Evaluation of the dead zones in the welded joints of hydraulic turbine runners

By : Mohammad Ebrahim Bajgholi

Département de Génie Mécanique, École de Technologie Supérieure (ETS)
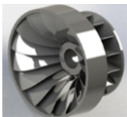
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Alberta

Outline

Problem Statement

Introduction

Results and discussion

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Problem Statement

▶ In Quebec province, the vast majority of electrical power is produced by hydraulic turbines.

▶ In an attempt to insure equipment reliability and to control production costs, IREQ has developed a life estimation model which is based on the distribution and the size of structural discontinuities in turbines.

➤ Undetected flaws may lead to unplanned failure.
➤ Unplanned failure results in high repair costs and long down time.

Life estimation model

⬇

Discontinuity Size

⬇

NDT
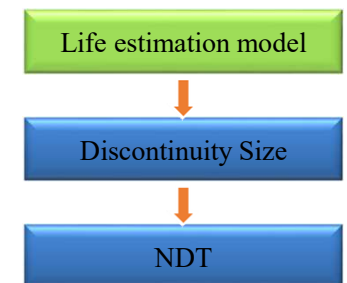
♦ NDT methods are used to detect, locate, and size flaws.

♦ Reliability of a specific NDT method depends on flaw type, size, and location and it is evaluated through POD analysis.

♦ The current project aims at providing IREQ with reliable flaw data (both measured and simulated) for their life estimation model.
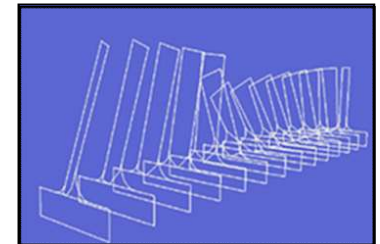
Introduction

Francis Turbine Runner

* The Francis turbine runners of Beauharnois hydroelectric power station will be the subject of current study.

* Runners are the heart of any turbine

* Runners: multivariable section components.
  * 15 to 90 mm blade thickness

* The turbine runner weld is a series of Y-type joints.
  * 60° to 120° angle

Welding Flaws

* The multipass Flux-cored arc welding (FCAW) used for turbine runner joints, generates some discontinuities.

  Thermal cycles

  Solidification

  Cooling distortion

  Residual stresses

* Welding discontinuities

  Volumetric (Porosities, Slag inclusions)

  Planar (LOF, LOP, Cold and Hot cracks)

* Slag inclusions and LOF are the most important discontinuities

* Welding discontinuity

* Dynamic stress concentration

  Failure probability

* The critical weld region is approximately 300 mm from the trailing edge for both blade-to-crown and blade-to-web welds.

Blade to crown

Blade to web
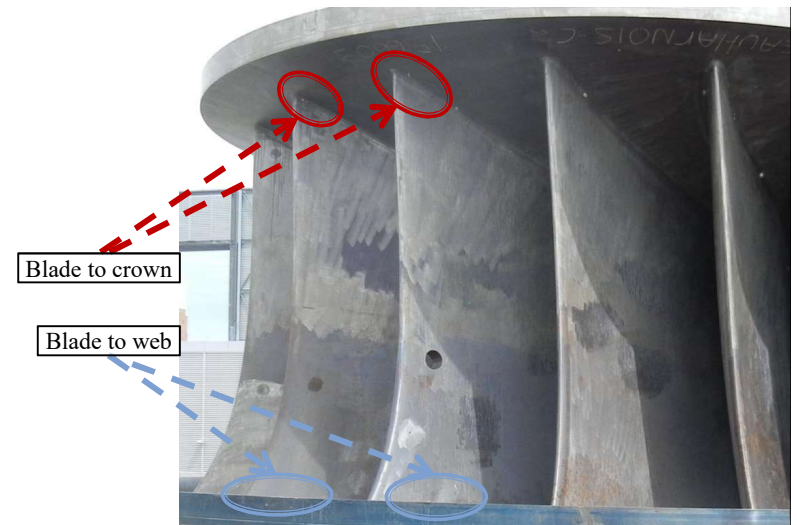
NDT Methods

Non-destructive Testing (NDT)

Technical method to examine materials or components in order to detect, locate, measure and evaluate flaws without causing damage.

Limited inspection space

Complex geometry

Ultrasonic Testing → Lower signal quality → Low Probability of Detection (POD)

Capabilities in the inspection of complex shape structures

High detectability of randomly oriented flaws

Speed of testing

✦ Phased array (PA) has attracted the experts' attention

Conventional UT   Phased Array

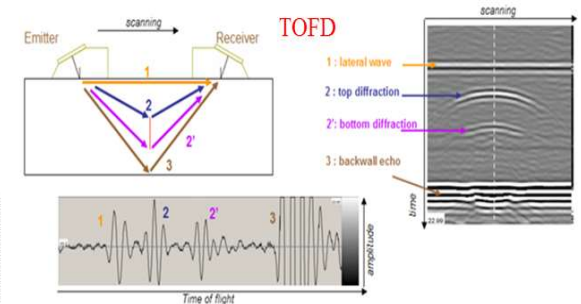Scan whole thickness of the weld at one time

Advanced NDT Methods

✤ Different techniques with phased array in advanced ultrasonic inspection:

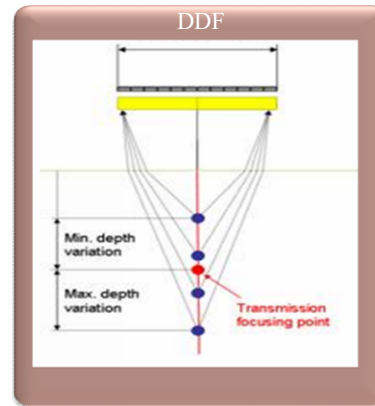❖ Time-of-Flight Diffraction (TOFD):

TOFD uses the difference in the time of received waves, instead of their amplitude for defect.

DDF

TOFD

❖ Dynamic depth focusing (DDF):
Scanning is performed with different focal depths and provides higher sensitivity.

❖ Full Matrix Capture (FMC) and Total Focusing Method (TFM):
FMC is a UT data collection process and TFM is data processing to produce an image which is focused at every specified point.


TFM
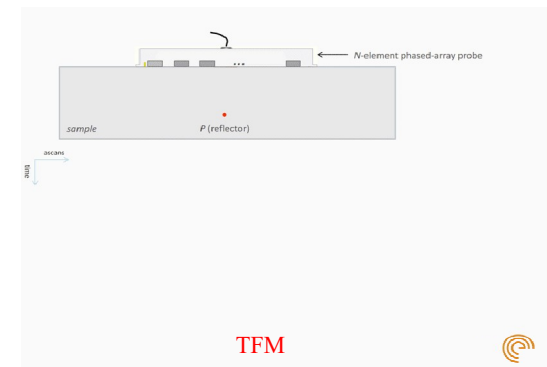
Probability of Detection (POD)

❧ POD is a statistical estimation of the probability to detect, with a given inspection system, a discontinuity of a certain size with a certain level of confidence.

❧ POD curves can be built for two forms of data. Binary response where the information is in form of hit / miss and signal response where data is in a quantitative form to build a more detailed scenario.

Hit / Miss

❧ Defect is
- Detected – Hit- 1
- Not detected – Miss- 0

❧ More data required for POD

❧ Larger uncertainty intervals compare to signal response analysis

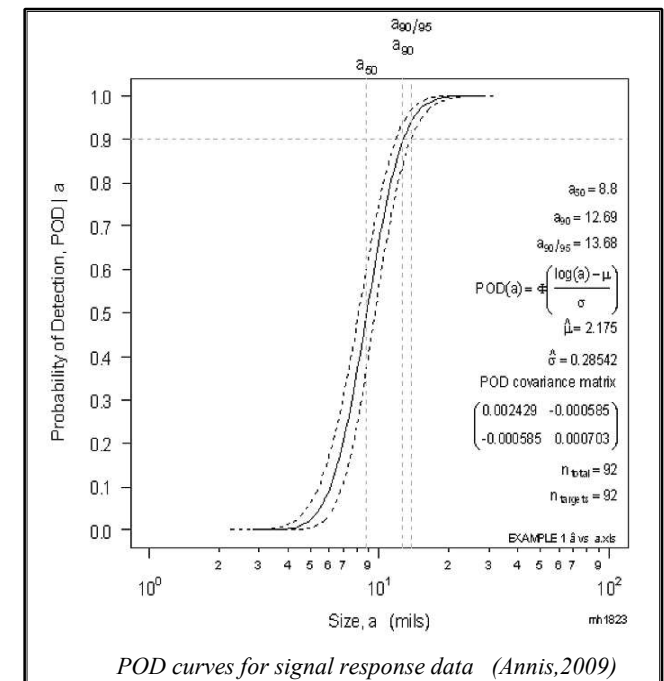❧ ASTM E2862-12: Standard practice for probability of detection analysis for hit/miss data

POD curves for hit/miss data (Annis,2009)
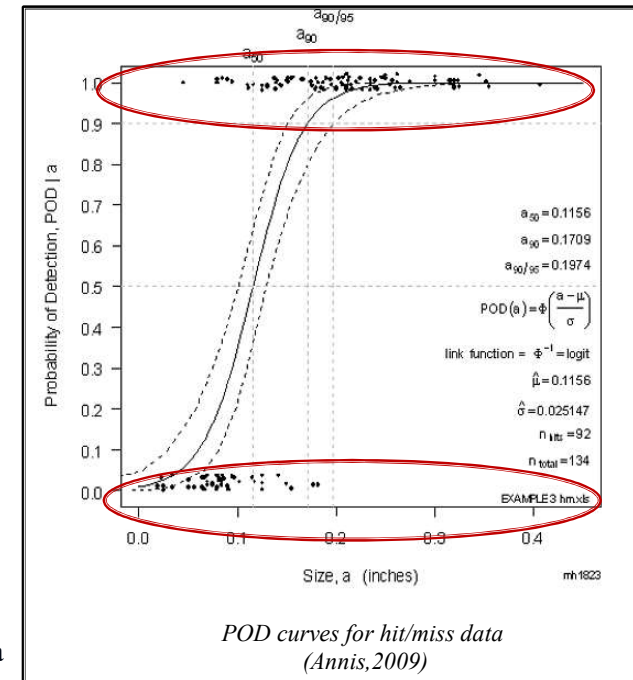
Probability of Detection (POD)

Signal response ($\hat{a}$) vs. flaw size (a)

❋ It has more information compare to hit or miss

❋ Less data points required for POD

❋ Maximum likelihood relationship between signal response ($\hat{a}$) and flaw size (a)

❋ A critical point in signal response data is the definition of the decision threshold

(signal above threshold: defect, signal below threshold: noise)

❋ ASTM E3023-15: Standard practices for probability of detection
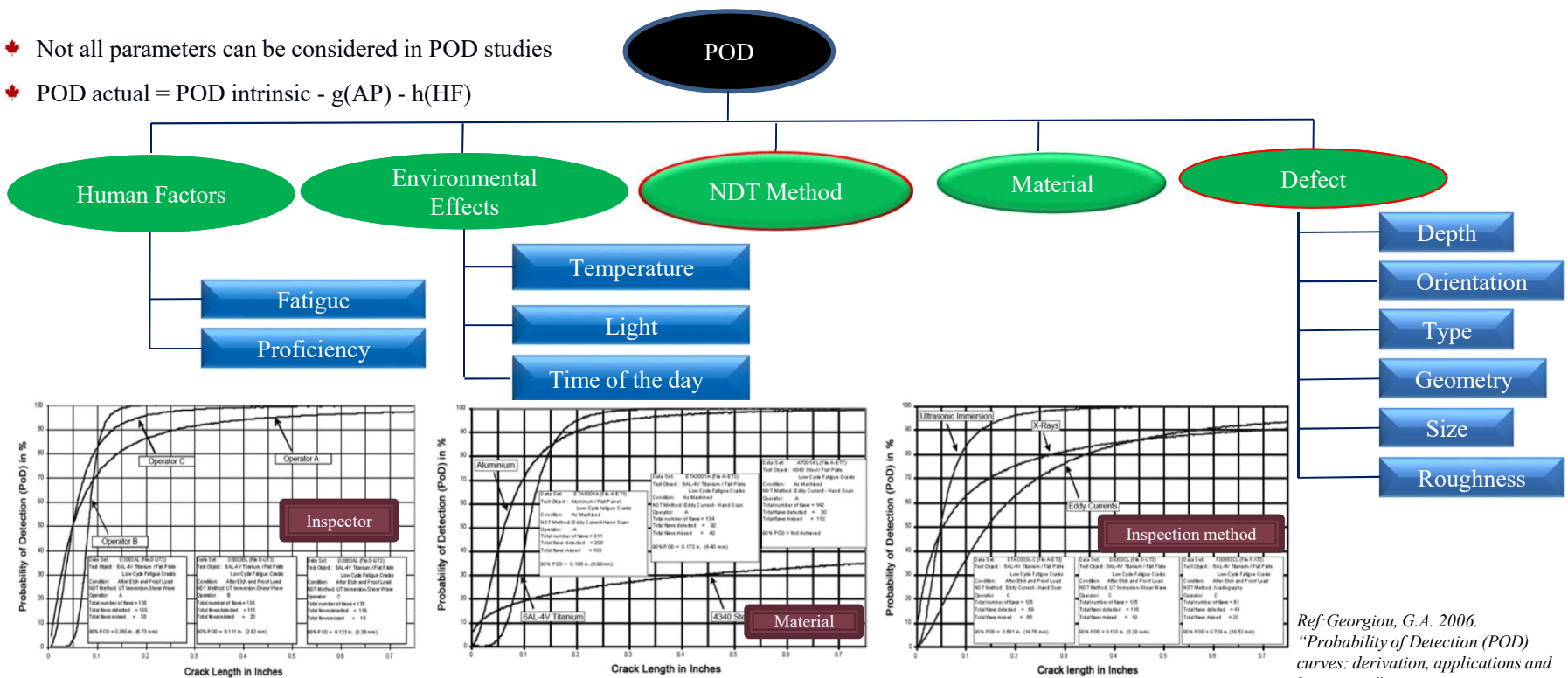analysis for â versus a data

> Different results will be obtained when the two POD analysis
> methods are applied to the same data set.

$a_{90/95}$
a_{90}
a_{50}

$a_{50} = 8.8$
$a_{90} = 12.69$
$a_{90/95} = 13.68$

$POD(a) = \Phi\left(\dfrac{\log(a) - \mu}{\sigma}\right)$

$\hat{\mu} = 2.175$
$\hat{\sigma} = 0.28542$

POD covariance matrix

$\begin{pmatrix} 0.002429 & -0.000585 \\ -0.000585 & 0.000703 \end{pmatrix}$

$n_{total} = 92$
$n_{targets} = 92$

EXAMPLE 1 â vs a.xls

Probability of Detection, POD | a

Size, a (mils)

mh1823

POD curves for signal response data (Annis,2009)

Probability of Detection (POD)

- Not all parameters can be considered in POD studies
- POD actual = POD intrinsic - g(AP) - h(HF)

POD

Human Factors

Environmental Effects

NDT Method

Material

Defect

Fatigue
Proficiency

Temperature
Light
Time of the day

Depth
Orientation
Type
Geometry
Size
Roughness

Inspector

Material

Inspection method

Ref: Georgiou, G.A. 2006. "Probability of Detection (POD) curves: derivation, applications and limitations"

Simulation

* CIVA can simulate the most common inspection methods and it is composed of simulation, imaging and analysis modules.

* Probes : Single element, dual element, TOFD, immersion, phased array.

* UT simulation tools in CIVA Software includes

* **"Beam computation":** Beam propagation simulation
* **"Inspection Simulation":** Beam interaction with flaws and specimen
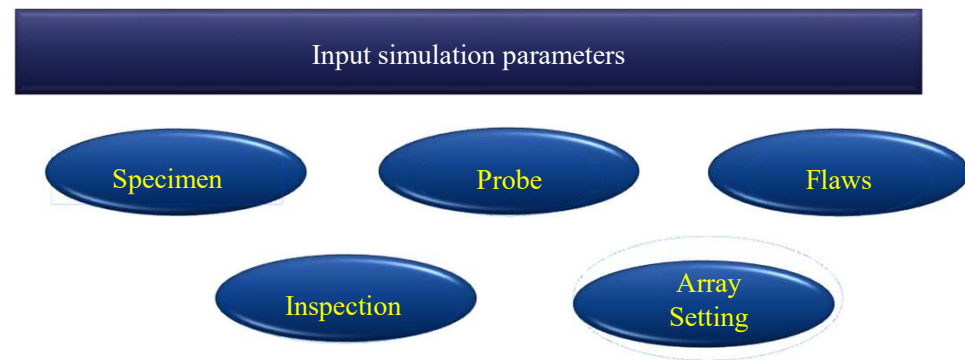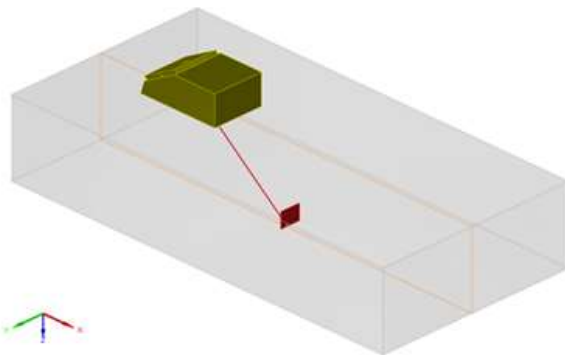
Input simulation parameters

Specimen | Probe | Flaws

Inspection | Array Setting

Evaluation of the Dead Zones

Evaluation of the Dead Zones

* Geometry of welding joint was applied to the turbine runners similar to the T-joint configuration.

* To evaluate the dead zone, T-joint configuration of martensitic stainless steel (UNS S41500) was considered.

* The 64-elements transducer probe with a frequency of 5MHz was considered in the simulation.

* The ray tracing method was performed in two steps which are called first half skip and second half skip.

* It was found that the dead zone is smaller in the first half skip.
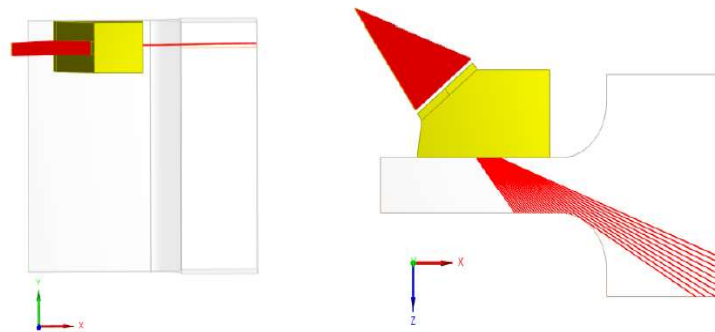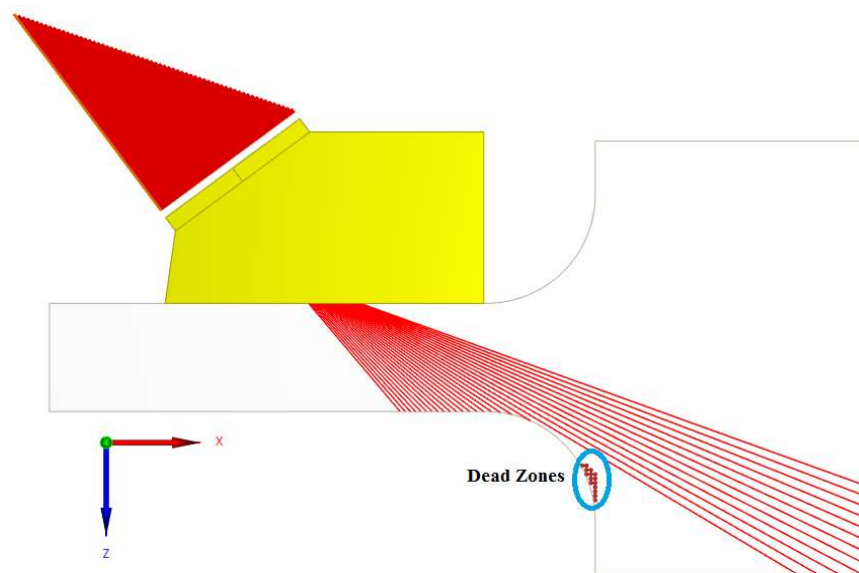

(a)   (b)
First-half skips with considering of HAZ; (a) top view, (b) cross-section view
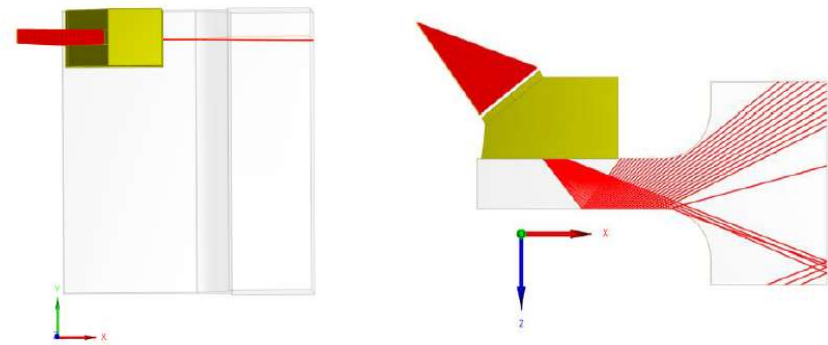
(a)   (b)
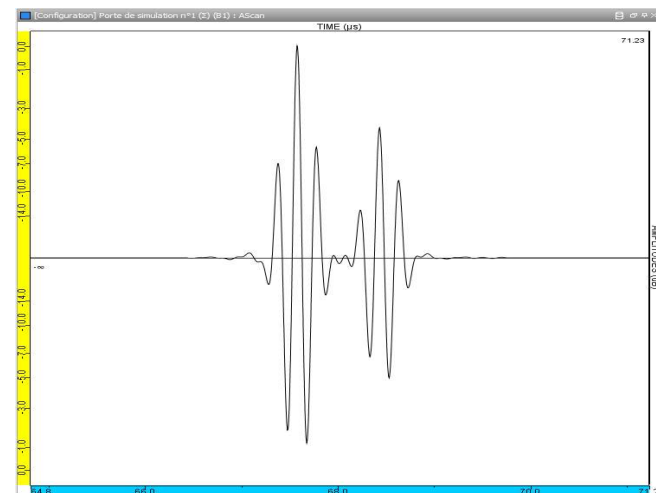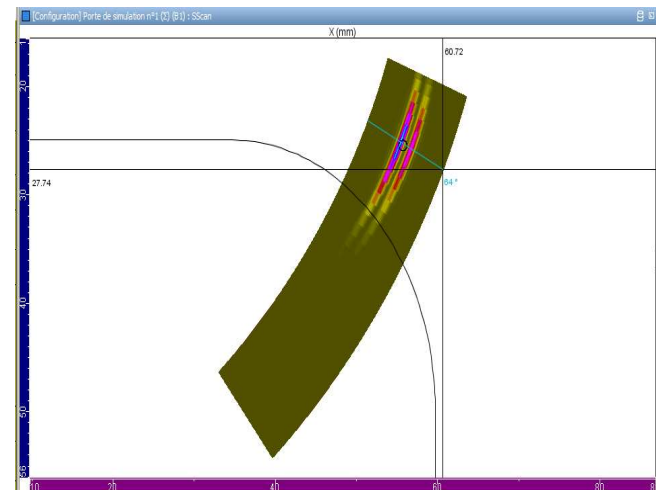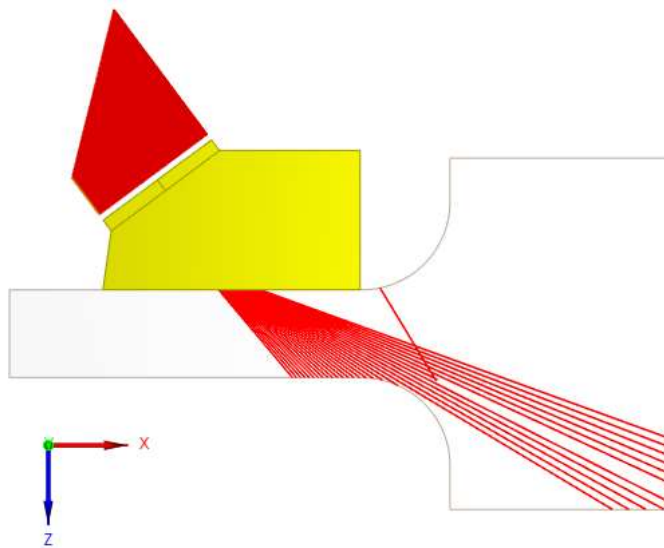Second half skip (a) top view, (b) cross-section view

Area 1-Dead Zones

Defect	Positioning		
Number	X	Y	Z
1	-62	40	33
2	-62	40	32
3	-62	40	31
4	-62	40	30
5	-62	40	29
6	-62	40	28
7	-62	40	27
8	-63	40	29
9	-63	40	28
10	-63	40	27
11	-63	40	26
12	-64	40	27
13	-64	40	26
14	-64	40	25
15	-65	40	25

I put 15 defect on the dead zone and CIVA does not show the result in the dead zone.

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Area 3-high POD

web Flang

Area 3 - High POD

Area 2 - Weak POD

Area 3 - Zero POD
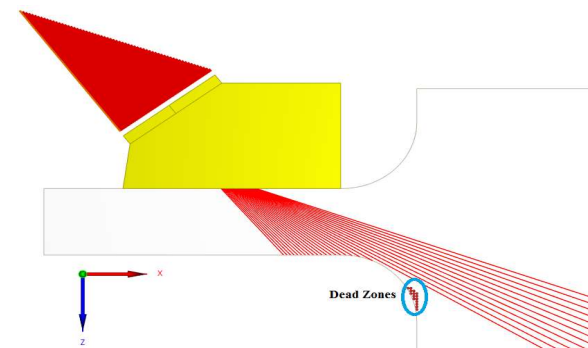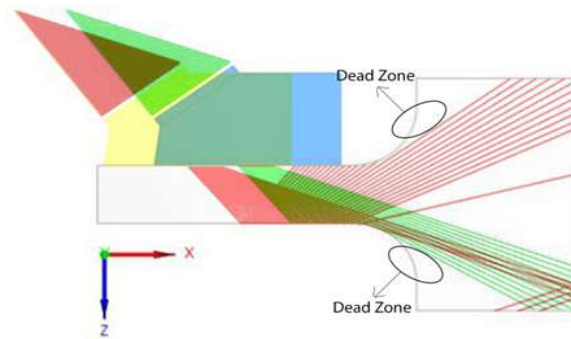Dead Zones

X

z
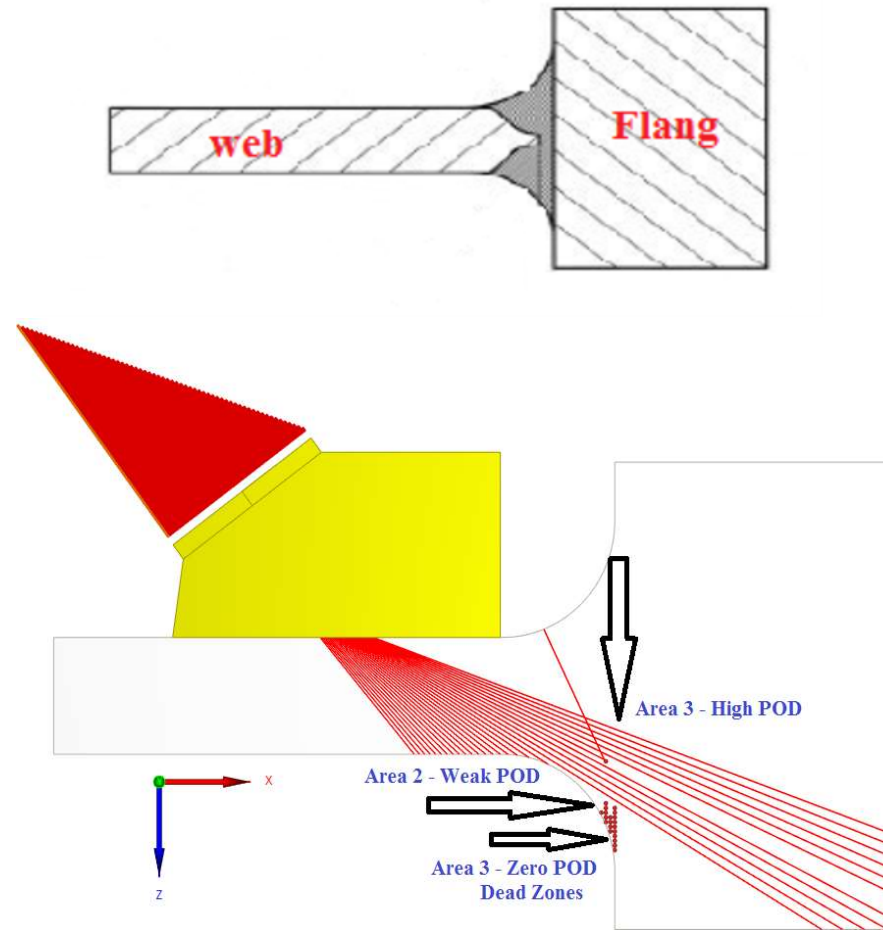
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✤ Although, dead zones could be roughly estimated using simple ray tracing method, more accurate and realistic estimation is provided using beam computation method.

(a)　　　　　　　　　　　　(b)
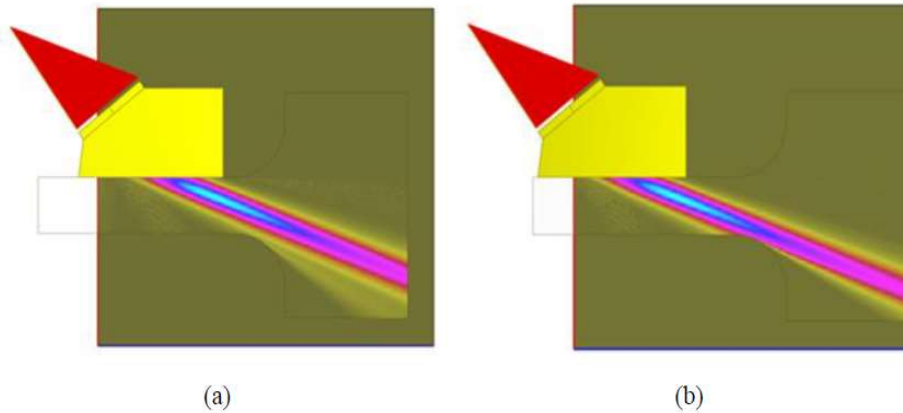
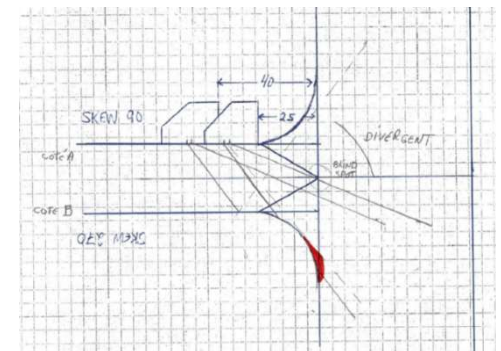Beam Computation; (a) first half skip, (b) second half skip

Conclusions

- The existence of dead zones is a challenging issue in the assessment of the integrity of a welded joint when these dead zones are in highly stressed areas.

(a) Dead zone locations, (b) CIVA does not show the result in the dead zone with 15 defects

- Due to runner geometry and inspection limitations, some areas cannot be covered by the ultrasound (the tip of the blade is the most problematic area).

- CIVA does not show the result in the dead zone

- Complementary NDT methods will be proposed to avoid this issue.

Thank you for your attention

Beauharnois Hydroelectric Generating Station, Montréal