Flow Loop Testing and Validation of Thermal Binding Model for Wedge Gate Valves

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Abstract

This paper presents a validated methodology to predict unwedging thrust for gate valves that are exposed to temperature and pressure changes between closing and opening strokes. The simplified methodology is based upon first principle models that were exercised over a wide range of variations in design parameters, operating condition parameters and thermal binding scenarios, increasing or decreasing the unwedging thrust. Flow loop tests were performed to systematically vary these parameters.

Methodology provided bounding predictions for all test data. The paper also summarizes the applicability and implementations of the methodology.

Introduction

The capability of gate valves to open can be critical to the safe operation of a nuclear power plant. The thrust required to unwedge solid and flexible wedge gate valves can increase, potentially compromising the ability to open, when subjected to temperature changes between the time the valve is closed and when it is required to open [1 through 6[*]]. This phenomenon is referred to as "gate valve thermal binding."

U.S. Nuclear Regulatory Commission Generic Letters 89-10 (Supplement 6) and 95-07 recommend that all U.S. nuclear power plants identify and address the potential for pressure locking and thermal binding in gate valves in safety-related systems. The industry has developed validated pressure locking methodologies [7,8,9]. However, the thermal binding phenomenon is significantly more complex, and until now, no validated thermal binding methodology has been available to predict the increase in unwedging thrust under thermal binding scenarios.

To meet this industry need, EPRI undertook the development and validation of a gate valve thermal binding methodology, as described in earlier papers [10 and 11]. A first principles analytical model was developed that takes into account all the important parameters that contribute to the thermal binding phenomenon. The model is comprised of the mechanical and thermal model. The analytical model was exercised over a wide range of valve design parameters and operating conditions resulting in the development of a simplified, closed-form, hand calculation methodology to predict unwedging thrust.

A series of tests was conducted on a gate valve under various thermal binding conditions. In addition, data were obtained from thermal binding tests performed by Omaha Public Power District (OPPD), Fort Calhoun Nuclear Plant. Analytical predictions made using the simplified methodology were compared to all available test results to validate the model. Model development, testing, and validation tasks were performed under the Kalsi

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[*] Numerals in brackets denote references listed at the end of this paper

Engineering, Inc. quality assurance program, which meets the requirements of 10CFR50, Appendix B. The model development and validation are documented in a four volume report [12].

This paper summarizes the development of EPRI gate valve thermal binding methodology, including a description of the mechanical model, simplified temperature prediction model, flow loop testing, and comparison of methodology predictions to test data. The paper also presents applicability and implementation of the methodology.

Thermal Binding Methodology Description

The EPRI thermal binding model is applicable to flexible wedge disc designs (Fig. 1) with or without a bonnet fluid communication feature, as well as solid wedge disc designs. The methodology does not account for traditional pressure locking conditions. Consequently, it is applicable only to valves in which the bonnet pressure is equal to or less than the upstream pressure.

Thermal Binding Scenarios

Two basic scenarios can cause a gate valve to thermally bind: *Scenario 1,* in which valve is closed hot and opened cold (CHOC), and *Scenario 2*, in which valve is closed cold and opened hot (CCOH). Additionally, the valve may be subjected to changes in upstream and downstream pressures either apart from or in conjunction with the temperature changes. It should be noted that pressure changes can influence unwedging thrust due to pressure-induced disc pinching phenomenon, as described in References 8 through 11. The methodology addresses both of these thermal binding scenarios, as well as changes in pressures.

Thermal Binding Mechanisms

The following mechanisms can influence the unwedging thrust after the valve is wedged closed and are included in the model:

- Changes in disc-to-seat interference (and contact force) due to changes in temperature as well as due to differences in coefficients of thermal expansion of disc, body, seat rings, and overlay materials,

- Differential expansion/contraction between the stem and valve topworks (i.e., upper body and yoke) due to differences in temperature and coefficients of thermal expansion,

- Changes in coefficients of friction as a function of differences between closing and opening temperatures.

- Changes in pressures upstream, downstream, and in the bonnet cavity of the valve body.

External piping loads can also influence unwedging thrust, however, they are excluded from the methodology.

Model Description

The required unwedging thrust after a valve is subjected to temperature and pressure changes under a thermal binding scenario is given by the following equation.

$$F_O = \frac{F_{sr} + F_{vert} + F_{pack} - F_p + F_w}{TRF}$$

Where

F_O = Required unwedging thrust, lb

F_{sr} = Seat frictional resistance force based on final seat reaction forces, R_1, R_2, and friction coefficient μ, before opening, lb

= $(2 R_{relx} R_1 + R_2 - R_1)(\mu\cos\theta - \sin\theta)$

R_{relx} = Ratio of seat unwedging/wedging seat contact forces derived from static wedging/unwedging thrust, lb

F_{vert} = Pressure load on projected areas of the wedge disc along the stem axis due to differences in bonnet, upstream and downstream pressures, lb

= $\pi A^2 \sin\theta (2 Pb - Pu - Pd)$

F_{pack} = Stem packing friction force, lb

F_p = Stem piston force, lb

F_w = Disc and stem assembly weight, lb

TRF = Torque reaction factor (dimensionless)

The important factors for calculating the unwedging thrust and their technical bases are described below.

Seat Friction Force, F_{sr}

F_{sr} is the key term that dictates increase/decrease in unwedging thrust under a thermal binding scenario. F_{sr} depends upon seat reaction forces, R_1 and R_2, and disc to seat friction coefficient μ. Changes in valve component temperatures, pressures and disc to seat friction coefficients between the time the valve is closed and when it is required to open contribute towards an increase/decrease in unwedging thrust as compared to the normal unwedging thrust. The sequence of pressure and temperature changes is also important in determining the final magnitude of F_{sr}. This requires iterative calculations that consider disc equilibrium along the pipe axis, disc equilibrium along the stem axis, and potential for further wedging of the disc due to these changes. The detailed model equations, their derivations, bases, and calculation procedures using data sheets are included in Reference 12.

Seat Contact Force Relaxation Ratio, R_{relx}

Test results show that under constant temperature conditions, the actual stem unwedging thrust is usually lower than the theoretically predicted value for a given wedging thrust. This is due to the fact that when the stem forces are reversed from compression to tension, there is a change in the seat contact forces caused by changes in stresses in the disc and due to Poisson's ratio effect. In the thermal binding methodology (and in the EPRI MOV PPM, Ref. 13) this is defined as structural relaxation effect. R_{relx} accounts for the decrease in the seat contact force between wedging and unwedging from the theoretically calculated values due to structural relaxation effects. The magnitude of R_{relx} is calculated from static wedging/unwedging thrusts using equations described [12]. The model also provides a bounding value for R_{relx} when test data are not available.

Disc, Body, Topworks Flexibility

To calculate changes in seat contact forces, stiffnesses of the disc, body, and valve topworks must be known. Valve body geometry is relatively complex. However, closed-form equations have been developed to calculate body stiffnesses [9-12]. These equations are based on a matrix of three-dimensional finite element analysis (FEA) results to cover variations in valve body geometries related to size, pressure class, and valve manufacturers.

The methodology also provides for closed-form equations to calculate disc stiffness. The disc stiffness equations are based upon classical formulas for plate stresses and deflections. These formulas were refined by performing a matrix of FEA's to account for elasticity of the hub and to cover variations in disc geometries based upon size, pressure class and manufacturers.

The valve topworks stiffness is calculated using stem dimensions and data from the static closing thrust signature for a MOV. Data sheets are provided in the methodology for calculating body, disc and valve topworks stiffnesses.

Disc to Seat Friction Coefficients

Under EPRI MOV PPM [13], extensive separate effects tests and flow loop tests were performed to determine friction coefficient between disc and seat faces overlaid with Stellite 6 hard facing. The friction coefficient depends upon fluid medium, fluid temperature, and contact stress. Even under the same conditions, friction coefficient can vary significantly. The EPRI thermal binding methodology provides different values for closing and for opening strokes based upon these parameters and variations in friction coefficients.

Component Temperature Predictions

The methodology provides simplified closed-form temperature algorithms for calculating component temperatures required in the model to predict unwedging thrust, based upon dimensions shown in Figure 2.

Lumped Parameter Model (LPM) and CFD Analyses

The simplified algorithms are based upon an extensive matrix of steady state thermal analyses performed using a Lumped Parameter Model (Fig. 3) that simulates thermal

characteristics of a wedge gate valve both in the open and closed positions. The gate valve thermal characteristics were also modeled using a three-dimensional Computational Fluid Dynamics (CFD) approach. Figure 3 shows the detail of the lumped parameter model. Figures 4 and 5 show the details of the coupled fluid flow and heat transfer CFD model.

The LPM was developed to efficiently calculate results for a large number of analyses to address variations in valve design and operating parameters.   The CFD model was developed to benchmark and verify the assumptions of heat transfer coefficients and modeling simplifications incorporated in the LPM, which is based upon simple conduction and convection equations for extended fin surfaces. Figure 6 shows typical temperature distributions for an open valve. For an open valve, the disc seat and the body are at a relatively uniform temperature and the temperature gradients are primarily in the stem and yoke. For a closed valve, significant temperature gradients are also present in the valve disc and body from the upstream side to the downstream. Detailed comparisons of the temperature distributions and convective heat transfer film coefficients, obtained by CFD analyses in the upstream, bonnet cavity and downstream regions of the valve, confirmed the adequacy of the LPM.

The LPM was then exercised over a wide range of variations of the following parameters to provide detailed thermal maps:

- Disc in the open and in the closed positions.
- For closed valve, different fluid mediums in the upstream, bonnet, and downstream regions;
- Key dimensions that vary with valve size, pressure class, and the manufacturer;
- Valve component materials;
- Fluid temperature;
- Flow rate;
- Insulation thickness;

In the parametric analyses, the nominal valve geometry selected was based on average dimensions from a number of valve manufacturers' designs for 6", ANSI 900 conventional wedge gate valves. The geometric variations covered wide variations in key dimensions found over the size range from 2" to 18," and pressure classes from ANSI class 150 to 2500. Typical results showing variations in temperatures with valve size for a valve exposed to 650°F are shown in Figures 7 and 8. Figure 7 is for an open valve and Figure 8 is for a closed valve with no bonnet fluid communication to upstream side.

Simplified Temperature Prediction Algorithms

Closed-form equations to calculate valve component temperatures from the LPM results of parametric thermal analysis were developed for use in the EPRI thermal binding methodology. Simplified temperature prediction algorithms predict the component temperatures based upon the fluid temperature, valve size, valve dimensional ratios that define distortions from the nominal valve proportions, the specific material combination being used for various components of the valve and whether the valve is insulated or not.

Temperature predictions for a specific valve size and geometry use the nominal valve size predictions which are modified by multiplying with a number of Adjustment Factors, A_{ij} to cover design parameters and operating parameters applicable for that analysis. The methodology provides separate graphs and tables for Adjustment Factors to cover three major categories of analysis: (1) open valve, (2) closed valve with no bonnet communication to the upstream fluid, and (3) closed valve with bonnet communication to the upstream fluid.

Figure 9 shows an example Adjustment Factor for a bonnet wall thickness ratio effect for a closed valve with no bonnet to upstream fluid communication. Figure 10 shows an adjustment factor for insulation thickness for the closed valve with no bonnet to upstream fluid communication. The simplified methodology uses piecewise linear interpolation for all geometrical ratio dependent Adjustment Factors, (e.g., for bonnet wall thickness ratio effect) and discreet Adjustment Factors for some parameters, (e.g., for insulation or no insulation cases and for six combinations describing fixed material choices for various valve components).

Applicability

The EPRI thermal binding model is applicable to gate valves with the following features:

Disc types:	Single-piece, flexible or solid wedge
Valve sizes:	2" to 18" (Note: Body stiffness predictions have been validated against FEA results only from 3" to 14" sizes.)
Valve materials:	The methodology is applicable to the following six base material combinations; with the disc and seat faces being hard-faced with Stellite 6 in all cases.

Material Combination	Body	Disc	Seat	Stem	Bonnet Cap	Yoke
1	C.S.	C.S.	C.S.	C.S.	C.S.	C.S.
2	C.S.	C.S.	C.S.	410 S.S.	C.S.	C.S.
3	C.S.	C.S.	C.S.	17-4 S.S.	C.S.	C.S.
4	C.S.	C.S.	C.S.	316 S.S.	C.S.	C.S.
5	316 S.S.	316 S.S.	316 S.S.	316 S.S.	316 S.S.	C.S.
6	316 S.S.	316 S.S.	316 S.S.	316 S.S., 410 S.S., or 17-4 S.S.	316 S.S.	316 S.S.

Insulation:	Both insulated and uninsulated valves
Fluid type:	Steam or water
Fluid temperature:	35ºF to 650ºF
Bonnet Pressure:	Valves with bonnet pressure equal to or less than the upstream pressure

Thermal binding scenarios: (1) Valve closed hot and opened cold (CHOC) or opened at lower temperature
- With differential pressure while closing
- Without differential pressure while closing

(2) Valve closed cold and opened hot (CCOH)
bonnet in communication with upstream side
bonnet not in communication with upstream side

Note: The model assumes that relatively steady-state thermal conditions have been achieved. Consequently, it is considered applicable to the typical reactor heat-up and cool-down rates for PWRs and BWRs; rapid thermal transients are outside the scope of the model.

External piping loads: Not included in the model

Methodology Implementation

Fig. 11 shows key steps in implementing the methodology. Detailed data sheets, tables and figures are provided in Reference 12 to calculate the unwedging thrust bases on all the relevant valve design parameters, data from static in-situ tests, and history of changes in fluid temperatures and pressure between wedging and unwedging. Figure 2 shows the dimensional data required to perform temperature calculations.

Flow Loop Testing

To validate the analytical model, flow loop tests were performed by EPRI to cover a wide range of thermal binding scenarios. Additionally, data were obtained from thermal binding tests performed by Omaha Public Power District (OPPD) at Wylie Test Laboratories. The test specimens and the test matrix for these flow loop tests are described below. All test data meet 10CFR Appendix B QA requirements.

Test Specimens

EPRI Test Valve is a 3-inch, Class 1500 Velan wedge gate valve (Fig. 12) in which both a flexible wedge and a solid wedge were tested (Fig. 13). The valve is of a pressure sealed bonnet design comprised of the following basic components and materials: The valve body, seat, disc and yoke were made out of carbon steel material, and the valve stem was made of 410 stainless steel. Both the disc and seat were hard-faced with Stellite 6.

OPPD Test Valve is a 2.5-inch, Class 2500 Crane-Aloyco flexible wedge gate valve with a pressure sealed bonnet design (Fig. 14). The valve is comprised of the following basic components and materials: Valve body seat disc and stem were made of 316 stainless steel and the valve had a carbon steel yoke. Both disc and seat faces were hard-faced with Stellite 6.

Test Matrix

EPRI Valve Test Matrix

EPRI Test Valve was extensively instrumented to provide external and internal temperature measurements at various locations on the valve components in addition to thrust, pressure, and differential pressure data (Fig. 15). Table 1 summarizes the overall test matrix for EPRI Test Valve. The following parameters were systematically varied in the test matrix, which consisted of 15 test cases:

Thermal binding scenarios: The valve was tested under both thermal binding scenarios, i.e., closed hot, opened cold (CHOC), and closed cold, opened hot (CCOH). The last two test cases in Table 1are modifications of Scenario 1 in which the valve was closed hot and allowed to cool down to a lower temperature, instead of ambient temperature, before opening.

Pressure-induced disc pinching. Tests were performed with and without pressure induced disc pinching effect in conjunction with the appropriate thermal binding scenarios.

Disc stiffness: Two different disc designs, flexible and solid wedge, were used to evaluate effect of disc stiffness on unwedging thrust under similar thermal binding scenarios.

Operating temperature: Operating steam temperatures of 650ºF, 450°F, and 350ºF were used to determine the fluid temperature effect on unwedging thrust. The corresponding pressures for saturated steam range were approximately 2,200 psi, 430 psi, and 125 psi.

Insulation: Valves operated at high temperatures are usually insulated. Test matrix covered evaluation of the effect of no insulation in one of the tests. All other tests were performed with insulated valve.

In addition to the above test cases to determine the effect of thermal binding, static wedging and unwedging tests were performed for both flexible and solid wedge discs to obtain the baseline wedging/unwedging characteristics under ambient temperature conditions. These data were used to calculate the seat contact force reduction ratio, R_{relx}, due to structural relaxation. The disc-to-seat friction coefficients for both upstream and downstream seats were measured under the appropriate fluid temperature conditions before wedging and after unwedging.

OPPD Valve Test Matrix

Flow loop tests on OPPD Test Valve were performed by OPPD with the primary objective of determining the maximum unwedging thrust the PORV block valves at their plant to operate under applicable thermal binding scenarios (Fig. 16). Only the exterior of valve body was instrumented with thermocouples at selected locations. No tests were performed to determine the disc-to-seat friction coefficient. The valve was not insulated in any of the tests. OPPD Test Valve thermal binding testing involved heating the valve to a steady state condition, with steam at approximately 650ºF, then closing the valve and allowing it to cool to a predetermined temperature before reopening.

The first series of tests were performed in which the valve was allowed to cool down to some intermediate temperature before opening. In these tests, it was not possible to confirm that steady state conditions were reached before unwedging due to the fact that

thermocouples were applied only on the outside surface of the body; no temperature measurements of the disc, stem or yoke were attempted. Additionally, cooling of the test valve in these tests was achieved by closing an upstream valve instead of bringing down the temperature of the upstream fluid to the intermediate value. Therefore, data from this series of tests were not used for validation of the methodology due to the concern that the valve component temperatures may deviate significantly from the quasi-steady state conditions.

The second series of tests allowed the valve to cool to ambient temperature and achieve steady state conditions before opening. This series of tests, consisting of three test cases, was used in the methodology validation as tabulated in Table 2. All of these wedging/ unwedging strokes were performed under similar operating conditions.

Flow Loop Test Results

Figure 17 summarizes results of all thermal binding tests performed by EPRI and OPPD. The unwedging thrust after the valve is subjected to a specific thermal binding scenario is compared to the estimated baseline unwedging thrust (with no thermal binding effect). The baseline unwedging thrust in the EPRI test is estimated by assuming a constant unwedging/wedging thrust ratio for a given valve obtained by ambient testing and applying this ratio to different closing thrusts for each test case to account for different closing thrusts due to changes in torque switch trip settings.

One can see that there is a wide variation in the unwedging thrust after valve is subject to a thermal binding scenario. The wedging thrust can increase significantly, exhibit a modest increase or even decrease as compared to the estimated baseline unwedging thrust, based on ambient conditions. The maximum increase in unwedging thrust from EPRI test was found for a solid wedge, closed cold, opened hot valve that was insulated. The maximum increase in unwedging thrust for the OPPD test was found for a closed hot, opened cold case for the uninsulated valve when the valve was under a transient thermal condition.

In general, higher thrust increases were found for the solid wedge/high stiffness disc, as expected. The CCOH scenario was found to result in modest increases, and in several cases, even a decrease in unwedging thrust for test cases in which bonnet to upstream side fluid communication is provided. This is due to the fact that fluid communication to the bonnet tends to eliminate the disc to body temperature differences. The test results also show large increases in unwedging thrust for the CCOH scenarios in which the bonnet to upstream fluid communication is not permitted. This is attributed to the higher thermal gradients in the disc and body. The results show that bonnet to upstream communication that is provided in some applications to eliminate the traditional pressure locking conditions can also significantly reduce the thermal binding effect under CCOH scenarios.

Validation Results

The thermal binding methodology was validated by comparing model predictions to test data for EPRI and OPPD test valves. Figure 18 shows the comparison of opening thrust predictions to test results for both valves. This figure shows that the methodology predictions bound the test results for all test cases. As described in the test matrix, the

validation comparisons include different thermal binding scenarios, pressure-induced disc pinching effect, disc stiffness, fluid temperature, bonnet to upstream fluid communication, and insulated versus uninsulated valves.

Figure 18 also shows a relatively wide scatter of test data versus predictions. The main contributing factors to the scatter are (1) the disc-to-seat friction coefficient can vary over a wide range, as observed in the EPRI valve thermal binding tests and other industry experience including EPRI MOV Performance Prediction Program [13], and (2) the valve component temperatures cannot be precisely predicted, due to the complex nature of the heat transfer phenomenon. Actual component temperatures can vary significantly, even under the same operating conditions, due to variations in convective heat transfer coefficients caused by fluctuations in ambient conditions, e.g., the degree of air circulation, and leakage of hot fluid across the upstream seat into the bonnet cavity for valves having no intentional bonnet fluid communication feature.

In spite of these variations and the complexity of the thermal binding phenomenon, the methodology provided bounding predictions for the required opening thrust for all test cases.

Conclusions

A first-principles model for predicting the required unwedging thrust for a wedge gate valve under thermal binding conditions has been developed. The model accounts for both closed hot, opened cold and closed cold, opened hot thermal binding scenarios. The model is applicable to solid wedge and flexible wedge gate valves with or without bonnet to upstream fluid communication. The model also accounts for superimposed effect of changes in upstream, bonnet, and downstream pressures that can affect the unwedging thrust. Traditional pressure locking phenomena is not included in the methodology. The methodology provides closed-form equations for predicting unwedging thrust.

The methodology was validated by comparing model predictions for opening thrust against flow loop test data under both thermal binding scenarios: closed hot opened cold as well as closed cold opened hot. The methodology predictions were found to bound test results for all test cases. Tests included different thermal binding scenarios, pressure-induced disc pinching effect, variations in disc stiffnesses, valve designs with and without bonnet communication to the upstream fluid, changes in fluid temperatures, and tests with and without insulation. The overall ratio of measured thrust divided by predicted thrust ranged from 0.338 to 0.957 for all test cases.

Comparisons show that predictions for closed hot opened cold scenarios are in a closer agreement than the closed cold opened hot scenarios for valve designs that do not have a bonnet fluid communication to the upstream side. This is due to the fact that thermal gradients for closed valves that have hot fluid present only on the upstream side of the disk are significantly affected by conditions that can not be controlled in practice, e.g., upstream seat-to-bonnet leakage, amount of air trapped in the upstream piping or the bonnet cavity. In spite of these effects, the methodology provides bounding predictions with reasonable conservatism for all cases.

The development of a validated thermal binding methodology is a significant milestone in the industry.

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12. **EPRI Gate Valve Thermal Binding Unwedging Thrust Methodology, Volumes 1 through 4**, Electric Power Research Institute, E210203, October 2001.

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Flow Loop Testing and Validation of
Thermal Binding Model for Wedge Gate Valves

Table 1   EPRI Valve Test Cases for Methodology Validation

Test Case*	Disc	Insu-lated?	Closing Conditions		Opening Conditions	
			Pressures (P_u, P_b, P_d), psi	Fluid Temp, ºF	Pressures (P_u, P_b, P_d), psi	Fluid Temp, ºF
1-1, CHOC, 650	Flex	Yes	0, 0, 0	643	0, 0, 0	93
1-2, CHOC 650P	Flex	Yes	2100, 2100, 2100	638	0, 0, 0	90
1-3, CCOH, 650UB	Flex	Yes	0, 0, 0	94	0, 0, 0	649
1-4, CCOH, 650U	Flex	Yes	0, 0, 0	86	0, 0, 0	649
2-1, CHOC 650	Flex	No	0, 0, 0	649	0, 0, 0	90
3-1, CCOH, 350 UB	Solid	Yes	0, 0, 0	83	0, 0, 0	359
3-2, CHOC 350P	Solid	Yes	125, 125, 125	348	0, 0, 0	75
4-1, CCOH, 450 UB	Solid	Yes	0, 0, 0	100	0, 0, 0	447
4-1R, CCOH, 450UB	Solid	Yes	0, 0, 0	99	0, 0, 0	450
4-2, CHOC, 450P	Solid	Yes	430, 430, 430	457	0, 0, 0	62
5-1, CCOH, 650UB	Solid	Yes	0, 0, 0	89	0, 0, 0	649
5-2, CHOC, 650P	Solid	Yes	2103, 2103, 2103	650	0, 0, 0	70
6-1, CCOH, 650U	Solid	Yes	0, 0, 0	72	0, 0, 0	641
7-1, CHOL, 650P	Solid	Yes	2163, 2163, 2163	647	0, 0, 0	572
8-1, CHOL, 350P	Solid	Yes	132, 132, 132	354	0, 0, 0	272

*The following nomenclature is used to describe test cases in this table:

CHOC = Valve was closed hot and opened cold (ambient temperature).
CCOH = Valve was closed cold and opened hot
CHOL = Valve was closed hot and opened lower (75ºF lower than the closing temperature)
650/450/350 = Test temperature level
P = Closed with pressure for closed hot cases
U = Heated upstream side of the disc only for closed cold cases
UB = Heated upstream side of the disc and bonnet for closed cold cases

Table 2   OPPD Valve Test Cases for Methodology Validation

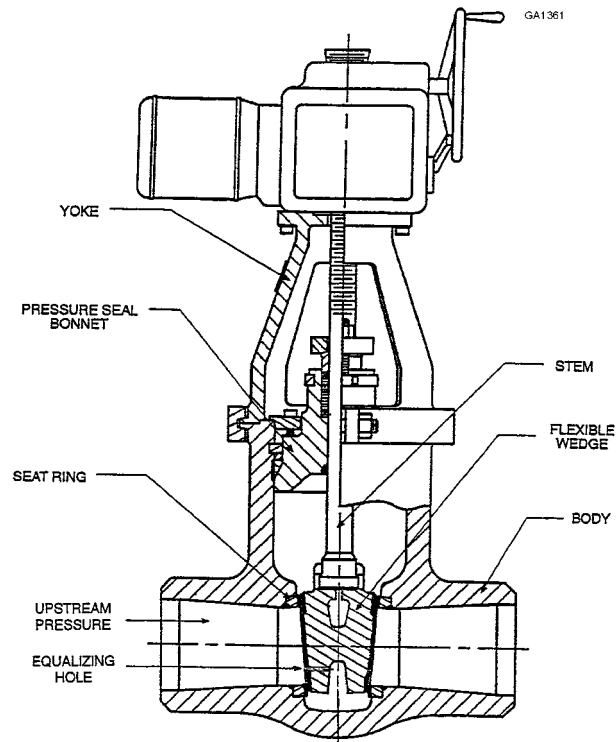| Test Case	Disc	Insu-lated?	Closing Conditions		Opening Conditions	
			Pressures (P_u, P_b, P_d), psi	Fluid Temp, ºF	Pressures (P_u, P_b, P_d), psi	Fluid Temp, ºF
HTC2/13A	Flex	No	2262, 2262, 2262	637	0, 0, 0	73
HTC3/13B	Flex	No	2264, 2264, 2264	637	0, 0, 0	76
HTC3/13C	Flex	No	2226, 2226, 2226	632	0, 0, 0	57

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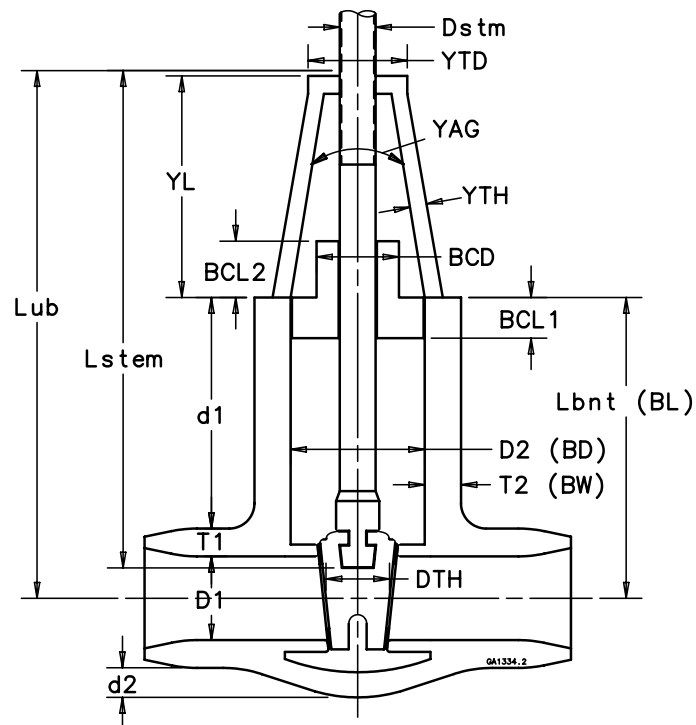**Figure 1 Typical Motor-Operated Wedge Gate Valve Assembly**

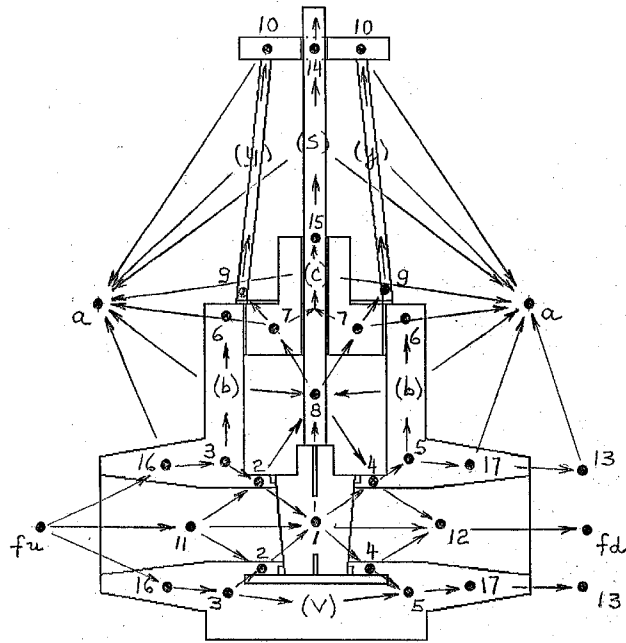**Figure 2 Dimensions required for Performing Thermal Binding Calculations**

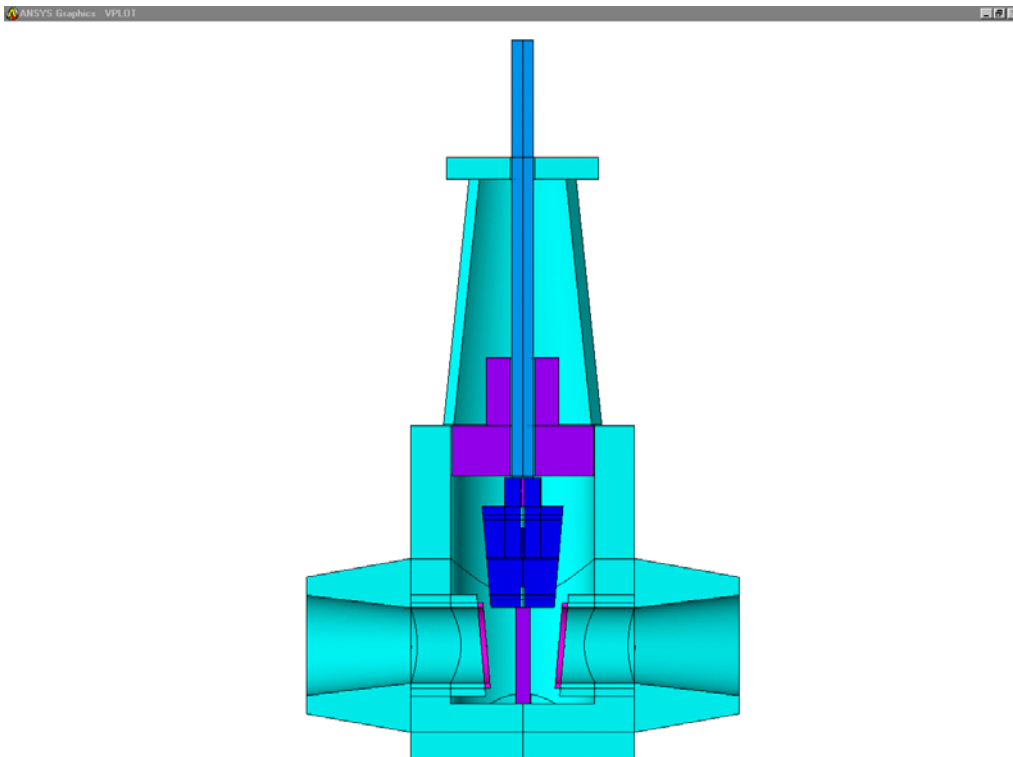**Figure 3 Schematic of the Closed Valve Lumped Parameter Thermal Model**

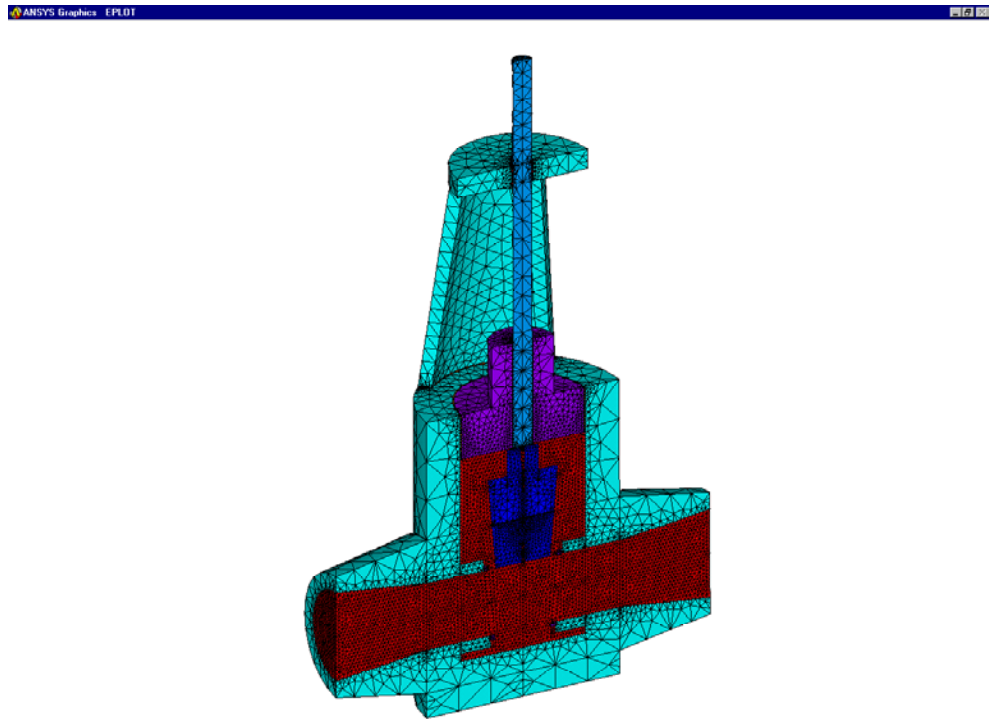**Figure 4 Simplified 3-D FEA Thermal Model of a Typical Gate Valve**
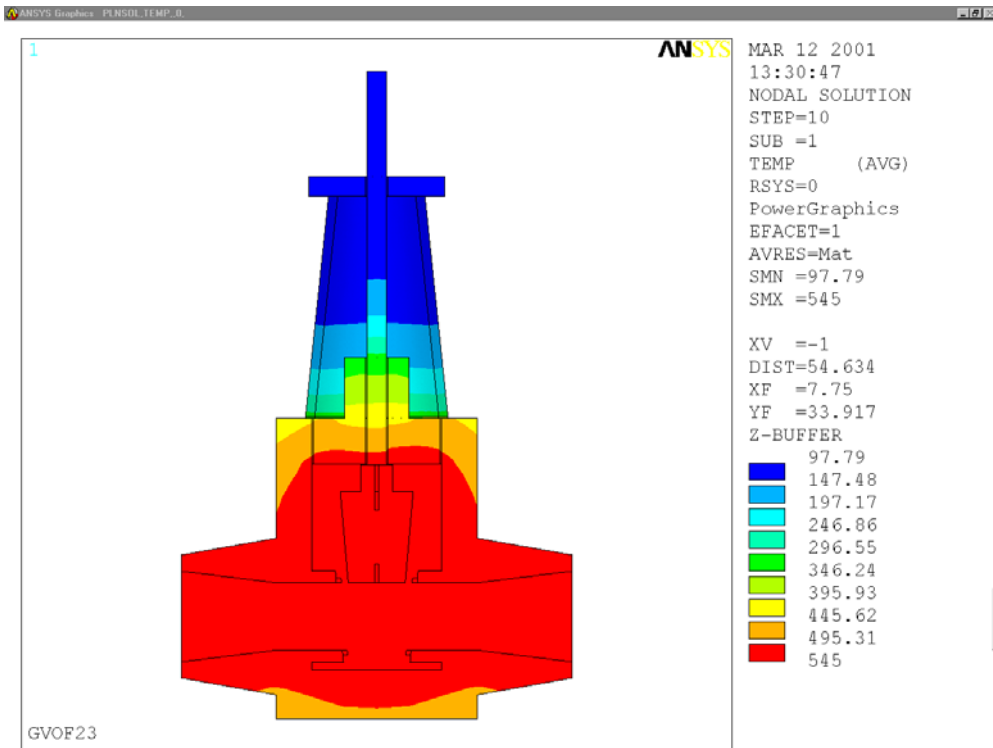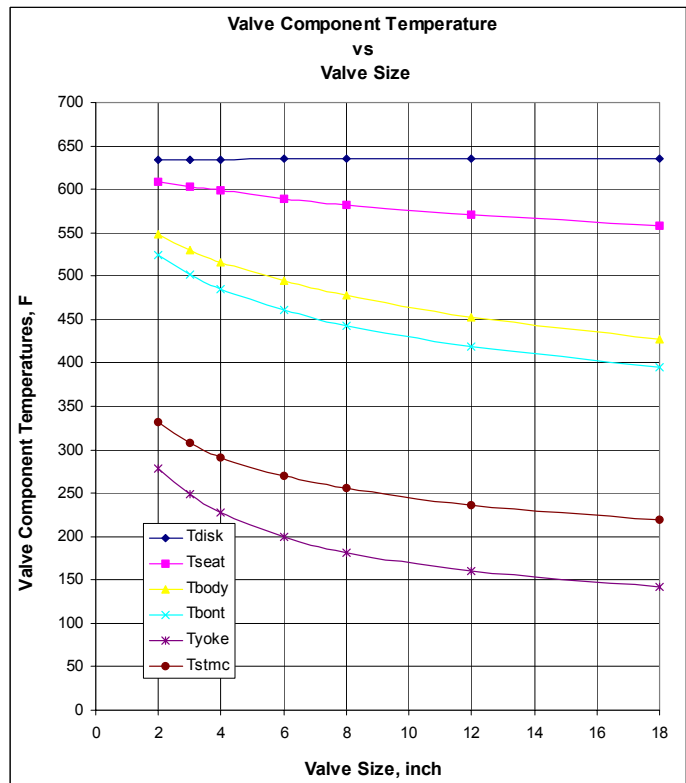
Figure 5 Open Valve Model Finite Element Meshing

Figure 6 Open Valve Model Temperature Field Solution
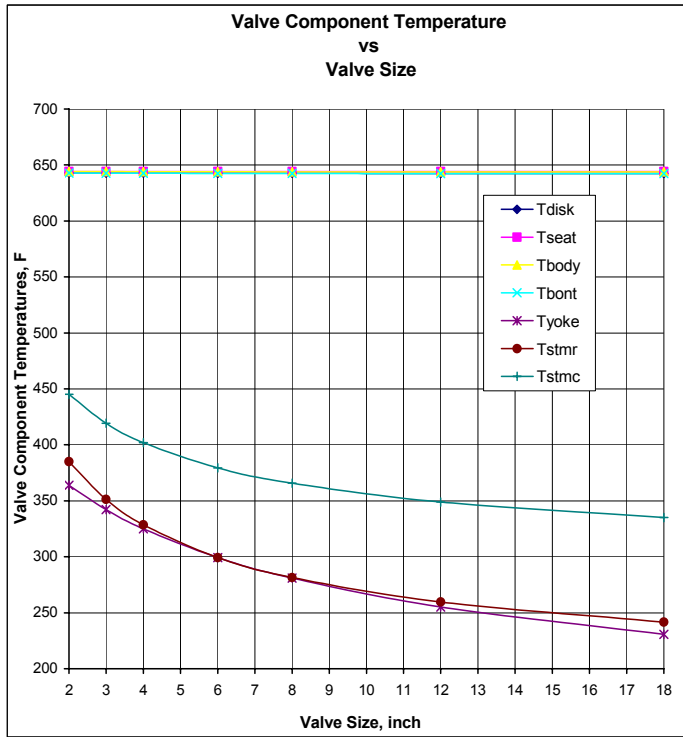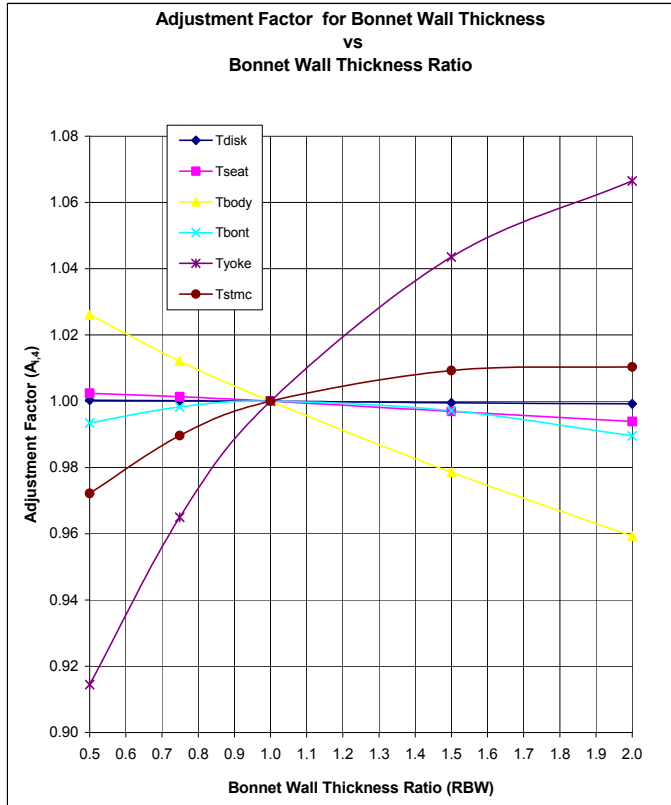
Figure 7 Valve Component Temperature Predictions for Open Valve

Figure 8 Valve Component Temperature Predictions for Closed Valve With No Bonnet to Upstream Fluid Communication
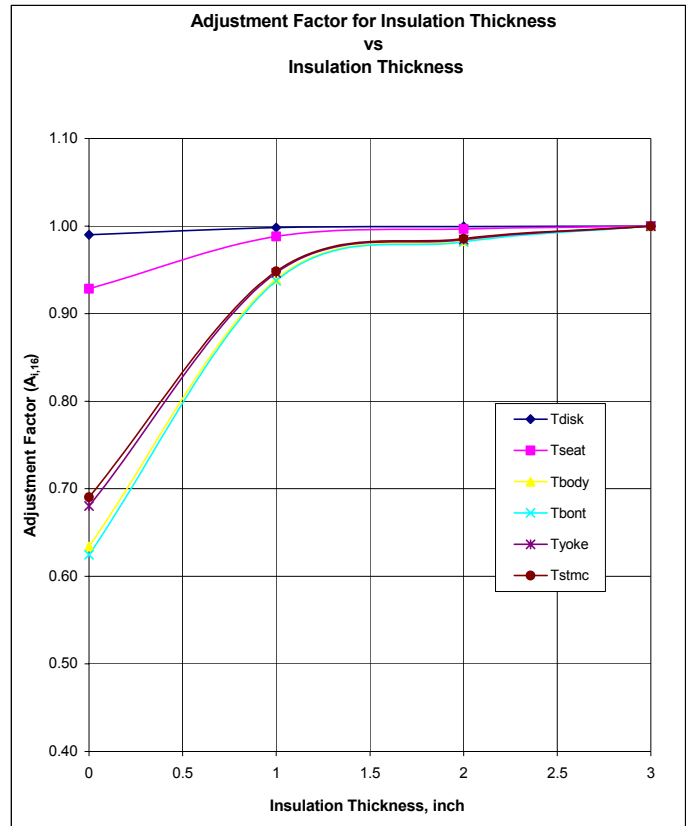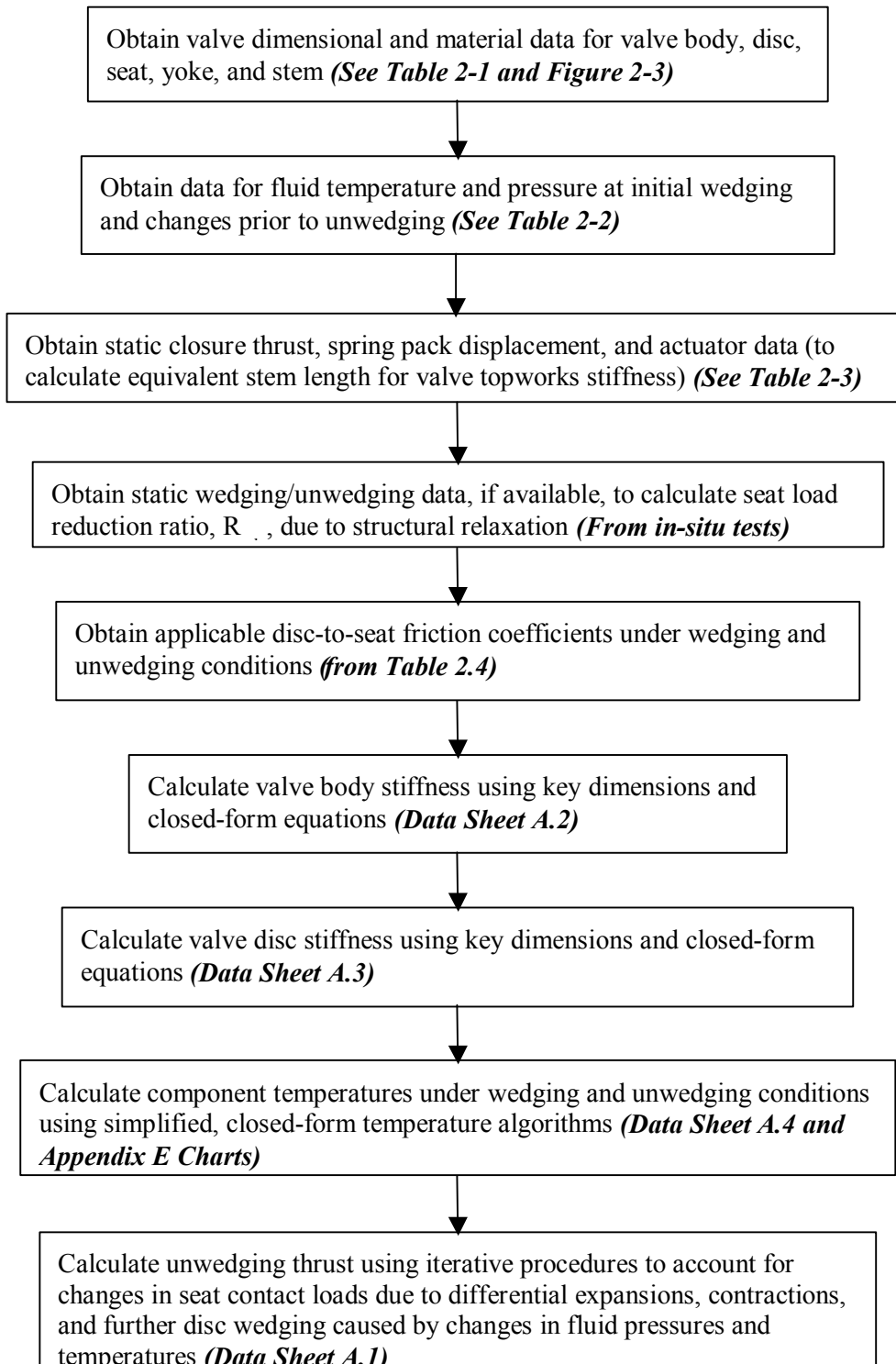

16

Figure 9 Example of Adjustment Factor for Bonnet Wall Thickness for Closed Valve With No Bonnet to Upstream Fluid Communication

Figure 10 Example of Adjustment Factor for Insulation for Closed Valve With No Bonnet to Upstream Fluid Communication

Obtain valve dimensional and material data for valve body, disc, seat, yoke, and stem *(See Table 2-1 and Figure 2-3)*

Obtain data for fluid temperature and pressure at initial wedging and changes prior to unwedging *(See Table 2-2)*

Obtain static closure thrust, spring pack displacement, and actuator data (to calculate equivalent stem length for valve topworks stiffness) *(See Table 2-3)*

Obtain static wedging/unwedging data, if available, to calculate seat load reduction ratio, R, due to structural relaxation *(From in-situ tests)*

Obtain applicable disc-to-seat friction coefficients under wedging and unwedging conditions *(from Table 2.4)*

Calculate valve body stiffness using key dimensions and closed-form equations *(Data Sheet A.2)*

Calculate valve disc stiffness using key dimensions and closed-form equations *(Data Sheet A.3)*

Calculate component temperatures under wedging and unwedging conditions using simplified, closed-form temperature algorithms *(Data Sheet A.4 and Appendix E Charts)*

Calculate unwedging thrust using iterative procedures to account for changes in seat contact loads due to differential expansions, contractions, and further disc wedging caused by changes in fluid pressures and temperatures *(Data Sheet A.1)*

Figure 11 Thermal Binding Methodology Implementation

*Note: Tables, figures, and datasheets in this figure pertain to Reference 12.
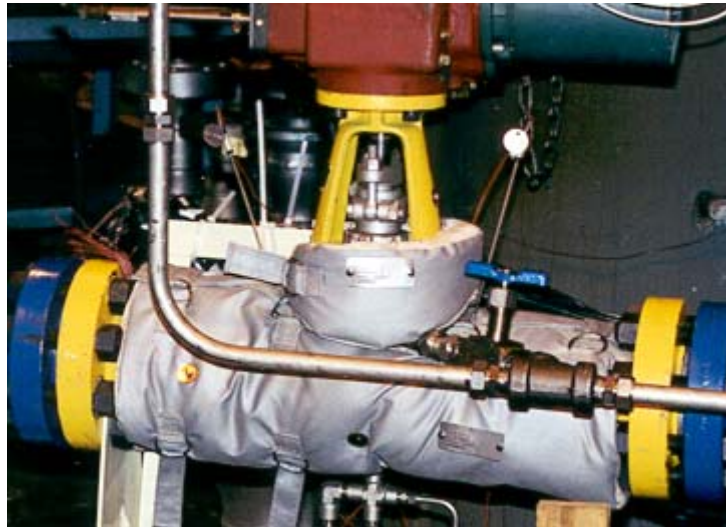
Figure 12 EPRI Valve Test Setup

Flexible	Solid

Figure 13 Flexible Wedge and Solid Wedge Discs Used in the EPRI Test Valve
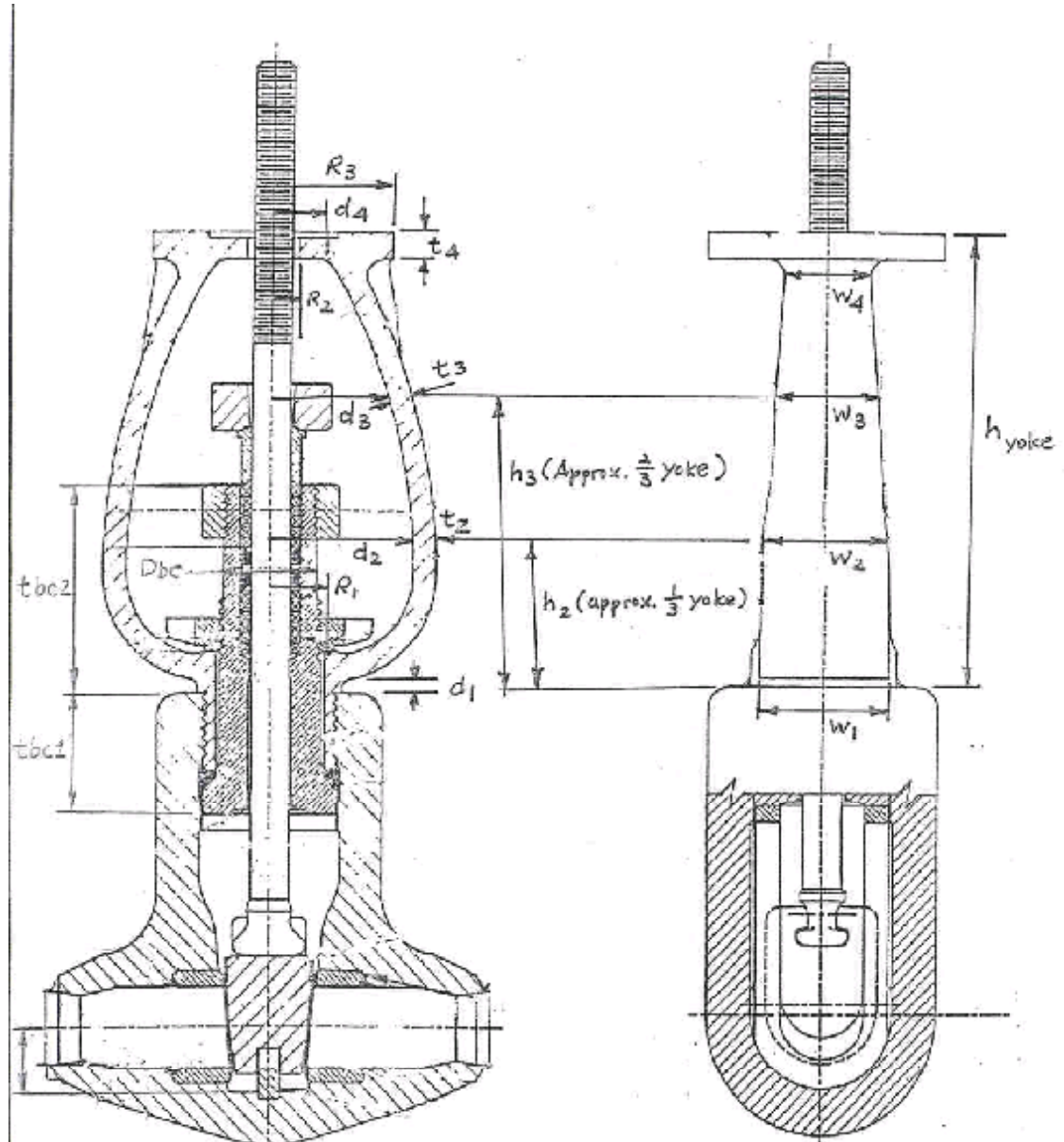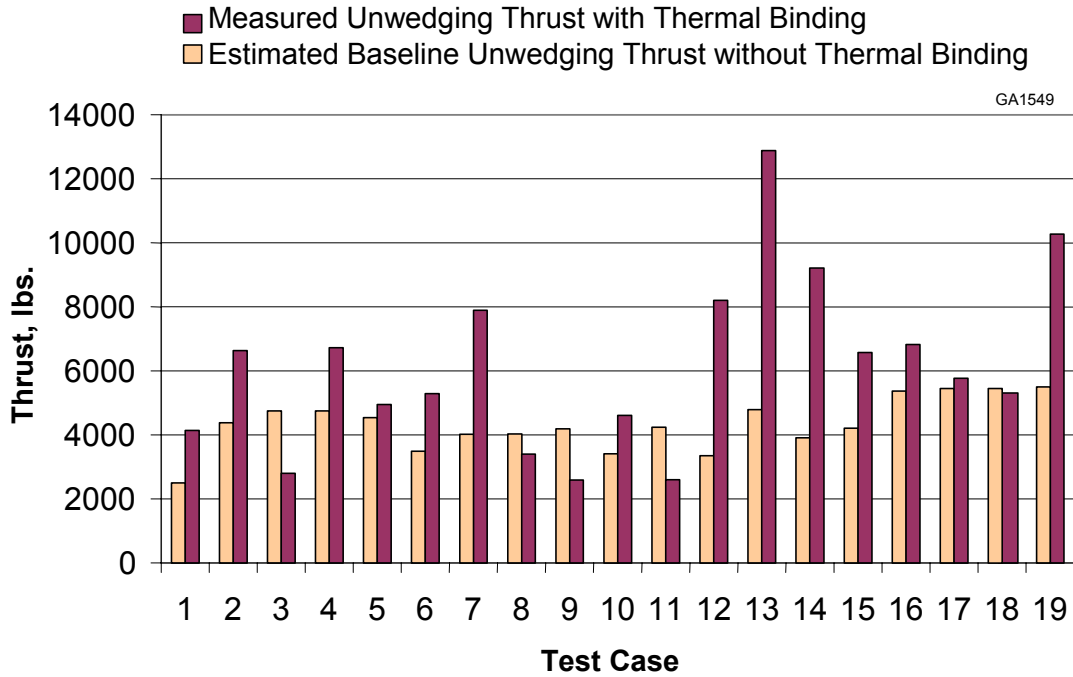
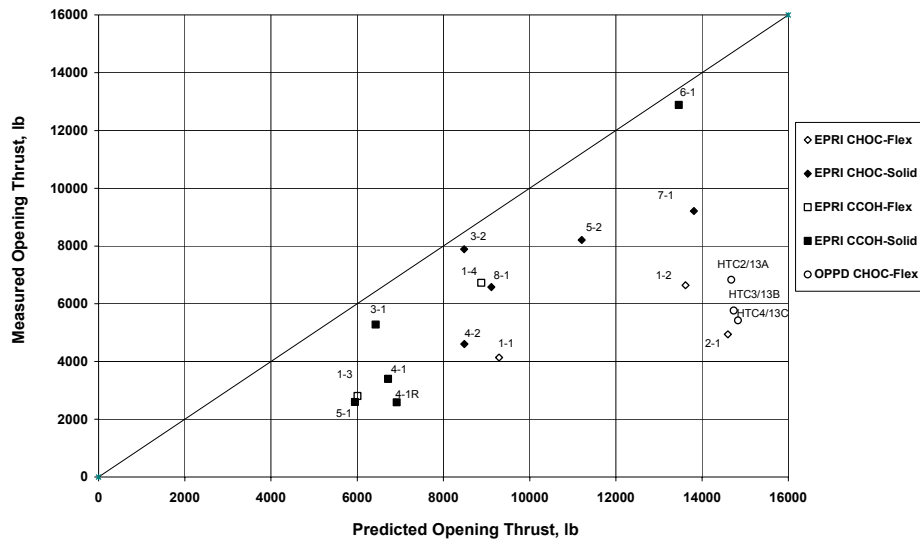**Figure 14   OPPD Test Valve**

GA1344.2
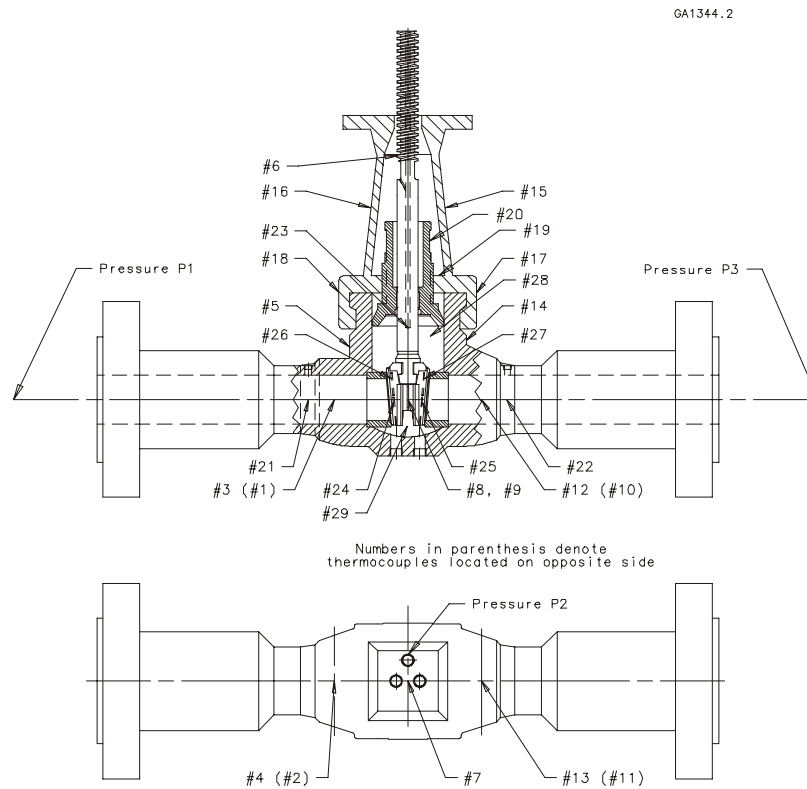
Figure 15 Thermocouple and Pressure Transducer Placement in EPRI Test Valve
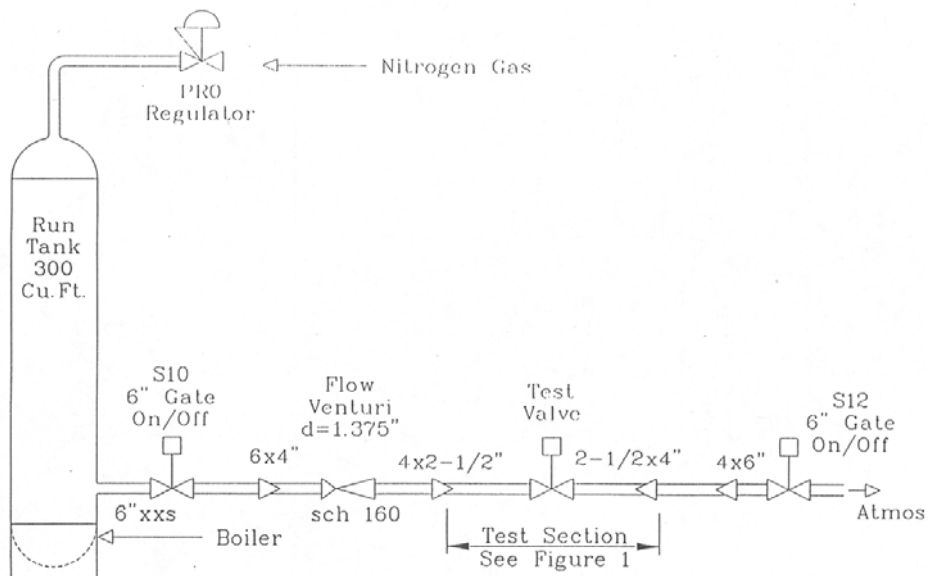
Figure 16   Flow Loop Test Setup of OPPD Test Valve

Figure 17   Comparison of Measured Unwedging Thrust for Various Thermal Binding Tests to the Estimated Baseline Wedging Thrust

Figure 18   Comparison of Opening Thrust Predictions to Test Results Using Default Friction Coefficients and Simplified Methodology