

San Onofre Replacement Steam Generator Tube Wear

February 7, 2013

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Types of Tube Wear in SONGS Units 2 and 3 Replacement Steam Generators (RSG)

Tube-to-Tube Wear (TTW)

- Wear in U-bend region caused by contact with adjacent tubes

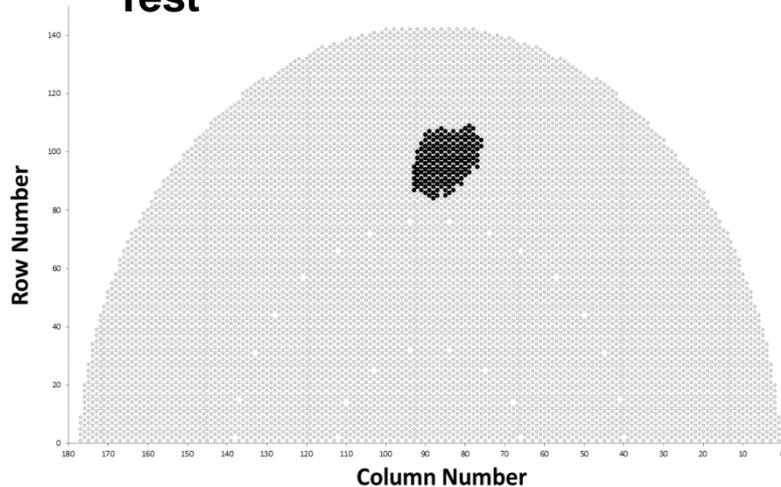
Other Tube Wear

- Tube wear at Anti-Vibration Bar (AVB) intersections
- Tube wear at Tube Support Plate (TSP) intersections
- Tube wear caused by vibration of adjacent retainer bar

SG89 Tube-To-Tube Wear

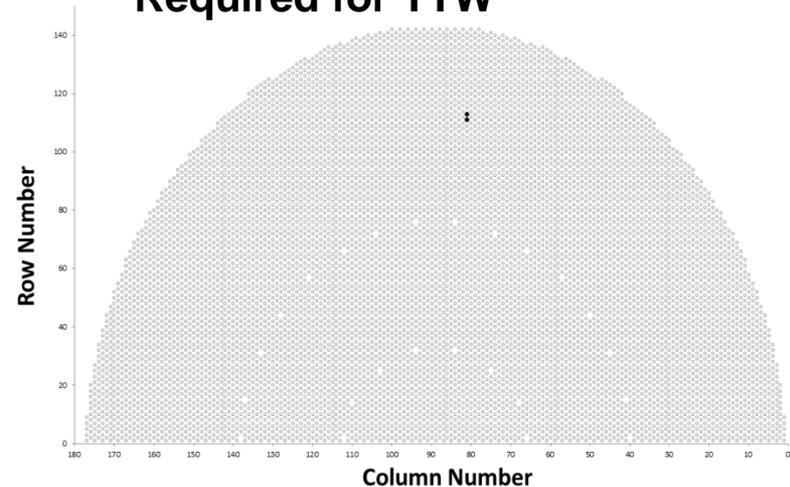
Unit 3

Operating Period 11 months
Maximum TTW Depth 100 %
Maximum TTW Length 41 inches
326 tubes (total in SG 88 and 89)
8 tubes failed In-Situ Pressure Test



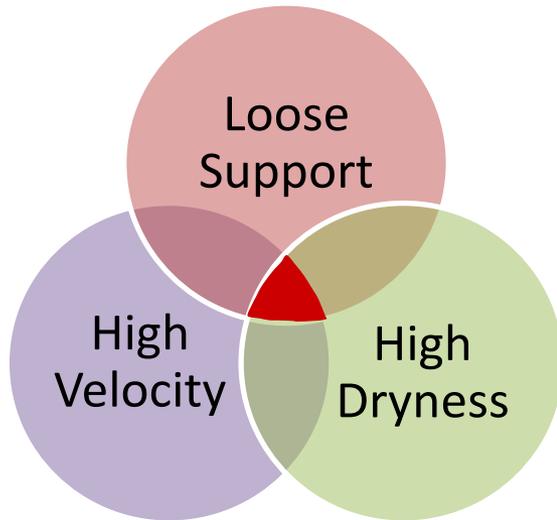
Unit 2

Operating Period 21 months
Maximum TTW Depth 14%
Maximum TTW Length 6 inches
2 tubes (total in SG 88 and 89)
No In-Situ Pressure Tests Required for TTW



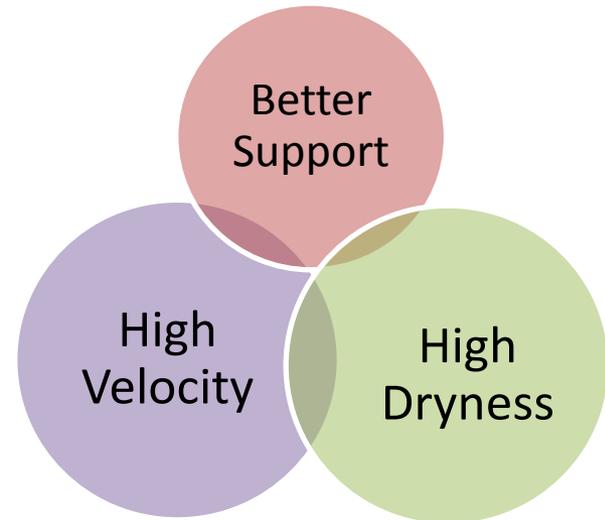
Contributors to In-plane Fluid Elastic Instability (FEI)

Unit 3



All three conditions required for FEI existed concurrently for many tubes

Unit 2



AVB supports are more effective in Unit 2, reducing potential for in-plane FEI

Differences Between Unit 2 and Unit 3

- Deep TTW in multiple tubes only in Unit 3 - after 11 months (approximately 7,000 full power hours); AVB wear also more extensive in Unit 3 than Unit 2
- Fabrication differences during manufacture of SONGS RSGs
 - Unit 3 AVB have greater flatness due to greater pressing force
 - Confirmed by 20 times more signals indicative of contact in Unit 2 in pre-service inspections
 - Unit 3 tube roundness is more controlled
 - Confirmed by pre-service measurements

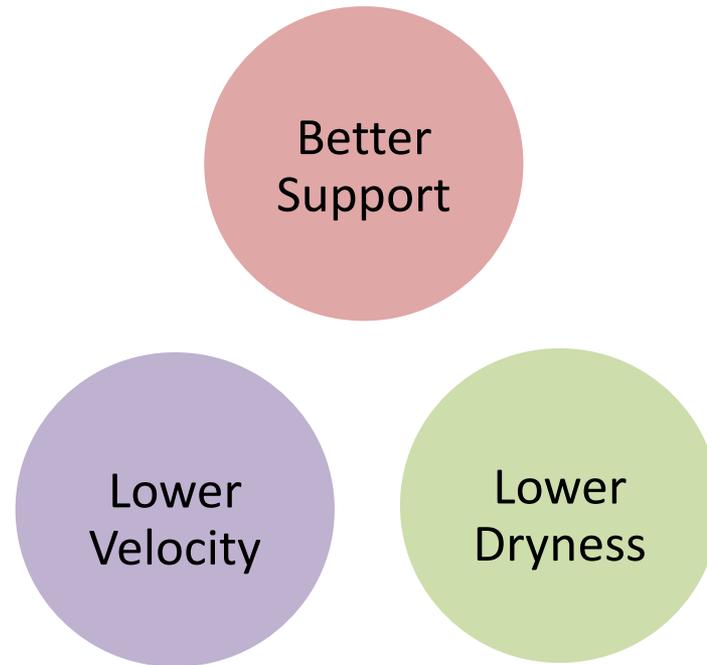
Differences Between Unit 2 and Unit 3

- Detailed tube bundle model shows that differences in fabrication result in substantially increased contact forces (reduced looseness) between tubes and AVBs for Unit 2
- More effective AVB support conditions allowed Unit 2 to operate at 100% power for 21 months (approximately 12,500 full power hours) with minimal TTW and less extensive AVB wear

Resolution of In-plane FEI Concerns Achievable with Multiple Layers of Margin

- Assure adequate support
- Reduce velocity
- Increase damping by decreasing dryness
(insure adequate moisture levels in bundle)
- Demonstrate acceptable in-plane FEI stability ratios based on conservative assumptions
- Compare and justify the operating conditions based on those of satisfactory service in existing steam generators

In-plane FEI can be Precluded



Eliminating the concurrent combination of high velocities, high dryness and inadequate support can preclude FEI

Insights from SONGS Experience

- In-plane FEI was unexpected but industry and plant specific measures worked as designed to detect the resulting tube leak and safely shutdown the plant
- Existing Industry requirements and criteria are strong and have been applied effectively to address tube-to-tube wear and other wear mechanisms
- Significant independent expert participation has been instrumental in developing conclusions
- Operating experience is being shared