



— BUREAU OF —  
RECLAMATION

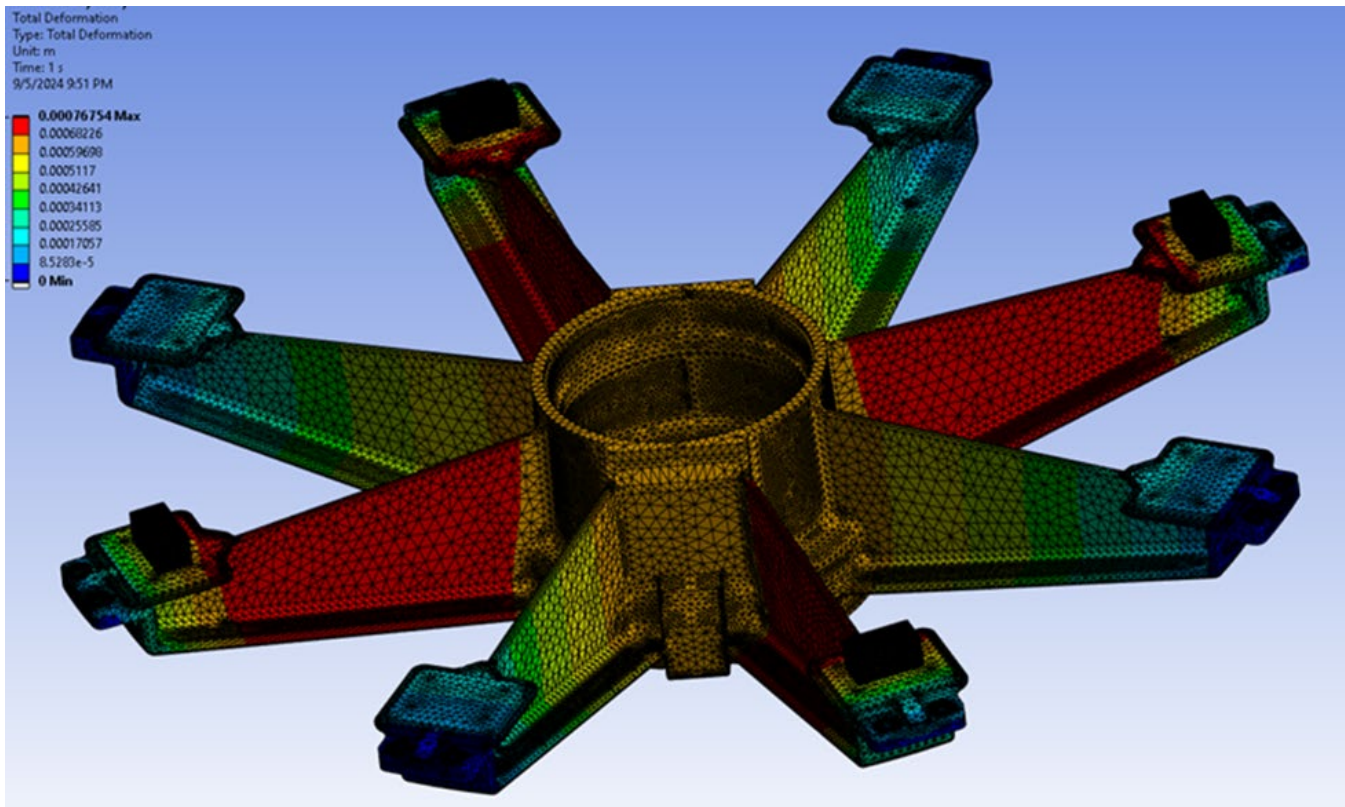
Final Report No. ST-2024-21091-01

# Evaluation and Validation of Fatigue on Aging Hydro Mechanical Components using Finite Element Analysis

Research and Development Office

**Science and Technology**

Research Program



REPORT DOCUMENTATION PAGE			Form Approved OMB No. 0704-0188		
<p>The public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing the burden, to Department of Defense, Washington Headquarters Services, Directorate for Information Operations and Reports (0704-0188), 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.</p> <p>PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS.</p>					
1. REPORT DATE (DD-MM-YYYY) September 30, 2024		2. REPORT TYPE Research		3. DATES COVERED (From - To) 2021 - 2024	
4. TITLE AND SUBTITLE Evaluation and Validation of Fatigue on Aging Hydro Mechanical Components using Finite Element Analysis			5a. CONTRACT NUMBER XXXR4524KS-RR4888FARD2103401		
			5b. GRANT NUMBER		
			5c. PROGRAM ELEMENT NUMBER 1541 (S&T)		
6. AUTHOR(S) Marcel Sorel, Mechanical Engineer			5d. PROJECT ID NUMBER Final Report ST-2024-21091-01		
			5e. TASK NUMBER		
			5f. WORK UNIT NUMBER		
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Bureau of Reclamation U.S. Department of the Interior Denver Federal Center PO Box 25007, Denver, CO 80225-0007			8. PERFORMING ORGANIZATION REPORT NUMBER		
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) Science and Technology Program Research and Development Office Bureau of Reclamation U.S. Department of the Interior Denver Federal Center PO Box 25007, Denver, CO 80225-0007			10. SPONSOR/MONITOR'S ACRONYM(S) Reclamation		
			11. SPONSOR/MONITOR'S REPORT NUMBER(S) (if applicable) Final Report ST-2024-21091-01		
12. DISTRIBUTION/AVAILABILITY STATEMENT Final Report may be downloaded from <a href="https://www.usbr.gov/research/projects/index.html">https://www.usbr.gov/research/projects/index.html</a>					
13. SUPPLEMENTARY NOTES					
14. ABSTRACT The goal of this project was to evaluate and validate the effect fatigue has on aging mechanical components using Finite Element Analysis (FEA). FEA is a method of calculating and predicting how complex systems react to real-world forces with the aid of a computer system. This project analyzed several mechanical components from Reclamation Powerplants using a developed FEA process. This report will provide results of the analysis, outline the processes used, and make recommendations for further FEA studies.					
15. SUBJECT TERMS Finite Element Analysis, Fatigue, FEA					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON Marcel Sorel
a. REPORT U	b. ABSTRACT U	c. THIS PAGE U			19b. TELEPHONE NUMBER (Include area code) 303-445-2803

## Mission Statements

The U.S. Department of the Interior protects and manages the Nation's natural resources and cultural heritage; provides scientific and other information about those resources; honors its trust responsibilities or special commitments to American Indians, Alaska Natives, Native Hawaiians, and affiliated Island Communities.

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

## Disclaimer

Information in this report may not be used for advertising or promotional purchases. The data and findings should not be construed as an endorsement of any product or firm by the Bureau of Reclamation, Department of Interior, or Federal Government. The products evaluated in the report were evaluated for purposes specific to the Bureau of Reclamation mission. Reclamation gives no warranties or guarantees, expressed or implied, for the products evaluated in this report, including merchantability or fitness for a particular purpose.

## Acknowledgements

The Science and Technology Program, Bureau of Reclamation, sponsored this research. LDV Consulting provided training and support on FEA topics, and PADT provided training and support on Ansys Software use. Thanks to the Reclamation facilities that partnered with researchers to provide projects, scoping, and support.

**Cover Image** – Three-dimensional digital rendering of a hydroelectric generator thrust bracket with a fine mesh overlayed onto the structure. The image is color graded to display total deformation from blue to red. (Bureau of Reclamation)



# **Evaluation and Validation of Fatigue on Aging Hydro Mechanical Components using Finite Element Analysis**

**Final Report No. ST-2024-21091-01**

Prepared by:

**Technical Service Center  
Marcel Sorel, Mechanical Engineer  
Turbines and Pumps Group 86-68470**



# Peer Review

## Bureau of Reclamation Research and Development Office Science and Technology Research Program

Final Report No. ST-2024-21091-01

### Evaluation and Validation of Fatigue on Aging Hydro Mechanical Components using Finite Element Analysis

---

Prepared by: Marcel Sorel  
Mechanical Engineer, TSC, Turbines & Pumps

---

Peer Review by: Jordan Lemer, P.E.  
Mechanical Engineer, TSC, Turbines & Pumps

---

Approved by: Nathan Myers, P.E.  
Manager, TSC, Turbines & Pumps

This document has been reviewed under the Research and Development Office Discretionary peer review process, consistent with Reclamation Policy CMP P14. It does not represent and should not be construed to represent the Bureau of Reclamation's determination, concurrence, or policy.





# Acronyms and Abbreviations

ASME	American Society of Mechanical Engineers
ASTM	American Society Testing and Materials International
BPVC	boiler and pressure vessel code
CAD	computer-aided design
ft <sup>3</sup> /s	cubic feet per second
FEA	finite element analysis
ft	foot
ft-lbs	foot-pounds
GCPO	Grand Coulee Power Office
HP	horsepower
in	inch
lbf	pound-force
lbs	pounds
mils	thousandths of an inch
OEM	original equipment manufacturing
PADT	Phoenix Analysis and Design Technologies, Inc
psi	pounds per square inch
Reclamation	Bureau of Reclamation
ROI	regions of interest
TSC	Technical Service Center
U.S.	United States

## Symbols

=	equal to
%	percent



# Contents

	Page
Executive Summary .....	1
1.0 Introduction.....	1
1.1 Project Background.....	1
1.2 Study Objectives .....	1
1.3 Team and Partners.....	1
2.0 Finite Element Analysis .....	2
2.1 Overview of Finite Element Analysis.....	2
2.2 Software Options .....	2
2.3 Finite Element Analysis Training .....	3
3.0 Methods.....	4
3.1 Finite Element Analysis Modeling Process .....	4
3.2 Data Collection and Analysis Methods.....	6
4.0 Results.....	7
4.1 LDV Training Thrust Bracket.....	7
4.1.1 Objective Statement .....	7
4.1.2 Geometry .....	8
4.1.3 Boundary Conditions.....	8
4.1.4 Analysis.....	9
4.1.5 Result Analysis.....	10
4.2 Canyon Ferry Thrust Bracket.....	10
4.2.1 Objective Statement .....	10
4.2.2 Geometry .....	11
4.2.3 Boundary Conditions.....	12
4.2.4 Calculation Comparison.....	13
4.2.5 Results Analysis .....	14
4.3 Marys Lake Shaft.....	16
4.3.1 Objective Statement .....	16
4.3.2 Geometry .....	17
4.3.3 Boundary conditions and loading.....	18
4.3.4 Calculation Comparison.....	19
4.3.5 Result Analysis.....	20
4.4 Grand Coulee Mechanical Seal.....	21
4.4.1 Objective Statement .....	21
4.4.2 Geometry .....	22
4.4.3 Boundary Conditions and Loading .....	23
4.4.4 On-site measurement comparison .....	24
4.4.5 Result Analysis.....	25
4.4.6 Real World Implications .....	27
4.5 Glen Canyon Wye Branch .....	27

4.5.1	Objective Statement .....	27
4.5.2	Geometry .....	28
4.5.3	Boundary conditions and loading.....	28
4.5.4	Calculation Comparison.....	30
4.5.5	Result Analysis.....	30
4.5.6	Real world implications .....	31
5.0	Conclusion .....	32
5.1	Key Findings.....	32
5.2	Limitations and Areas for Improvement.....	33
5.3	Implementation within Reclamation.....	33
5.4	Recommended Future Research .....	33
5.5	Final Thoughts .....	34
6.0	References.....	35

**Tables**

1.—	Material properties of the Canyon Ferry thrust bracket.....	11
2.—	Weight of Canyon Ferry generator and turbine components.....	12
3.—	Material properties of the Marys Lake turbine shaft .....	18
4.—	Operation points used for finite element analysis torque loading application.....	18
5.—	Total weight applied as loading condition to Marys Lake shaft.....	19
6.—	Comparison of finite element analysis results and calculations for Marys Lake shaft.....	19
7.—	Stress and fatigue analysis of the Marys Lake shaft transition radius .....	20
8.—	Stress and fatigue analysis of the Marys Lake shaft sleeve keyway.....	21
9.—	Material properties of the mechanical seal .....	23
10.—	Comparison of FEA and on-site deformation results for model B .....	25
11.—	Predicted factors of safety and number of cycles for original geometry .....	27
12.—	Predicted factors of safety and number of cycles for upgraded geometry “model B” .....	27
13.—	Material properties of the Glen Canyon wye branch.....	28
14.—	Glen Canyon Wye hand calculation deviation.....	30
15.—	Predicted factors of safety and number of cycles for the Glen Canyon wye branch.....	31

**Figures**

1.—	Finite element modeling flowchart. ....	5
2.—	LDV Training Thrust Bracket geometry.....	8
3.—	Load application of the unit’s rotating mass on the jack cylinder. ....	9
4.—	Geometry section used for symmetry analysis. ....	9
5.—	Deflection results of full LDV thrust bracket model. ....	10
6.—	Canyon Ferry thrust bracket model with bolted arms.....	11
7.—	Canyon Ferry thrust bracket section plane with applied load in red.....	12
8.—	Location of thrust bracket fixed supports. ....	13

9.—Deformation results of the Canyon Ferry thrust bracket. .... 14  
10.—von Mises stress results of the Canyon Ferry thrust bracket. .... 15  
11.—von Mises stress results of the Canyon Ferry thrust bracket with peak stress at bolt  
holes. .... 15  
12.—Plugged air admission ports in the shaft flange radius. .... 16  
13.—Boundary and loading conditions of Marys Lake complete shaft model. .... 17  
14.—Loading conditions of the Marys Lake partial shaft model. .... 18  
15.—Shaft sleeve key stresses. .... 20  
16.—Cracking on the Grand Coulee Unit 23 mechanical seal. .... 22  
17.—Model A: Mechanical seal finite element analysis model. .... 22  
18.—Exterior loading applied to mechanical seal. .... 23  
19.—Interior pressure loading on mechanical seal. .... 24  
20.—Deformation at 19 psi for upgraded “model B” ..... 25  
21.—von Mises stress at 19 psi on the original mechanical seal “model A”. .... 26  
22.—von Mises Stresses at 19 psi on the upgraded mechanical seal “model B”. .... 26  
23.—Glen Canyon wye branch geometry for finite element analysis model. .... 28  
24.—Section cut of wye showing internal pressure applied load. .... 29  
25.—Fixed support location. .... 29  
26.—High stress region on the wye internal face. .... 30  
27.—Highest stress region at the inlet of the wye. .... 31

**Appendix**

A Finite Element Modeling Flow Charts



## Executive Summary

Many of the Bureau of Reclamation's (Reclamation) hydroelectric powerplants were designed in the early to mid-20<sup>th</sup> century. Engineers of that era did not have the advanced engineering modeling tools or computing capacity to perform fatigue analysis that are available today. As these hydro units continue to operate 70 years later there are increasing signs of fatigue failure such as cracking and broken weld joints. It is important to ensure that existing mechanical components are able to withstand the changes in dynamic forces as these units are overhauled with new runners, uprated windings, increased power output, operational changes, and other modifications to the original design.

The goal of this project was to evaluate and validate the impact of fatigue on aging mechanical components. This was accomplished by using finite element analysis (FEA). Finite element analysis is a method of calculating and predicting how complex systems react to real-world forces with the aid of a computer system. Elements of a system are broken into a mesh (small solvable portions of a larger component) and run through a solver, such as Ansys, to gain usable data and information. The results from FEA are used to analyze and predict characteristics of existing hydropower equipment such as high-stress concentrations, abnormal vibration resonances, or modes of failure like fatigue.

In order to increase Reclamation's ability in the above, it was proposed to instrument the thrust bearing bracket of a vertical Francis hydro unit with strain gauges prior to a turbine runner replacement. An FEA model was created to estimate fatigue life and predict the future stresses that would be experienced with the new runner. Following the runner replacement, the model would be validated by taking a final set of empirical thrust bracket data. Due to unforeseen circumstances during the unit overhaul, this portion of the research was unable to be performed as planned. The research team adapted by generating five finite element models of hydro components: two (2) thrust brackets, a single turbine shaft, a mechanical seal, and a piping wye branch.

The findings and capabilities from this research are expected to have far-reaching and lasting effects on Reclamation's ability to proactively prevent catastrophic failures and reduce unplanned downtime. Inspections can be more targeted and effective by identifying specific high-stress areas. Advanced computational analyses will facilitate precise calculations and estimations that were previously reliant on assumptions and approximations, optimizing initial designs and corrective repairs with fewer iterations. This program is intended for expansion to include permanently installed cranes, large gates/valves, bearing brackets, operating rings, head covers, generator rotors, stator frames, and much more. Leveraging these new capabilities, Reclamation anticipates significant cost savings through reduced construction expenses from iterative designs, avoiding the need to contract these services to third parties, increased unit availability, and enhanced operational safety.



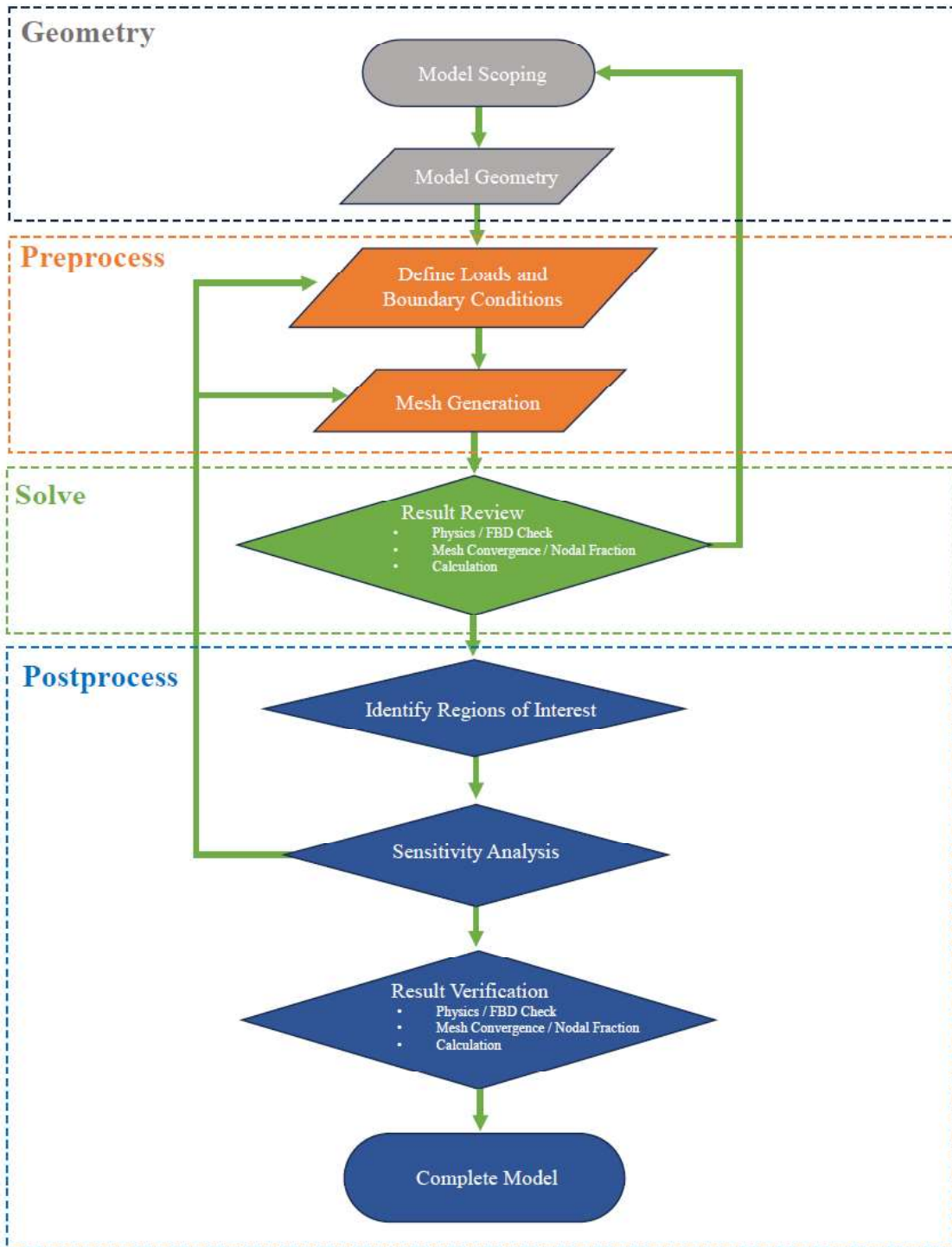


# **Appendix A**

Finite Element Modeling Flow Charts



### Finite Element Modeling Flow Chart

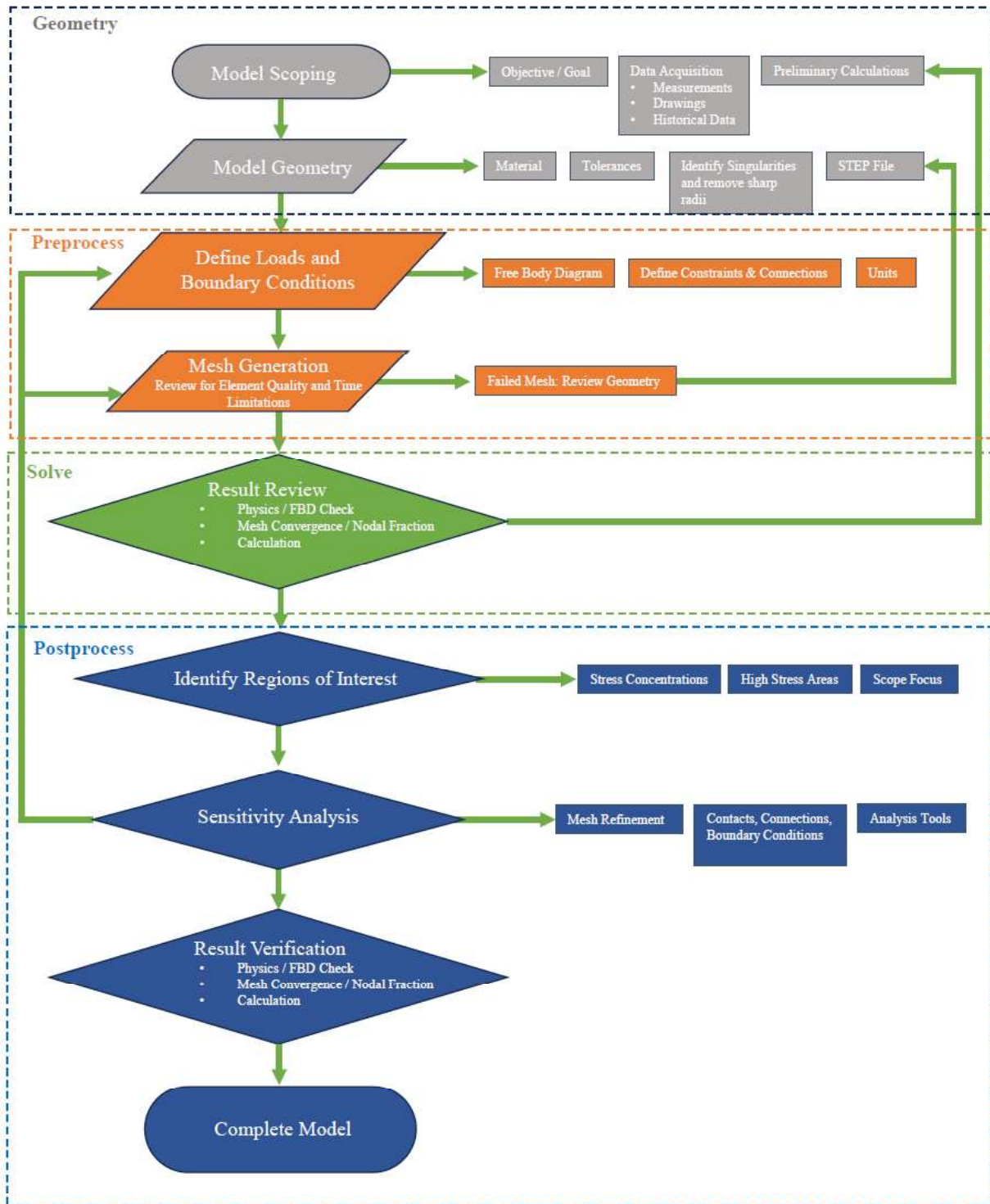


Last Updated: 8/23/2024

Figure A-1.—Finite element modeling flowchart.

Evaluation and Validation of Fatigue on Aging Hydro Mechanical Components using Finite Element Analysis – Appendix A

Finite Element Modeling Detailed Flow Chart



Last Updated: 09/04/2024

Figure A-2.—Detailed finite element modeling flowchart.