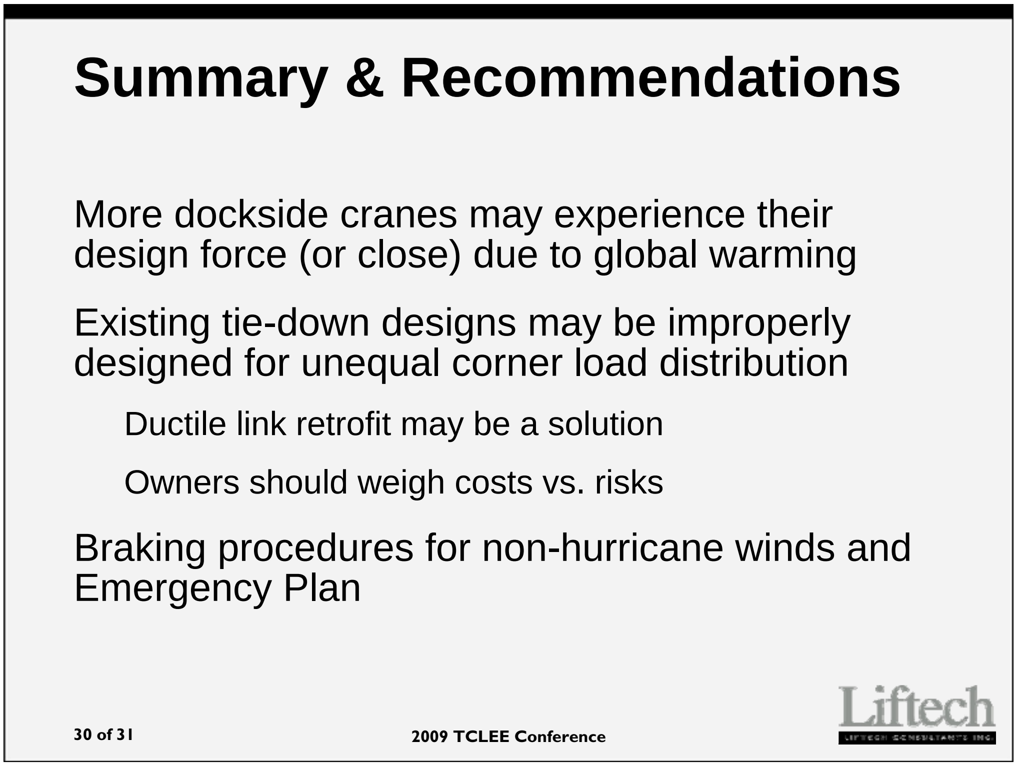
At the “light” corner, braking capacity may not be developed due to insufficient friction force

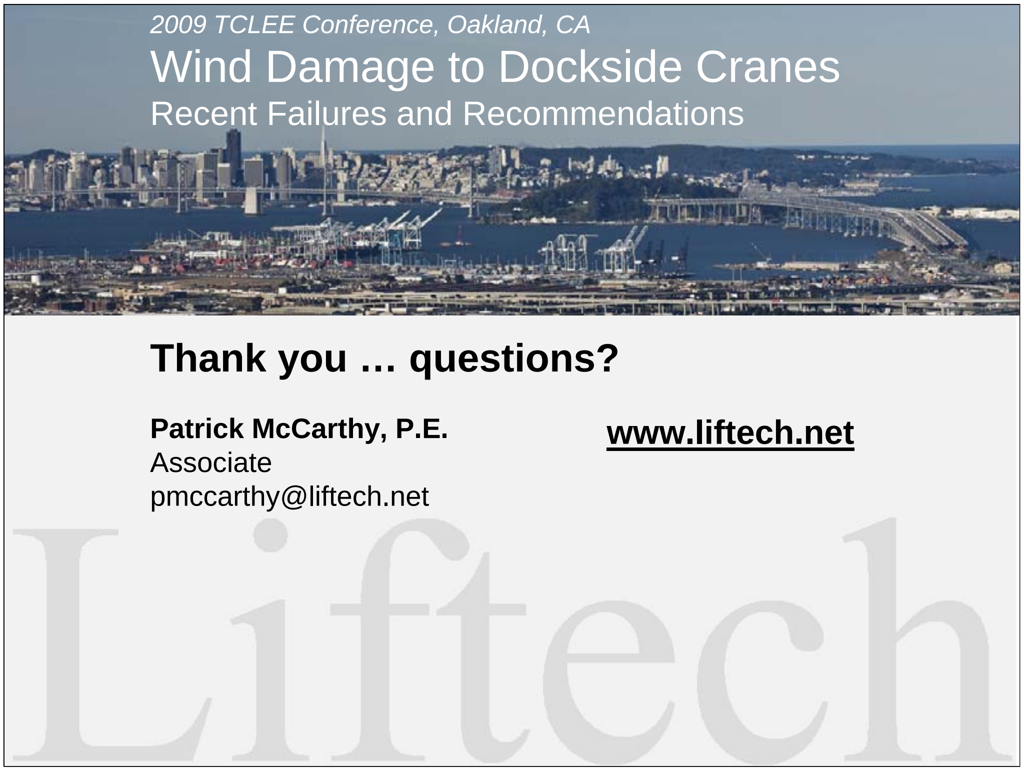
Prying reduces vertical reaction due to lateral forces.



In closing, we recommend owners review their options.

Ductile links may be an attractive solution for increasing crane stowage reliability in a changing environment.

Develop emergency plan and properly train for high winds during operations.



Thank you!

See the paper for references and more information.

See our website (in a week or two) to download this presentation, the paper, and other material or email me.

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