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YOUNGBLOOD,B.J. Licensing Branch 1

SUBJECT: Forwards methodology for calculating submerged structure drag loads to close SER Outstanding Issue 29.

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May 14, 1981

Mr. B. J. Youngblood, Chief
Licensing Branch No. 1
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555

Docket Nos. 50-387
50-388

SUSQUEHANNA STEAM ELECTRIC STATION
SER OUTSTANDING ISSUE 29
ER 100450 FILE 841-2
PLA-758

Dear Mr. Youngblood:

Attached is the methodology for calculating submerged structure drag loads.

This response completes our action to close SER Outstanding Issue 29.

Very truly yours,

NW Curtis

N. W. Curtis
Vice President-Engineering and Construction-Nuclear

CTC/mks

Attachment

cc: R. M. Stark - NRC

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Provide methodology for calculating submerged structure drag loads.

Response:

The following write-up will be included in Subsection 4.2.2.5 of Revision 6 to the SSES Design Assessment Report.

Condensation Oscillation and chugging induce flow fields in the suppression pool causing drag loads on the submerged structures (i.e., SRV lines, downcomers, etc.). The methodology for calculating these drag loads to be combined with the other design basis loads (see Section 5.0) is presented below.

In 1904, Prandtl (Reference 1) enunciated a theory describing the flow of a fluid past a body as (i) the viscous flow in the thin boundary-layer, and (ii) the classical inviscid flow about a new body consisting of the original body enhanced by the thickness of a boundary layer plus possibly a wake (Reference 2). Thus, the force exerted on a submerged structure by a fluid moving relative to it is equal to the surface integral of the normal pressure and tangential shear stresses acting on the structure (Reference 3). The tangential shear stresses are important for Reynolds numbers less than one (Reference 4), but for the flow fields due to CO and chugging and the SSES submerged structures, the Reynolds numbers are much greater than one. Thus, the tangential shear stresses will not be considered here. Thus

$$\vec{F} = \oint p\,d\vec{S} \qquad (1)$$

where p is the fluid pressure acting on the area increment $d\vec{S} = \hat{n}dS$ and $\hat{n}$ is an inward-pointing normal unit vector at the centroid of dS.

The flow pattern of the fluid about the structure is as follows. At large Reynolds numbers the field of flow may be subdivided into an external region and a thin boundary-layer near the structure together with a wake behind it. In the external region potential flow theory can be used to evaluate the flow field while in the boundary-layer and wake, the Navier-Stokes equation must be used (Reference 5 and 6). Therefore, the surface integral in Eq. (1) can be divided into an integral over the structure surface outside the wake region, and an integral over the surface inside the wake. Hence

$$\vec{F} = \oint_{S_\Phi} p_\Phi \, d\vec{S} + \oint_{S_W} p_W d\vec{S} \qquad (2)$$

where S_Φ and S_W are the time-dependent areas adjacent to the potential and wake flows. The pressure p_Φ corresponds to the potential flow region and for a linear isentropic fluid is given by the equations of potential flow combined with Euler's Equation (Reference 7).

By adding and subtracting the integral $\oint_{S_W} p_\Phi d\vec{S}$ Eq. (2) becomes

$$\vec{F} = \oint_{S} p_\Phi \, d\vec{S} + \oint_{S_W} (p_W - p_\Phi) d\vec{S} \qquad (3)$$

where S is the boundary-layer surface S_Φ plus the surface of the structure adjacent to the wake. Since the boundary-layer is thin, the thickness being inversely proportional to the square root of the Reynolds number, negligible error is incurred by approximately S with the structures surface.

Thus the total force is the sum of an acceleration force $\vec{F}_A$ and an unsteady drag force $\vec{F}_D$. The acceleration force can be expressed as in terms of a pressure gradient via Gauss' theorem or a uniform flow acceleration $\dot{U}_\infty$ (Reference 8).

$$
\begin{aligned}
\vec{F}_A &\equiv \oint_S p_\phi \, dS \\
&= \oint_S \nabla p_\phi dV \qquad (4) \\
&= \rho V_A \dot{\vec{U}}_\infty
\end{aligned}
$$

Where V_A is the acceleration volume which is equal to the sum of the structure volume plus the classical hydrodynamic mass (Reference 10) divided by the fluid density. For a cylinder of diameter D, length L with $\dot{\vec{U}}_\infty$ normal to the cylinder axis, $V_A = \frac{1}{2} D^2 L$ (Reference 11).

The unsteady drag force $\vec{F}_D$ can be expressed in the same mathematical form as the drag for steady flow by defining an unsteady drag coefficient C_A

$$
\begin{aligned}
\vec{F}_D &\equiv \oint_{S_W} (p_W - p_\phi) dS \\
&= \tfrac{1}{2}\rho C_A A \left|\vec{U}_\infty\right| \left|\vec{U}_\infty\right| \qquad (5)
\end{aligned}
$$

where A is the projected area and $\vec{U}_\infty$ is the steady flow velocity. A somewhat limited conclusion can be drawn from the comparison of Eq. (5) with experimental data (Reference 12). For cylinders or spheres in unidirectional flow acceleration where the Reynolds Number range gives approximately constant values for the steady flow drag coefficient C_D, the unsteady drag coefficient C_A is less than twice the steady value i.e., $C_A/C_D < 2$. For finite plates the ratio C_A/C_D may be as large as six.

Thus, the force on a submerged structure (neglecting forces due to shear stress) is the sum of an acceleration force due to a pressure gradient in the flow field plus an unsteady drag force

$$\vec{F} = \vec{F}_A + \vec{F}_D \qquad (6)$$

Under certain conditions the pressure gradient is of sufficient magnitude so that the submerged structure force is essentially the acceleration drag force and can be determined from the action of that force times a correction factor which is approximately unity. To show this Eq. (6) is written in the following form

$$\vec{F} = \vec{F}_A \left(1 + \frac{F_D}{F_A} \right)$$

$$= \vec{F}_A \left[1 + \frac{g\ C_A}{SrC_D} \right] \qquad (7)$$

where $Sr = \frac{U_\infty D}{U_\infty^2}$ is the Strouhal number (Reference 13) and $g = \frac{C_D \cdot A \cdot D}{4 \cdot \P \cdot V_A}$

is a geometric factor of order $C_D/\P$. Thus, where the pressure gradient is large such that $(g/Sr) \cdot (C_A/C_D)$ is small, the total force on a submerged structure is properly given by the integration of p_ϕ over the structure surface:

$$\vec{F} = \left(1 + \frac{g\ C_A}{Sr\ C_D} \right) \oint p_\phi\, d\vec{S} \qquad (8)$$

For a cylinder, which is the most common geometrical shape for a SSES submerged structure, $g \cdot (C_A/C_D) < 2$. Therefore, to ignore the drag force compared to the acceleration force, the Strouhal Number should be of the order of ten or greater. For SSES, the Strouhal Number is greater than 30, and in some cases much higher, and negligible error will be incurred by ignoring the drag force. Thus, for calculating the SSES submerged structure drag forces, Eq. (8) reduces to

$$\vec{F} = \oint_S p_\phi d\vec{S}$$

The pressure p_ϕ as a function of time and position is calculated by the IWEGS/MARS acoustic model of the SSES suppression pool. Thus, p_ϕ is calculated in an analogous manner as the symmetric wall loads (see DAR Subsection 9.5.3.4.1), except that the pressures are calculated at the submerged structure locations instead of the containment boundary. For each structure being analyzed (i.e., downcomer), a pressure time history (PTH) is calculated for every 60° increment circumferential around the structure at each elevation corresponding to a nodal point of the structural model (see DAR Figure. 7-10 for downcomer structural model). Thus, for each node point elevation, six pressure time histories are calculated. This is repeated for each source. These sets of PTHs, calculated for each source, are then integrated across the structure's surface to give force time histories for structual analysis.

REFERENCES:

1. L. Prandtl, "Über Flüssigkeitsbewgung bei sehr Kleiner Reibung," Proc. Third Int. Math. Congress, Heidelberg, 1904.

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3. S. Eskinazi, Principles of Fluid Mechanics, Second Edition, Allyn and Bacon, Inc., Boston, 1968, p. 436.

4. H. Schlichting, Boundary-Layer Theory, Sixth Edition, McGraw-Hill Book Company, New York, 1968, p. 104 ff.

5. Ibid., p. 22.

6. L.D. Landau and E.M. Lifshitz, Fluid Mechanics, Pergamon Press, London, 1959, p. 169.

7. Ibid., p. 3, Eq. (2.3); p. 19, Eq. (9.2).

8. F.J. Moody, "Forces of Submerged Structures in Unsteady Flow," Proceeding of the ANS Topical Meeting on Thermal Reactor Safety July 31-August 4, 1977, Sun Valley, Idaho, p. 3-516 ff.

9. K.T. Patton, "Tables of Hydrodynamic Mass Factors for Translation Motion," ASME Paper No. 65-WA/UNT-2, 1965.

10. L.M. Milne-Thomson, op. cit., pp. 246-247.

11. F.J. Moody, op. cit., p. 3-592.

12. Ibid., p. 3-591.

13. H. Schlichting, op. cit., p. 32.

The following write-up will be included in Subsection 4.2.1.7 of Revision 6 to the SSES Design Assessment Report.

During the drywell air purge phase of a LOCA an expanding bubble is created at the downcomer exits. These rapidly expanding bubbles eventually coalesce into a "blanket" of air which leads to the pool swell phenomena. The bubble charging process creates fluid motion in the suppression pool which causes drag loads on the submerged structures.

The submerged structure drag loads due to air clearing, prior to pool swell, are calculated in the same manner as the drag loads due to CO and chugging presented in DAR Subsection 4.2.2.5. However, the chugging and CO sources are replaced with a source representing the bubble growth prior to pool swell. This source will be derived from the original 4T data. All sources are assumed in-phase (87 sources).