3rd Consultancy Meeting on Development of TECDOC on Fluid Structure Interaction (FSI)

23 July, 2014, Anaheim USA

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International Atomic Energy Agency







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Part I: Summary of 2nd Consultancy Meeting



Summary of 2nd Consultancy Meeting

- The meeting was held on **7-11 July 2013** in VIC.
 - The process for review of the finalised draft of the TECDOC was discussed.
- Participants:
 - Kunio Hasegawa, JNES Japan
 - Shiro Takahashi, Hitachi Japan
 - Fumio Inada, CRIEPI Japan
 - Bob Ainsworth, University of Manchester, UK
 - Kim, NSNI, IAEA

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Byung Kwon Lim, IAEA





Descriptions of New Inputs

- At the meeting, the participants described **the new sections** that they had provided for the draft TECDOC.
- **Bob Ainsworth** summarised a draft section on Pipewhip based on UK experience in Section 4;
 - Dr Hasegawa to provide a figure showing a PWR pipewhip restraint;
 - More detail to be provided on thrust force (Shiro Takahashi and Bob Ainsworth to pursue); and
 - A link to be made between the pipewhip section and related text on flutter in pipes containing fluid flow (Dr Inada).



- **Dr Hasegawa** described a new section dealing with evaluation of structural strength for flow induced vibration.
 - The associated Figure 3.1-2 was for ferritic steels (not as described in the caption);
 - Additional figures for other materials;
 - Provided a new table for Appendix A dealing with steam generator tube wear at San Onofre-2, 3;
 - Will provide an electronic version of the new table dealing with steam generator tube wear to Dr Kim;
 - Will provide a list of numbers of NUREG reports containing FSI examples to Dr Kim;



- **Dr Inada** described a number of inputs he had provided based on his own work and that of colleagues in Japan.
 - In Section 2: a sub-section dealing with plates in the section on vortex induced vibration; a section on self-excited vibration; some additional paragraphs in the section on flutter in pipes containing fluid flow; some additional information in the section on fluid-elastic vibration of tube bundles in single-phase flow and two-phase flow; and text on forced vibration.
 - In Section 3, a **new section** dealing with BWR RPV internals and new text on valves had also been supplied.
 - to confirm the notation used in equation (2.3(2)-3) and in the surrounding text;
 - to check whether the term A in equation (3) on valves was the same as the effective area A_v in the related Figure 2.



- **Dr Takahashi** described a number of additions that he had made to the text:
 - some additional definitions related to terms in tables and figures in the section on acoustic resonance at branch pipes;
 - some additional definitions related to terms in the section on forced vibration of pipes downstream of pumps;
 - a **new section** dealing with BWR RPV internals for Section 3; and new advice on acoustic fatigue.
 - to expand the description above the new equation (4) in the section on acoustic resonance at branch pipes;
 - to obtain an improved Figure 3.4-1 on Rod amplitude.



- **Dr Jung and Dr Kim** had supplied new text related to computational methods for Sections 5.
 - There was a need to focus on more practical methods and applications because the draft was rather long.
 - Dr Kim to add new examples for application in Section 5.2.



3. Contents List of Proposed FSI TECDOC

- Following the discussion of the new additions to the draft TECDOC, the contents list of the latest draft was discussed in detail. A number of changes were made to sub-section numbering to make the format of the contents more consistent.
- The inclusion of information related to **the events following the tsunami at Fukushima** was also discussed. It was agreed that it was not possible to provide detailed information at this stage but that it would be useful to provide a one-page summary on the current activities and strategy of the JSME working group as an Appendix to the document.
- Dr Inada to ask Prof. Kaneko to provide a **one-page summary** related to post-Fukushima activities.
- An updated contents list was produced at the meeting by Dr Kim, supplied electronically to attendees.



Review of the Draft FSI TECDOC

- Before the draft TECDOC was circulated for independent peer review, it was agreed that **the draft sections would be reviewed by attendees** at this meeting and/or subsequently.
- During the meeting, significant changes were made to the document as a result of the individual assignments, discussed by all attendees and collated into an updated draft. Where it was not possible to finalise a particular part of the text (for example, due to the need to discuss with other colleagues or to obtain a better quality figure), **actions were highlighted in the updated text**.



Disseminate the Draft TECDOC

 To disseminate the contents of the TECDOC, holding a technical workshop and/or the 2014 ASME PVP conference in Anaheim, USA on 20-24th July was discussed.



Timescales Required for Production of the TECDOC

- End-August 2013: All to complete inputs to main sections of the TECDOC
- End-September 2013: Additional examples for Appendices A and B
- End-September 2013: Fumio to draft 1-page summary for Appendix C
- End-October 2013: Man to complete first draft of total document and circulate to technical group for review
- End-November 2013: All to return comments to Man
- End-December 2013: Complete finalised draft of total document.
- End-March 2014: Send finalised draft for independent peer review.
- End-April 2014: Independent review comments received.
- June 2014: Technical Group meeting to finalise the TECDOC.



Agreed Actions

- A summary of the actions agreed during the meeting, as described in more detail above, is given below.
- Dr Hasegawa to provide a figure showing a BWR pipewhip restraint;
- More detail to be provided on thrust force related to pipewhip (Shiro Takahashi and Bob Ainsworth to pursue);
- A link needs to be made between the pipewhip section and related text on flutter in pipes containing fluid flow (completed at the meeting).
- Dr Hasegawa to provide additional endurance figures for other materials.
- Dr Hasegawa to provide an electronic version of the new table dealing with steam generator tube wear to Dr Kim;
- Dr Hasegawa to provide a list of numbers of NUREG reports containing FSI examples to Dr Kim;
- Dr Kim to summarise more examples in the format of Appendix A from the list provided by Dr Hasegawa.



Agreed Actions

- Dr Inada to confirm the notation used in equation (2.3(2)-3) and in the surrounding text (completed at the meeting);
- Dr Inada to check whether the term A in equation (3) on valves was the same as the effective area A_v in the related Figure 2.
- Dr Takahashi to expand the description above the new equation (4) in the section on acoustic resonance at branch pipes;
- Figure 2.4(4)-1 is the same as a figure in Section 3.5 (Dr Kim to remove the latter figure and insert a reference to the earlier figure);
- Dr Takahashi to obtain an improved Figure 3.4-1 on Rod amplitude.
- Dr Kim to remove duplicate text from Section 3.5.2 on water hammer (completed at the meeting);
- Dr Kim to shorten the remaining Section 3.5.2(completed at the meeting).
- Dr Inada to ask Prof. Kaneko to provide a one-page summary related to post-Fukushima activities (completed at the meeting but response awaited).



Agreed Actions

- Dr Kim to shorten and re-arrange the text in Section 5 (completed at the meeting).
- Dr Kim to add new examples for application in Section 5.2.
- All to progress the actions highlighted in the updated draft TECDOC.
- Dr Kim/Bob Ainsworth to prepare an overview paper on the TECDOC for the 2014 ASME PVP Conference.
- Fumio Inada to prepare a paper on Design and Maintenance against FSI for the 2014 ASME PVP Conference with Prof Nakamura.
- Kunio Hasegawa/Shiro Takahashi to prepare a paper on FSI Plant Issues for the 2014 ASME PVP Conference.
- Dr Kim to prepare a paper on Computational Methods for for the 2014 ASME PVP Conference with Dr Jung or Dr Longatte.



Contents of Draft TECDOC on FSI

FOREWORD (Man)

1. INTRODUCTION

1.1 Background (Man)

1.2 Objectives and Scope (Bob)

1.3 Structure (Man)

2. GENERAL DESCRIPTION OF FLUID STRUCTURE INTERACTION

2.1 Added mass, damping, and stiffness coefficients (Japanese group)

(1) Single cylinder

(2) Tube bundle

(3) Gap between structures

2.2 Vortex induced vibration (Japanese group)

(1) Single cylinder

(2) Tube bundle

(3) Plate .



- 2.3 Self-excited vibration (Japanese group)
 - (1) Flutter of pipe containing fluid flow
 - (2) Fluid-elastic vibration of tube bundle in single-phase flow and two-phase flow
 - (3) Leakage flow induced vibration
 - (4) Vibration by overflow weir
 - (5) Acoustic resonance at branch pipe
- 2.4 Forced vibration (Japanese group)
 - (1) Turbulence-induced vibration of a tube in cross flow
 - (2) Turbulence induce vibration of tube bundle in cross flow
 - (3) Turbulence induced vibration of tube and tube bundle in parallel flow
 - (4) Pipe downstream of pressure control valve
 - (5) Pipe downstream of pump
- 2.5 Water hammer (review by Kunio)
- 2.5.1 Causes water hammer
- 2.5.2 Finding practical solution
 - (1) Valves
 - (2) Pumps



- 3. DESIGN AND MAINTENANCE AGAINST FLUID STRUCTURE INTERACTION
- 3.1 Flow Induced Vibration in Nuclear Components (Bob)
- 3.1.1 Industrial Codes for FIV (Prof Nakamura)
 - (1) Vortex shedding
 - (2) Fluid elastic instability
 - (3) Turbulence induced vibration
 - (4) Axial flow
- 3.1.2 Evaluation structural strength for FIV
 - (1) Stress evaluation
 - (2) Fatigue strength evaluation
- 3.2 Fuel assembly and heat transfer tube (Japanese group)
 - (1) Fuel assembly
 - (2) Steam Generator
- 3.3 Thermowell (Bob)
 - (1) Avoiding or suppressing vortex-induced vibrations
 - (2) Calculation of bending stress due to stead drag force
 - (3) Evaluation of stress amplitude by turbulence-induced random vibration
 - 4 RPV internal (new for All)



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3.4.1 Flow induced vibration of reactor internals in PWR

- (1) Flow induced vibration in down-comer region
- (2) Flow induced vibration of reactor control rods
- 3.4.2 Flow induced vibration of reactor internals in BWR
 - (1) Jet Pumps
 - (2) Control Rod Drive Housings, Guide Tubes and Instrumentation Pipes
 - (3) Spargers and Piping
 - (4) Steam Dryers and Their Assemblies
 - (5) BWR Fuel Bundle
- 3.5 Pipe
- 3.5.1 Acoustic fatigue (Bob)
- 3.5.2 Water hammer (Man will shorten the text and Kunio will review)
 - (1) Operation Experiences
 - (2) Regulatory Requirements
 - (3) Analysis Methodology



3.5.3 Pipewhip Jet Force (Kunio)

- (1) Procedure
- (2) Break locations
- (3) Thrust at the break (bob supports text)
- (4) Pipe motion
- (5) Rigorous pipework analysis
- (6) Damage assessment
- (7) Pipe restraints
- 3.5.4 Maintenance of small bore pipe (Shiro)
- 3.6 Valve (new for All)
 - (1) Turbulence-induced valve vibration
 - (2) Self-excited vibration of flow-restriction valves
 - (3) Small bore pipe vibration and malfunction of steam pipe pressure switch caused by pressure control valve
 - (4) Cavity tone excitation of relief valve



- 4. PLANT ISSUES
- 4.1 Flow-induced vibration (Bob)
 - (1) NUCIA record
 - (2) Monju thermo well
 - (3) SG tube failure at Mihama and North Anna
- 4.2 Water Hammer (Kunio and Man)
 - (1) NUCIA record
 - (2) Major incidents
- 4.3 Acoustic fatigue (Inada)
- 4.4 Vibration by overflow weir (Bob)
 - (1) Core Internals at Super Phenix-1



5. COMPUTATIONAL METHODS (EDF France representative, Ms Elizabeth for peer review) (new for all)

- 5.1 Mathematical Equations and Numerical Modelling
- 5.1.1 Mathematical Equations
 - (1) Governing Equations
 - (2) Turbulence Modelling
- 5.1.2 Numerical Modelling
 - (1) LES
 - (2) DNS
 - (3) Lattice-Boltzmann Method
 - (4) Finite Element Method (FEM)
- 5.2 Computational Fluid Dynamic Method
- 5.2 1 Coupling Methodology
- 5.2.2 Applications
 - (1) Reactor vessel internals



Main Steam Line and Dryer

6. CONCLUSIONS (Man) References (Man) Contributors to Drafting and Review (Man) Glossary (draft by Man and review by all) Abbreviations (draft by Man and review by all) Nomenclature (draft by Man and review by all) Executive Summary (TBD) **APPENDIX:** Plant Issues **APPENDIX A: Flow Induced Vibration (Kunio)** APPENDIX B: Water Hammer (Kunio and Man) APPENDIX C: (Fumio to ask Prof. Kaneko)



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Part II: 3rd Consultancy Meeting: Future Actions and Timescale



Objective

- The objective of this consultancy meeting to be held jointly with <u>a</u> special technical session, FSI-9, *IAEA Activities on Fluid Structural Interaction for Nuclear Components* of ASME PVP conference is as followings:
 - To disseminate the draft technical document for verification of its applicability **in the ASME PVP conference.**
 - To finalize the draft technical document with comments from ASME PVP conference and consultancy meeting.



Requests to Participants

- The Consultants are requested to deliver a presentation relevant to their related topics for the ASME PVP FSI-9 session.
- For attending the consultancy meeting, the participants are requested to review the draft document in advance and prepare their review comment and new input.



Overview of Draft Agenda

- Review and Updating meeting for feedback from FSI sessions and comments from attendees.
 - Add seismic design referred to ASME Sec III App. N1200 and N1200 on method and dynamic analysis
 - Numerical method: coupled method and mesh guideline
- Review draft document and agreement on following tasks
 - What are further needed?
 - Hold international technical meeting (workshop) in cooperation with ASME PVP FSI Committee.
- **Other issue**: Regularly participation in ASME PVP Conference for sharing information





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Thank you – Questions?

