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hydro
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January 31, 2019

The Board of Commissioners of Public Utilities
Prince Charles Building
120 Torbay Road, P.O. Box 21040
St. John's, NL A1A 5B2

Attention: Ms. Cheryl Blundon
Director Corporate Services & Board Secretary

Dear Ms. Blundon:

Re: Holyrood Thermal Generating Station Unit 2 Stack Movement Assessment

On November 30, 2018, Hydro submitted a report entitled *"Holyrood Thermal Generating Station Unit 2 Stack Movement Assessment"* outlining the various actions undertaken by Hydro to confirm the structural integrity of the Unit 2 exhaust stack. In the report Hydro committed to providing the Board with an engineering analysis by January 31, 2019, including a structural analysis of the observed stack movement and an assessment of necessary upgrades to decrease and/or quantify future movement.

Enclosed with this letter please find one (1) original plus eight (8) copies of the Hatch Engineering Report entitled *"Holyrood Thermal Generating Station for Exhaust Stack No. 2"*.

Should you have any questions, please contact the undersigned.

Yours truly,

NEWFOUNDLAND AND LABRADOR HYDRO

SWalsh

Shirley A. Walsh
Senior Legal Counsel – Regulatory
SAW/kd

cc: Gerard Hayes – Newfoundland Power
Paul Coxworthy – Stewart McKelvey
Dennis Browne, Q.C. – Brown Fitzgerald Morgan & Avis

ecc: Dean Porter – Poole Althouse
Van Alexopoulos – Iron Ore Company
Senwung Luk – Olthuis Kleer Townshend LLP
Denis J. Fleming – Cox & Palmer
Benoît Pepin – Rio Tinto

HATCH

Newfoundland and Labrador Hydro
St. John's, NL, Canada

Holyrood Thermal Generating Station

For

Exhaust Stack No. 2

H358827-00000-240-230-0002
Rev. 1
January 28, 2019

Newfoundland and Labrador Hydro
St. John's, NL, Canada

Holyrood Thermal Generating Station

For

Exhaust Stack No. 2

H358827-00000-240-230-0002
Rev. 1
January 28, 2019

HATCH

Newfoundland and Labrador Hydro
Holyrood Thermal Generating Station
H358827

Engineering Report
Mechanical Engineering
Exhaust Stack No. 2

Final Report

Exhaust Stack No. 2

H358827-00000-240-230-0002

REGISTERED PROFESSIONAL ENGINEER
PEG Newfoundland and Labrador PROFESSIONAL ENGINEERS AND GEOSCIENTISTS
GREGORY SAUNDERS
SIGNATURE
January 30, 2019
DATE
NEWFOUNDLAND & LABRADOR

PROVINCE OF NEWFOUNDLAND AND LABRADOR
PEG Newfoundland and Labrador PROFESSIONAL ENGINEERS AND GEOSCIENTISTS
PERMIT HOLDER
This Permit Allows
HATCH LTD
MLRC 01626
To practice Professional Engineering in Newfoundland and Labrador.
Permit No. as issued by PEG D0090 which is valid for the year 2019

2019-01-30	1	Final	G. Saunders	P. Botha	P. Jokovic
2019-01-28	0	Final	G. Saunders	P. Botha	P. Jokovic
DATE	REV.	STATUS	PREPARED BY	CHECKED BY	APPROVED BY

Disclaimer

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1. Executive Summary

On the morning of November 15, 2018 Hydro personnel at the Holyrood Thermal Generating Station noticed what appeared to be an unusual amount of sway in exhaust stack No. 2 while there was no visible movement in the exhaust stacks for Units No. 1 and No. 3. The winds at the time were gusting over 100 km/hr.

Hydro contacted Hatch and Mr. Greg Saunders, P.Eng., visited the plant. Observations were made of the movement of the stack and its exterior condition. There was no observed distress of the exhaust stack's concrete or its base connection to the foundation. As a result of the inspection Hatch recommended the generating unit and stack continue operation.

On November 16 the wind speed had reduced and there was no observed movement of the stack. A close-up inspection was performed by Hatch and Hydro personnel and there were no signs of distress, such as cracked and spalled concrete and exposed steel reinforcing rods, due to the previous day's observed motion of the stack.

Hatch recommended a thorough inspection be performed as early as possible of the concrete, steel liner and bumpers, platforms and ladders by a trained inspection company. This was performed by Tacten in early December 2018. The results of the inspection indicated there was no visual deterioration of the interior or exterior concrete or steel liner. Some minor issues were identified requiring routine maintenance.

Hatch recommended completing a vortex shedding analysis using the wind data recorded November 14th to 16th to determine if the observed motion could have been caused by the observed wind speed and direction. This was confirmed and in addition it was determined that the proximity of Exhaust Stack No.1 to Exhaust Stack No. 2 likely caused a wake interference effect on Exhaust Stack No. 2, causing it to oscillate perpendicular to the direction of the wind.

In addition to the vortex shedding calculations, Hatch performed a stress analysis on the concrete stack and a fatigue check of the steel reinforcement based on the original design drawings and observed motion. The results of the stress analysis determined the concrete was not overstressed, confirming the visual observations. The fatigue analysis was based on the maximum displacement or sway observed by Hydro personnel and as such can only be considered an approximation. The results indicated that the steel reinforcement fatigue capacity is many times greater than number of cycles the stack was subjected to during the wind event.

In Hatch's opinion, Exhaust Stack No.2 is structurally sound and fit for purpose. No modifications to the stack to reduce the effects of vortex shedding are recommended.

Continued monitoring during similar wind speed and direction events is recommended.

2. Introduction

The Holyrood Thermal Generating Station located in Holyrood was constructed in two phases. The first phase was constructed in the late 1960s and consisted of two units each of which has its own exhaust stack.

These stacks were designed by Francis Hankin and Company Limited and consisted of a tapered steel reinforced concrete shell with a self-supporting steel liner. The stacks are approximately 300 feet high, 26 feet 8 inches outside diameter at the base and 16 feet 8 inches outside diameter at the top. The wall thickness of the concrete is 14 inches at the base and 7 inches at the top. The concrete shell is constructed in a series of cans formed one on top of the other and at each can intersection there is a circumferential construction or cold joint. The exhaust stack base is connected to a large concrete foundation by steel reinforcing rods or dowels.

These two exhaust stacks are positioned 86 feet apart on the north side of the powerhouse.

A third thermal generating unit was added to the plant in the late 1970s with a separate exhaust stack approximately 360 feet high.

All three stack centers are inline and are exposed to unobstructed winds from the sea. The exhaust stack for Generating Unit No. 2 is located between the exhaust stacks for Units No. 1 and No. 3.

On the morning of November 15, 2018 Hydro personnel noticed what appeared to be an unusual amount of sway in exhaust stack No. 2 while there was no visible movement in the exhaust stacks for Units No. 1 and No. 3. The winds at the time were gusting over 100 km/hr.

Hydro contacted Hatch and Mr. Greg Saunders P.Eng. visited the plant that day and observed the movement of the stack. Hatch also brought along a survey company, EPCO Services Inc., to the site to remotely measure the top displacement of the stack.

3. Code and Standards References

CICIND	Comité International Des Construction Industrielles – Concrete Chimney Model Code
CSA S6	Canadian Standards Association – Canadian Highway Bridge Code
AS 3600	Australia Standard – Concrete Structures
ASME STS-1	American Society of Mechanical Engineers – Steel Stacks

4. Observations

4.1 November 15

Visual inspections were made from four sides approximately 90 degrees apart using binoculars and where possible, due to the wind, the survey instrument lens. The side of the exhaust stack closest to the plant had restricted visibility due to the powerhouse building elevation and due to safety concerns, access was restricted to within 30m of the base.

Based on the observations from the ground there appeared to be no cracking or displacement at any of the circumferential construction joints, no new vertical cracks formed on the exterior or significant patches of missing or spalled concrete. The noticeable stack movement appeared to start approximately one quarter to one third up from the base. The sway of the exhaust stack was likely elliptical however most of the movement was perpendicular to the direction of the wind and appeared to have a constant period or frequency similar to be a first order resonance of a fixed base cantilevered structure. This would be similar to the slow back and forth movement of a musical metronome.

A meeting was held with senior Hydro operations staff regarding safety and operation of the plant. Hatch agreed that although the stack was swaying there were no obvious signs showing on the exterior that would indicate the stack would fail catastrophically. It was decided to closely monitor the stack for any visible signs of concrete failure, new cracks, exposed rebar or spalled concrete, and any increase in the stack movement.

Unfortunately, the total station survey instrument was unable to give accurate measurements as it was unable to lock on the moving stack.

4.2 November 16

Mr. Saunders of Hatch completed a visual inspection of Exhaust Stack No. 2. The wind speed at the time of the inspection had reduced to 30 to 40 km/hr and there was no visible swaying of Exhaust Stack no. 2 or the two adjacent stacks. Due to the change in conditions and no visible signs of damage, a closeup inspection of the base and the structure was undertaken. In addition to a walk around the perimeter of the base and a look inside through the door opening a visual inspection was made from the adjacent powerhouse roof. A photographic record was made of this inspection and this was forwarded to Hydro for their review. A select few photographs have been included in Appendix A.

The following is a summary of the observations:

- No obvious new cracks or displaced concrete at any of the joints, that could be seen from the two vantage points, were visible.
- There was no evidence of significant concrete missing from the surface or large pieces on concrete on the ground at the base of the stack.
- There was no obvious displacement of the vertical ladders, platforms or electrical cables.

- The interior access at ground level required confined entry. Observations were made from the doorway and there was no evidence of fallen concrete from the concrete stack or issues with the steel liner and its foundation. Hydro personnel entered this area and walked around the liner and inside diameter of the concrete stack and made a photographic record of their inspection which was issued to Hatch for review. There was no visible evidence of distress i.e. cracks, fallen concrete or distorted metal. One area of the concrete stack was noted to have a different interior profile from the rest of the concrete which looked like a localized inward bulge. An inspection of the exterior at this location did not show any signs of distress in the concrete.
- Hydro personnel climbed the vertical ladder and accessed the first platform level. Three small pieces of concrete were found on the platform grating. A visual inspection was made of these pieces and it was concluded they did not appear to be from new cracks. One had a flat face from a concrete saw blade and another contained caulking which likely came from one of the circumferential construction joints.

5. Recommended Actions

Based on the observations made during the two visits it appeared to Hatch the cause of the movement was a vortex shedding effect caused by the wind and wind direction. Under the right set of conditions, the vortexes that are created when the air strikes an object of circular cross section can cause it to move or vibrate. The wind direction appeared to be directly in line with the three stacks striking the stack for Unit No.1 first.

As a result of the inspections, Hatch recommended the following be completed by Hydro.

- Inspect the interior of the exhaust stack at the base.
- Inspect the concrete stack and steel liner by a qualified inspection company with staff trained in fall arrest and confined entry.
- Obtain for review by Hatch the wind speed and direction records for November 14, 15 and 16th.
- Obtain for engineering review all available drawings of the exhaust stack.
- Obtain for engineering review recent inspection reports.
- Have a high level structural analysis performed to verify if vortex shedding was likely the cause of the movement under the observed environmental conditions and calculate the stress in the concrete shell. Based on the results of the high-level analysis it would be determined if any computer modelling and finite element analysis would be required.

5.1 Structural Assessment

A high level structural assessment of Stack No.2 using a standard engineering approach was used to determine if the original design, completed back in 1969, would meet the design criterial of the latest Comité International Des Construction Industrielles (CICIND) Concrete Chimney Model Code which is a commonly used international standard. The details of the analysis can be found in Appendix B.

The results of the Calculations are as follows.

- The first mode natural frequency of Stack No. 2 in its as-design condition is 0.87Hz, the mode shape has been provided in Appendix B. Considering the crack observed on the Stack wall, potential concrete aging effect (Stack was built late 1960s) and interaction between the foundation and subgrade, the analyzed structure frequency will be reduced and comparable to the frequency of 0.65Hz estimated based on the video of the movement provided Hatch by Hydro.
- With reference to the wind speed data on November 14, 2018 and November 15, 2018, it was observed that the site wind speeds fall into the calculated critical wind speed zone of stack Unit No.2 which is between 13.8m/s (49.7km/h) and 21.6m/s (77.8km/h) (Refer to Appendix B for wind diagrams). This indicated that a significant amplitude due to the

vortex shedding force will occur, as the shedding frequency coincides with the structural frequency and potential wake interference effect due to the close spacing to the upstream stack.

- The estimated maximum deflection at top of stack is approximately 140mm considering a potential aerodynamic “Wake Interference” effects due to the reduction of Strouhal number according to ASME STS-1. It appears to provide a conservative design check approach as the CICIND Steel Chimneys Model Code indicated that when the Scruton Number exceeds 25 (the assessed stack is 37), the response amplitude is expected to be minimum.
- The calculated stack section bending capacities is adequate compared to the design load due to wind vortex shedding effect and wake interference effect. Detailed calculation has been provided in Appendix B.
- Fatigue assessment was carried out at three critical locations at different heights of Exhaust Stack No. 2, the rebar stress ranges at these locations are within the allowable limit calculated according to CSA S6-14 (R2016) Canadian Highway Bridge Design Code. This code was used as it provides guidance on rebar fatigue.
- Sensitivity calculations have been carried out considering the maximum top deflection approximately 300mm and structural period of 1.54 seconds estimated based on the video of the stack movement provided by Hydro as referenced in Appendix B.
  - The results indicated there is no strength concern for the stack,
  - Fatigue stress range at Section 2 of the stack, See diagrams in Appendix B, exceeds the allowable fatigue stress limit of 125MPa as specified in CSA S6. However, there is no relevant clauses in CSA S6 providing a fatigue cycle number calculation using the design stress range. As such, AS 3600, Australia Concrete Structures Code, was used as a guidance to calculate the stack operational service life under the stress range of 152MPa calculated based the deflection of 300mm. The result indicated an operational life of 2.2 million cycles (approximately 940 hours).
  - Above calculated fatigue stress range of 152MPa is expected to be conservative, as the deflection due to the subgrade settlement was not excluded from the calculation. An improved fatigue cycle may be achieved by employing a foundation and subgrade interaction design model.
  - Note the calculated valve of 940 hrs has to be compared to the number of hours the stack was moving at a maximum deflection of 300 mm. Based on observations the stack was moving approximately 24 hours and the deflection would have ramped up and down over that period of time.

5.2 Structural Assessment Summary:

The completed structural calculation indicated the observed Stack No.2 vibration/deflection is most likely due to the vortex shedding effect and aerodynamic wake interference effect. However, the actual deflection maybe greater than the value calculated in accordance with the CICIND Steel Chimney Model Code.

The amplified structural design load due to vortex shedding effect and wake interference effect was adopted for the Stack section capacities check and no strength issues were identified.

Continued long term movement of the stack could lead to fatigue of the rebar however, as this was an isolated event, this is not considered a significant risk.

5.2.1 Tacten Structural inspection

Tacten completed a visual inspection of the stack from December 1 to December 5, 2018 in accordance with several codes and standards as listed in their report including CICIND Model Code for Concrete Chimneys. A copy of their report number PID 501025 is included in Appendix C. This included the following inspection areas:

- Access Ladder
- Platforms and Catwalk
- Annular Space between Concrete Stack and Steel Liner
- Internal Steel Liner
- Exterior Concrete Shell
- Steel Liner Bumper System

The results of their inspection stated the stack was in good condition. There were no new cracks or missing concrete or signs of distress in any of the concrete or steel components inspected.

6. Conclusions

The concrete exhaust stack's motion was caused by the wind conditions that took place November 15th, 2018. Due to the proximity of Exhaust Stack No. 2 to Exhaust Stack No.1, the wind speed and its direction, there was likely an amplification effect sometimes referred to wake, from vortex shedding, proximity interference that induced the motion that was observed.

Based on anecdotal information provided Hatch by Hydro it is our understanding this was the first time this amplitude of motion has been observed thus it is our opinion this was likely a unique event.

The analysis of a singular stack indicates vortex shedding motion can occur at the wind speeds recorded.

The stresses based on the observed motion of the exhaust stack are in an acceptable range. It should be noted all stacks, whether of concrete or steel construction, are designed to move in the wind.

There is no visible damage to the concrete stack and foundation, steel liner, or attachments such as the ladders and platforms.

In our opinion, Exhaust Stack No.2 is in operational condition and the current 3 year yearly maintenance and inspection is adequate.

7. Recommendations

No additional monitoring is required other than visual inspection during wind events where

- Wind speed in excess of 50km/h, and
- Wind direction in line with the three stacks

We do recommend investigating the purchase of a wind speed and direction measuring device to be used to measure environmental conditions closer to the stack. A local attachment point could be the roof of the adjacent cooling water pump house.

The Tacten Inspection report stated three minor findings:

- Ladder supports not in contact with concrete surface (Section 7.01). These should be tightened or repaired during the next inspection.
- Vertical cracks 30’ to 50’ long in the annular space up from the breaching (Section 7.03). Tacten identified the cracks are pre-existing thus they only require monitoring during normal inspections.
- Caulking from a previous repair has come loose on the cold joints (Section 7.05). These should be repaired during normal inspection.

We do not recommend a foundation inspection of the concrete or soil. There were no visual indications of cracking at the stack base to foundation connection or any soil displacement around the foundation.

Appendix A
Photographs

Base of Exhaust Stack No.2

Exhaust Stack No. 2 Internal View of the Concrete Shell to Foundation Connection

View of Exhaust Stack No. 2 Looking Upward from East Side. – Circumferential Construction Joints are Visible

Exhaust Stack No. 2 View Looking Upward from the West Side

Small Pieces of Concrete found on the Lower Platform

Appendix B
Structural Analysis Reports

HATCH

Prepared by: J.Z. Date: 11/01/2019
Checked by: C.L. Date: 11/01/2019

Engineering Calculation
Calculation for As-Design Stacks

Reference File:

[1] CICIND Concrete Chimneys Model Code - 2011
[2] Drawing D10575 Rev2
[3] ASME STS-1

Design Input:

TC	I		Terrain category.	
ρ	1.25	kg/m^3	Air density	
z	91.44	m	Height above ground level	Refer Drawing D10574 Rev.2
d_{bottom}	8.128	m	Outer diameter of bottom of chimney	
d_{top}	5.08	m	Outer diameter of top of chimney	
f_1	0.8688	Hz	First mode natural frequency of chimney structure	Refer FEA result
m_o	7256.3	kg/m	Equivalent mass per unit length	Calculated based on FEA result
ξ	0.016		$\xi=c/c_{cr}$, structural damping ratio	REF [1] CL 7.2.4.2
St	0.166		Strouhal number	REF [3]
u^2dz	19.52		$u^2dz=\int_0^h u_1^2(z)\cdot dz$	
k(z)	1.539		Height factor for the top third of chimney	REF [1] Table 7.2
a	1.18		Factor	REF [1] Table 7.2
b	0.12		Factor	REF [1] Table 7.2
c	0.14		Factor	REF [1] Table 7.2

Calculation: (refer REF[1] CL7.2.4.1 & CL7.2.4.2)

d1	Average outer diameter over the top third	=	5.59	m	
I	Turbulence intensity	=	0.107		REF [1] CL 7.2.2.2
B	Width of the lift spectrum	=	0.207		
Ka	Aerodynamic damping parameter	=	0.610		
Sc	Scruton number	=	37.4		
Ca	Factor	=	5.55E-05		
c1	Factor	=	-0.310		
c2		=	0.000015		
$\sqrt{c1+\sqrt{c1^2+c2}}$		=	0.0048468		
Kp	Peak factor	=	4.076		
y_{top}	Top amplitude of chimney	=	**110.4**	mm	
y'_{top}	Top amplitude increased by 25% for possible maximum amplitude	=	**138.0**	mm	
Vcr	Critical wind speed	=	26.6	m/s	
Vb_{10}	Critical basic wind speed at 10m above ground	=	17.3	m/s	

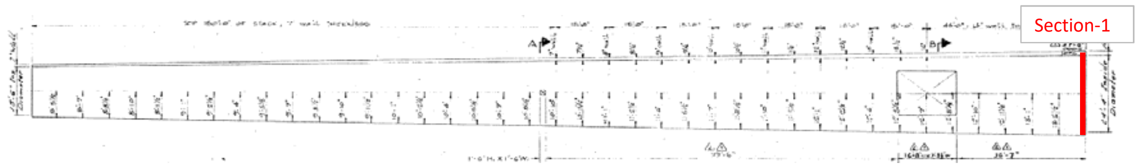
Potential critical wind speed range: 21.6 m/s to 13.8 m/s

Reference File:

[1] CICIND Concrete Chimneys Model Code - 2011
[2] CSA S6-14 (R2016) Canadian Highway Bridge Design Code

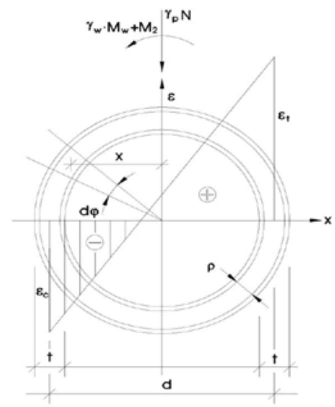
Assumption:

[1] Assume that yield strength of rebar is 250MPa
[2] No corrosion allowance on rebar is considered.



Design Input:

Es	210000	MPa	Elastic modulus of rebar
t	355.6	mm	Wall thickness
fc	27.58	MPa	Compressive strecgth of concrete
fy	250	MPa	Yield strength of rebar
D	7705	mm	Diameter of stack section
n	97		No. of Rebars
d	22.2	mm	Rebar Diameter
N*	-10193	kN	Design axial force
M*	63137	kN*m	Design bending moment due to vortex shedding
ε_c	-0.002		Max strain of concrete
ε_t	0.001		Max strain of steel



Calculation:

r	Radius of stack section	r= 3852.5	mm		
X	Location of nutrual axis	X= -1284.2			
fcu	Design strength of concrete	fcu= 15.6	MPa	Refer CL 5.5	
ε_{ty}	Rebar strain at its yield stress	ε_{ty}= 0.00104			
S	Rebar spacing	S= 249.5	mm		
ρ	Ratio of reinforcement	ρ= 0.00437			
N	Section axial compression capacity	N= -64039.5	kN		
	Utilization	**15.9%**		**Comply**	
M	Section bending capacity	M= 171101.4	kN*m		
	Utilization	**36.9%**		**Comply**	

Assessment for Rebar Fatique Strength, based on CSA S6-14 (R2016)

$\Delta\sigma_s$	Design stress range in rebar	$\Delta\sigma_s$ = 98.3	MPa	
$\Delta\sigma_{s.a}$	Allowable stress range in straight bars. Refer CL 8.5.3.1	$\Delta\sigma_{s.a}$ = 125.0	MPa	**Comply**

Prepared by:	J.Z.	Date: 11/01/2019
Checked by:	C.L.	Date: 11/01/2019

Engineering Calculation

Calculation for Strength of Stack Section-2

Reference File:

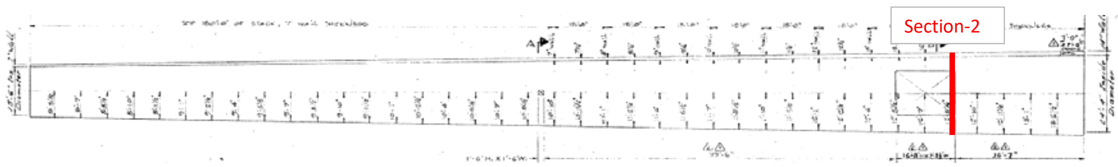
[1] CICIND Concrete Chimneys Model Code - 2011

[2] CSA S6-14 (R2016) Canadian Highway Bridge Design Code

Assumption:

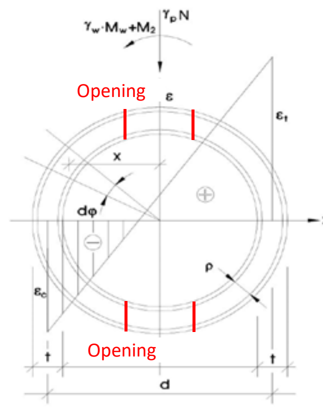
[1] Assume that yield strength of rebar is 250MPa

[2] No corrosion allowance on rebar is considered.



Design Input:

Es	210000	MPa	Elastic modulus of rebar
t	355.6	mm	Wall thickness
fc	27.58	MPa	Compressive strecgth of concrete
fy	250	MPa	Yield strength of rebar
D	7444	mm	Diameter of stack section
n	78		No. of Rebars
d	22.2	mm	Rebar Diameter
N*	-9308.9	kN	Design axial force
M*	55492.8	kN*m	Design bending moment due to vortex shedding
ε_c	-0.002		Max strain of concrete
ε_t	0.001		Max strain of steel



Calculation:

r	Radius of stack section	r=	3722	mm	
X	Location of nutrual axis	X=	-1240.7		
fcu	Design strength of concrete	fcu=	15.6	MPa	Refer CL 5.5
ε_{ty}	Rebar strain at its yield stress	ε_{ty}=	0.00104		
S	Rebar spacing	S=	242.8	mm	
ρ	Ratio of reinforcement	ρ=	0.00363		
N	Section axial compression capacity	N=	-41381.8	kN	
		Utilization	**22.5%**		**Comply**
M	Section bending capacity	M=	125068.8	kN*m	
		Utilization	**44.4%**		**Comply**

Assessment for Rebar Fatigue Strength, based on CSA S6-14 (R2016)

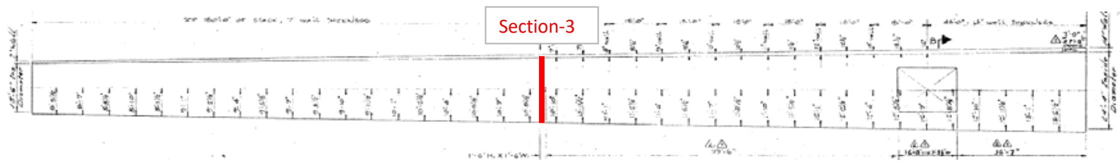
$\Delta\sigma_s$	Design stress range in rebar	$\Delta\sigma_s$ =	120.5	MPa	
$\Delta\sigma_{s.a}$	Allowable stress range in straight bars. Refer CL 8.5.3.1	$\Delta\sigma_{s.a}$ =	125.0	MPa	**Comply**

Reference File:

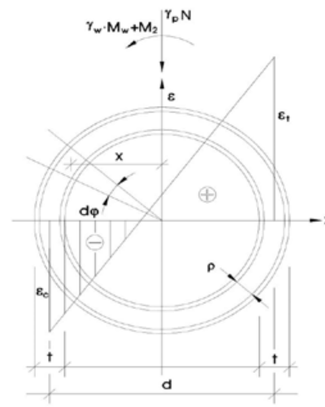
[1] CICIND Concrete Chimneys Model Code - 2011
[2] CSA S6-14 (R2016) Canadian Highway Bridge Design Code

Assumption:

[1] Assume that yield strength of rebar is 250MPa
[2] No corrosion allowance on rebar is considered.



Design Input:



Es	210000	MPa	Elastic modulus of rebar
t	177.8	mm	Wall thickness
fc	24.1	MPa	Compressive strecgth of concrete
fy	250	MPa	Yield strength of rebar
D	6248	mm	Diameter of stack section
n	78		No. of Rebars
d	16.0	mm	Rebar Diameter
N*	-3352	kN	Design axial force
M*	19193.1	kN*m	Design bending moment due to vortex shedding
ε_c	-0.002		Max strain of concrete
ε_t	0.001		Max strain of steel

Calculation:

r	Radius of stack section	r=	3124	mm	
X	Location of nutrual axis	X=	-1041.3		
fcu	Design strength of concrete	fcu=	13.7	MPa	Refer CL 5.5
ε_{ty}	Rebar strain at its yield stress	ε_{ty}=	0.00104		
S	Rebar spacing	S=	251.6	mm	
ρ	Ratio of reinforcement	ρ=	0.00449		
N	Section axial compression capacity	N=	-22815.7	kN	
		Utilization	**14.7%**		**Comply**
M	Section bending capacity	M=	49991.7	kN*m	
		Utilization	**38.4%**		**Comply**

Assessment for Rebar Fatigue Strength, based on CSA S6-14 (R2016)

$\Delta\sigma_s$	Design stress range in rebar	$\Delta\sigma_s$ =	103.1	MPa	
$\Delta\sigma_{s.a}$	Allowable stress range in straight bars. Refer CL 8.5.3.1	$\Delta\sigma_{s.a}$ =	125.0	MPa	**Comply**

Reference File:

[1] CICIND Concrete Chimneys Model Code - 2011

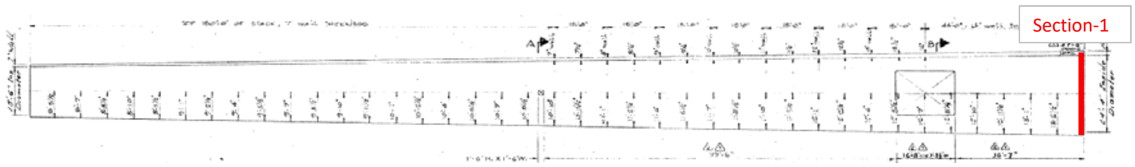
[2] CSA S6-14 (R2016) Canadian Highway Bridge Design Code

Assumption:

[1] Assume that yield strength of rebar is 250MPa

[2] No corrosion allowance on rebar is considered.

[3] Design bening moment calculated based on 300mm top amplitude and 0.65Hz oscillation observed on site.



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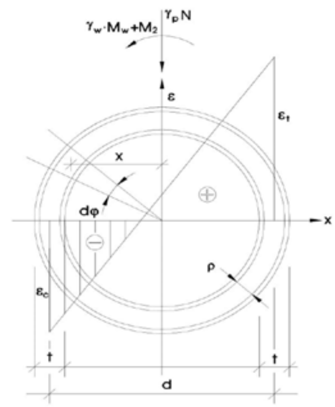


Es	210000	MPa	Elastic modulus of rebar
t	355.6	mm	Wall thickness
fc	27.58	MPa	Compressive strecgth of concrete
fy	250	MPa	Yield strength of rebar
D	7705	mm	Diameter of stack section
n	97		No. of Rebars
d	22.2	mm	Rebar Diameter
N*	-10193	kN	Design axial force
M*	76847.5	kN*m	Design bending moment due to vortex shedding
ε_c	-0.002		Max strain of concrete
ε_t	0.001		Max strain of steel

Calculation:

r	Radius of stack section	r=	3852.5	mm	
X	Location of nutrual axis	X=	-1284.2		
fcu	Design strength of concrete	fcu=	15.6	MPa	Refer CL 5.5
ε_{ty}	Rebar strain at its yield stress	ε_{ty}=	0.00104		
S	Rebar spacing	S=	249.5	mm	
ρ	Ratio of reinforcement	ρ=	0.00437		
N	Section axial compression capacity	N=	-64039.5	kN	
		Utilization	**15.9%**		**Comply**
M	Section bending capacity	M=	171101.4	kN*m	
		Utilization	**44.9%**		**Comply**

Assessment for Rebar Fatigue Strength, based on CSA S6-14 (R2016)

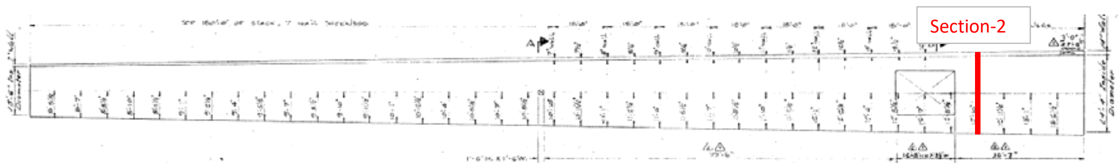
$\Delta\sigma_s$	Design stress range in rebar	$\Delta\sigma_s$ =	122.9	MPa	**Comply**
$\Delta\sigma_{s.a}$	Allowable stress range in straight bars. Refer CL 8.5.3.1	$\Delta\sigma_{s.a}$ =	125.0	MPa	

Reference File:

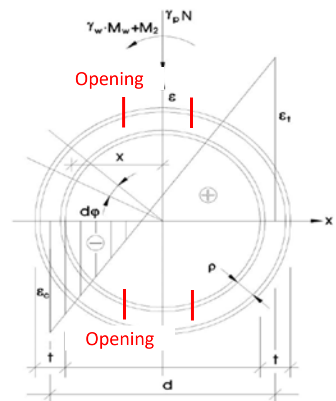
[1] CICIND Concrete Chimneys Model Code - 2011
[2] CSA S6-14 (R2016) Canadian Highway Bridge Design Code

Assumption:

[1] Assume that yield strength of rebar is 250MPa
[2] No corrosion allowance on rebar is considered.
[3] Design bening moment calculated based on 300mm top amplitude and 0.65Hz oscillation observed on site.



Design Input:



Es	210000	MPa	Elastic modulus of rebar
t	355.6	mm	Wall thickness
fc	27.58	MPa	Compressive strecgth of concrete
fy	250	MPa	Yield strength of rebar
D	7444	mm	Diameter of stack section
n	78		No. of Rebars
d	22.2	mm	Rebar Diameter
N*	-9308.9	kN	Design axial force
M*	67542	kN*m	Design bending moment due to vortex shedding
ε_c	-0.002		Max strain of concrete
ε_t	0.001		Max strain of steel

Calculation:

r	Radius of stack section	r=	3722	mm	
X	Location of nutrual axis	X=	-1240.7		
fcu	Design strength of concrete	fcu=	15.6	MPa	Refer CL 5.5
ε_{ty}	Rebar strain at its yield stress	ε_{ty}=	0.00104		
S	Rebar spacing	S=	242.8	mm	
ρ	Ratio of reinforcement	ρ=	0.00363		
N	Section axial compression capacity	N=	-41381.8	kN	
		Utilization	**22.5%**		**Comply**
M	Section bending capacity	M=	125068.8	kN*m	
		Utilization	**54%**		**Comply**

Assessment for Rebar Fatigue Strength, based on CSA S6-14 (R2016)

$\Delta\sigma_s$	Design stress range in rebar	$\Delta\sigma_s$ =	152.0	MPa	**Exceed the allowable limit, further check**
$\Delta\sigma_{s.a}$	Allowable stress range in straight bars. Refer CL 8.5.3.1	$\Delta\sigma_{s.a}$ =	125.0	MPa	

Calculation for Rebar Fatigue Strength, based on AS3600-2018 Section18

$\phi_{s,fat}$	0.85		Fatigue strength reduction factor
N_{Rsk}	1000000		Number of cycles for resistance of constant amplitude stress $\Delta\sigma_{Rsk}$
m	9		Factor
$\Delta\sigma_{Rsk}(N_{Rsk})$	195.6	MPa	Resisting stress range for cycles of N_{Rsk}
$\Delta\sigma_{s.0}$	152.3	MPa	Resisting stress range for design cycles
nsc	2.20E+06		Calculated operational cycle numbers

Note: Equivlant to 940 Hours

Reference File:

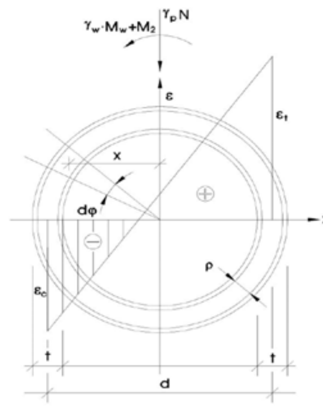
[1] CICIND Concrete Chimneys Model Code - 2011
[2] CSA S6-14 (R2016) Canadian Highway Bridge Design Code

Assumption:

[1] Assume that yield strength of rebar is 250MPa
[2] No corrosion allowance on rebar is considered.
[3] Design bening moment calculated based on 300mm top amplitude and 0.65Hz oscillation observed on site.

Design Input:

Es	210000	MPa	Elastic modulus of rebar
t	177.8	mm	Wall thickness
fc	24.1	MPa	Compressive strecgth of concrete
fy	250	MPa	Yield strength of rebar
D	6248	mm	Diameter of stack section
n	78		No. of Rebars
d	16.0	mm	Rebar Diameter
N*	-3352	kN	Design axial force
M*	23359.4	kN*m	Design bending moment due to vortex shedding
ε_c	-0.002		Max strain of concrete
ε_t	0.001		Max strain of steel



Calculation:

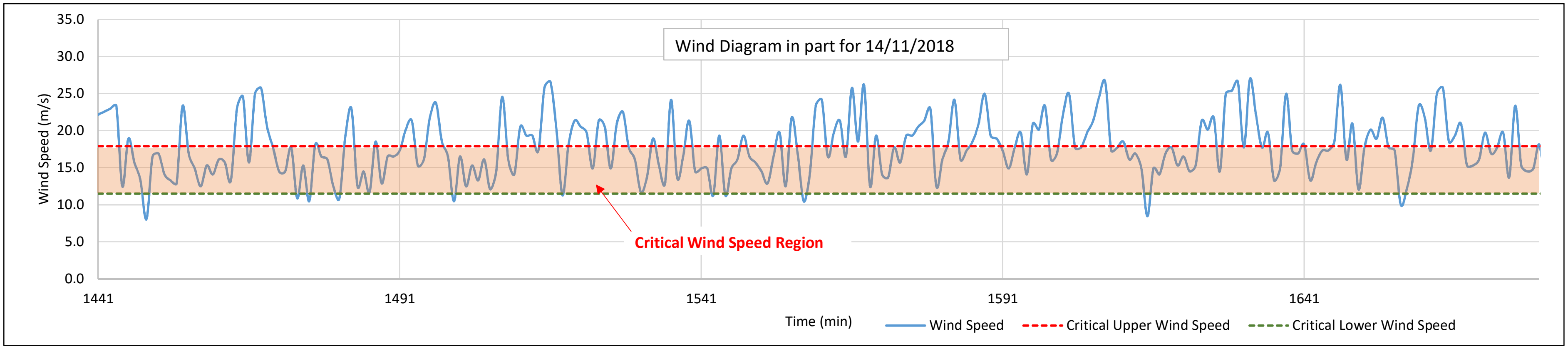
r	Radius of stack section	r=	3124	mm	
X	Location of nutrual axis	X=	-1041.3		
fcu	Design strength of concrete	fcu=	13.7	MPa	Refer CL 5.5
ε_{ty}	Rebar strain at its yield stress	ε_{ty}=	0.00104		
S	Rebar spacing	S=	251.6	mm	
ρ	Ratio of reinforcement	ρ=	0.00449		
N	Section axial compression capacity	N=	-22815.7	kN	
		Utilization	**14.7%**		**Comply**
M	Section bending capacity	M=	49991.7	kN*m	
		Utilization	**46.7%**		**Comply**

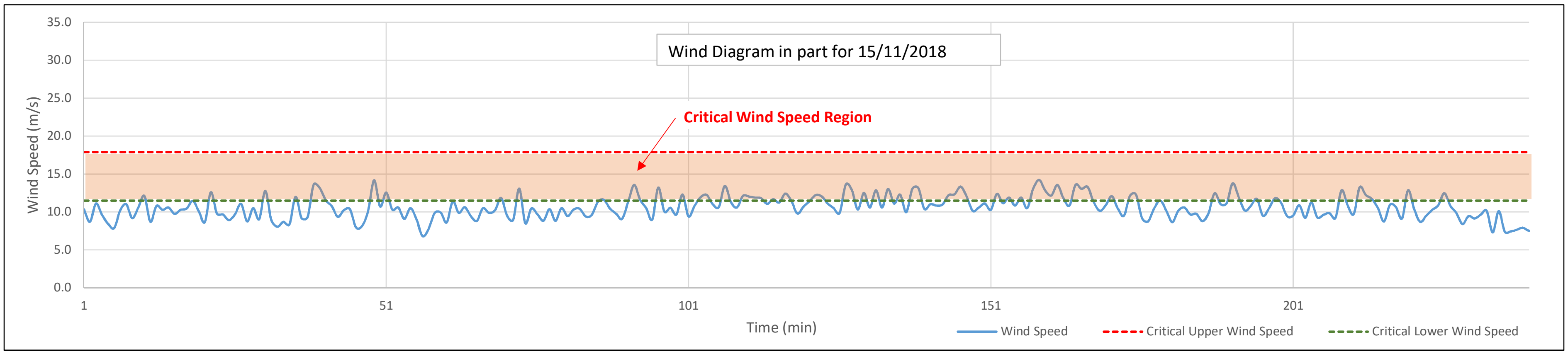
Assessment for Rebar Fatigue Strength, based on CSA S6-14 (R2016)

$\Delta\sigma_s$	Design stress range in rebar	$\Delta\sigma_s$ =	128.9	MPa	**Marginal Exceed the limit, no fatigue concerns**
$\Delta\sigma_{s.a}$	Allowable stress range in straight bars. Refer CL 8.5.3.1	$\Delta\sigma_{s.a}$ =	125.0	MPa	

Critical Wind Speed for As-Design Stack

Note: With reference to CICIND Model Code for Concrete Chimneys – 2011, it deems to be reasonable to consider +/- 25% as a critical wind speed range for vortex shedding assessment.





Appendix C
Tacten Inspection Report

Tacten
61 Atlantic Street
Dartmouth, NS, Canada B2Y 4P4
www.tacten.ca

Integrated Industrial Services

Phone: 902.434.4405
Fax: 902.463.2053

Newfoundland Hydro

Holyrood Generating Station Stack 2 Inspection

Rev	Date	Description	By	Approval
0	17-Dec-18	Review	CD	
0	17-Dec-18	Submission	NS	

TABLE OF CONTENTS

TACTEN

INSPECTION REPORT

Client:	Newfoundland Hydro	Date:	Dec 1-5
Attention:	Dana Dalton	Tacten Job #	501025
Address:	Thermal Plant Rd.	Procedure:	TP-0022
	Conception Bay South, NL	Project:	Stack Inspection

1.0 JOB DESCRIPTION

Location:	Holyrood	Facility:	Power Generation
Equipment Name:	Chimney Stack 2	Equipment #:	NA
		Serial #:	NA
Inspection Scope:	Visual inspection of exterior shell, liner, annular space, bumper system		

2.0 TEST DETAILS-VISUAL

Code/Standard:	Client Information	Revision:	0
Procedure:	CAN-VT-14P001	Method:	Direct
Equipment Type:	Camera	Manufacturer:	Olympus
Model:	Coolpix AW130	Serial #:	20347/ 41996
Light Source:	Flashlight/Ambient	Illumination:	>100 Foot-Candles

3.0 SIGNATURES

Inspection & Report:	Nelson Seniuk	Reviewed By:	Cory Dearman
Certification:	CWB 178.2 VT Lv 1	Certification:	CWB 178.2 VT Lv 2
Certification #:	15620	Certification #:	10705
Signature:		Signature:	

4.0 INSPECTION SCOPE

At the request of Newfoundland Hydro., Tacten Industrial Inc. conducted a visual inspection on the chimney stack at the Holyrood Generating Station, looking for signs of stress or damage from recent high winds. The following is a summary of the inspection scope:

• Access Ladder and Back Cage
• Platforms and Catwalk
• Annular Space
• Internal Liner
• Exterior Concrete Shell
• Liner Bumper System

5.0 INSPECTION TECHNIQUES

The inspection of the chimney stack was completed using rope access techniques in accordance with the Industrial Rope Access Trades Association (IRATA) International Code of Practice (ICOP) and Tacten Rope Access Procedure CAN-SMS-10P026 R02.

6.0 REFERENCES

The inspection of the fixed ladder and chimney stack was performed using the following references:

● ASTM D610 - 08 Standard Practice for Evaluating Degree of Rusting on Painted Steel Surfaces
● ANSI-A14.3-2008 Fixed Ladder Safety Requirements
● CAN/CSA-B72-M87 Installation Code for Lightning Protection Systems
● CICIND-Chimney Maintenance Guide
● CICIND-Model Code for Steel Linings
● CICIND-Inspection and Maintenance of Brick and Concrete Chimneys
● CICND-Model Code for Concrete Chimneys

7.0 INSPECTION SUMMARY

All chimney stack components were inspected within arms reach on December 1 - 5, 2018. Overall, the stack is in good condition with no concrete debris found on any of the platforms or inside annular space.

7.01 ACCESS LADDER

The access ladder was found to be in good condition. There were a few areas where the ladder supports were not fully seated on the concrete shell.

See Photos 1-2

7.02 PLATFORMS AND CATWALK

Platforms are in good condition, no signs of debris found anywhere on walkways. All connection points to concrete are in good condition. Note that one bulb of the east aviation lighting is burnt out.

See Photos 3-5

7.03 ANNULAR SPACE

Annular space inspection took place from 150' to the base of the stack. No signs of damage due to high winds was found. There were vertical hairline cracks noticed above both breeches extending 30'-50' upwards. Both cracks appear to be previously existing.

Video of the annular space inspection has been provided.

See Photos 6-8

7.04 INTERNAL LINER

Internal liner was found to be in good condition throughout entire length with no cracks, bulges or deformations found. Transition from stainless to carbon was in good condition. Small amount of flyash debris was found on the weld seams and the testing ports.

Video of the liner drop has been provided to client.

See Photos 9-11

7.05 EXTERIOR CONCRETE SHELL

Four inspection drops were completed from 150' to the ground on cardinal points. Three drops were completed via rope access and one drop was completed from the access ladder while two drops were completed from the top platform to the lower platform, North and South. Everything was found to be in good condition with the exception of the caulking from previous repairs which is deteriorating and has come loose on the cold joints. Two drops done from top platform to lower platform, North and South

See Photos 12-16

7.06 BUMPER SYSTEM

6/8 liner bumpers were visually inspected from upper inspection ports on the rain cap. No damage was found to the liner or bumper system. All interior bumper connections to concrete shell were found to be in good condition. Liner favors NE side of stack.

Very limited access and egress was available to bumper system.

See Photos 17-24

8.0 PHOTO RECORD

Photo: 1

Location:
External Ladder

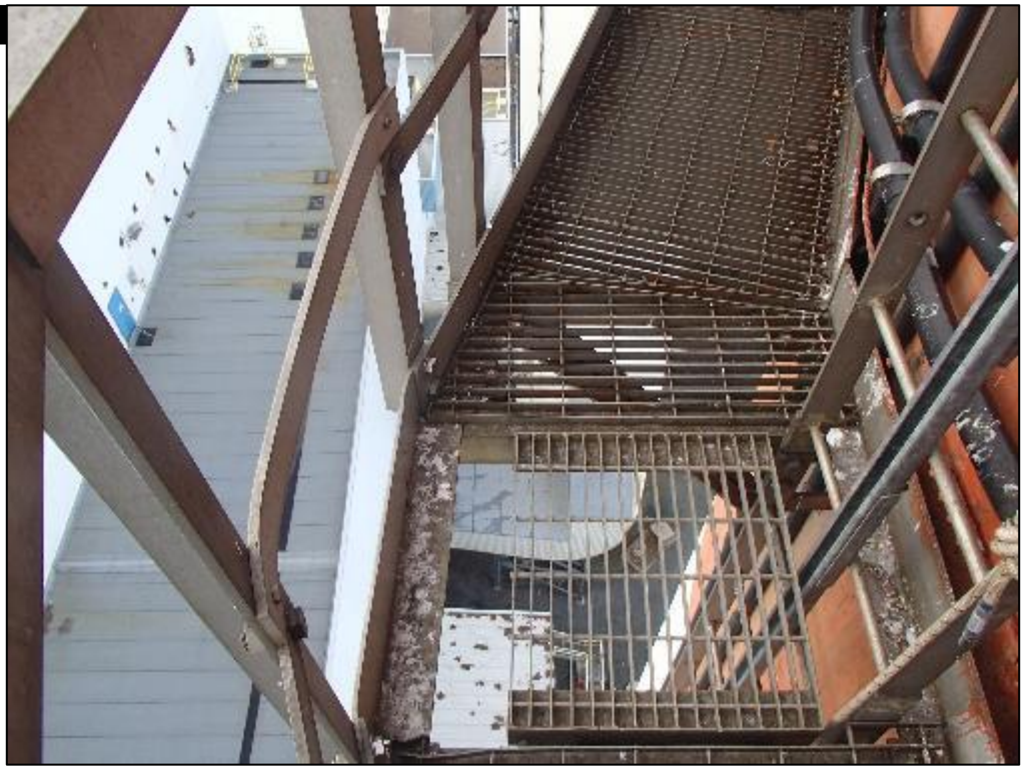
Description:
Shows ladder support not fully seated to concrete shell

Photo: 2

Location:
External Ladder

Description:
General of ladder support connection.

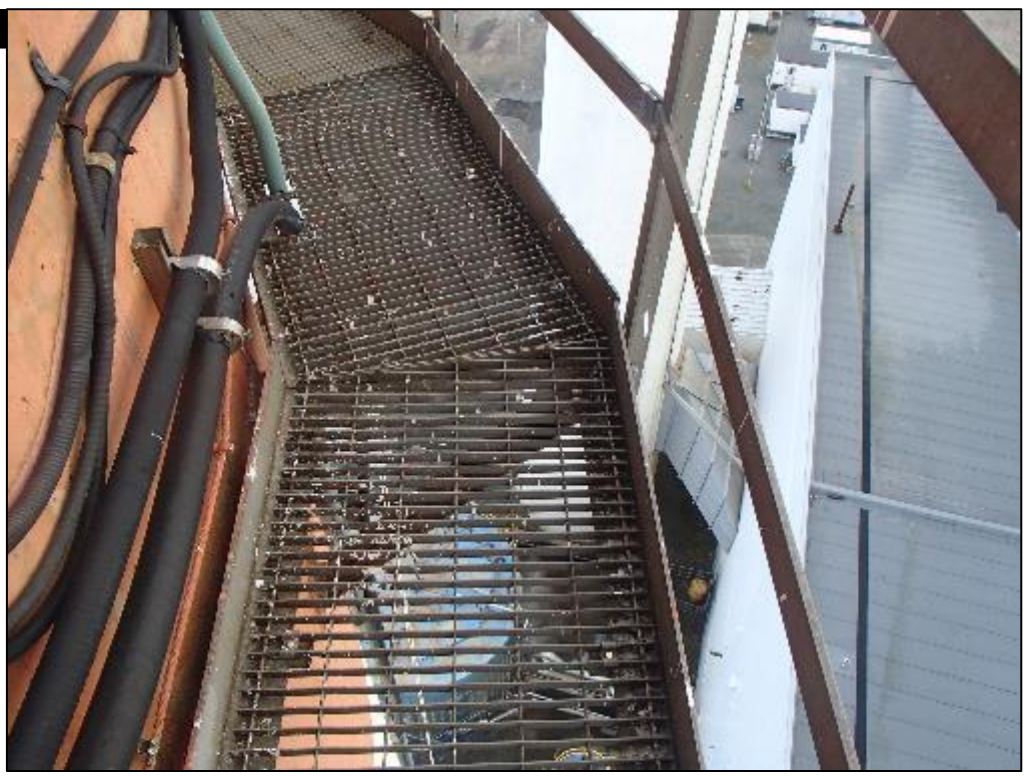
Photo: 3



Location:
Lower Platform

Description:
General of lower platform showing no signs of concrete debris.

Photo: 4



Location:
Lower Platform

Description:
General of lower platform showing no signs of concrete debris.

Photo: 5

Location:
Lower Platform

Description:
Northeast aviation light. One bulb burnt out.

Photo: 6

Location:
Annular Space

Description:
General of liner ground anchors.

Photo: 7

Location:
Annular Space

Description:
Hairline cracks extending 30-50' above breeches. East side.

Photo: 8

Location:
Annular Space

Description:
Hairline cracks extending 30-50' above breeches. West side.

Photo: 9

Location:
Internal Liner

Description:
General of liner transition showing good condition.

Photo: 10

Location:
Internal Liner

Description:
General of weld seam condition inside liner.

Photo: 11

Location:
Internal Liner

Description:
Debris build up inside test ports

Photo: 12

Location:
External Concrete Shell

Description:
General of area requested to be inspected by client at 25' East of ladder.

Photo: 13

Location:
External Concrete Shell

Description:
General photo of cold joint elevation 60' West side.

Photo: 14

Location:
External Concrete Shell

Description:
Previous repair in good condition, no further or new damage noticed. Elevation 30' south side.

Photo: 15

Location:
External Concrete Shell

Description:
Previous repair using caulking on cold seam to prevent seeping of water. Caulking falling out and or missing. Elevation 100' North East side.

Photo: 16

Location:
External Concrete Shell

Description:
West breech, general photo, good condition. Elevation 50' North West side.

Photo: 17

Location:
Bumper System

Description:
Top down view of NE bumper, restricted visibility and access, no signs of any damage to bumper system liner or concrete

Photo: 18

Location:
Bumper System

Description:
General photo of NE bumper in contact with liner. No damage.

Photo: 19

Location:
Bumper System

Description:
General photo of East bumper, no damage to shell or liner.

Photo: 20

Location:
Bumper System

Description:
General photo of SW bumper. More room which indicates liner is favoring the NE bumper.

Photo: 21

Location:
Bumper System

Description:
General photo of West bumper showing no signs of damage to liner or concrete.

Photo: 22

Location:
Bumper System

Description:
General photo of North external bumper system, no new signs of damage.

Photo: 23

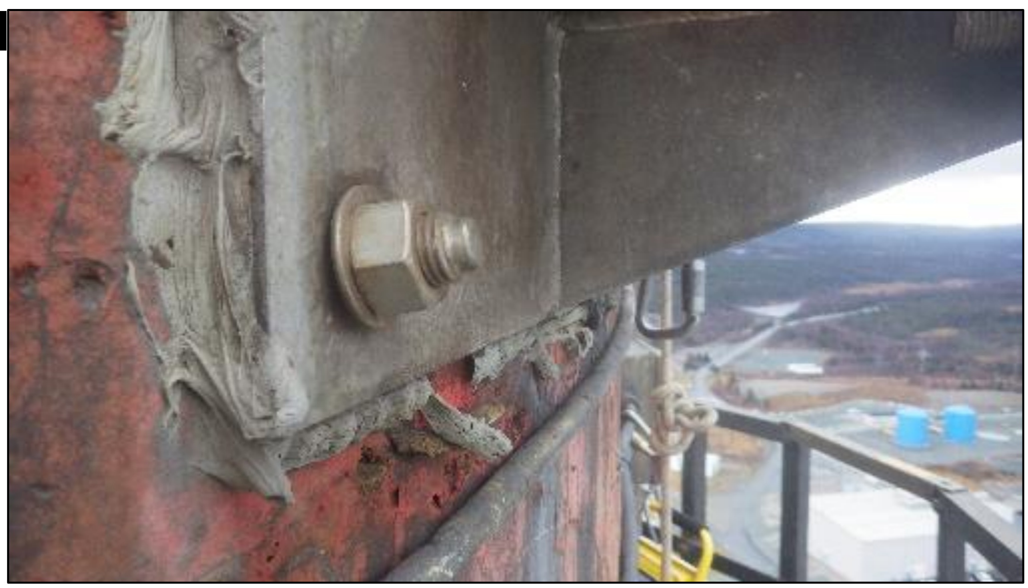
Location:
Bumper System

Description:
General photo of N bumper shows gap filled with caulking from bumper installation.

Photo: 24

Location:
Bumper System

Description:
Picture shows bolts not square with shell, from installation.



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