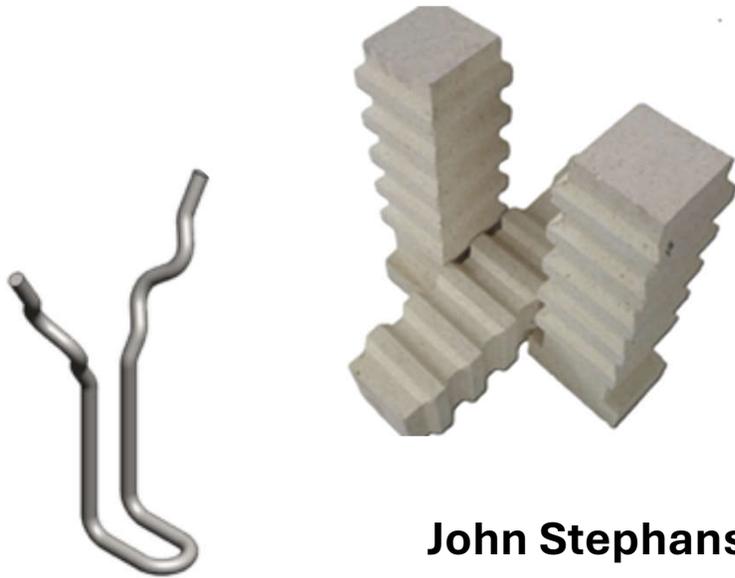


# “Refractory Anchoring: Challenges and Considerations”



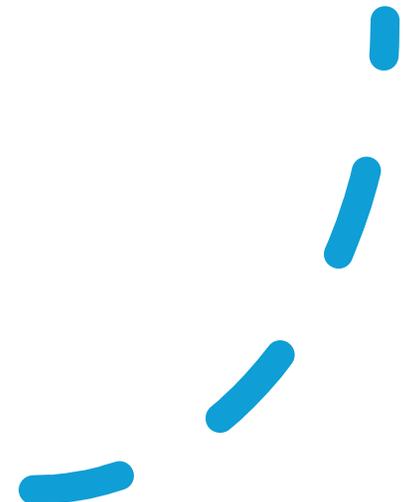
John Stephansky  
IEEE-West Coast Cement  
Conference  
October 16<sup>th</sup>-17<sup>th</sup>



Florida Rock, Newberry, FL (1999)  
Holcim, Florence, CO (2001)  
Holcim, Holly Hill, SC (2003)  
Cemex, Brooksville, FL (2003)  
TXI, Oro Grande, CA (2007)  
American Cement, Sumterville, FL (2009)  
TXI, New Braunfels, TX  
Rinker, Miami (2000)  
Lone Star, Greencastle, IN (2000)  
Cemex, Victorville, CA (2001)  
TXI, Midlothian, TX (2001)  
Signal Mountain, Chattanooga, TN (2001)  
Phoenix Cement, Clarksville, AZ (2002)  
Monarch Cement (retro-fit), Humboldt, KS (#5-2002  
#4-2005)  
Cemex (Rinker Materials), Brooksville, FL (2008)  
Holcim, St. Genevieve, MO. (2009)  
Ash Grove, Foreman, AR (2010)  
Lehigh, Mitchell, IN (#2-2002 and #1-2003)  
Holcim, Devils Slide, UT  
Holcim, Midlothian, TX (2000)  
Cemex, Kosmosdale, KY (2000)  
Cemex, New Braunfels, TX (2008)  
Holcim, Hagerstown, MD (2015)  
Capitol Cement, TX (2012)

## Background

- Started working on Cement Plant Capital Projects in the US in 1998.
- Florida Rock
  - First greenfield Cement Plant built in the US in 20 years
- And a few more followed ....



# Challenges

- Meeting OEM specifications
  - Products
  - Lining profile
  - Thermal profiles
  - Anchorage
  - Total weight of lining

# What happened (1998-2003):

---



**Catastrophic anchor failures and shell corrosion were problematic**



# ***Anchor System Initially Employed***

**Two component anchoring  
system**



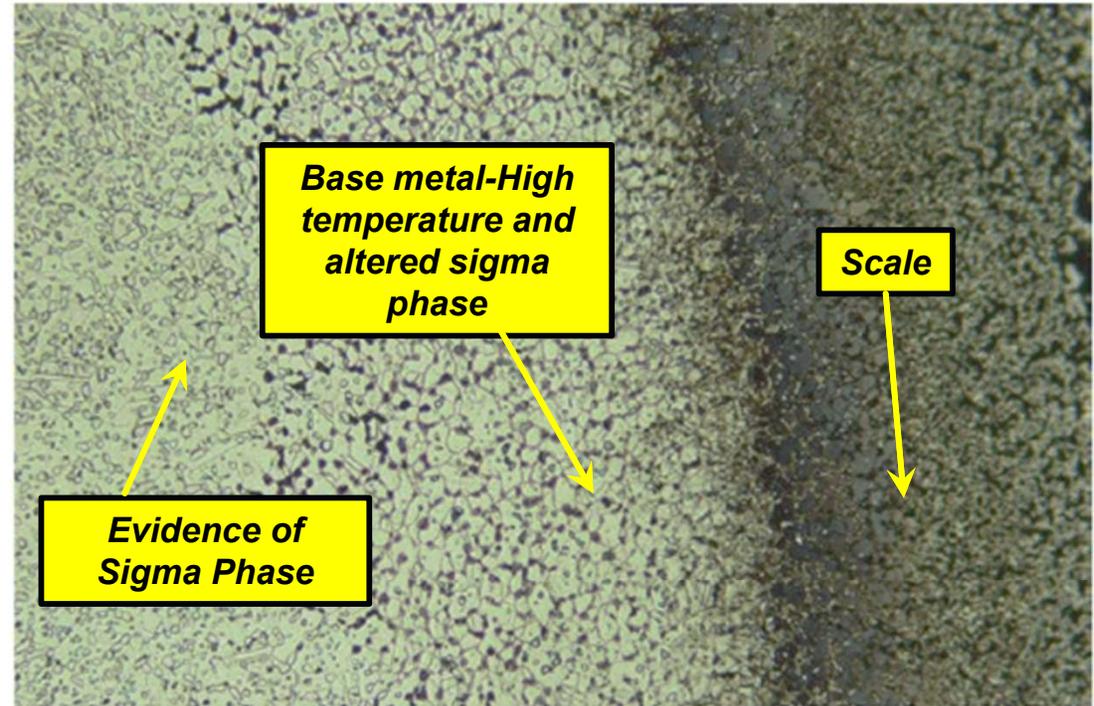
# Anchor failures were showing up everywhere



- **Cross-sectional view shows the brittle characteristics of the failures.**



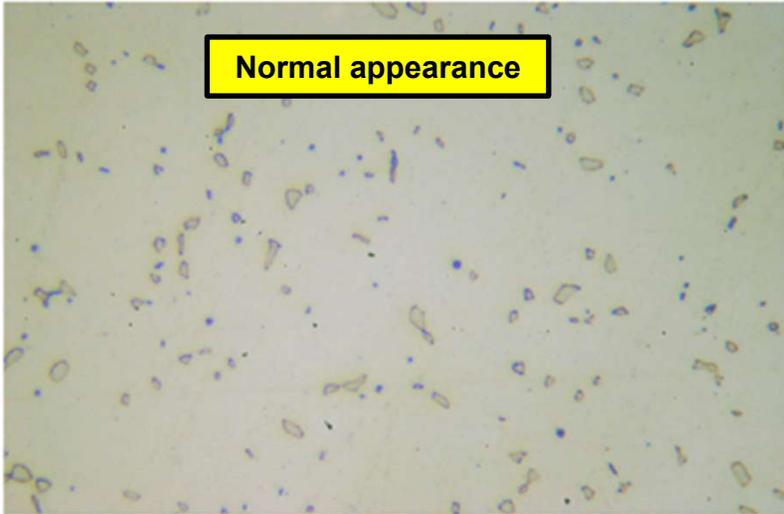
Sectional  
Analysis  
indicated  
*Sigma*  
*Phase* as  
the failure  
mode



**Figure 5a:** High magnification view at edge of base metal. The area on the far left shows sigma phase (blocky phase). The center area is still base metal where high temperature attack, from diffusion of species in and out of the metal, has occurred and is likely oxides, sulfides, and altered sigma. The dark region on the right side is high temperature scales at the 310 SS surface. 190X; glyceresia etch

# ***Sigma Phase Appearance***

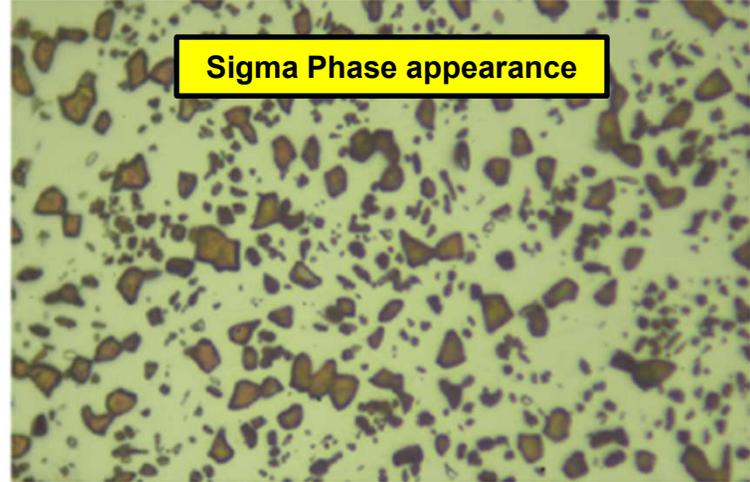
**Normal appearance**



**Figure 6c:** Cold end from same anchor as Figure 6a. Blocky phase is likely some ferrite formed during mill manufacturing or heat treating of 310 SS. Obvious amounts of sigma are not present since the cold ends do not operate in the sigma forming range. 760X; Modified Murakami's etch

***Cold End***

**Sigma Phase appearance**



**Figure 6a:** Hot end base metal clearly confirming extensive sigma phase (reddish-brown "blocky" phase) and some likely ferrite (gray). Carbides, which etch dark with this etchant, are not apparent. ~760X; modified Murakami's etch

***Hot End***

# ***Sigma Phase- Basic Definition***

- **Sigma Phase** is an iron, chromium, nickel and molybdenum phase that is observed in duplex SS in the microstructure of the metal
  - Mechanical properties, ductility and toughness
- **Sigma formation can cause embrittlement** below 1100°F(593°C)
- High temperature oxidation, sulfidation and embrittlement due to sigma formation are primary failure mechanisms of metallic anchoring systems.
- **Chi ( $\chi$ ) Phase**

**Where do we  
go from here?**

---

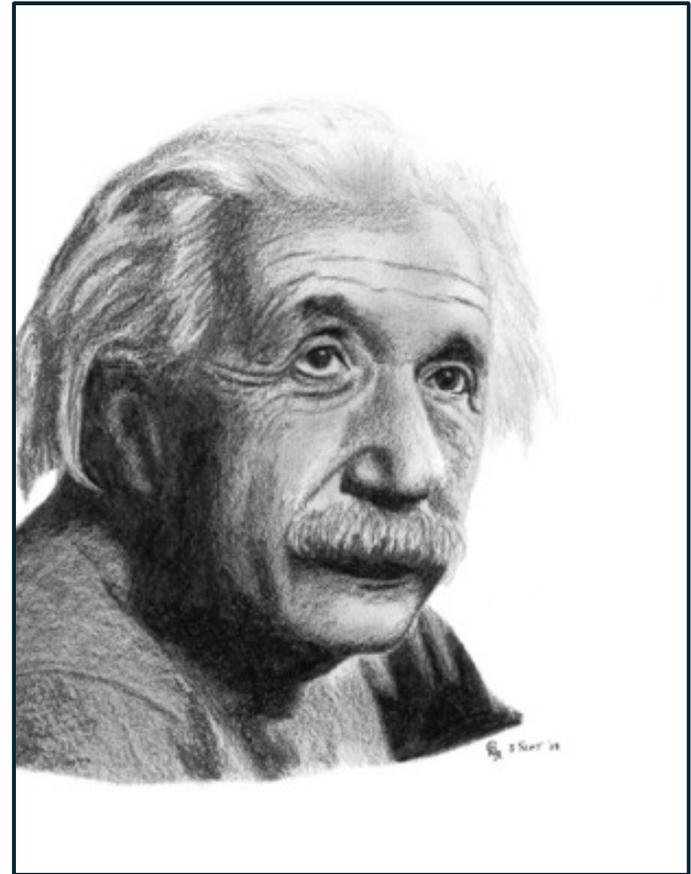


Went back to the  
drawing board.....

---

*You can never solve a  
problem on the level  
on which it was  
created*

*-Albert Einstein*



# ***What we learned:***

---

- 1. Lining profiles were heavily insulated.**
- 2. Shell temperatures were too low to combat condensation of sulfates, chlorides, and alkalis.**
- 3. Alloys of the metal anchors were not adequate for intermittent use.**
- 4. High temperature tensile strength was compromised.**
- 5. Alternative anchoring systems were not employed.**
- 6. And the big one: Alternative Fuel usage began in earnest.**

# **WHAT WE DETERMINED SHOULD BE ROUTINE**

- **Inspect failed anchor systems.**
- **Review the thermal profile of the lining to be installed.**
- **Specify the anchor arrangement.**
- **Specify the anchoring system and alloy qualities to be used by the area to be lined.**
- **Inspect the welding on the anchors. Are they welded properly?**
- **Check to see if the correct anchor quality is installed.**

# **Evaluate Anchor System and Shell's Expansion**

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# Simple Cost Analysis

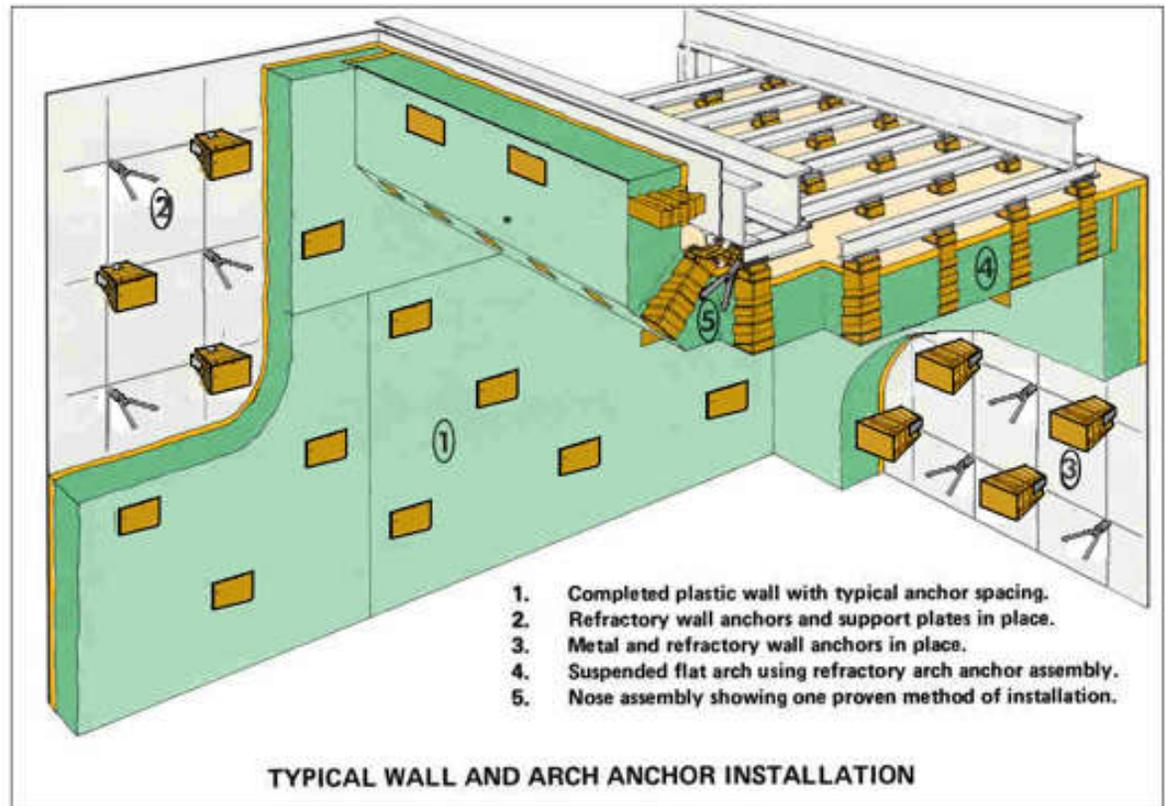
- 12in<sup>2</sup> panel 9” thick lining
  - 6” dense high-quality material
  - 3” lightweight material
- @ 160#/Ft<sup>3</sup> = 80#’s material
  - @ \$0.80/lb = \$64.00
- @ 28#/Ft<sup>3</sup> = 7#’s material
  - @ 0.25/lb = \$1.75
- Total refractory cost = \$65.75
- Installation cost @1.5 x Ref = \$98.63
- Total installed cost=\$164.38 Ft<sup>2</sup>

***Does it make sense to hang this with a \$7.00 anchor without considering the technical attributes of the anchoring system?***

# Purpose of an Anchoring System

Function : Anchors attach monolithic walls and roofs to the load-bearing structure of a furnace.

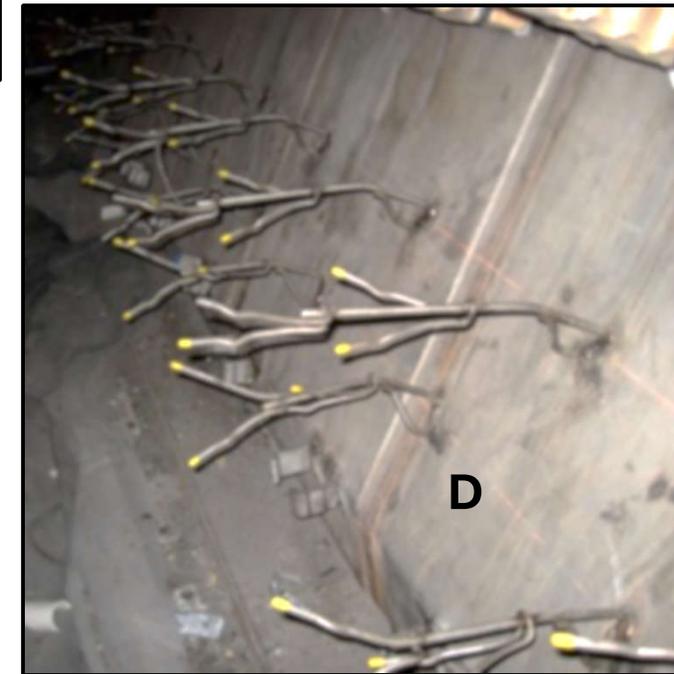
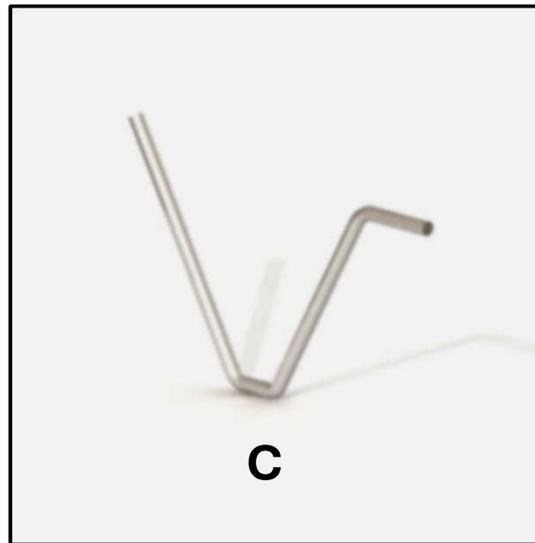
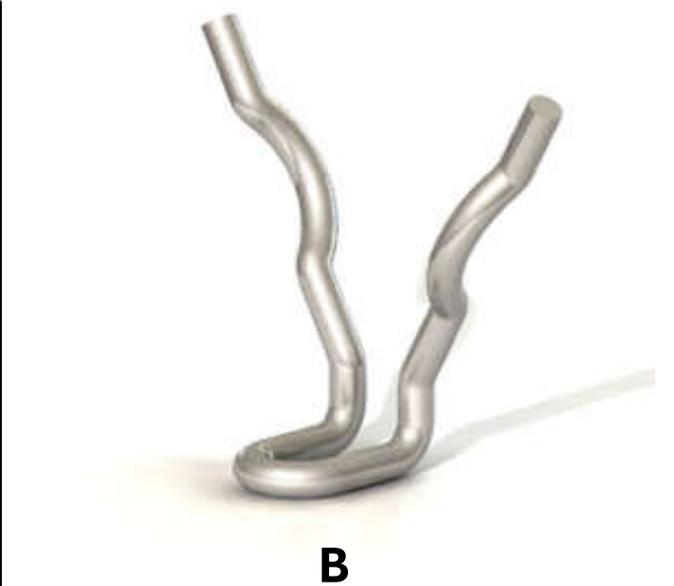
Fact: Anchors are the most critical but the weakest link in monolithic linings.



**If they fail, your lining FAILS!**

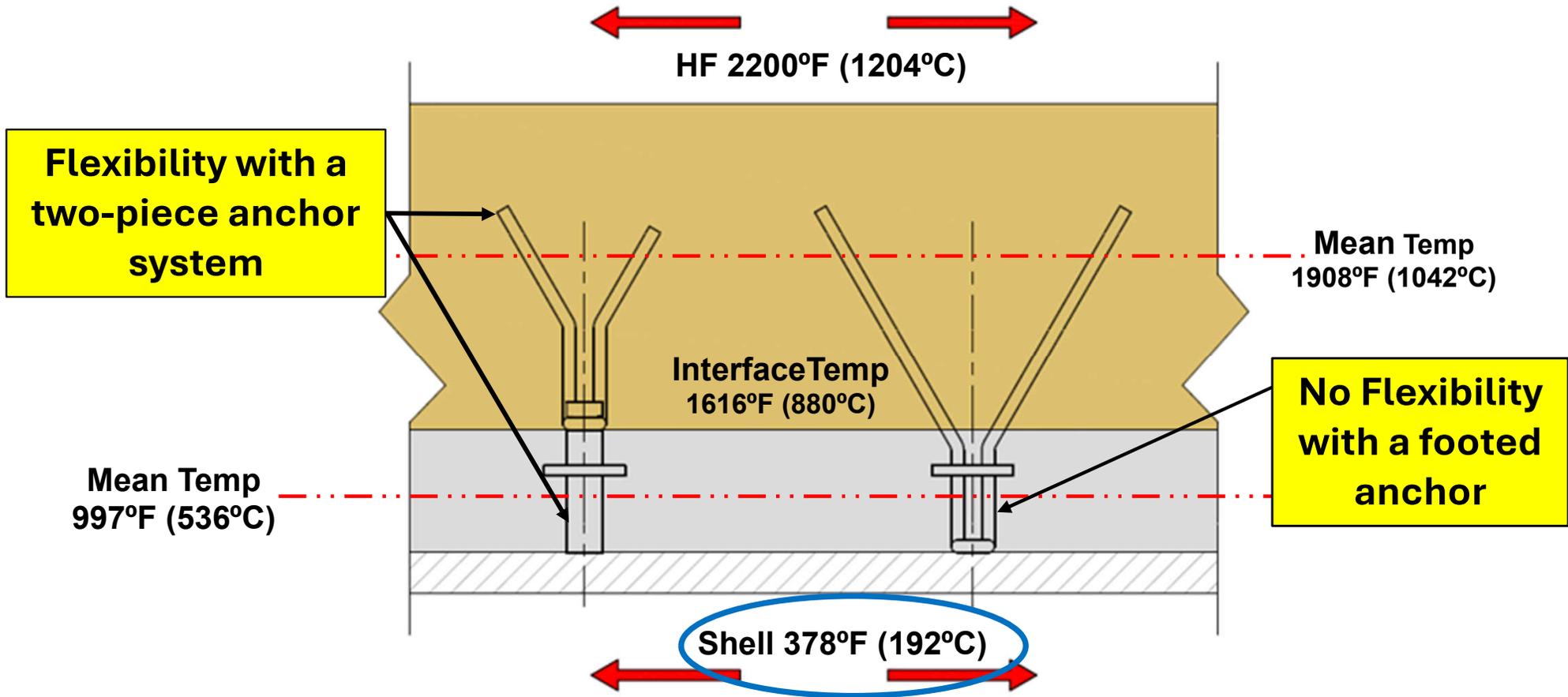
# Styles of Metal Anchorage

- **A**-Breakaway-Burner Pipes
- **B**-Single Component Linings – **Medium Duty** Dense Materials over 6" Thick Heavy Rod- 5/16" to 3/8"
- **C**-Single Component Linings – **Light Duty** Lightweight Insulating Materials or Dense Materials less than 6" Thick Thin Rod- 1/4" thickness
- **D**-XMAS Tree – Usually used for thick linings-Cooler Horseshoes and Curbs.



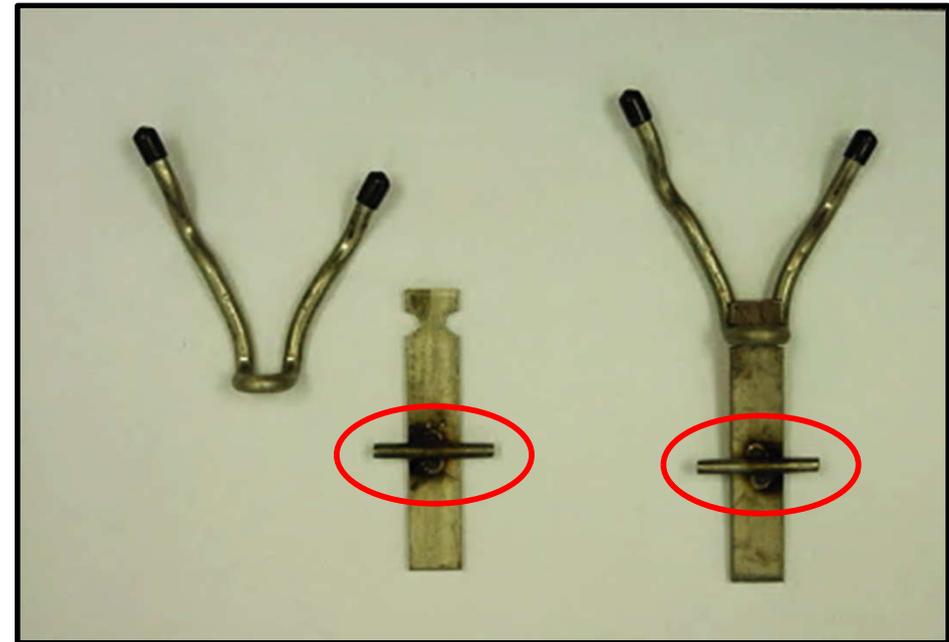
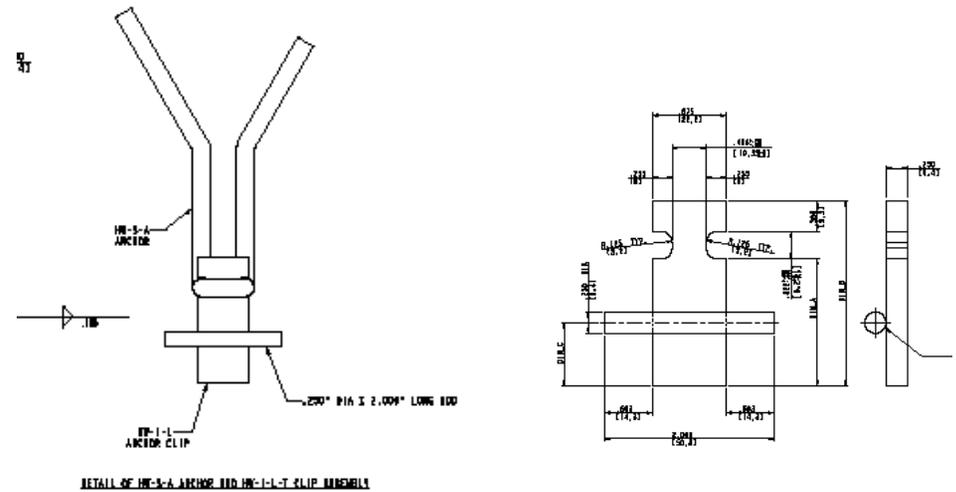
# Expansion of Shell vs Refractory

HF Expanding +7.64% more than steel shell and 33% more than the Interface



# L-Clip Anchoring System

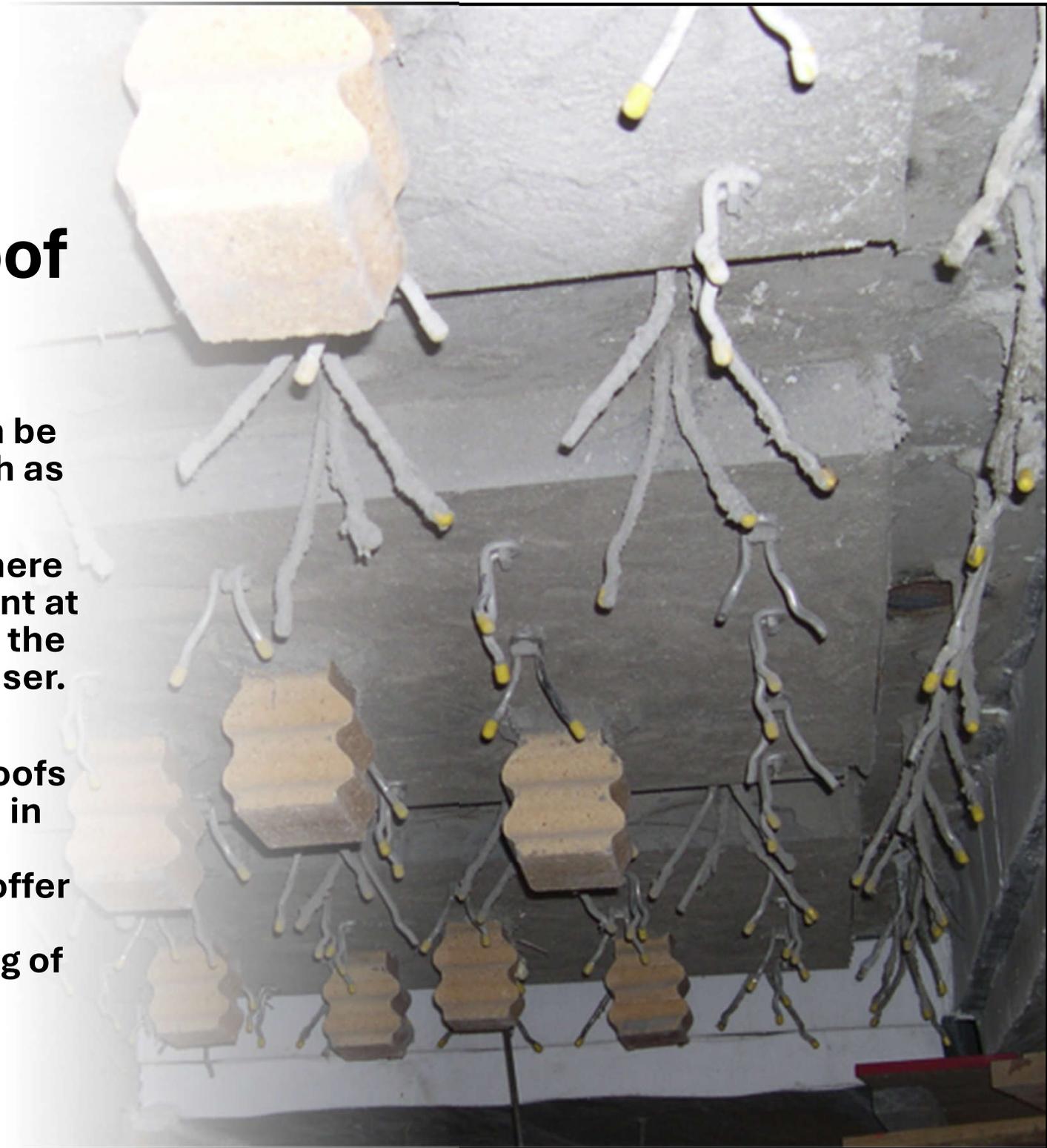
*Welding is easier and better than a footed anchor and the weld is removed from the interface*



**“T-Bar” facilitates anchoring of the back-up lining during installation**

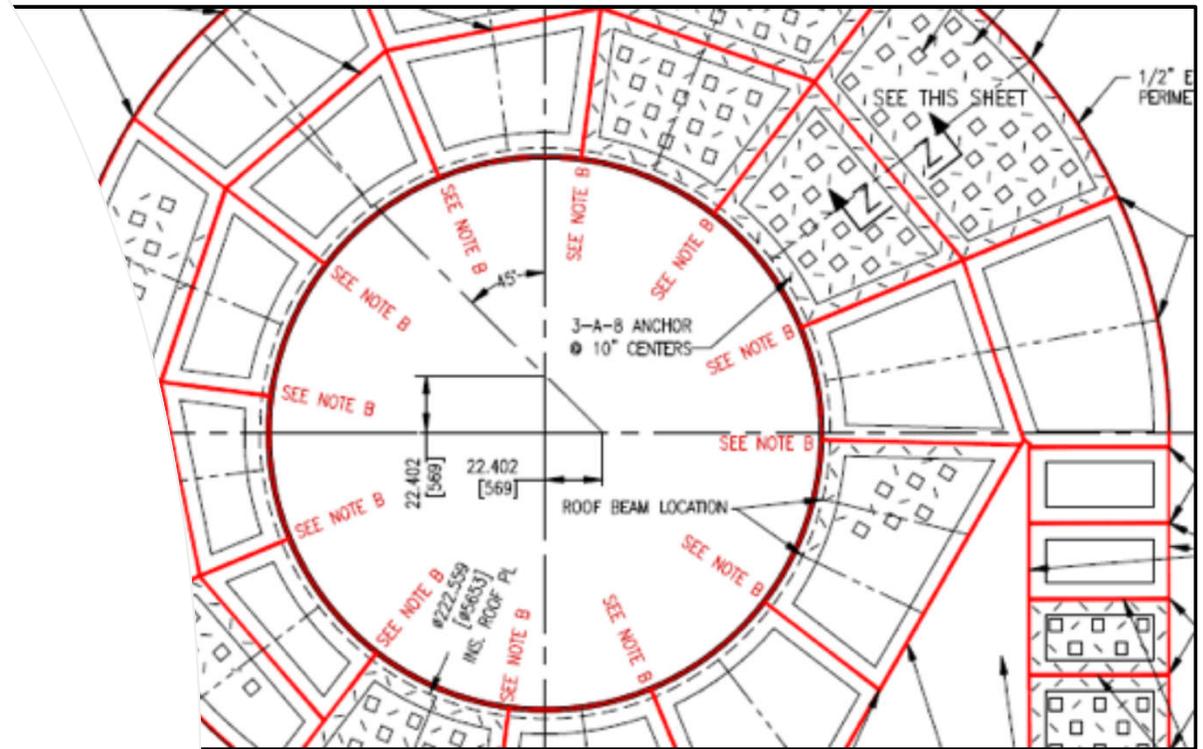
# L-Clips in Cyclone Roof

- Cyclone Roofs can be preloaded as much as 40 mm's (1.6").
- In some designs there is an expansion joint at the intersection of the cyclone roof and riser.
- Due to the upward expansion of the roofs and barrel, L-Clips in combination of Ceramic anchors offer the flexibility to minimized cracking of the refractory.



# Expansion Joints in Cyclone Roof

Cyclone linings require flexibility in their design



# Evaluate the Anchor Alloys

---



# Difference between continuous use and intermittent use temperatures

<b>MAXIMUM Temperature of Metallic Components <u>Continuous Use</u></b>	<b>MAXIMUM Temperature of Metallic Components <u>Intermittent Use</u></b>	<b>Alloy</b>
1300°F (700°C)	<b>500°F (260°C)</b>	carbon steel
1650°F (900°C)	<b>1500°F (820°C)</b>	304 SS
2100°F (1150°C)	<b>1850°F (1010°C)</b>	310 SS

## Definition of Intermittent:

Not happening regularly or continuously,  
stopping and stopping repeatedly with  
periods in-between

## Definition of Continuous:

NOT Stopping!

# Tensile Strength

Tensile Strength of Stainless-Steel Alloys (psi / MPa)			
Temperature	304 SS	309 SS	310 SS
77°F (25°C)	90,000 / 620	90,000 / 620	89,500 / 615
1500°F (816°C)	23,000 / 160	28,500 / 195	30,300 / 210
1800°F (982°C)	No data	10,000 / 70	11,000 / 75

Tensile strength of 310SS at:

@ 70°F (22°C) it is 89,500 psi (12,800 Kpa)

@ 1500°F (815°C) it is 30,300 psi (4,350 Kpa)

*High temps results in a ~66% reduction in Tensile Strength*

# Advantages of Nickel and Chromium

---

- **Nickel**

- High temperature strength.
- Enhances oxidation resistance.

- **Chromium**

- Chromium significantly enhances corrosion resistance.
- Forms a protective oxide layer on the surface.
- Sulfidation attack can occur if this oxide layer spalls or is damaged.
  - Forms chromium sulfate, nickel sulfide forms a low melting phase and failure in metallic anchors.



# Typical Anchor Alloys

	304SS	310SS	330SS	253MA	Inconel 601	Inconel HR160
Cr	18-20	24-26	17-20	21	10-14	28
Ni	8-10.5	19-22	34-37	11	58-63	39
Co						29
Max Temp	925°C	1150°C	1035-1150°C	1150°C	1200°C	1200°C
Continuous	1700°F	2100°F	1895-2100°F	2100°F	2200°F	2200°F
Intermittent	820°C	1010°C	*1037°C	1010°C	** -NR	1904°C
Service Temp	1500°F	1850°F	*1900°F	1850°F	** -NR	2000°F
*-Recommended use temperature						
**-Not Reported						

- All alloys offer advantages and disadvantages.
- 304 and 330 do not suffer from long term Sigma Phase.
- 253 MA requires an oxidizing atmosphere to maintain its oxidation resistance. And suffers from sigma phase faster than 310SS when subjected to thermal cycling.

**The Inconel's (Super Alloys) offer the highest temperature usage, but the cost is considerably higher, and their use is limited primarily to areas like Burner Pipes**

**NOTE: When several different alloys could be used, it is suggested that the alloy for the highest service temperature be used for all areas**

***How do you  
choose the  
best alloy?***

**A lot of research papers identify causes of failures and solutions for metallic anchoring systems.**

**The best answer to this question is:**

**“The choice of the alloy for the metallic anchor should be based on the process conditions and thermal load.”**

# ***The Best non-alloy anchor for High Temperature use!***

---

***High Quality—High Fired—High Strength  
Ceramic Anchors***

***Maximum use temperature: >2200°F (1204°C)***

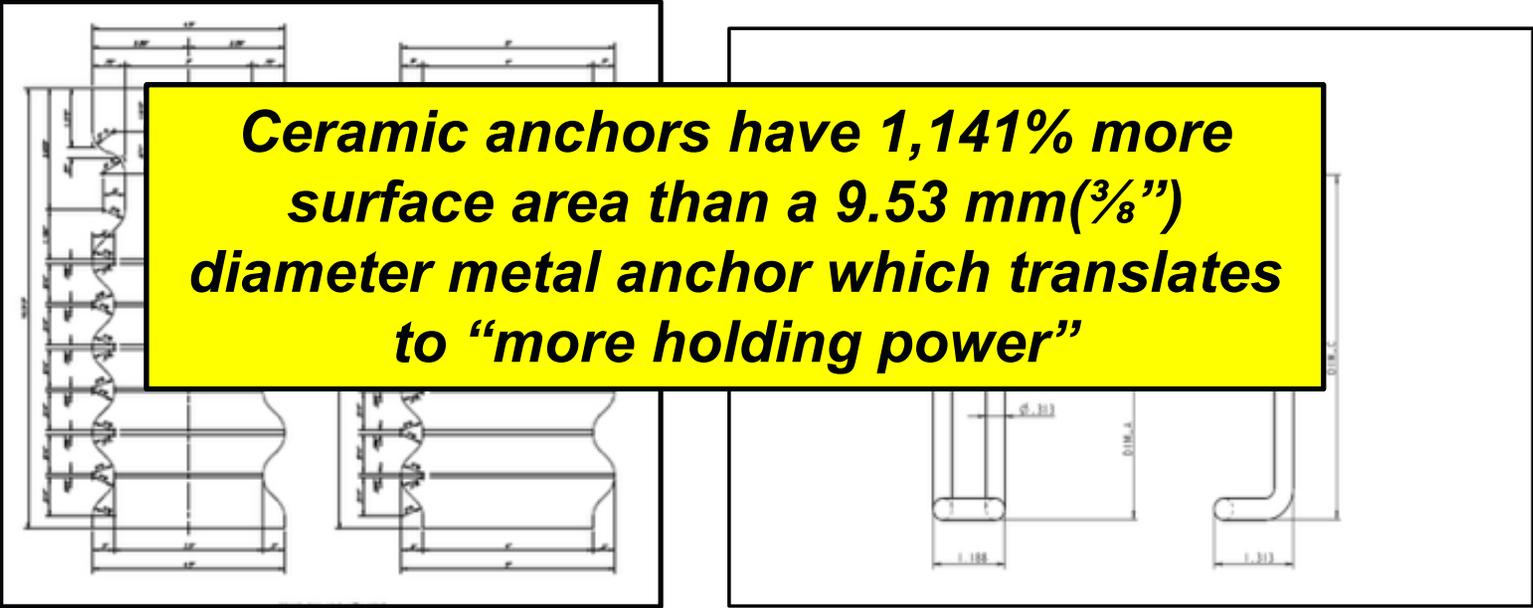
***Not affected by intermittent use***

Good hot use temperature, high refractoriness, alkali resistance and is not affected by sigma phase formation. Ceramic anchors come in a large range of qualities. Ensure high quality, high burned, ceramic bonded anchors are used. Some varieties include Silicon Carbide and Andalusite for added alkali resistance.



# ***Holding Power Comparison***

---



***Ceramic anchors have 1,141% more surface area than a 9.53 mm ( $\frac{3}{8}$ " diameter metal anchor which translates to "more holding power"***

The image contains technical drawings of two types of anchors. On the left, a ceramic anchor is shown in cross-section and side view, featuring a complex, multi-lobed profile with various dimensions. On the right, a wire anchor is shown in cross-section and side view, featuring a simpler, cylindrical profile with a diameter of 9.53 mm and a length of 1.18 inches. The ceramic anchor's surface area is significantly larger than the wire anchor's.

***Ceramic anchor surface area: 1309.5cm<sup>2</sup> (202.97in<sup>2</sup>)***

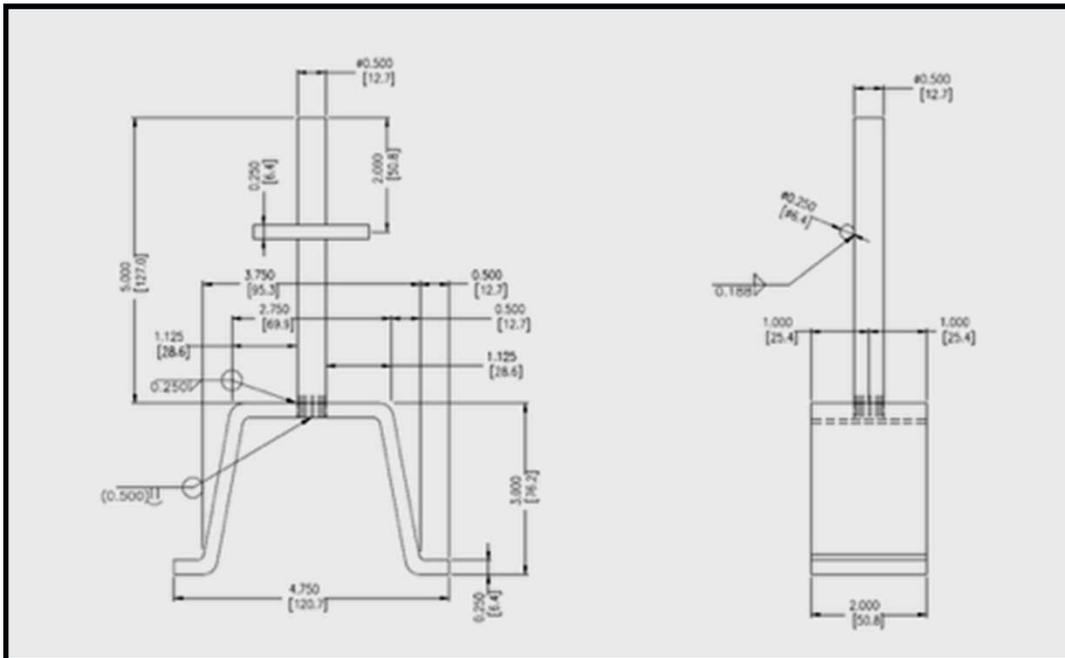
***A 7½" Wire anchor's surface area is: 105.5cm<sup>2</sup> (16.36in<sup>2</sup>)***



**Ceramic  
Anchors Also  
Aid In Forming**



# There is not much holding power in a wire anchoring system



**Bell anchors offer ~217% more surface area than  $\frac{3}{8}$ " diameter metal anchor**



# Analyze the Thermal Profile

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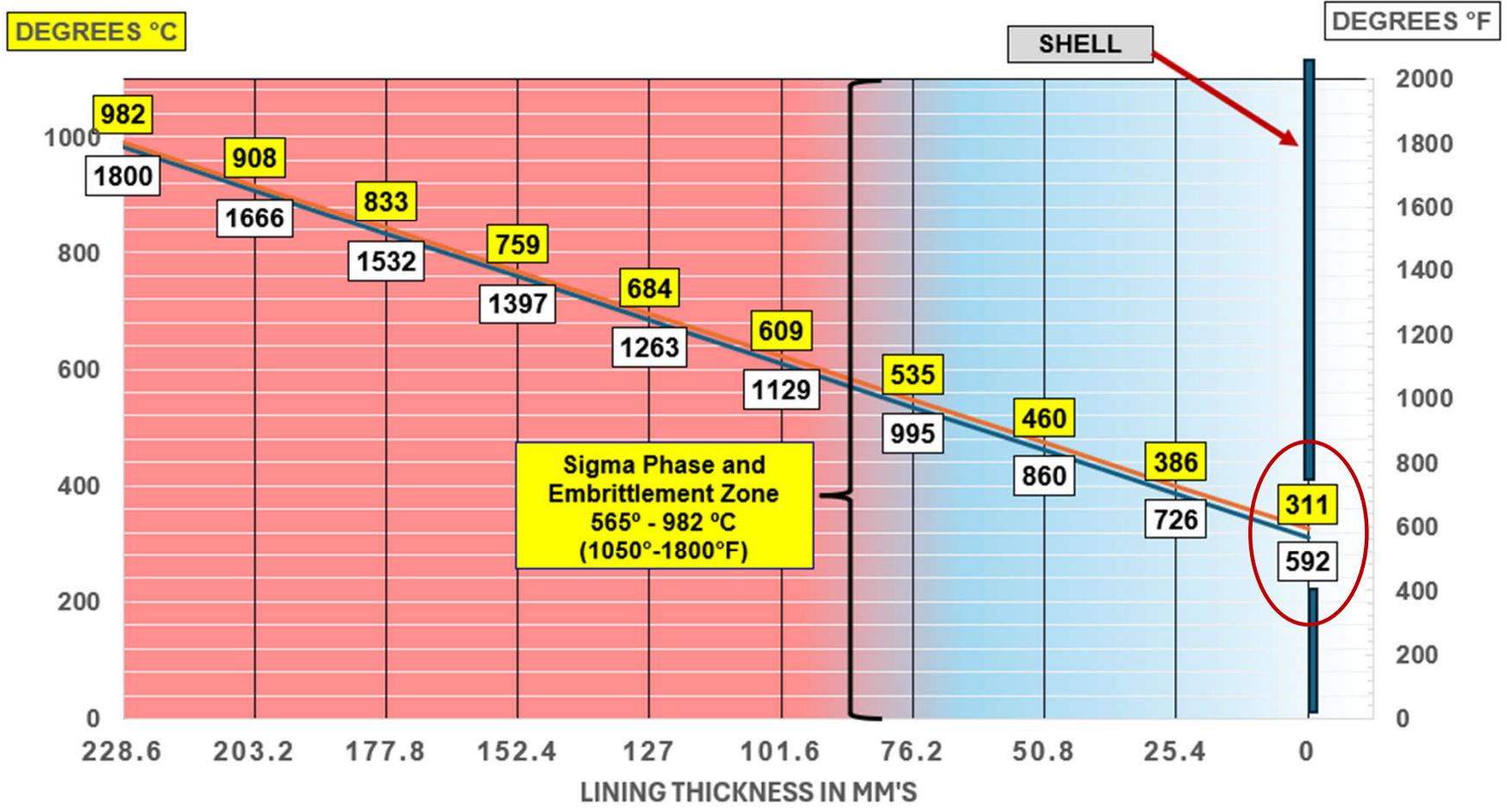


# Thermal Profile

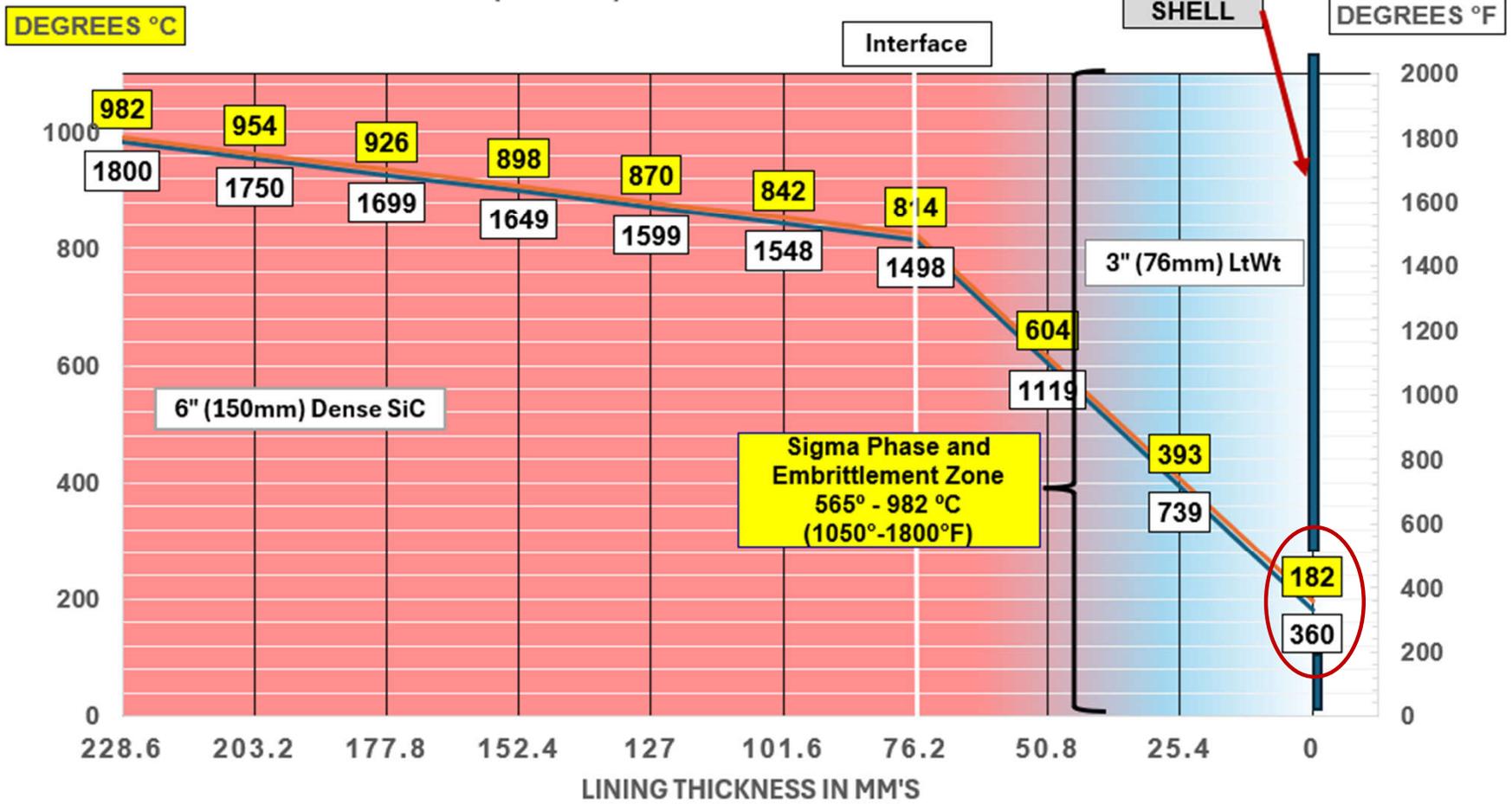
WITH THE CORRECT INFORMATION THE SUPPLIER CAN PROVIDE THE SHELL TEMPERATURE AND HEAT LOSS

Material	Thickness (in)	K-factor (BTU-in/hr-ft <sup>2</sup> -F)	Temperature (F)	
DENSE CASTABLE	4.50	10.42	1800	Hot Face Temp. (F)
LIGHTWIGHT CASTABLE	4.00	2.20	1509	
	8.50		289	Cold Face Temp. (F)
			673	Heat Loss (BTU/sq.ft/hr)
			31197	Heat Storage (BTU/Sq.ft)
Ambient Temperature = 60 (F) Windspeed = 0 (MPH) Emissivity = 0.95 Construction = Sidewall				

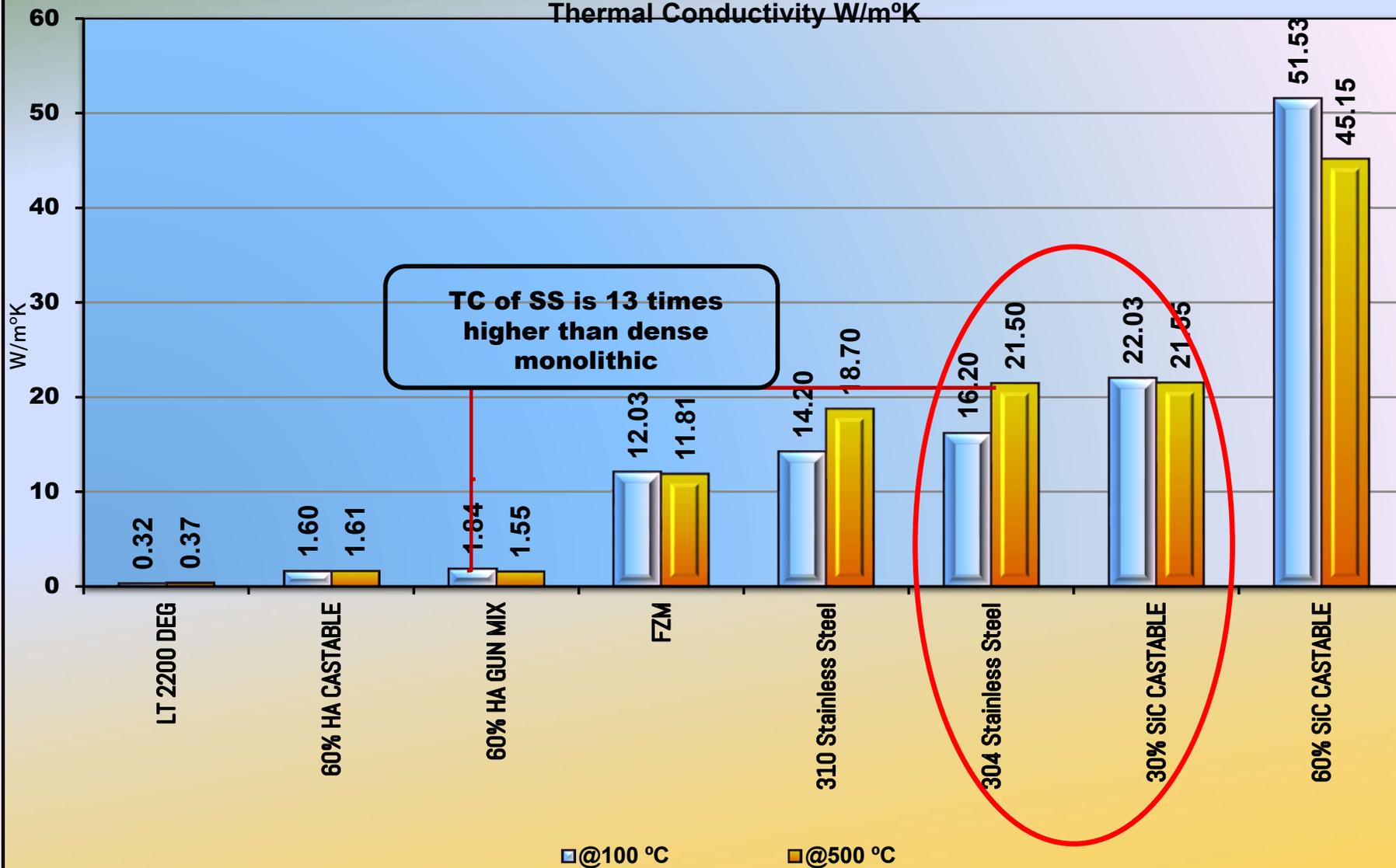
# THERMAL PROFILE OF 9"(220MM) SIC(25%) MONO



## THERMAL PROFILE OF 6"(159MM) SIC(25%) WITH 3"(76MM)LTWT MONO

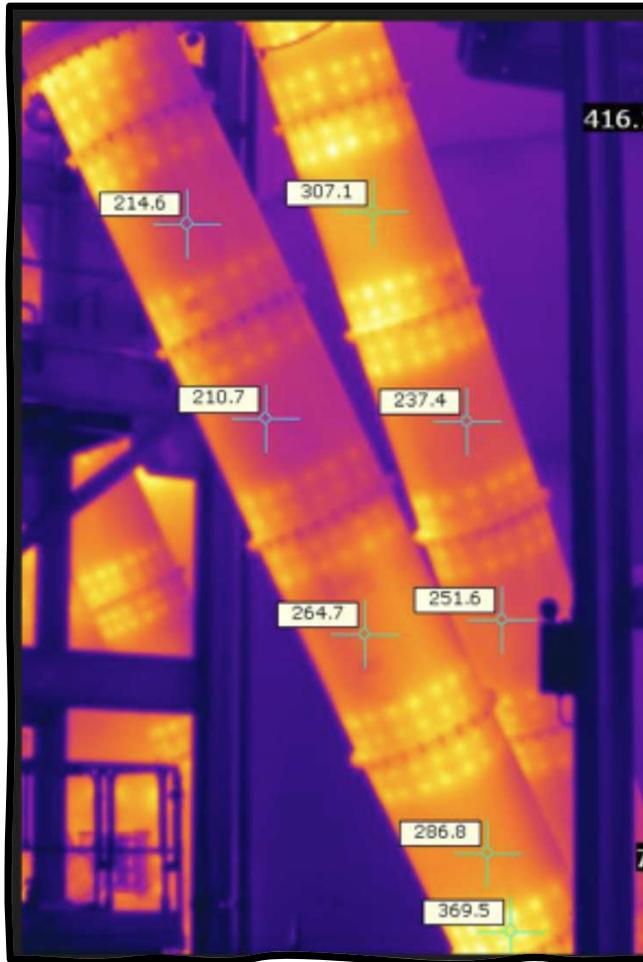


# Thermal Conductivity W/m°K



IR

IR



## Shell Temperatures

Notice the Ceramic and Metallic anchor thermal image on the calciner wall/feed pipes/cyclone

# Adopted the Hot Shell Design

---

***Hot Shell Design to an extent, addressed the shell corrosion problem.***

- The condensation temperature of chlorides and acids on steel shells occur below 300-350°F (150-180°C) it has been the accepted practice in many industries to keep the shells at this threshold to minimize condensation. This is commonly referred to as the “***Hot Shell Design***” ***but required a closer look at the anchoring systems and lining profiles employed.***
- If excessive shell temperatures are reached, they can be addressed by using a combination lining arrangement of a dense and lightweight refractory, or dual lining.

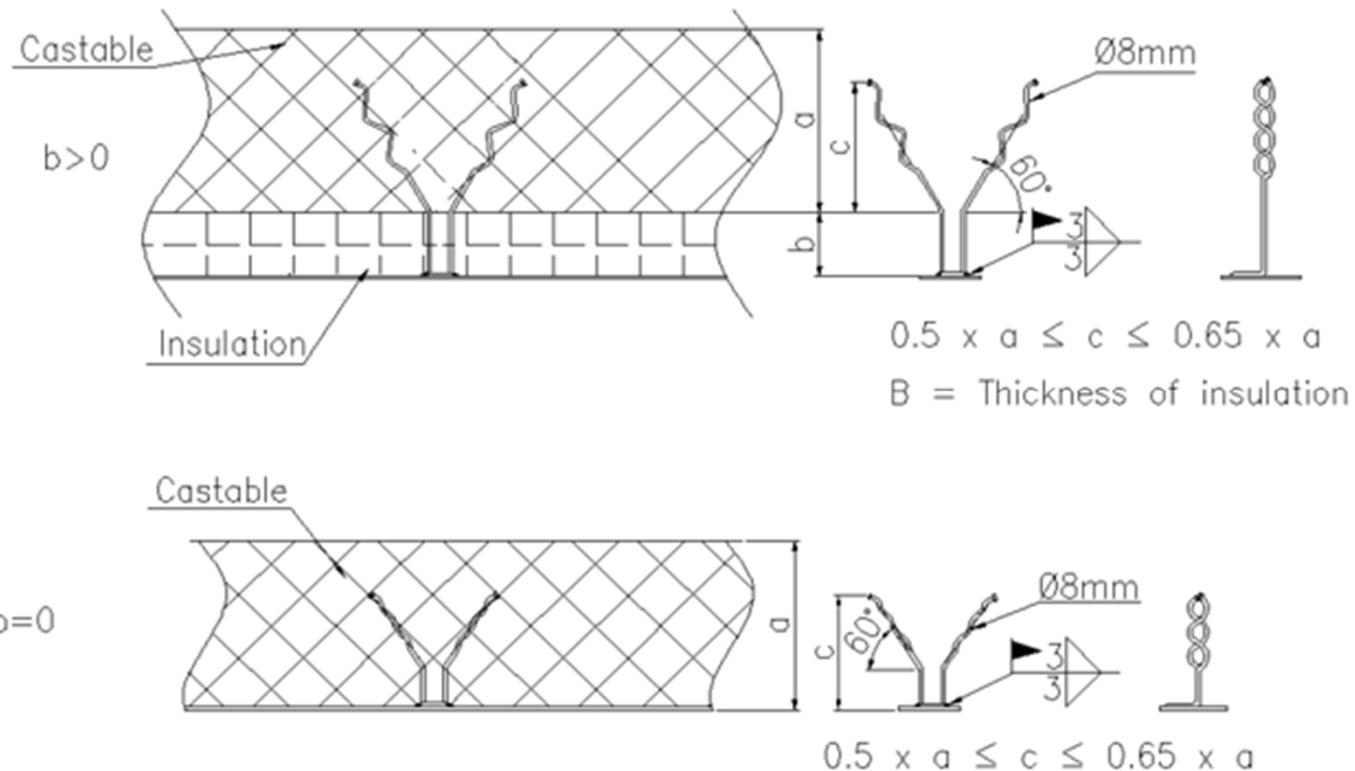
## ***For all High Temperature Areas: Ceramic and Metallic Anchors***

- The use of ceramic and metallic anchors with the metallic anchors at 60% of the lining thickness.
  - Moves them back to a cooler region of the lining <math><870^{\circ}\text{C}</math> (<math>1600^{\circ}\text{F}</math>)
- The metallic anchors assist in installation of the lightweight installed between the ceramic anchors
- Aids in holding the dense material between the ceramic anchors



# Anchor Lengths (OEM)

- Typically anchor lengths are 80% of the lining thickness
- This specification calls for max of 65% of the dense monolithic



# ***Ceramic and Metallic Anchoring System***

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- **Bullnose was in service for +10 years....**
  
- **The Cooler sidewalls performed well over 20 years**



# **Anchor Spacing and Welding**

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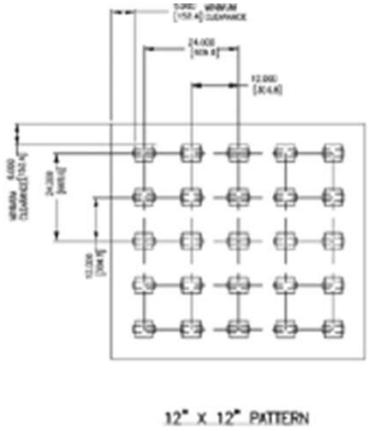
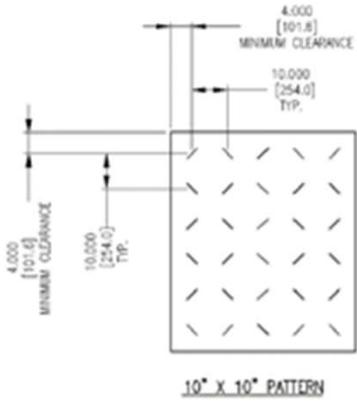
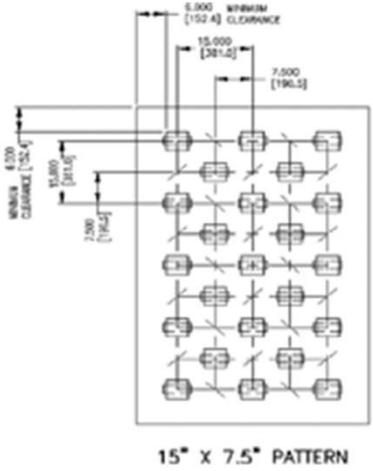
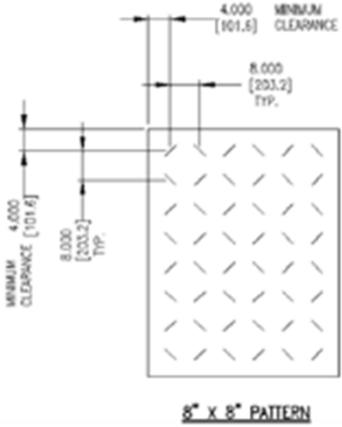
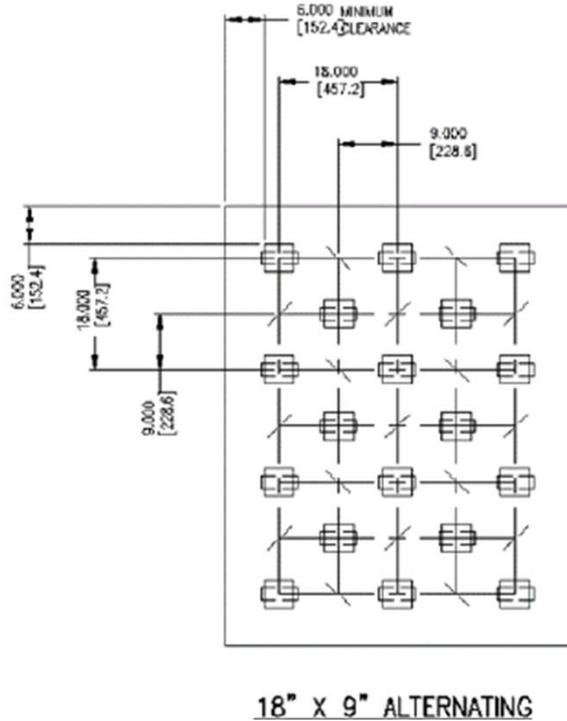
***Despite what  
you may have  
been told: This  
is not a  
recommended  
anchoring  
pattern!***

---



# Anchoring Patterns

- Dependent on the thickness of the lining.
- The anchors
  - Wire
  - Ceramics
  - Mixed
- The method of installation of the monolithic
  - Casting
  - Shotcreting
  - Guniting



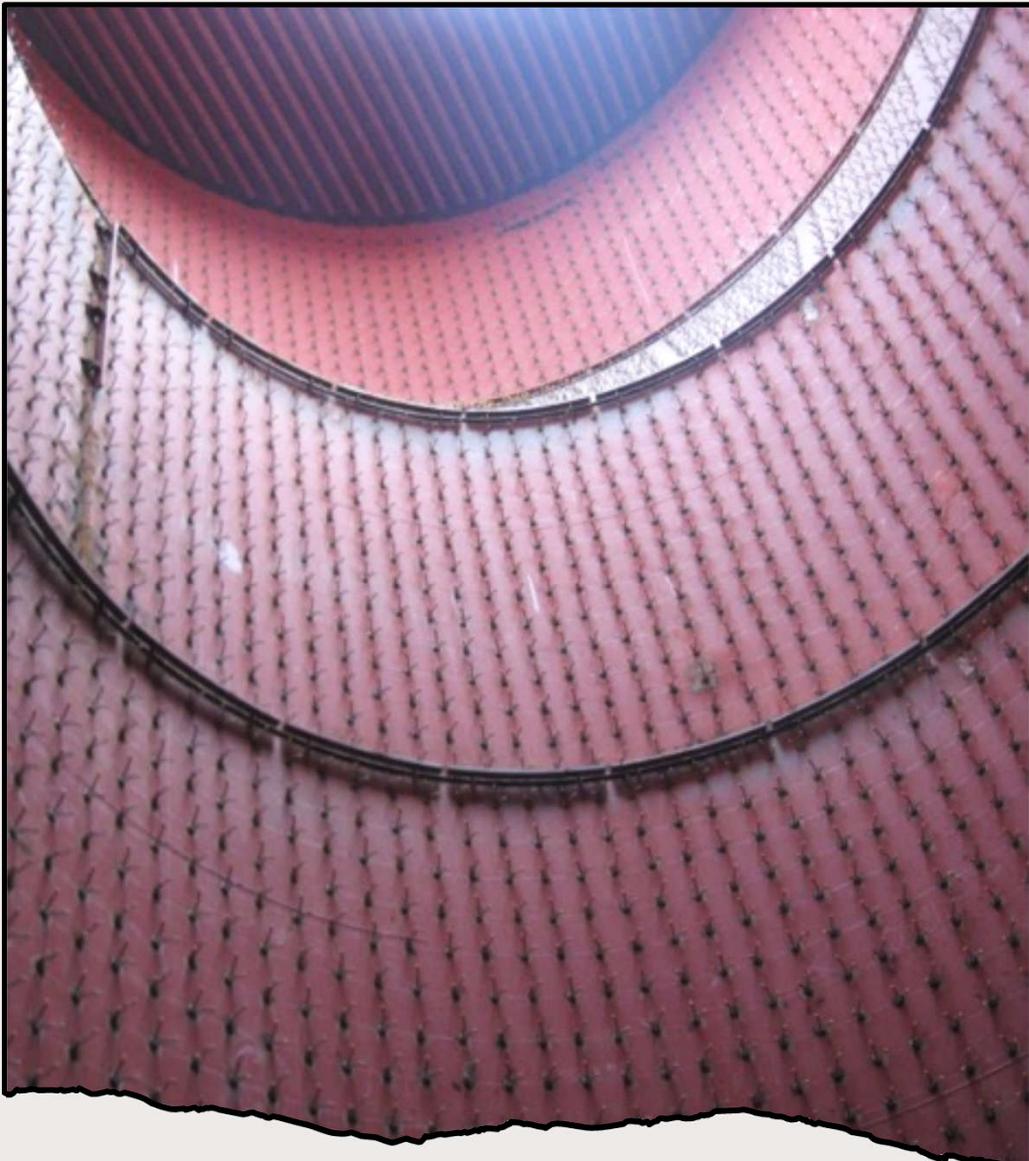
## Improper placement of anchor

**Never span  
any anchor  
over a  
construction  
or expansion  
joint**





***Preferred anchoring  
arrangements for High  
Temperature Areas***



***Preferred anchoring arrangements for  
Single and Dual linings in Lower  
Temperature Areas***



***A good example of anchoring in a lower temperature area after the backup lining is installed***

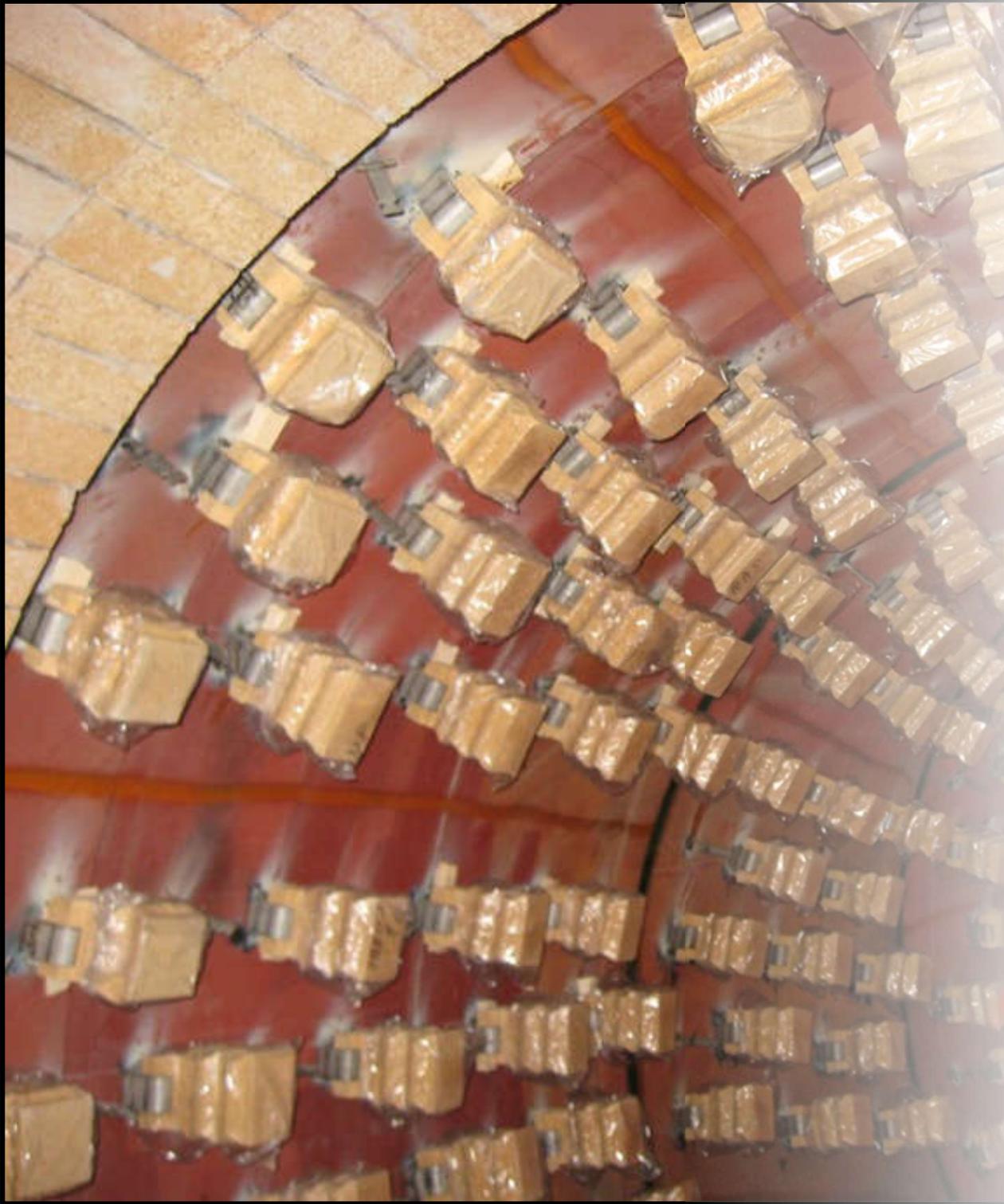


**Anchorage on Firing Hood Bullnose**



Overhead  
Installation

Example of where **Ceramic Anchors** should  
have been used.

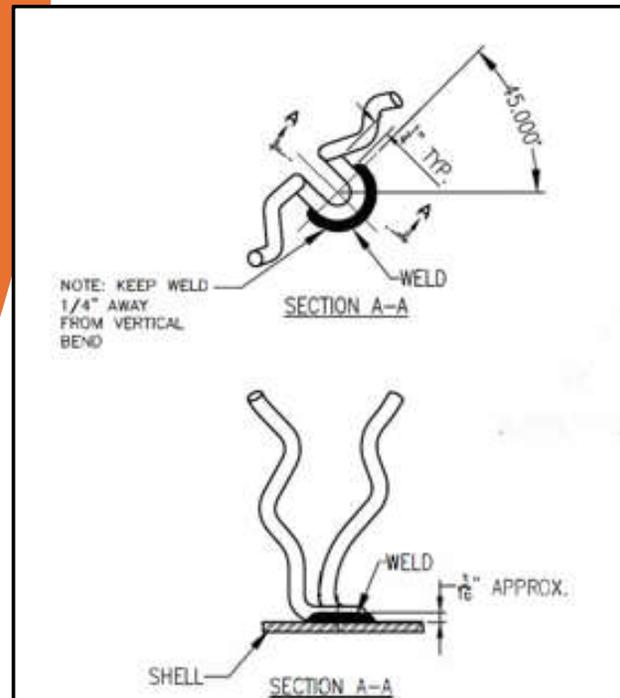
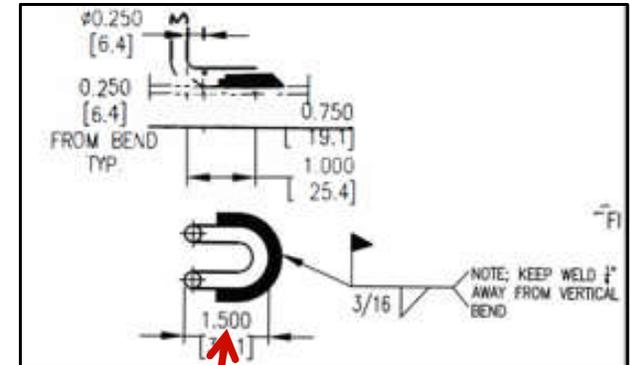


## Ceramic Anchors in TAD - bagged

- The use of bags is to keep the lightweight gunned backup sticking to the anchor and compromising adhesion of the dense monolithic to the anchor.
- The bags are removed prior to installing the dense monolithic.

# Welding of Anchors

Improper welding causes embrittlement of Stainless Steel and potential for failure as weld is too close to cold formed bend



Proper way to weld footed anchors by keeping the weld away from cold formed bend

# ***Anchor failure-Welding***

**Welding too close to the bend in the anchor caused catastrophic failure on this burner pipe.**





# Embrittlement

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**Catastrophic failure of anchors due to welding at the bend of the foot**

# Poor Welding Techniques

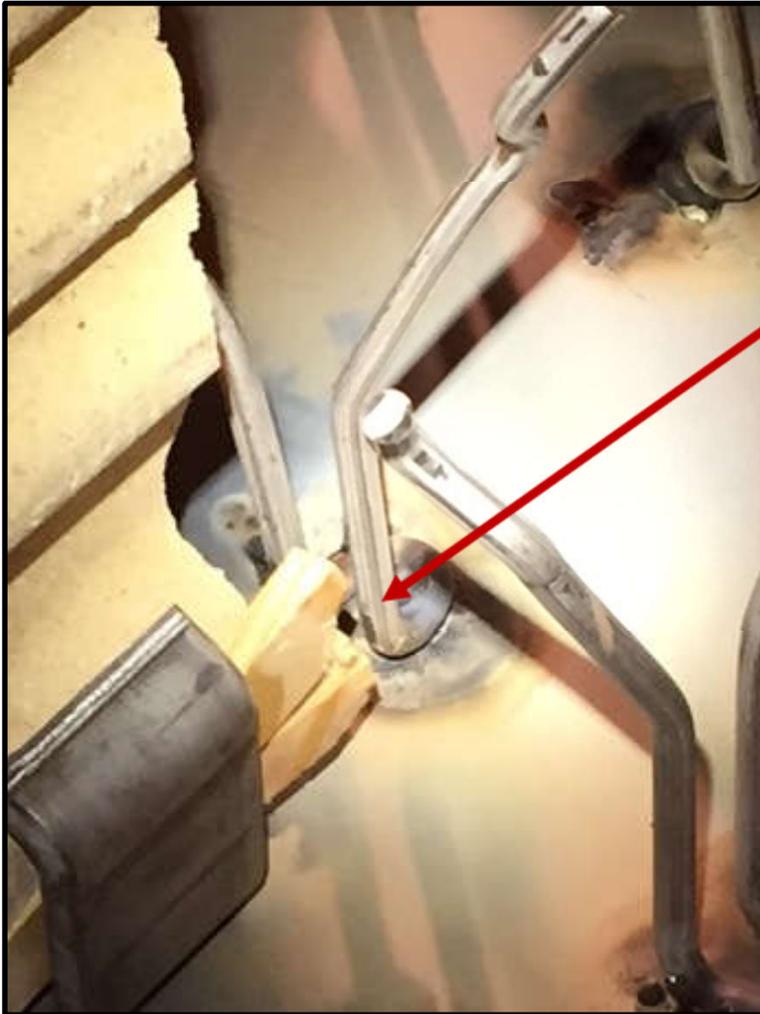


**Never Weld on inside of  
anchor foot**



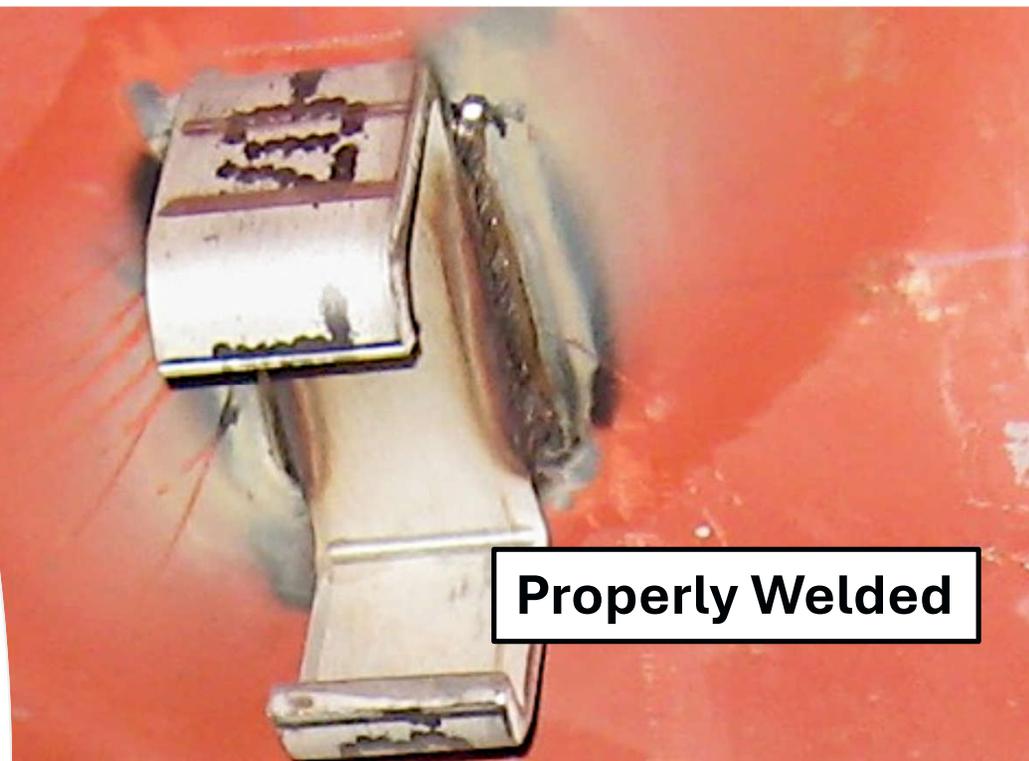
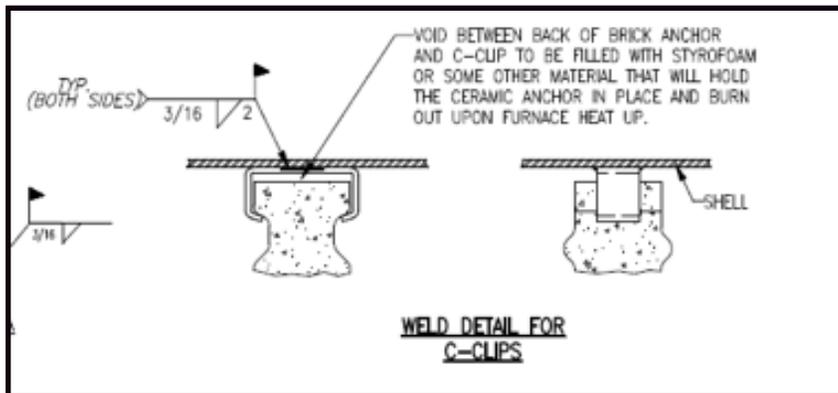
# Improper shim and placement of metallic anchor

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**Shim in wrong direction and metallic anchor too close to ceramic anchor**

Difference between a properly welded C-Clip and not properly welded one.



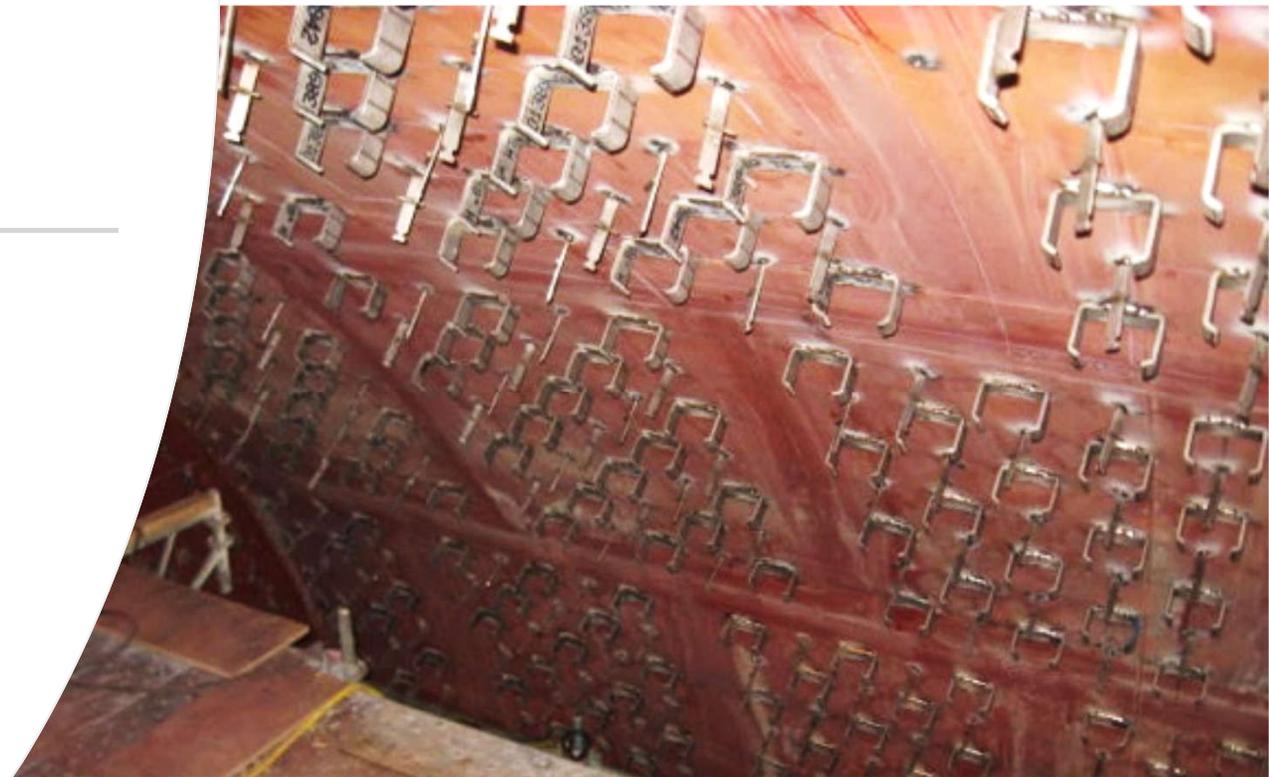
**Properly Welded**



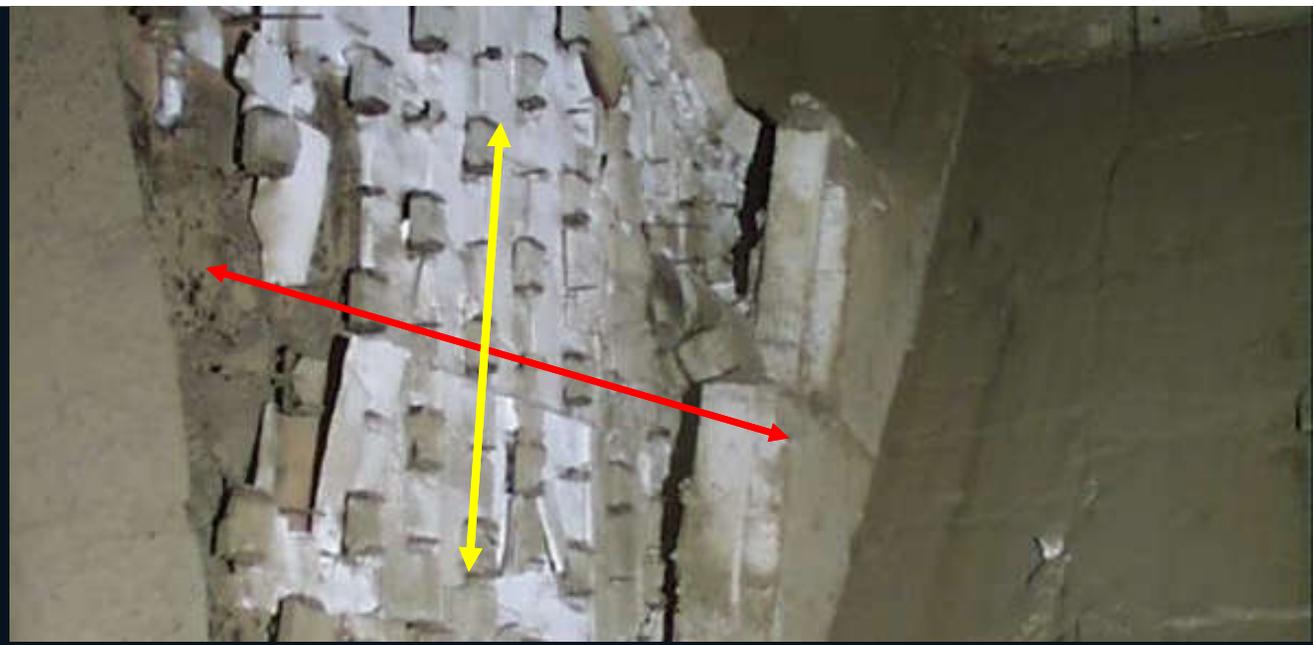
**Not Properly Welded**

C-CLIPS should be welded properly and aligned in the direction of the highest stress

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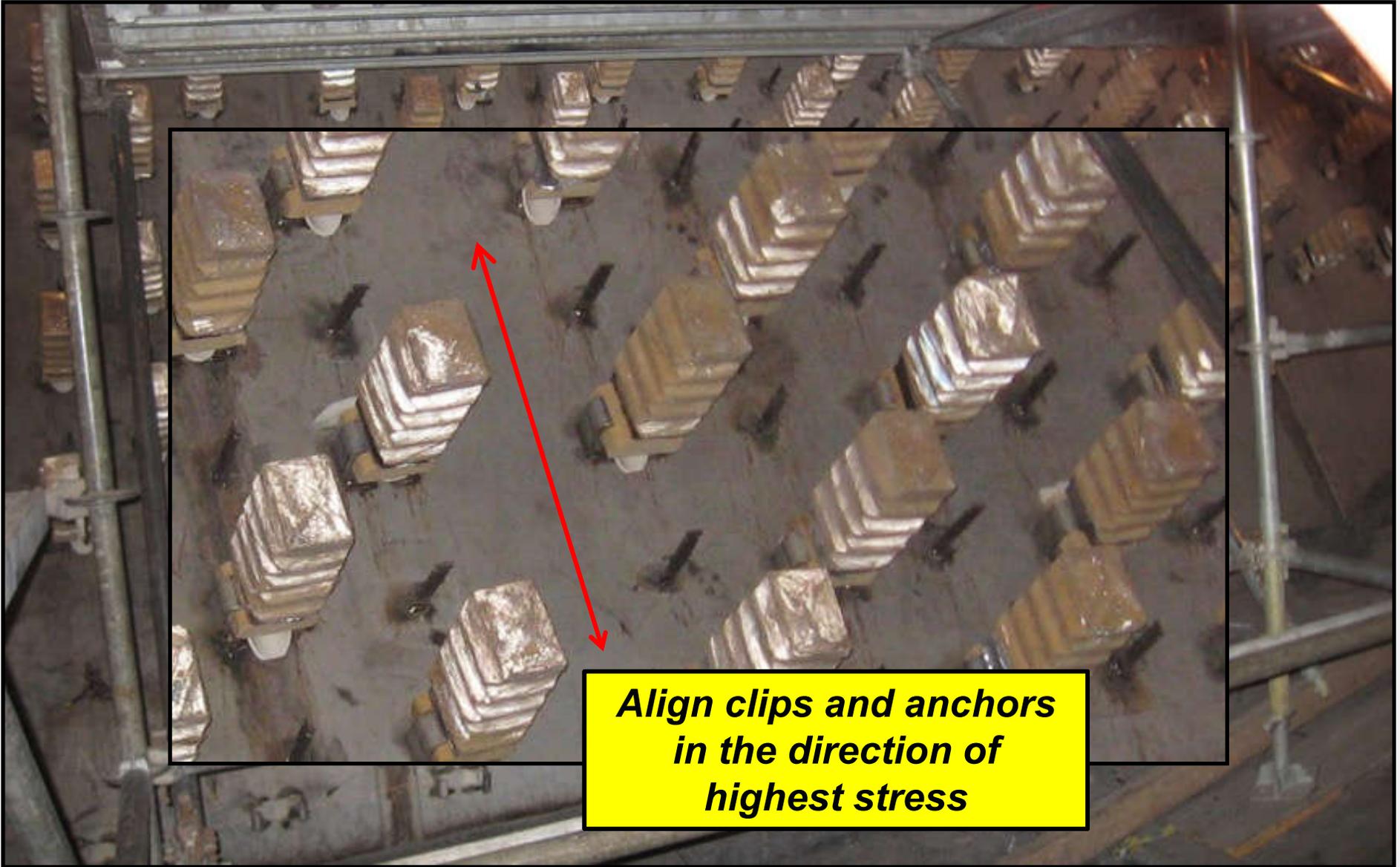


**Proper *orientation*  
is important**



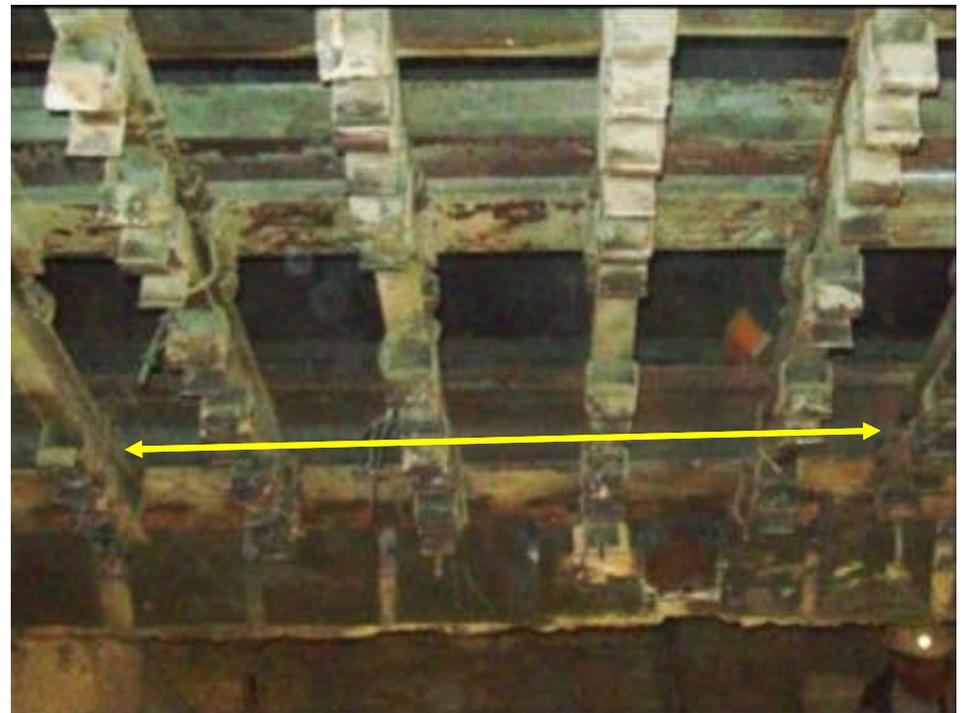
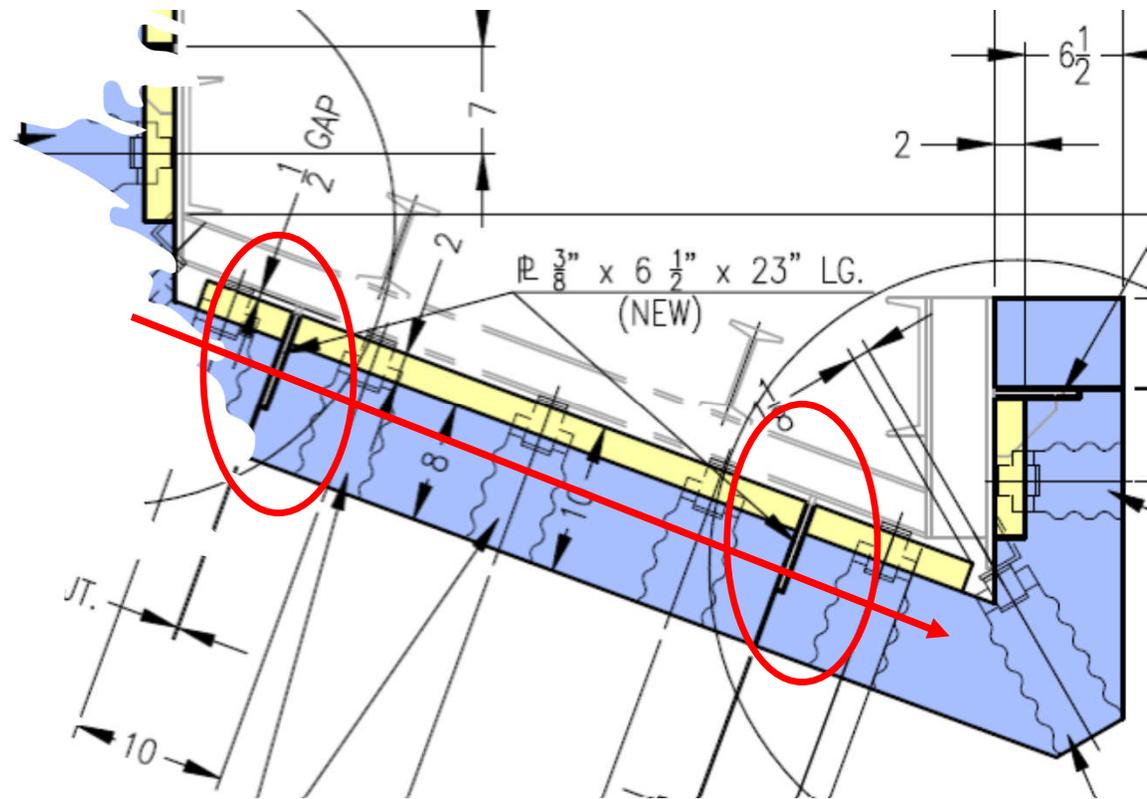
**The incorrect orientation  
resulted in shearing of the  
ceramic anchors in this  
cooler sidewall**

## Notice C-Clip *Orientation*



# Sloped Cooler Roof

- Orientation of C-Clips should be open in the downward direction
- Load relieving plates should be located at the top and bottom of sloping section.

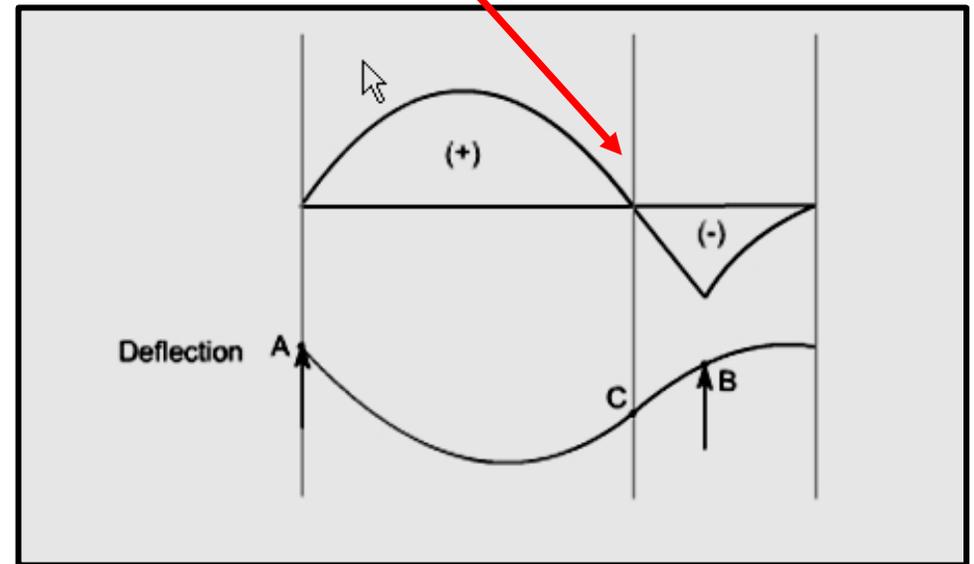
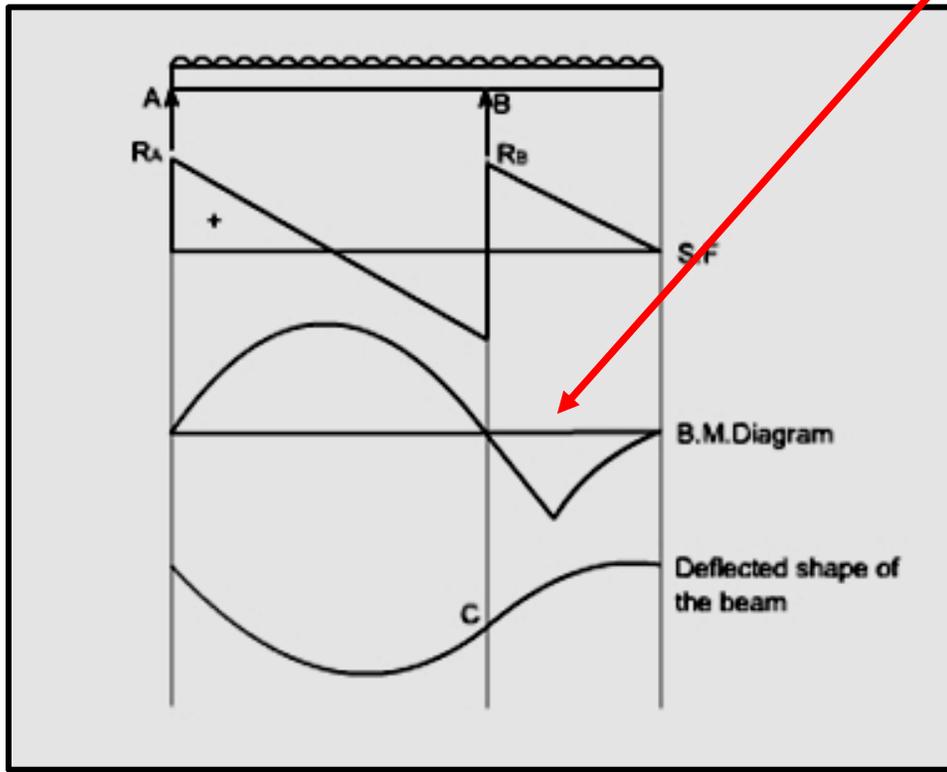


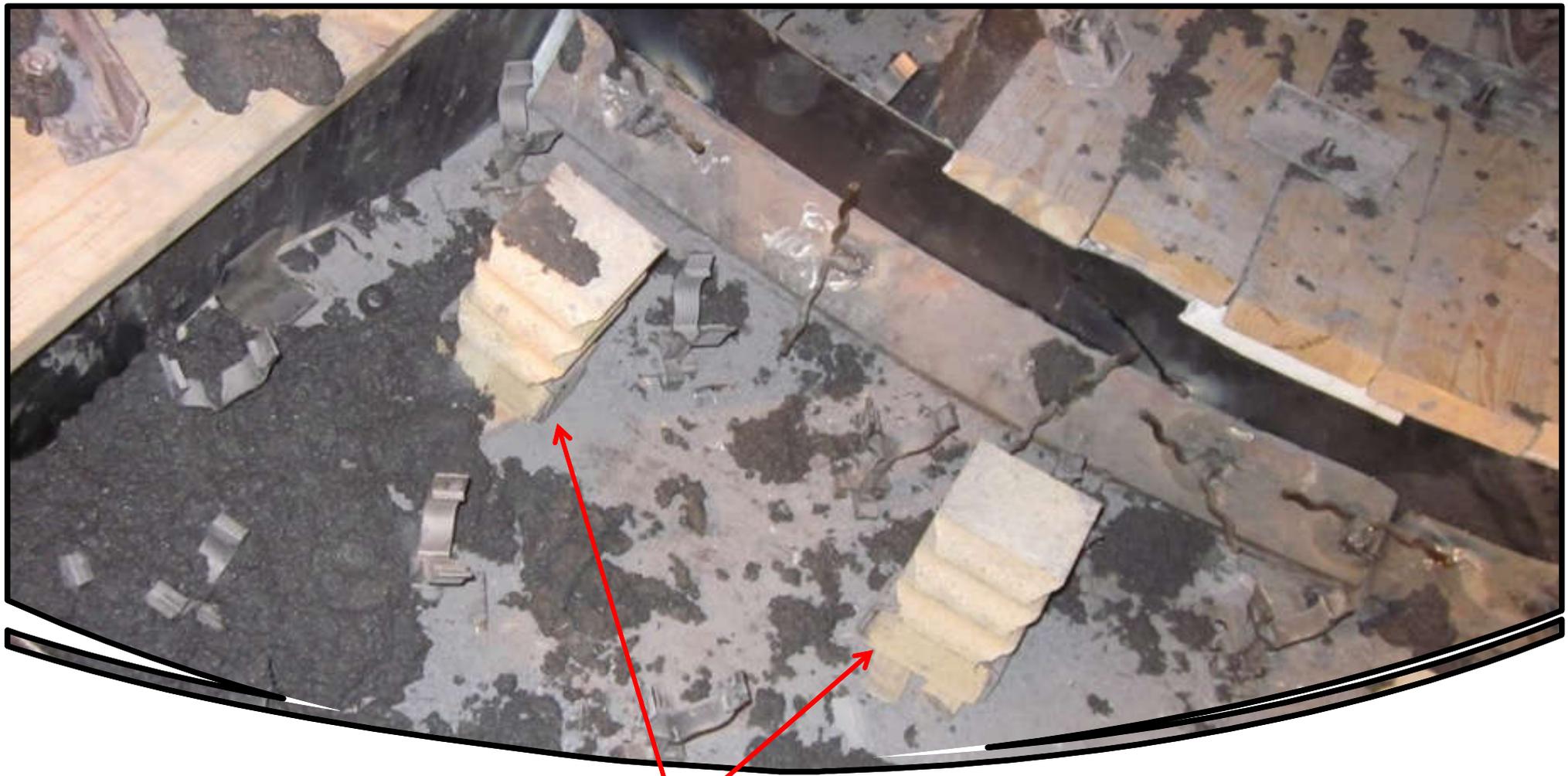
Wrong Orientation of C-Clips

# Nose Rings

*“why are they problematic?”*

Notice change in the Bending Moment to negative then positive-don't forget this is rotating!





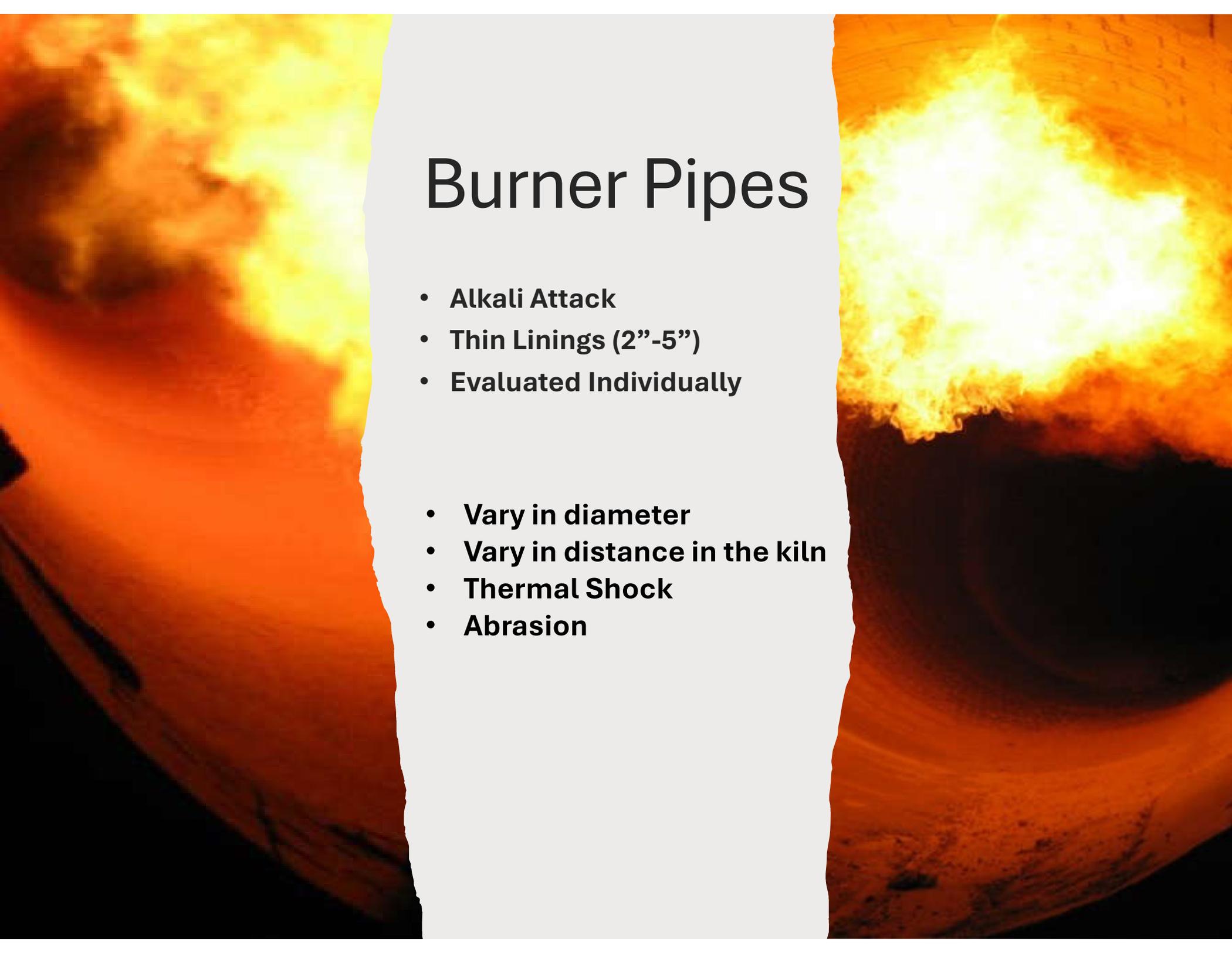
***C-Clip Orientation  
On A Nose Ring  
(Wrong)***

**Installing a C-Clip in a nose ring in the direction of the kiln rotation puts excessive stress of the ceramic anchor often resulting in cracking of the anchorage.**



***C-Clip  
Orientation On A  
Nose Ring  
(Correct)***

***Open end of the C-Clip should be in  
the direction of the kiln rotation***



# Burner Pipes

- **Alkali Attack**
- **Thin Linings (2"-5")**
- **Evaluated Individually**
  
- **Vary in diameter**
- **Vary in distance in the kiln**
- **Thermal Shock**
- **Abrasion**

# ***Thermal Corrosion and Sulfidation***

---



Various Failures  
modes



***Field Bending  
of anchors  
should never  
be permitted-  
anywhere!***

***Use the right  
anchor for the job  
note: these  
anchors are way  
too long for a  
burner pipe to  
begin with***





**.....*a spacing problem***

**Not the best way to anchor a Burner Pipe**

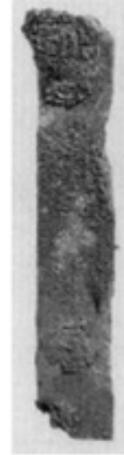
Sulfidation  
Resistance  
HR 160 Alloy

No. 2 fuel oil with 1.0% sulfur 1650°F (900°C) for 500 hours

253 MA alloy



RA330 alloy



RA85H alloy



alloy 800H



556 alloy



HR-160 alloy

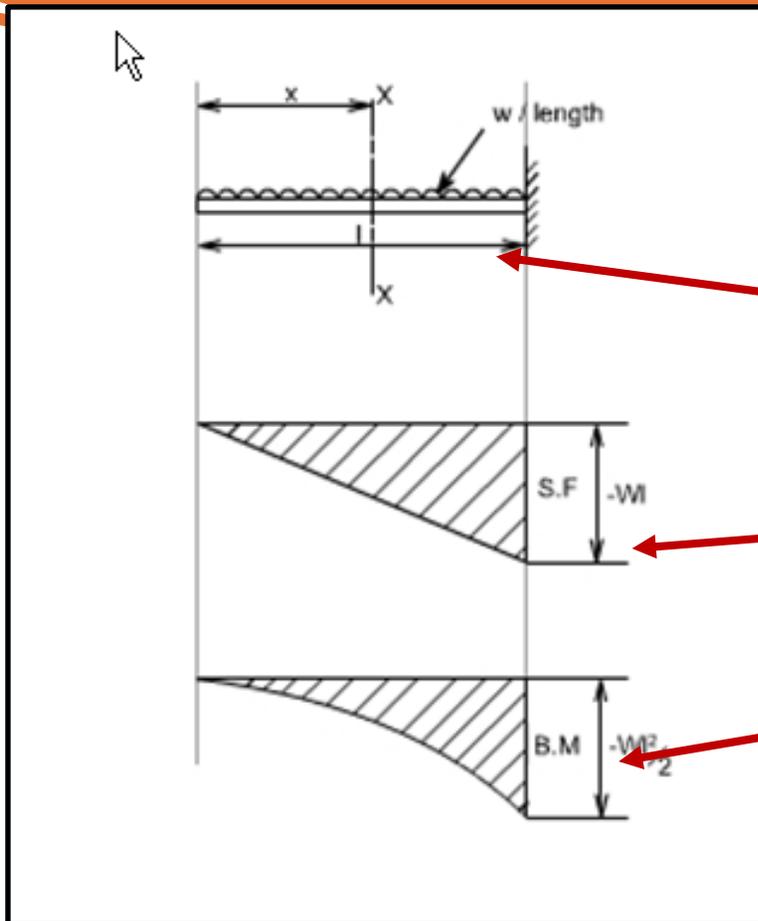




**-Top Cracking-**

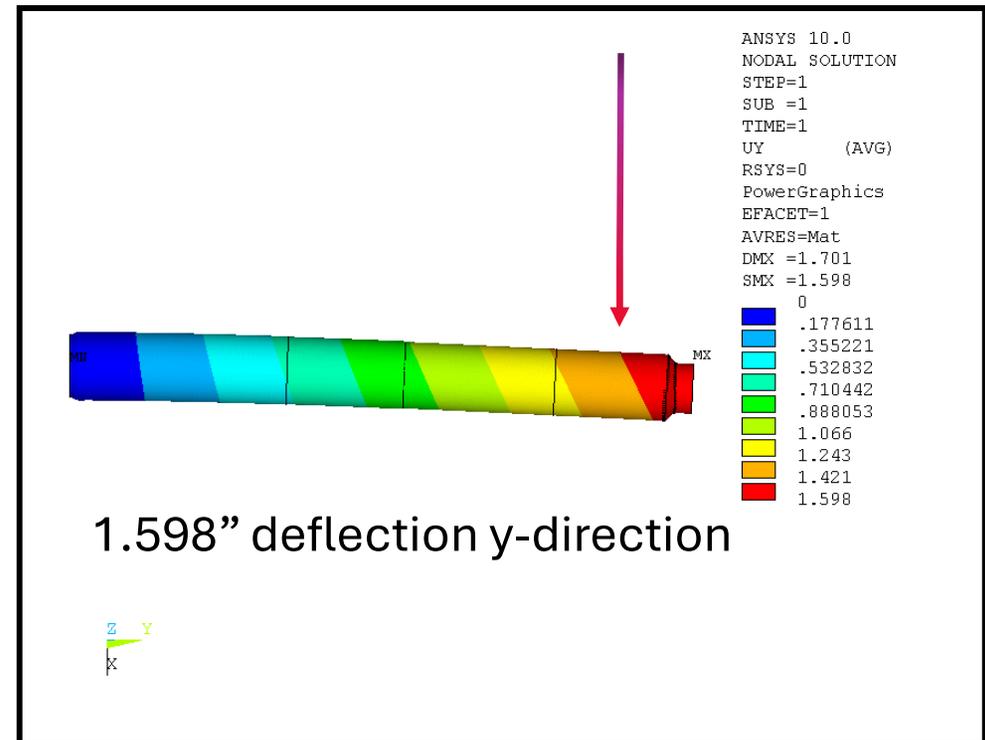
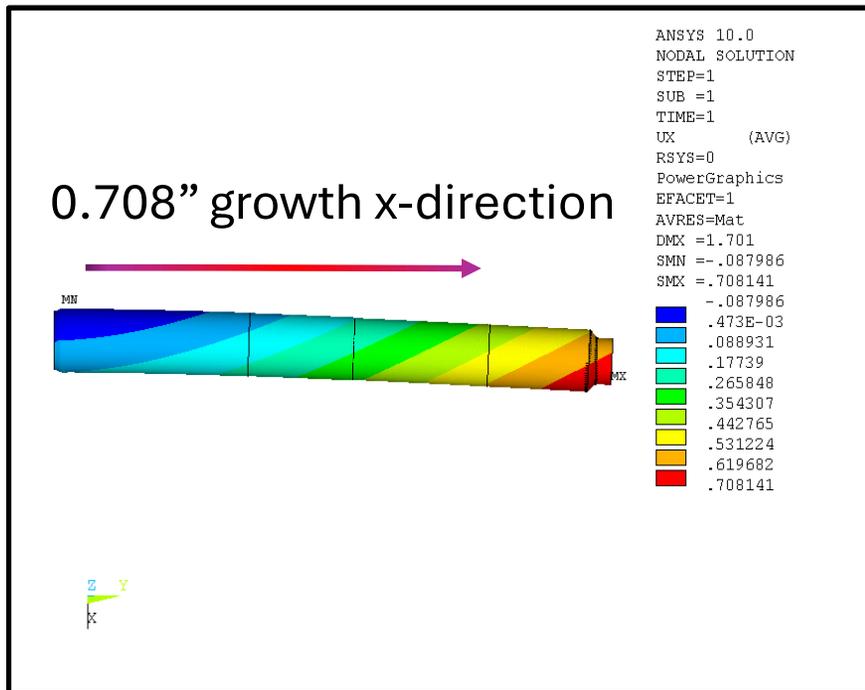
# Loading Diagram – Burner Pipe

Have to consider the loading on the pipe



- **Nothing more than:**
- Simply supported beam
- With a Shear Force
- And a Bending Moment

# Finite Element Analysis on Hot Burner Pipe (9 m long)



## The Take-Away

Thermal expansion and flexing must be considered when designing a lining and anchor



**SOLID FOOTED  
ANCHOR  
AFFORDS- NO  
FLEXIBILITY**

**AND IS NOT IN  
ACCORDANCE  
WITH ANY OEM  
SPECIFICATION**

# OEM SPECIFICATION ON BP ANCHORS

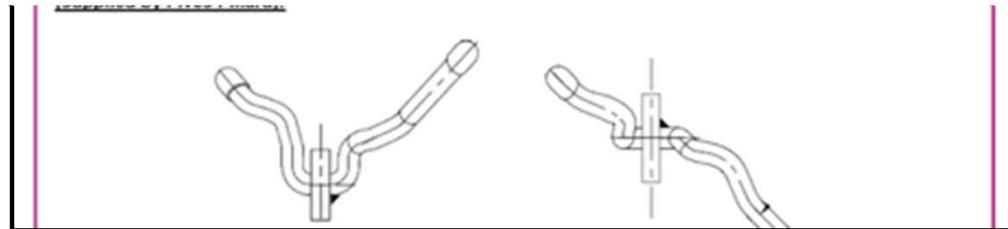
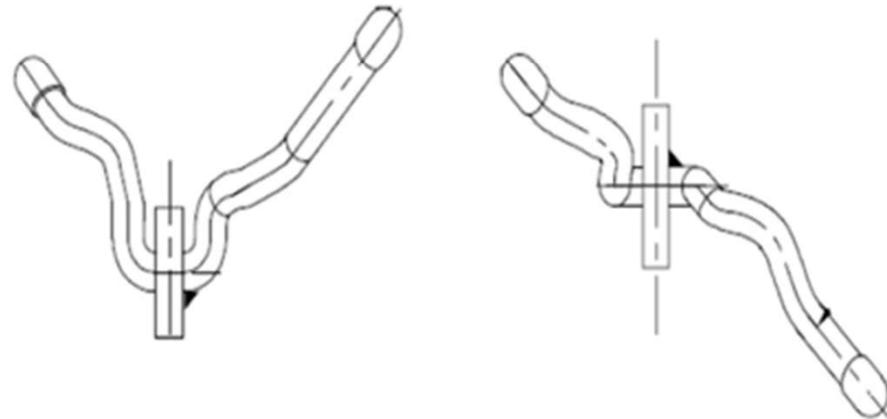
	USER'S GUIDELINES	O/ref: 20.44.2383
		1 / 33

## 1.1 REFRACTORY LINING FOR KILN BURNER

**Anchors: V shaped moveable anchors with welding loop**

**1.1 Burner tip zone : (From burner tip to 1.0 m)**

Refractory type: Calde cast LB 76 G10 or Reframullite 63 LCC or Calde cast GIBRAM with the addition of 3% mass wire drawn metallic needles 30 mm long / 0.4 diameter / hook type / made of AISI 310.

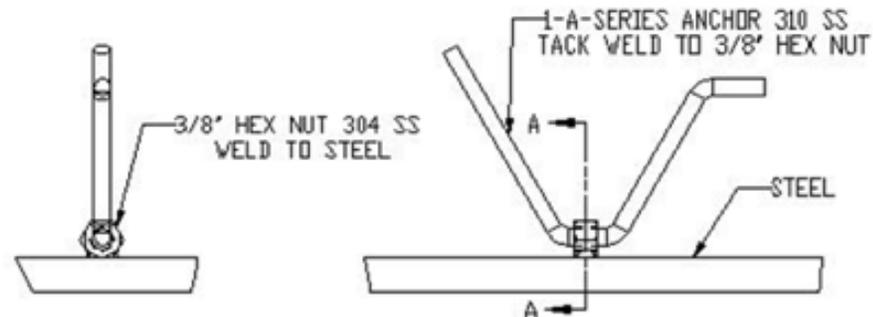


# Floating break-away anchors

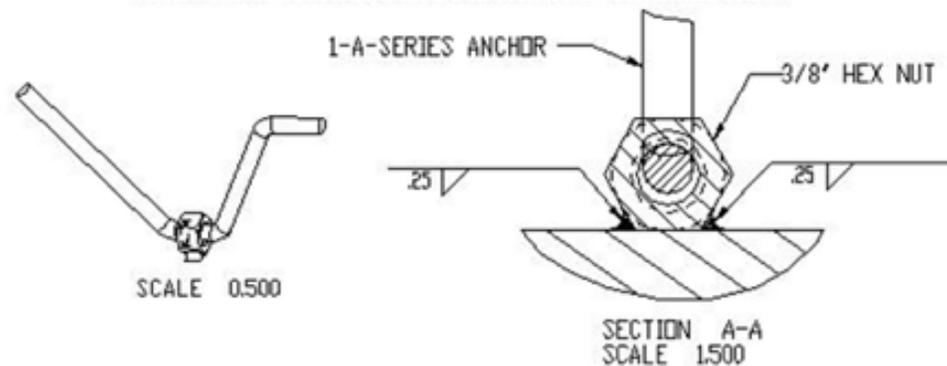
## Floating V-Anchors

### GENERAL INSTRUCTIONS:

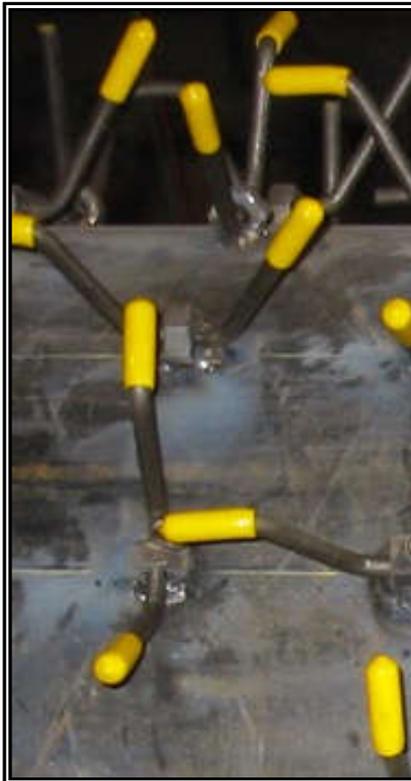
- 1) WELD 3/8" SS HEX NUT TO STEEL
- 2) INSERT 310 SS 1-A-SERIES ANCHOR THROUGH HEX NUT (ANCHORS TO BE SUPPLIED WITH ONLY ONE PLASTIC TIP INSTALLED AND SECOND PLASTIC TIP FOR EACH ANCHOR SUPPLIED IN BULK)
- 3) TACK WELD 1-A-SERIES ANCHOR TO HEX NUT
- 4) PLACE PLASTIC TIP ON EXPOSED END OF 1-A-SERIES ANCHOR

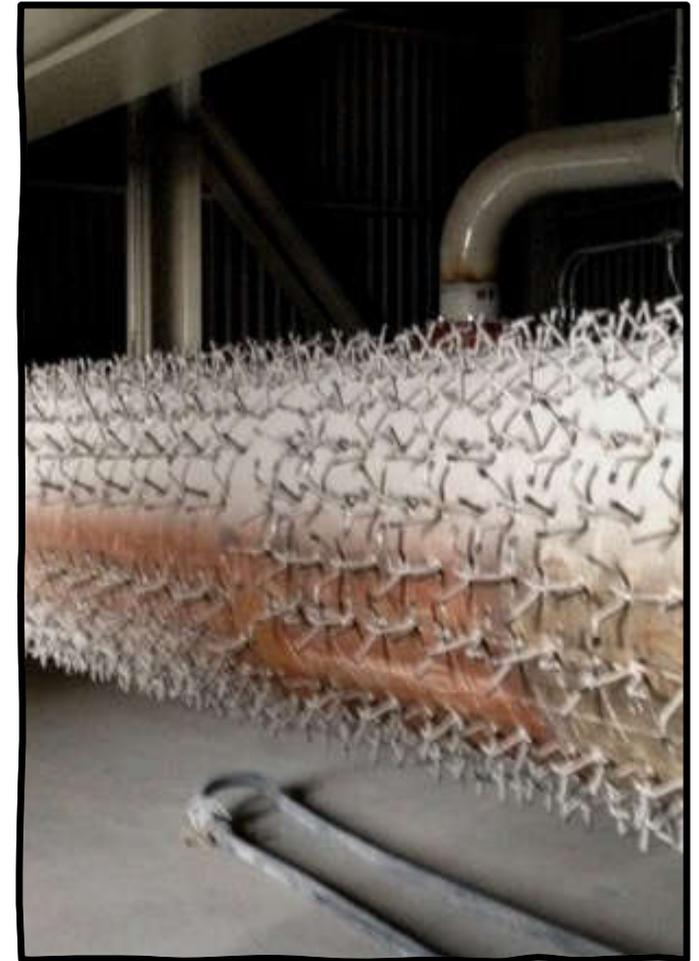


FLOATING V-ANCHOR INSTALLATION AND ASSEMBLY



NOTE:  
FOR APPLICATIONS (OTHER THAN BURNER PIPES) WITH THICKER REFRACTORY LININGS, THE FLOATING V-ANCHOR MAY BE CREATED BY USING A 5/16" DIA WIRE ANCHOR WITH A 1/2" HEX NUT





Anchoring  
before  
casting

Notice anchor spacing and break-away  
anchoring system. Plastic tips installed

# **Anchor Identification**

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# All Stainless Steels Look Alike



**Impossible to tell the alloy of this anchor**



**Brand Stamping is the only way to ensure the correct alloy is installed**

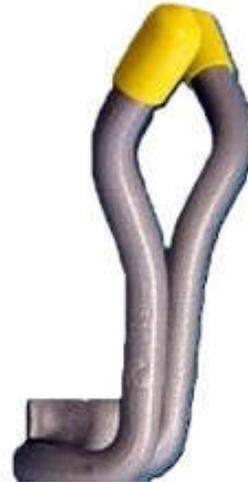
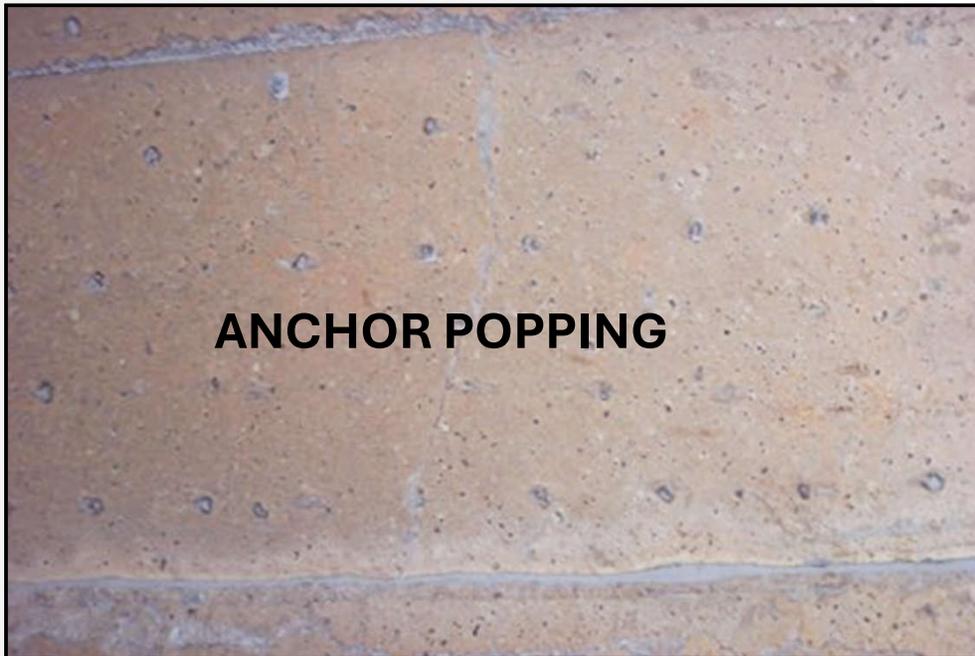
# ***Packaging and Shipment***

- **Anchors are an expensive investment!**
- **Bucket packaging offers:**
  - **Weatherproofing over cardboard boxes.**
  - **No on-site shrinkage.**
  - **Easy identification of the contents.**
  - **Easy to store and inventory.**
  - **Easy transportation to the unit to be lined.**



# Plastic Tips Necessary?

- Research indicates carbonization of the SS can occur in an oxidizing environment.
- Stainless Steel expands 3 times more than dense monolithics.
  - Expansion must go somewhere.



# One OEM's Specification on Metal Anchor Expansion

- Prior to placement, the anchors must be provided with a suitable covering layer to allow them to expand when the lining is heated without causing damage to the surrounding castable.
- Particular care is needed to ensure that the ends of the anchors have sufficient expansion capability.
- Unless otherwise specified on the final lining drawings, the anchor ends must be provided with a layer of 1-2 mm and the remaining part of the anchors with a layer of 0.5 mm.
- The covering layer may take the form of plastic, paper tape, cardboard, bitumen or paraffin wax.

## Conclusion.....

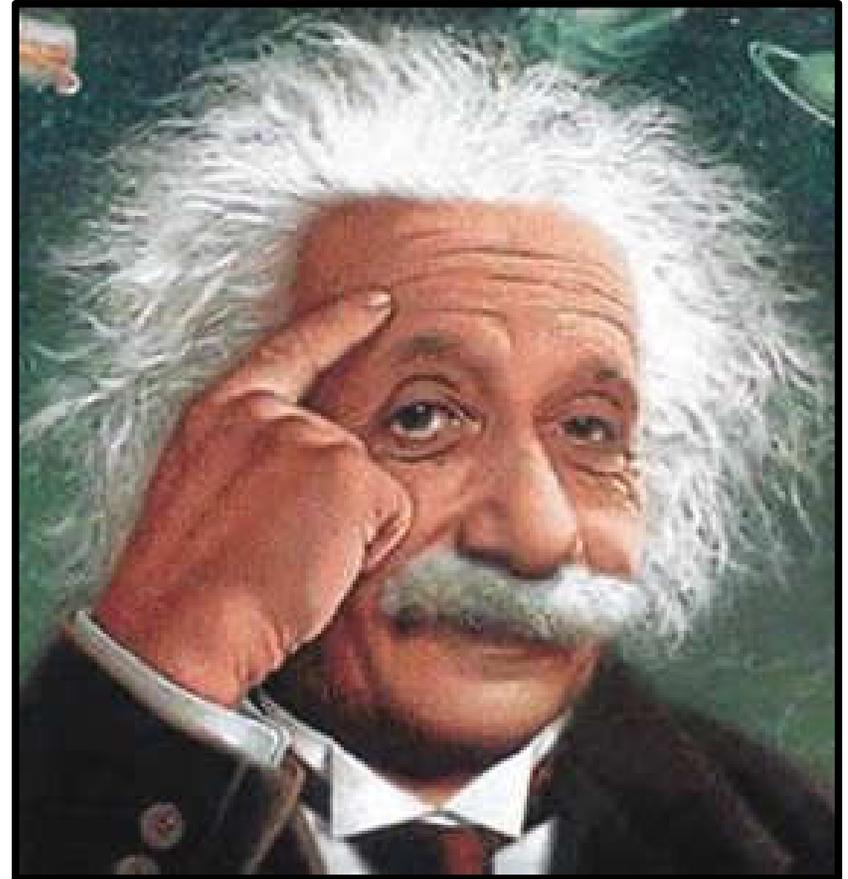
- Take the time to analyze the anchoring system including
  - Alloys
  - Thermal profile
  - Process
  - Welding
  - Spacing
  - Application Area
  - Prior failure modes



**Just remember “when choosing  
your anchors.....”**

***Insanity is doing  
the same thing  
over – and - over  
again and  
expecting  
different results.***

***-Albert Einstein....***



Thank you  
for your attention!

Questions?

