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Robert L. Cloud and Associates, Inc.

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METHODOLOGY AND DESIGN CRITERIA FOR PIPE SUPPORTS UTILIZING U-BOLTS TO MAINTAIN STABILITY

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TECHNICAL REPORT

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Methodology and Design Criteria for Pipe Supports Utilizing U-Bolts to Maintain Stability

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1.0 BACKGROUND

During the Integrated Design Inspection (IDI), the Nuclear Regulatory Commission (NRC) Staff expressed a concern with the ability of U-bolts to provide adequate stability to pipe support components against overturning effects due to eccentric loading and other causes such as seismic self excitation. This concern was heightened by the rotation of a lateral snubber restraint with a trapeze arrangement (63-1S1S-R109), when it was subjected to an externally applied eccentric load.

2.0 PURPOSE

This document provides the detailed methodology and design criteria for pipe support assemblies utilizing U-bolts to maintain stability of the support components.

3.0 SCOPE

The scope of this document is limited to design features that are associated with stability. The specific pipe support assemblies at Watts Bar Nuclear Plant (WBNP) which utilize this design concept are identified by the database given in Appendix A.

The overall design criteria for structural design of these pipe support components is specified in WB-DC-40-31.9 (Ref. 1). For stability considerations, design criteria specified in this document govern and will be incorporated in Reference 1.

4.0 METHODOLOGY

4.1 GENERAL

Historically, the nuclear and fossil power plant industries have successfully employed pipe support assemblies that utilize U-bolt tension to maintain stability of associated support components.

The underlying design concept is founded on the basic principles of structural mechanics. Frictional forces generated between U-bolt and pipe contact surfaces caused by tension in the U-bolt provide the resistive forces needed to counteract overturning effects from the applied loads.

The implementation of the above design concept is based on ensuring minimum tension in the U-bolt for specific support configuration and range of applied loads to ensure stability. The design concept should address anticipated losses from relaxation, thermal cycling, normal vibration, and seismic loads. Further, an adequate design factor should be used to cover variations in coefficient of friction and other controlling parameters to ensure that a design margin exists for stability.

While preload in the U-bolt creates a stabilizing effect, it also induces localized load effects in the pipe wall. Local stresses are induced in the vicinity of the U-bolt due to the forces between U-bolt and pipe contact surfaces. In addition, local stresses are induced due to "line load" application between the pipe and the cross piece or attachment to the cross piece such as a trunnion.

Local load effects in the pipe wall is a potential design constraint to the amount of preload that can be applied without exceeding applicable acceptance criteria.

To substantiate technical validity of the underlying design concept, a comprehensive applied development program was conducted in the mid 1980's. The program included analytical and experimental evaluations for protypical environments and loading conditions.

In July 1984, Westinghouse Electric Corporation completed an extensive analytical and experimental evaluation of four different U-bolt support configurations (Refs. 2 and 3). These tests were comprehensive and addressed all relevant factors mentioned above. The conclusion of this test program was that with appropriate tension, U-bolts will develop stability to satisfy intended design function.

In September 1986, Robert L. Cloud & Associates, Inc. completed a comprehensive design review, with further analytical evaluations, of U-bolt pipe supports (Ref. 4). These evaluations included:

- review of existing tests and analyses (Refs 2 and 3)

- performance of complementary, confirmatory finite element analyses

- development of conservative design procedure

- definition of acceptance criteria consistent with applicable Code requirements.

It was concluded that when a U-bolt support is designed and preloaded in accordance with the procedure and acceptance criteria provided in the report (Ref. 4), the cinched U-bolt support will perform the intended design function. A combination of results from full scale tests and detailed finite element analyses were used to verify the conservatism inherent in the design procedure.

During the IDI, TVA performed a test on pipe support assembly 63-1S1S-R109. The results of this test also demonstrated viability of the technical concept. Revised torque value to provide stability against eccentric dead weight effect was calculated. The load was applied in the field using a hydraulic jack. The test load at which slippage occurred matched the calculated load within 13%. These results are documented in a Test Report (Ref. 5).

The integrated methodology provided in this document to resolve WBNP technical concerns and address governing parameters incorporate:

- Improvements in design criteria to ensure that calculations address all contributory factors.

- Improvements in design to minimize preload losses and assure support stability.

- Application of the improved methodology to define preload requirements.

- Improvements in installation specification to achieve proper tension in U-bolts.

- In situ confirmation test program.

The use of this integrated methodology will provide WBNP with stable U-bolt supports and a means to verify field confirmation of performance.

4.2 INITIAL PRELOAD

The initial preload is the U-bolt preload required for support stability at the time of installation. The initial preload includes conservatively estimated relaxation during the service life of the plant. The initial preload is defined by the following equation:

$$U_{IL} = U_{DL}(1 + RF) \qquad (1)$$

where:

U_{IL} = Initial Preload, [1b]

U_{DL} = Design Preload, [1b] (See Section 4.3)

RF = Relaxation Factor, - (See Section 4.3.4)

4.3 DESIGN PRELOAD

The equations defining the design preload, U_{DL}, in this section are dominated by the frictional resistance required to prevent rotation of the U-bolt when subjected to inclined strut loading and eccentric self-weight excitation of the cross piece. In addition, the equations incorporate preload compensation terms to account for those elastic reductions in U-bolt tension that occur when the cross piece is forced against the pipe by strut or snubber loads and, to a lesser extent, by cross piece self-weight excitation. These compensating terms are recognized in the equations as those that incorporate relative pipe and clamp stiffness.

The preload determined by the equations in this section are based on conservative, worst case combinations of strut/snubber loads, maximum swing angles, and the most disadvantageous directions of seismic self-weight excitation.

4.3.1 Stability Equations for Single Strut/Snubber Configurations

Equations (2), (3) and (4) below contain the primary conditions on the magnitude of preload required in a single strut/snubber assembly to prevent slippage of the clamp around the pipe. Nomenclature used in the equations is defined at the end of this subsection.

Preload required to resist inclined strut/snubber load:

$$U_{0,P} \geq (DF)\,\frac{P}{2}\left[\frac{SIN\theta}{2\mu}\left(\frac{A}{R}+1\right)+\frac{1}{\alpha\left(\frac{K_P}{K_{CL}}+1\right)}-\frac{1}{2}\right] \tag{2}$$

Preload required to resist self-weight excitation:

$$U_{0,X} \geq (DF)\,\frac{W_{CP}}{2}\left[\frac{1}{2\mu\,R}\left(a_1 e_2 + a_2 e_1\right)+a_1\left(\frac{1}{\alpha\left(\frac{K_P}{K_{CL}}+1\right)}-\frac{1}{2}\right)\right] \tag{3}$$

The primary criterion determining the minimum required U-bolt preload, U_0, under the combined effects of inclined strut/snubber loading and eccentric self-weight excitation is, therefore:

$$U_0 = U_{0,P} + U_{0,X} \tag{4}$$

Equation (4) defines the minimum preload, U_0, required to prevent slippage under the combined effects of inclined strut loads and self-weight excitation. For equation (4) to be valid, the following requirement also has to be satisfied in order to ensure that adequate U-bolt tension is preserved:

$$U_1 \geq (DF)\ x\ \frac{1}{2}\left(P + W_{CP}\,a_1\right)\left[\frac{1}{\alpha\left(\frac{K_P}{K_{CL}}+1\right)}\right] \tag{5}$$

The design preload, U_{DL}, is the larger of U_0 and U_1 as determined by equations (4) and (5) above:

$$U_{DL} = Max\,(U_0, U_1) \tag{6}$$

The nomenclature in the above equations is as follows:

U_{DL} = Design Preload, [lb]

DF = Design Factor, - (See Section 4.3.5)

P = External Strut/Snubber Total Load, - [lb] (See Figure 1)

θ = Angle of Inclination (Swing Angle) of External Strut/Snubber Load, - [Degrees] (For Design θ is Limited to 5 Degrees - See Figure 1)

μ = Friction Factor Relating Rotational Friction Resistance to U-Bolt Tension (See Section 4.3.6)

A = Distance Between the Pipe-to-Crosspiece Assembly Contact Point and Centerline of Pin in Crosspiece [in] (See Figure 1)

R = Outside Radius of Pipe, [in]

α = Pipe Stiffness Distribution Factor (See Section 4.3.7)

K_p = Stiffness of Pipe, [lb/in] (See Section 4.3.7)

K_{CL} = Stiffness of Clamp Assembly, [lb/in] (See Section 4.3.8)

W_{CP} = Weight of Cross Piece, and Attached Components, Subjected to Self-Weight Excitation [lbs]

a_1 = Spectral Acceleration of weight W_{CP} in Direction Parallel to Struts or Snubbers [g]

a_2 = Spectral Acceleration of Weight W_{CP} in Direction Perpendicular to Struts or Snubbers [g]

e_1 = Eccentricity of Weight, W_{CP}, Relative to Pipe Center Line in Direction Parallel to Struts or Snubbers [in] (See Figure 1)

e_2 = Eccentricity of Weight W_{CP}, Relative to Pipe Center Line, in Direction Perpendicular to Struts or Snubbers [in] (See Figure 1)

4.3.2 Trapeze Configurations

A trapeze support (See Figure 1b) incorporating a pair of struts or snubbers in conjunction with a preloaded U-bolt is fundamentally different from the single strut/snubber configuration (Figure 1a) from the standpoint of stability under inclined or eccentric loading. Whereas the single strut case relies on friction to prevent rotational instability under inclined or eccentric loading, a trapeze configuration with two parallel struts is geometrically prevented from such rotation. The required U-bolt preload in a trapeze configuration is, therefore, not a function of strut/snubber loading, but is instead applied to:

- Prevent a snubber-equipped U-bolt from rotating about the pipe due to external loading when the snubbers are not activated (cf. the support mentioned in the Introduction)

- Prevent axial movement (slippage) of the U-bolt along the pipe due to external loading or self-weight excitation.

To accomplish these objectives, the preload for trapeze-type U-bolts will be based on a conservative application of seismic self-weight excitation, using the equations provided in Section 4.3.1 and acceleration values discussed in Section 4.3.3. The preload will be determined under the conservative assumption that rotation is not inherently prevented by the geometric constraints of the struts. Further, the preload will be based on the simultaneous application of enveloped seismic acceleration in two directions, namely, in the axial and lateral pipe directions.

4.3.3 Seismic Self-Weight Excitation

The preload required to resist U-bolt slippage under the influence of self-weight excitation is included in equations (3) through (6) in Section 4.3.1. These equations include expressions for seismic accelerations in the supported direction (a_1) and perpendicular to the supported direction (a_2).

The values of a_1, and a_2 will be obtained from the nodal acceleration output tables from the T-PIPE analysis for the piping.

4.3.4 Relaxation Factor

The prediction of potential preload losses is discussed in detail in Reference 4 and is supported by testing and finite element analyses (References 2,3, and 4). Based upon the evaluations provided in these referenced documents, it was concluded that:

- Preload losses may occur as a result of friction redistribution and U-bolt repositioning over surface imperfections that may have created temporary binding during initial torquing. Based on tests and analyses, a conservative upper bound loss of approximately 5% has been established for these phenomena.

- Preload losses may occur following high temperature thermal cycling as a result of permanent strains in a localized pipe wall region. Under extreme conditions these losses have been estimated at 18%.

- Losses due to gross plastic deformation of U-bolt components are prevented by limiting the maximum predicted stresses due to all causes in these components to the minimum specified yield stress at temperature.

- Losses due to short-term relaxation phenomena are negligible.

For design purposes, Reference 4 concluded that the total estimated preload loss (RF) can be conservatively addressed by increasing the required preload value by the following amounts:

(a) 30% for stainless steel pipe applications with:

- Maximum operating temperature exceeding 300 F, and
- D/t ratio exceeding 25, and
- Initial preload compression effect on the pipe exceeding 50% of allowable value at temperature.

(b) 20% for all other applications.

The use of Belleville washers in the U-bolt assemblies in WBNP applications (See Section 6.0) will ensure that the loss of preload will be significantly less than for the configurations evaluated in Reference 4. A relaxation factor of 20% will, however, be applied as a conservative measure.

4.3.5 Design Factor

Loss of stability for a single strut/snubber U-bolt assembly is defined as rotational slippage around the pipe when the U-bolt is subjected to an inclined, compressive strut load and/or eccentric self-weight excitation. A conservative methodology for the determination of minimum bolt preload required to prevent this type of instability for a given configuration and load condition is described in Section 4.3.1.

This methodology explicitly considers all predictable factors of significance that affect the stability condition, including allowance for time-dependent preload losses.

A design factor, DF, of 1.5 is included in the minimum design preload determined in accordance with Section 4.3.1.

4.3.6 Friction Factor

Friction is perhaps the most important design parameter in these evaluations where the main focus is to address adequacy of design against forces that cause instability.

Unlike the normal design process, where a designer is trying to accommodate frictional forces without creating additional stresses, in this situation friction is assisting the designer in his quest to provide stability. However, in this case, conservatism lies in using a lower bound friction factor. The friction factor to be used to demonstrate U-bolt stability is justifiably lower than the 0.3 factor provided in the WBN criteria (Ref. 1) and is based upon test results and evaluations given in References 2, 3 and 4. The factor, as determined from the tests, is not a constant as traditionally assumed for friction coefficients. The reason for this is that the friction factor as determined for U-bolt applications is not a local friction coefficient, but rather a global factor relating the overall resisting moment to the external load at failure. This factor thereby incorporates the effects from variations in total normal forces between the contact surfaces, as well as size-related effects. A given surface imperfection size (lack of perfect conformity) would for example have a more severe effect on a small pipe than on a large one. The variation in the friction factor observed in the tests is therefore expected.

Based on the review (Ref. 4) of the friction test results (Refs. 2 and 3), the friction factor to be used is as follows:

Nominal Pipe Diameter (in.)	Friction Factor (μ)
6 or less	0.12
8 to 22	0.16
24 or greater	0.22

4.3.7 Pipe Stiffness

The stiffness of the pipe is defined as the force required to produce a unit diameter reduction along the line connecting the points of contact with the cross piece and with the apex of the U-bolt.

The pipe is subjected to a concentrated compressive force from the cross piece and to a distributed, radial force from the U-bolt. The pipe stiffness is the inverse of the pipe displacement caused by one unit of force. As derived in Reference 4, the pipe stiffness of a single strut or trapeze configuration with the crosspiece in direct contact with the pipe is given by the following equation:

$$K_p = \left[\frac{0.744}{Et_p}\left(\frac{R_m}{t_p}\right)^{1.5} + \frac{0.321}{Et_p}\left(\frac{R_m}{t_p}\right)^{0.5}\right]^{-1} \qquad (7)$$

where,

R_m = Mean Radius of Pipe, [in]

t_p = Pipe Wall Thickness, [in]

E = Modulus of Elasticity at Operating Temperature, [psi]

All other terms are defined in Section 4.3.1.

The pipe stiffness (Kp) for other cross piece assembly configurations such as shown in Figure 1(b) may also be approximated by Equation 7. Such approximations will conservatively under-estimate the pipe stiffness and are, therefore, acceptable.

In the mathematical model of the pipe and U-bolt assembly discussed in Reference 4, the pipe is modeled by two springs in series, αK_p and βK_p., The spring αK_p represents the stiffness of the lower portion where the U-bolt and the pipe are in contact and a distributed contact force exists. Since αK_p and βK_p in series represent the total pipe stiffness, α and β must satisfy the following relationship.

$$\frac{1}{\alpha} + \frac{1}{\beta} = 1 \qquad (8)$$

This means that α or β can never be less than one.

In the circumferential direction, the unconfined portion of the pipe is subjected primarily to bending stresses, while the confined portion is subjected primarily to membrane stresses. The portion directly under the cross piece, which is represented by αK_p, is expected to deform more than the lower portion. In other words, α is always less than 2 and β is always greater than 2 leading to the following condition:

$$1 < \alpha < 2$$

The location of the dividing line between the pipe portion represented by α and β is dependent on the amount of lateral confining pressure provided by the U-bolt. As shown by finite element analyses (Ref. 4) the increasing stiffening effect provided by the tensioned U-bolt stabilizes to a constant value as soon as the preload exceeds a relatively low threshold values. This threshold preload corresponds to a U-bolt/pipe contact length over approximately 100 to 120 degrees.

It is therefore appropriate to select a constant value for the parameter α based on FEA results. The analyses described in Reference 4 result in an α-value of approximately 1.4. Since the value for α, based on expressions for "unconfined" and "confined" pipe stiffness, is relatively insensitive to pipe dimensions, the same value can be applied to all pipe sizes.

4.3.8 Clamp Assembly Stiffness

The stiffness of the U-Bolt clamp assembly (K_{cL}) consists of the combined stiffness of the cross piece and the U-bolt. In general the clamp assembly stiffness can be obtained by calculating the stiffness of individual parts and combining the results by using the formulations for springs in series as follows:

$$K_{cL} = \frac{K_c K_u}{K_c + K_u} \qquad (9)$$

4.3.8.1 U-Bolt

The U-bolt stiffness (K_u) is defined as the force required to induce a unit displacement at the U-bolt apex relative to the U-bolt nuts. The U-bolt stiffness is dependent on the degree of cinching and is therefore determined below in terms of upper and lower bounds.

In addition, the use of Belleville washers as described in Appendix B, introduces a controlled spring element that is activated under certain load conditions.

The U-bolt stiffness, as supplemented by the Belleville washers, affect the calculations of minimum required preload (Section 4.3.1) as well as the calculation of temperature and pressure effects (Section 4.4).

During the preloading process the Belleville washers are compressed, as the U-bolt nuts are tightened, until the spacer tube is in contact with a hardened washer at either end. This process produces a well-defined preload in the bolt and also a well-defined U-bolt clamping stiffness in situations where U-bolt tension is reduced. A compressive strut load acting on a single strut U-bolt increases the contact force between the cross piece and the pipe. As a result, the pipe is slightly compressed in the radial direction under the cross piece, and the U-bolt tension is reduced by a small amount, depending on the effective U-bolt stiffness. This reduction in U-bolt tension under compressive strut loading is addressed in the previously presented equations determining the preload required for stability (Equations (2), (3), (5), Section 4.3.1). The governing condition for stability involves a maximum inclined strut load acting in conjunction with maximum self-weight excitation when the pipe is cold and not pressurized. In this situation the

U-bolt tension is minimum and the effective U-bolt stiffness is primarily controlled by the Belleville washers.

A typical Belleville washer assembly for the WBNP U-bolts has a stiffness similar in magnitude to the lower bound U-bolt stiffness defined below. This relatively low stiffness causes the reduction in tension under strut loading to be much smaller.

When the pipe expands against the U-bolt/cross piece assembly, the bearing load on the U-bolt nut is transferred directly through the spacer tubes and the Belleville washers are not activated. In this situation the effective U-bolt stiffness tends to approach its upper bound value, which typically is an order of magnitude, or more, greater than the corresponding lower bound value. For the calculations of temperature and pressure effects on U-bolt tension, described in Section 4.4, the U-bolt stiffness will be taken as one half of the upper bound value defined below.

a. <u>Upper Bound (Fully Cinched)</u>

The U-bolt is treated as a frictionless cable with axial force only.

Thus, the upper bound of the U-bolt stiffness is

$$K_{u1} = \frac{a_u E}{\frac{\pi R}{4} + 0.5\ (R + H + h)} \qquad (10)$$

where:

R = Outside pipe radius [in]

h = The height of the cross piece [in]

H = The height of the stanchion [in]

a_u = The cross section area of the U-bolt [in.^{2}]

b. <u>Lower Bound (Uncinched)</u>

The lower bound of the U-bolt stiffness is calculated by assuming that the U-bolt deformation is primarily due to bending. The flexibility of the U-bolt is the deflection of the U-bolt apex due to a unit concentrated load, perpendicular to the cross piece at the nut locations.

By using the minimum energy theorem considering both axial and bending effects, the deflection at the tip relative to the nuts can be determined. The stiffness of the U-bolt can then be obtained by inverting the flexibility.

Thus, the lower bound stiffness is:

$$K_{u2} = \frac{a_u E}{\left[0.16 \dfrac{R^3}{r^2} + 0.5\ (R + H + h)\right]} \qquad (11)$$

where:

r = is the radius of the U-bolt cross section [in].

4.3.8.2 Cross Piece

The cross piece includes the structural members and standard parts that are used in transferring the piping loads to the struts or snubbers (excludes U-bolt which is covered in 4.3.8.1).

The stiffness of these parts is calculated using standard textbook solutions. Depending on the support configuration, it may be necessary to include shear deflection effects for the bending stiffness of short, deep beams. The combined stiffness (K_c) can be obtained using the following equation:

$$\frac{1}{K_c} = \frac{1}{K_1} + \frac{1}{K_2} + \frac{1}{K_3} + \ldots \frac{1}{K_i} \qquad (12)$$

4.4 TEMPERATURE AND PRESSURE EFFECTS

When subjected to increased temperature or internal pressure, an unconstrained pipe will expand radially. A pipe clamp, such as a preloaded U-bolt assembly, will restrict this radial expansion to a degree that is dependent on the clamp stiffness as well as the pipe stiffness.

The resultant clamp/pipe stiffness, K, that is the primary determinant of these restraining forces is defined by:

$$K = \frac{K_{CL} \, K_p}{K_{CL} + K_p} \qquad (13)$$

where:

K_{CL} = Clamp Assembly Stiffness from Equation (9) [lbs/in]

K_p = Pipe Stiffness from Equation (7) [lbs/in]

The differential, unconstrained thermal expansion between the pipe and the U-bolt, along a pipe diameter parallel to the U-bolt legs, is determined by:

$$\delta = \alpha_p \, \Delta T_p \, D_o - \alpha_u \, \Delta T_u \, D_o \qquad (14)$$

where:

α_p, α_u = Coefficient of Thermal Expansion for the Pipe and U-bolt, Respectively [in/in/deg F]

ΔT_p, ΔT_u = Temperature Change From Ambient for the Pipe and U-bolt, Respectively [deg F]

D_o = Outside Pipe Diameter [in]

The increase in U-bolt tension caused by the partially constrained thermal expansion is determined as follows:

$$U_T = 0.5 \, K \, \delta \qquad (15)$$

Similarly, the increase in U-bolt tension due to constrained, pressure-induced pipe expansion is determined as follows:

$$U_p = \frac{0.85Kp\ R_i\ R}{Et_p} \qquad (16)$$

where:

R_i = Inside Pipe Radius [in]

R = Outside Pipe Radius [in]

E = Young's Modulus for Pipe Material [psi]

t_p = Pipe Wall Thickness [in]

p = Internal Pipe Pressure [in]

K = Resultant Assembly Stiffness [lbs/in]

The increased U-bolt tension due to pipe pressure and temperature effects also leads to a corresponding increase in contact force between the pipe and the cross piece. This increase in contact force is twice the U-bolt tension increase as defined by the above equations.

4.5 LOAD EFFECTS ON PIPE AND U-BOLT ASSEMBLY

(a) U-Bolt

The tension in the U-bolt consists of the design preload and changes in tension due to externally applied strut loads, as well as tension increases due to pipe temperature and pressure effects. The resulting tension, U, in a U-bolt subjected to preload, U_o, external strut load, P, and pipe temperature and pressure effects is defined by the following equation:

$$U = U_{IL} - \frac{P}{2\alpha\left(\frac{K_P}{K_{CL}} + 1\right)} + U_T + U_p \qquad (17)$$

where:

U_T, U_p = U-Bolt Tension Due to Temperature and Pressure Effects as Defined By Equations (15) and (16) [lbs]

P = Total Strut Load (Positive for Loads Pushing the Cross Piece Against the Pipe) [lbs]

α, K_p, K_{CL} = Stiffness Terms Defined in Sections 4.3.7 and 4.3.8

(b) Cross Piece

The cross piece is affected by loading from the U-bolt tension, strut loads and compression at the point of contact with the pipe. Typically, the maximum bending moment occurs in the cross piece at the mid-point between the U-bolt legs. The magnitude of this bending moment is, generally, controlled by the maximum U-bolt tension force acting on a lever arm of half the distance between the U-bolt legs. For a trapeze support, this moment may be further affected by the strut or snubber force with a lever arm from the attachment bracket to the mid-point between U-bolt legs.

(c) Pipe

The controlling load effect on the pipe is the compressive force, F_p, between the cross piece and the pipe surface. The magnitude of this force is affected by the same parameters as the U-bolt tension discussed above:

$$F_P = 2\left(U_o + U_T + U_p + \frac{P}{2}\left(1 - \frac{1}{\alpha\left(\frac{K_P}{K_{CL}} + 1\right)}\right)\right) \qquad (18)$$

5.0 <u>ACCEPTANCE CRITERIA</u>

5.1 PRELOAD

Actual preload during the design service life shall not be less than design preload (U_{DL}), as defined by equation (6).

5.2 LOCAL CLAMP LOADS ON PIPE

The governing location for pipe load/stress acceptability is the region affected by the pipe-to-cross piece compressive interface. The contact surface area between the cross piece and the pipe is theoretically zero, in the form of a line, before a small amount of yielding causes the pipe surface, locally, to conform to the flat cross piece surface.

The local load effects in the pipe wall due to concentrated support line loads cannot be represented in a meaningful way by stresses calculated on an elastic basis. Such theoretical stress calculations result in extremely steep stress gradients in the immediate vicinity of a point load or line load. This means that highly localized yielding takes place directly under the line load at relatively low support loads. This, in turn, means that the contact surface changes, which invalidates the initial elastic stress calculations.

In an effort to evaluate the local pipe effects at concentrated support reactions in a more rational manner, a series of detailed, elasto-plastic finite element analyses were performed by R.L. Cloud & Associates as reported in Reference 8 and summarized in Reference 4. These analyses were performed for complete pipe spans, while maintaining a very detailed representation of the local pipe-to-support contact region, thereby ensuring that global load effects were included with the purely local effects under investigation. Under step-wise increasing pipe span inertia loading, the local pipe deformations at the support point were recorded.

Local pipe acceptability at support points were defined in terms of the ASME Code definition of "Collapse Load" (Ref. 6, II-1430 and NB3228). The analyses demonstrated this collapse load definition to be very conservative, as indicated by the substantial load carrying capacity remaining in the pipe beyond the "Collapse Load" without excessive deformation.
The results of these analyses were then used to formulate a generalized equation for determination of the pipe collapse load:

$$P_c = 0.84\ S_y\ t_p^2\ \left(\frac{2R_m}{t_p}\right)^{0.73}\left(\frac{b_c}{2R_m}\right)^{0.3} \qquad (19)$$

where:

P_c = Pipe Collapse Load as defined in ASME III, II-1430 [lbs]

Sy = Yield Strength of the Material at Normal Operating Temperature [psi]

b_c = Width of support cross piece [in]

Other terms are defined in Section 4.3.1.

The Code specifies two-thirds of the Collapse Load as the upper limit for acceptability of primary loading for Service Levels A and B. For Service Levels C and D higher fractions of the Collapse Load are permitted for primary loads.

Further analyses were performed (Refs. 4 and 8) demonstrating that progressive deformation (ratcheting) and fatigue damage were negligible under severe external loads and internal pressure, in conjunction with thermal cycling.

Based on References 4 and 8, the following conservative, local pipe acceptability criterion will be implemented for preloaded U-bolt applications at WBNP:

$$F_{p,\max} \leq 2/3 \; P_c \qquad (20)$$

where:

$F_{p,max}$ = Maximum Compression Exerted on the Pipe by the Cross Piece, Including Preload, Strut Load Effects, and Restrained Thermal and Pressure Effects, as Determined by Equation (18) [lbs]

P_c = Collapse Load, Defined by Equation (19) [lbs]

In addition to safety factors required by Code, the limitation imposed by Equations (19) and (20) is conservative in the following respects:

a. The limit load defined by equation (19) is based on unconfined pipe sections subjected to concentrated support reactions. The true limit load for a cinched U-bolt application is expected to be significantly higher due to the lateral confining effect of the preloaded U-bolt.

b. The Code requirements that form the basis for equations (19) and (20) are intended to satisfy primary load limitations. For reasons of procedural simplification in the U-bolt stability application, the local and secondary loads due to restrained pressure and thermal expansion are conservatively included with the primary load from strut reactions. This is clearly conservative since these load effects cannot contribute to collapse of the pipe section.

5.3 U-BOLT STRESS

The U-bolt stresses (F_t), calculated by dividing the governing bolt tension (Section 4.5) by the root cross sectional area, shall be limited by the following allowables:

$$(F_t) \leq 0.6\ Sy \text{ and } \leq 0.5\ S_u$$

$$(F_t)_{MAX} \leq 0.9\ Sy$$

where:

S_y = Yield Stress of U-Bolt Material [psi]

S_u = Ultimate Strength of U-Bolt Material [psi]

F_t = Maximum Stress in U-Bolt Leg from Preload and External Strut Load [psi], (See Section 4.5)

$(F_t)_{max}$ = Maximum Stress in U-bolt Leg from Preload, Restrained Pressure/Thermal Expansion and Strut Load [psi], (See Section 4.5)

5.4 CROSS PIECE STRESS

The stresses in the crosspiece and other items in the direct load path shall be evaluated in accordance with WB-DC-40-31.9 Table B-2 Limits for Supplemental Steel. For example, the "Normal & Friction" load condition bending stress limits are:

≤ 0.60 Sy (Non-Compact Sections)
≤ 0.66 Sy (Compact Sections)
≤ 0.75 Sy (Solid Plate)

The cross piece has a function identical to that of the U-bolt in elastically maintaining the preload forces in the assembly. The total maximum cross piece bending stresses due to all simultaneous load effects, therefore, shall be limited to 90% of the yield strength, consistent with the corresponding limitation on the U-bolt tensile stress.

6.0 DESIGN ENHANCEMENT

To provide additional assurance that U-bolt preload will be maintained throughout the design life of the plant, a design enhancement to the U-bolt supports is being implemented. The enhancement includes the use of Belleville washers (Ref. 7) that are designed to accommodate the design preload at a relatively constant level.

An example of the application of this enhanced design is given in Appendix B. The proposed design, shown in Details A & B incorporate Belleville Spring Discs to assure that the required tension in the U-bolt, which serves to maintain frictional resistance against rotation of the attached structural restraining element, is achieved for all operating modes of the piping system without overstressing the pipe. Section 4.3.8.1 contains a further discussion on the effects of the Belleville washers on the U-bolt effective stiffness and the stability evaluations.

7.0 INSTALLATION PROCEDURES

Existing procedures will be reviewed and revised to achieve proper installation as per intended design.

8.0 CONFIRMATION TESTS

In addition, static proof load tests of representative supports of the population will be performed to ensure that the design rotational resistance are properly achieved. The test procedure and acceptance criteria are specified separately.

9.0 REFERENCES

1. WB-DC-40-31.9, "Criteria For Design of Piping Supports and Supplemental Steel in Category I Structures," Revision 15, August 6, 1992 [RIMS T29 920806 857].

2. WCAP-10620, "Comanche Peak Steam Electric Station, U-Bolt Support/Pipe Test," Westinghouse Electric Corporation, July 1984.

3. WCAP-10627, "Comanche Peak Steam Electric Station, U-Bolt Finite Element Analysis," Westinghouse Electric Corporation, July 26, 1984.

4. RLCA/P142/01-86/004, "Cinched, Single-Strut U-Bolt Supports-Design Review, Application Procedure and Acceptance Criteria," Robert L. Cloud & Associates, Inc., September 1986.

5. TVA, Watts Bar Nuclear Plant, U-Bolt Test Report on Pipe Support 63-1S1S-R109, September 19, 1992.

6. ASME Boiler and Pressure Vessel Code, Section III, 1974 Edition.

7. National Disc Springs (Catalog No. 991), Rolex Company, National Disc Spring Division, Hillside, NJ, 1983.

8. RLCA/P142/01-86/005, "Acceptable Support Bearing Loads on Pipe Based on Plastic Analysis," Rev. 0, Robert L. Cloud & Associates, Inc., September 1986.

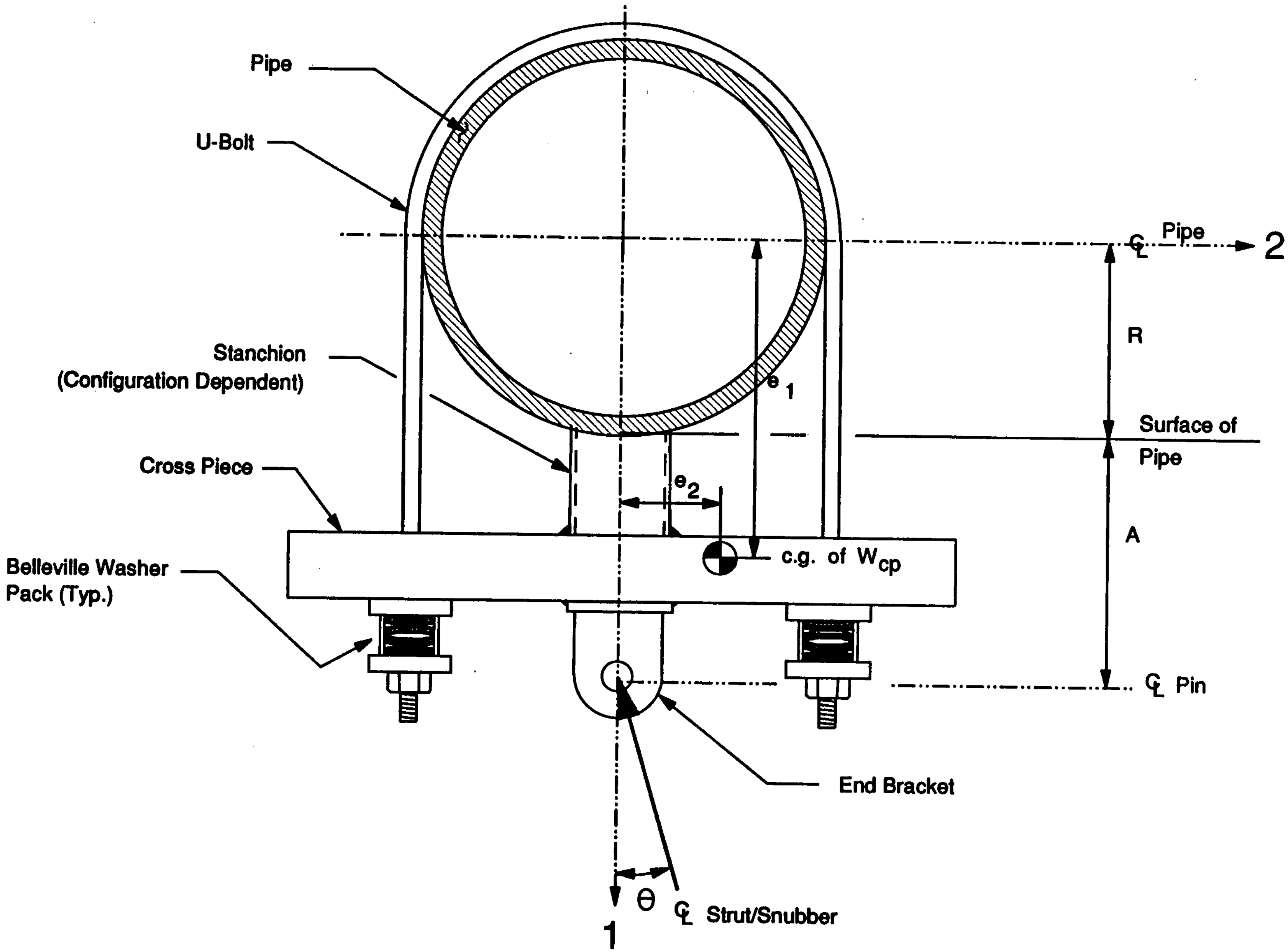


FIGURE 1(a): U-Bolt Assembly w/Single Strut

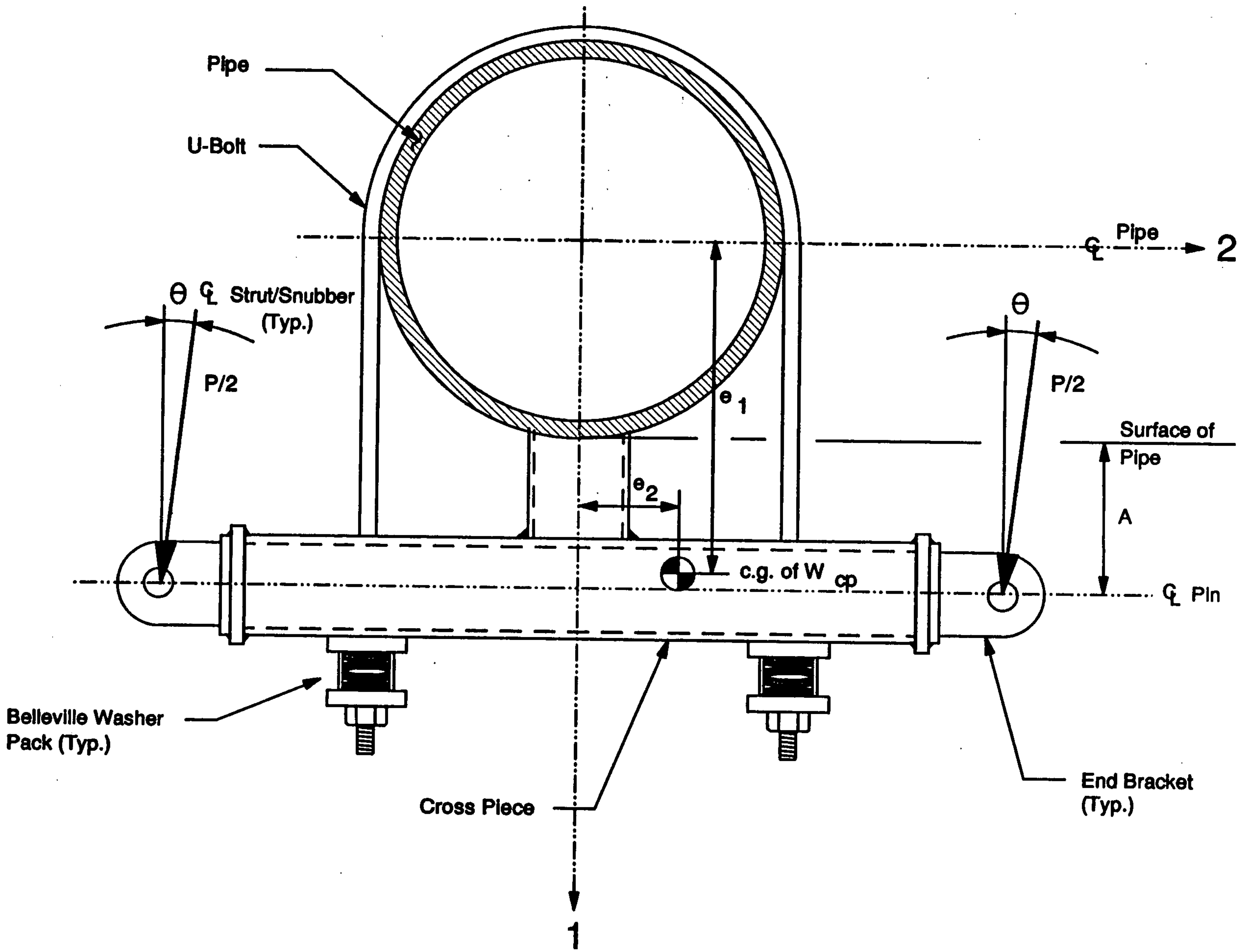


FIGURE 1(b): U-Bolt Assembly (Trapeze Arrangement)

APPENDIX A

WBNP U-BOLT DATA BASE

# U-BOLT EVALUATION SUMMARY BY SYSTEM NUMBER
CF=UBOLT8

SUPP ID	SYS NO	PIPE DIAM	TRAP	U-BOLT CAT NO	U-BOLT MATERIAL	BP NSP NO	TYPE STRUT	LC
** SYSTEM NUMBER 01								
** Subtotal **								
								11
** SYSTEM NUMBER 03								
** Subtotal **								
								38
** SYSTEM NUMBER 15								
** Subtotal **								
								14
** SYSTEM NUMBER 26								
** Subtotal **								
								4
** SYSTEM NUMBER 31								
** Subtotal **								
								1
** SYSTEM NUMBER 41								
** Subtotal **								
								1
** SYSTEM NUMBER 62								
** Subtotal **								
								48
** SYSTEM NUMBER 63								
** Subtotal **								
								45

# U-BOLT EVALUATION SUMMARY BY SYSTEM NUMBER
CF=UBOLT8

SUPP ID	SYS NO	PIPE DIAM	TRAP	U-BOLT CAT NO	U-BOLT MATERIAL	BP NSP NO	TYPE STRUT	LC
** SYSTEM NUMBER 67								
** Subtotal **								
								60
** SYSTEM NUMBER 68								
** Subtotal **								
								9
** SYSTEM NUMBER 70								
** Subtotal **								
								76
** SYSTEM NUMBER 72								
** Subtotal **								
								8
** SYSTEM NUMBER 74								
** Subtotal **								
								15
** SYSTEM NUMBER 77								
** Subtotal **								
								1
** SYSTEM NUMBER 78								
** Subtotal **								
								4
*** Total ***								
								335

# U-BOLT EVALUATION SUMMARY BY SYSTEM NUMBER
CF=UBOLT8

SUPP ID	SYS NO	PIPE DIAM	TRAP	U-BOLT CAT NO	U-BOLT MATERIAL	BP NSP NO	TYPE STRUT	LC
** SYSTEM NUMBER 01								
101A307	01	320		CLAMP		SP26462	SNUBBER	1
101A308	01	320	Y	SP283	A36		STRUT	1
101A313	01	320		SP283	A193 GRB	SP26441	SNUBBER	1
101A348	01	320	Y	283	A36		SNUBBER	1
101A350	01	320		SP26461	A193 GRB	SP26431	SNUBBER	1
101A389	01	320	Y	283	A36		SNUBBER	1
101A392	01	320	Y	SP26459	A193 GRB	SP26459	SNUBBER	1
101A424	01	320		283	A36	SP26445	SNUBBER	1
101A429	01	320	Y	SP283	A193 GRB	SP26445	SNUBBER	1
101A434	01	320		CLAMP		SP26463	SNUBBER	1
101A435	01	320		SP283	A193 GRB	SP26443	SNUBBER	1
** Subtotal **								
								11
** SYSTEM NUMBER 03								
03B1AFWR010	03	080		6502	A36		STRUT	1
03B1AFWR043	03	060		283A	A36		STRUT	1
03B1AFWR049	03	040		283	A36		STRUT	1
03B1AFWR121	03	040	Y	283A	A36		STRUT	1
03B1AFWR137	03	040	Y	283A	A36		STRUT	1
03B1AFWR146	03	040	Y	283A	A36		STRUT	1
03B1AFWR147	03	040		283A	A36		STRUT	1
03B1AFWR149	03	040		222	A36		STRUT	1
03B1AFWR161	03	040	Y	283A	A36		STRUT	1
03B1AFWR172	03	040		6175	A193 GRB		STRUT	1
03B1AFWR175	03	040	Y	283A	A36		STRUT	1
03B1AFWR187	03	040		283A	A36		STRUT	1
03B1AFWR191	03	040	Y	283A	A36		STRUT	1
03B1AFWR192	03	040		283A	A36		STRUT	1
03B1AFWR197	03	040		222	A36		STRUT	1
03B1AFWR202	03	040		283	A36		STRUT	1

U-BOLT EVALUATION SUMMARY BY SYSTEM NUMBER
CF=UBOLT8

SUPP ID	SYS NO	PIPE DIAM	TRAP	U-BOLT CAT NO	U-BOLT MATERIAL	BP NSP NO	TYPE STRUT	LC
03B1AFWR209	03	040	Y	283A	A36		SNUBBER	1
103A200	03	160	Y	SP26385	A193 GRB	SP26385	SNUBBER	1
103A205	03	160		SP283	A36		SNUBBER	1
103A240	03	160	Y	SP26386	A193 GRB	SP26386	SNUBBER	1
103A280	03	160	Y	BENT ROD	A193 GRB		SNUBBER	1
103A285	03	160		283A	A36		SNUBBER	1
103A320	03	160	Y	SP283	A36	SP26434	SNUBBER	1
103A323	03	160		6175	A193 GRB		SNUBBER	1
103A374	03	060	Y	283	A36		SNUBBER	1
103A450	03	060		6502	A36		SNUBBER	1
103A453	03	060	Y	283A	A36		SNUBBER	1
103A482	03	060		6502	A36		SNUBBER	1
103A487	03	060	Y	6502	A36		SNUBBER	1
103A582	03	020		6502	A36		SNUBBER	1
103A589	03	010		6502	A36		STRUT	1
47A40107035	03	060	Y	SP283	A193 GRB	SP26429	SNUBBER	1
47A42703007	03	040	Y	283A	A36		STRUT	1
47A42703041	03	020		6502	A36		SNUBBER	1
47A42705005	03	040		6502	A36		SNUBBER	1
47A42705023	03	060		6502	A36		STRUT	1
47A42708024	03	020		6500	A36		STRUT	1
47A42708028	03	100		6500	A36		SNUBBER	1
** Subtotal **								
								38
** SYSTEM NUMBER 15								
47A40006085	15	040		283	A36		SNUBBER	1
47A40006087	15	040		283	A36		SNUBBER	1
47A40006118	15	040	Y	SP26430	A193 GRB	SP26430	SNUBBER	1
47A40006123	15	020		6502	A36		SNUBBER	1
47A40006126	15	020		6500	A36		SNUBBER	1
47A40006191	15	040	Y	6500	A36		SNUBBER	1

U-BOLT EVALUATION SUMMARY BY SYSTEM NUMBER
CF=UBOLT8

SUPP ID	SYS NO	PIPE DIAM	TRAP	U-BOLT CAT NO	U-BOLT MATERIAL	BP NSP NO	TYPE STRUT	LC
47A40006196	15	040		283	A36		SNUBBER	1
47A40006197	15	040		SP283	A193 GRB	SP26413	SNUBBER	1
47A40006198	15	040		SP283	A193 GRB	SP26412	SNUBBER	1
47A40006199	15	040		SP283	A193 GRB	SP26414	SNUBBER	1
47A40006200	15	040		SP283	A193 GRB	SP26415	SNUBBER	1
47A40006259	15	030		6510	A36		SNUBBER	1
47A40007011	15	060	Y	SP26455	A193 GRB	SP26455	STRUT	1
47A40007012	15	060		283	A36		SNUBBER	1
** Subtotal **								
								14
** SYSTEM NUMBER 26								
261FPR122	26	080		283	A36		STRUT	1
261FPR154	26	080	Y	283	A36		STRUT	1
37A20601019	26	080		6502	A36		STRUT	1
37A20601020	26	080		6502	A36		STRUT	1
** Subtotal **								
								4
** SYSTEM NUMBER 31								
47A92031117	31	050		6500	A36		SNUBBER	1
** Subtotal **								
								1
** SYSTEM NUMBER 41								
47A49605012	41	040	Y	SP26492	A193 GRB	SP26492	SNUBBER	1
** Subtotal **								
								1
** SYSTEM NUMBER 62								
162A002	62	020	Y	283A	A36		SNUBBER	1
162A006	62	020		6502	A36		SNUBBER	1

U-BOLT EVALUATION SUMMARY BY SYSTEM NUMBER
CF=UBOLT8

SUPP ID	SYS NO	PIPE DIAM	TRAP	U-BOLT CAT NO	U-BOLT MATERIAL	BP NSP NO	TYPE STRUT	LC
162A034	62	020	Y	283	A36		SNUBBER	1
162A325	62	030		283	A36		SNUBBER	1
162A345	62	030	Y	283	A36		SNUBBER	1
162A348	62	030	Y	SP26469	A193 GRB	SP26469	STRUT	1
162A357	62	030	Y	SP26469	A193 GRB	SP26469	SNUBBER	1
162A366	62	030	Y	SP26469	A193 GRB	SP26469	SNUBBER	1
162A406	62	007		283	A36		SNUBBER	1
162A407	62	007		283	A36		SNUBBER	1
162A431	62	007	Y	6500	A36		SNUBBER	1
162A466	62	007	Y	222	A36		SNUBBER	1
162A536	62	020		6510	A36		STRUT	1
162A680	62	007		283	A36		SNUBBER	1
47A40608060	62	007		6500	A36		SNUBBER	1
47A40608068	62	007		6504	A36		SNUBBER	1
47A40608074	62	007		6500	A36		STRUT	1
47A40610018	62	007		283	A36		SNUBBER	1
47A40617002	62	020		6504	A36		STRUT	1
47A46503048	62	030	Y	6510	A36		SNUBBER	1
47A55503010	62	030	Y	283A	A36		STRUT	1
47A55503012	62	030	Y	283	A36		STRUT	1
47A55503013	62	030	Y	283	A36		STRUT	1
47A55503014	62	030		283	A36		STRUT	1
47A55503015	62	030	Y	283	A36		STRUT	1
47A55510042	62	020		283A	A36		STRUT	1
47A55510050	62	020		283A	A36		STRUT	1
621CVCR001	62	080	Y	283	A36		STRUT	1
621CVCR021	62	080		6502	A36		STRUT	1
621CVCR046	62	040	Y	283	A36		STRUT	1
621CVCR057	62	040	Y	283	A36		STRUT	1
621CVCR072	62	040	Y	283	A36		STRUT	1
621CVCR073	62	040		283	A36		STRUT	1
621CVCR102	62	030		6502	A36		STRUT	1

U-BOLT EVALUATION SUMMARY BY SYSTEM NUMBER
CF=UBOLT8

SUPP ID	SYS NO	PIPE DIAM	TRAP	U-BOLT CAT NO	U-BOLT MATERIAL	BP NSP NO	TYPE STRUT	LC
621CVCR115	62	010	Y	283	A36		STRUT	1
621CVCR224	62	010		SP283	A193 GRB	SP26419	SNUBBER	1
621LCVR074	62	030	Y	283	A36		STRUT	1
621LCVR079	62	030		283	A36		STRUT	1
621LCVR097	62	020		283	A36		STRUT	1
621LCVR098	62	030		283A	A36		STRUT	1
621LCVR099	62	030	Y	283	A36		STRUT	1
621LCVR215	62	030		283	A36		STRUT	1
621LCVR216	62	030		283	A36		STRUT	1
621LCVR222	62	030		283	A36		SNUBBER	1
621LCVR244	62	060	Y	283	A36		SNUBBER	1
621LCVV101	62	030		283	A36		STRUT	1
622LCVR002	62	030	Y	283	A36		STRUT	1
622LCVR005	62	030	Y	283A	A36		STRUT	1
** Subtotal **								
								48
** SYSTEM NUMBER 63								
163021	63	060		283	A36		SNUBBER	1
163030	63	080		283	A36		SNUBBER	1
163038	63	020	Y	SP283	A193 GRB	SP26409	SNUBBER	1
163055	63	080		283	A36		SNUBBER	1
163064	63	060		283	A36		SNUBBER	1
163081	63	060		283	A36		SNUBBER	1
163398	63	040		6502	A36		SNUBBER	1
163454	63	100	Y	SP283	A193 GRB	SP26411	SNUBBER	1
163462	63	060	Y	283	A36		SNUBBER	1
163572	63	020		283	A36		SNUBBER	1
163591	63	080		6500	A36		SNUBBER	1
47A43201005	63	140	Y	SP26425	A193 GRB	SP26425	SNUBBER	1
47A43201031	63	140	Y	SP26481	A193 GRB	SP26481	SNUBBER	1
47A43203003	63	080	Y	283A	A36		SNUBBER	1

U-BOLT EVALUATION SUMMARY BY SYSTEM NUMBER
CF=UBOLT8

SUPP ID	SYS NO	PIPE DIAM	T R A P	U-BOLT CAT NO	U-BOLT MATERIAL	BP NSP NO	TYPE STRUT	LC
47A43503005	63	240	Y	283A	A36		STRUT	1
47A43507060	63	100		CLAMP		SP26464	SNUBBER	1
47A43508023	63	007		283	A36		SNUBBER	1
47A43508087	63	100		SP283	A193 GRB	SP26410	STRUT	1
47A43509076	63	005		FAB PL	A36		SNUBBER	1
631SISR043	63	060		283	A36		STRUT	1
631SISR109	63	240	Y	SP26426	A193 GRB	SP26426	SNUBBER	1
631SISR112	63	240	Y	SP26427	A193 GRB	SP26427	SNUBBER	1
631SISR114	63	240	Y	SP26428	A193 GRB	SP26428	SNUBBER	1
631SISR115	63	240	Y	283	A36		STRUT	1
631SISR131	63	160		BENT ROD	A36		STRUT	1
631SISR137	63	140		283A	A36		STRUT	1
631SISR138	63	140		SP26478	A193 GRB	SP26478	STRUT	1
631SISR140	63	140		283	A36		STRUT	1
631SISR142	63	140	Y	283	A36		SNUBBER	1
631SISR161	63	140		283	A36		STRUT	1
631SISR162	63	140		283A	A36		STRUT	1
631SISR164	63	014		283A	A36		STRUT	1
631SISR182	63	140	Y	283	A36		STRUT	1
631SISR206	63	120		283	A36		STRUT	1
631SISR212	63	120	Y	283A	A36		SNUBBER	1
631SISR218	63	200		SP26433	A193 GRB	SP26433	STRUT	1
631SISR219	63	200		SP26422	A193 GRB	SP26422	STRUT	1
631SISR221	63	140		6500	A36		SNUBBER	1
631SISR226	63	120	Y	SP26421	A193 GRB	SP26421	SNUBBER	1
631SISR227	63	012		283	A36		STRUT	1
631SISR230	63	140	Y	SP26423	A193 GRB	SP26423	SNUBBER	1
631SISR238	63	120	Y	283	A36		STRUT	1
631SISR248	63	030	Y	SP26424	A193 GRB	SP26424	SNUBBER	1
631SISR266	63	010	Y	283	A36		STRUT	1
631SISR274	63	030		283	A36		STRUT	1

U-BOLT EVALUATION SUMMARY BY SYSTEM NUMBER
CF=UBOLT8

SUPP ID	SYS NO	PIPE DIAM	TRAP	U-BOLT CAT NO	U-BOLT MATERIAL	BP NSP NO	TYPE STRUT	LC
** Subtotal **								
								45
** SYSTEM NUMBER 67								
47A45002078	67	060	Y	283	A36		STRUT	1
47A45002110	67	080		SP283	A193 GRB	SP26420	STRUT	1
47A45003099	67	120		283A	A36		SNUBBER	1
47A45003100	67	120		6502	A193 GRB	SP26407	SNUBBER	1
47A45003154	67	300		SP283	A193 GRB	SP26416	STRUT	1
47A45003163	67	120	Y	6502	A36		SNUBBER	1
47A45004036	67	240		6502	A36	SP26432	STRUT	1
47A45021084	67	060	Y	283	A36		STRUT	1
47A45021098	67	060	Y	283	A36		STRUT	1
47A45021112	67	060	Y	283	A36		STRUT	1
47A45021126	67	060	Y	283	A36		STRUT	1
671ERCWR019	67	060	Y	222	A36		STRUT	1
671ERCWR030	67	240		283	A36		STRUT	1
671ERCWR046	67	200	Y	283	A36		STRUT	1
671ERCWR092	67	240	Y	283A	A36		STRUT	1
671ERCWR128	67	060		222	A36		SNUBBER	1
671ERCWR145	67	240	Y	283A	A36		STRUT	1
671ERCWR205	67	030		283	A36		STRUT	1
671ERCWR207	67	240	Y	283A	A36		STRUT	1
671ERCWR210	67	240		6175	A193 GRB		STRUT	1
671ERCWR220	67	240		6502	A36		STRUT	1
671ERCWR231	67	240	Y	283A	A36		STRUT	1
671ERCWR239	67	080		6502	A36		STRUT	1
671ERCWR258	67	030	Y	222	A36		STRUT	1
671ERCWR269	67	180		283	A36		STRUT	1
671ERCWR282	67	240		6502	A36		STRUT	1
671ERCWR283	67	240	Y	283	A36		STRUT	1
671ERCWR292	67	240		6502	A36		STRUT	1

# U-BOLT EVALUATION SUMMARY BY SYSTEM NUMBER
CF=UBOLT8

SUPP ID	SYS NO	PIPE DIAM	T R A P	U-BOLT CAT NO	U-BOLT MATERIAL	BP NSP NO	TYPE STRUT	LC
671ERCWR295	67	180	Y	283A	A36		STRUT	1
671ERCWR299	67	180	Y	283A	A36		STRUT	1
671ERCWR301	67	180	Y	283A	A36		STRUT	1
671ERCWR310	67	240	Y	SP283	A36		STRUT	1
671ERCWR312	67	240	Y	SP283	A36		STRUT	1
671ERCWR325	67	080	Y	283	A36		STRUT	1
671ERCWR348	67	360	Y	SP283	A36		STRUT	1
671ERCWR349	67	360	Y	6502	A36		STRUT	1
671ERCWR352	67	160	Y	283	A36		STRUT	1
671ERCWR360	67	060	Y	283A	A36		STRUT	1
671ERCWR365	67	080	Y	SP283	A36		SNUBBER	1
671ERCWR368	67	200	Y	283A	A36		STRUT	1
671ERCWR371	67	200	Y	283A	A36		STRUT	1
671ERCWR388	67	240	Y	283	A36		STRUT	1
671ERCWR389	67	240	Y	283A	A36		STRUT	1
671ERCWR436	67	360	Y	283A	A36		STRUT	1
671ERCWR440	67	360	Y	6502	A36		STRUT	1
671ERCWR463	67	180	Y	7155	A36		STRUT	1
671ERCWR496	67	080	Y	283A	A36		STRUT	1
671ERCWR525	67	060	Y	283A	A36		STRUT	1
671ERCWR529	67	060	Y	283A	A36		STRUT	1
671ERCWR532	67	060	Y	283	A36		STRUT	1
671ERCWR534	67	060	Y	283	A36		STRUT	1
671ERCWR542	67	060	Y	283A	A36		STRUT	1
671ERCWR546	67	060		283	A36		STRUT	1
671ERCWR552	67	060	Y	283A	A36		STRUT	1
671ERCWR555	67	060	Y	283A	A36		STRUT	1
671ERCWR558	67	060	Y	283A	A36		STRUT	1
671ERCWR561	67	060	Y	283A	A36		STRUT	1
671ERCWR563	67	060	Y	283	A36		STRUT	1
671ERCWR600	67	060		283	A36		STRUT	1
672ERCWR038	67	080	Y	SP283	A36		STRUT	1

U-BOLT EVALUATION SUMMARY BY SYSTEM NUMBER
CF=UBOLT8

SUPP ID	SYS NO	PIPE DIAM	TRAP	U-BOLT CAT NO	U-BOLT MATERIAL	BP NSP NO	TYPE STRUT	LC
** Subtotal **								
								60
** SYSTEM NUMBER 68								
168018	68	060	Y	BENT ROD	A36		STRUT	1
168022	68	040	Y	283	A36		STRUT	1
168031	68	040	Y	283	A36		SNUBBER	1
168036	68	040	Y	283	A36		SNUBBER	1
168427	68	060		283	A36		SNUBBER	1
47A46501066	68	040		6500	A36		SNUBBER	1
47A46502037	68	060		6500	A36		SNUBBER	1
47A46502040	68	060		6500	A36		SNUBBER	1
47A46508092	68	010	Y	BENT ROD	A36		STRUT	1
** Subtotal **								
								9
** SYSTEM NUMBER 70								
170329	70	030		283	A36		SNUBBER	1
47A46402237	70	160	Y	283	A36		STRUT	1
47A46403135	70	120	Y	283	A36		STRUT	1
47A46409001	70	240		283	A36		STRUT	1
47A46409149	70	120	Y	283	A36		STRUT	1
47A46420015	70	040		6175	A193 GRB		SNUBBER	1
701CCR062	70	200		283A	A36		STRUT	1
701CCR133	70	100		CLAMP	A36		STRUT	1
701CCR145	70	080	Y	283	A36		STRUT	1
701CCR147	70	080	Y	283A	A36		STRUT	1
701CCR155	70	180		283A	A36		STRUT	1
701CCR156	70	160	Y	283	A36		STRUT	1
701CCR176	70	080	Y	283A	A36		STRUT	1
701CCR177	70	080	Y	283A	A36		STRUT	1
701CCR178	70	080	Y	283A	A36		STRUT	1

U-BOLT EVALUATION SUMMARY BY SYSTEM NUMBER
CF=UBOLT8

SUPP ID	SYS NO	PIPE DIAM	TRAP	U-BOLT CAT NO	U-BOLT MATERIAL	BP NSP NO	TYPE STRUT	LC
701CCR180	70	080	Y	283A	A36		STRUT	1
701CCR181	70	080	Y	283A	A36		STRUT	1
701CCR228	70	180	Y	283A	A36		STRUT	1
701CCR230	70	180	Y	283A	A36		STRUT	1
701CCR239	70	240	Y	SP283	A36		STRUT	1
701CCR243	70	240		283A	A36		STRUT	1
701CCR249	70	240		283A	A36		STRUT	1
701CCR282	70	100	Y	6502	A36		STRUT	1
701CCR319	70	120	Y	283A	A36		STRUT	1
701CCR335	70	120	Y	283A	A36		STRUT	1
701CCR357	70	120	Y	283A	A36		STRUT	1
701CCR359	70	120	Y	283A	A36		STRUT	1
701CCR362	70	120	Y	283A	A36		STRUT	1
701CCR369	70	120	Y	283A	A36		STRUT	1
701CCR389	70	180	Y	SP283A	A36		STRUT	1
701CCR391	70	180	Y	283A	A36		STRUT	1
701CCR393	70	180	Y	283	A36		STRUT	1
701CCR404	70	180	Y	283	A36		STRUT	1
701CCR411	70	180	Y	SP283	A36		STRUT	1
701CCR418	70	180	Y	283A	A36		STRUT	1
701CCR421	70	180	Y	283A	A36		STRUT	1
701CCR428	70	180	Y	283A	A36		STRUT	1
701CCR440	70	040	Y	283A	A36		STRUT	1
701CCR443	70	180	Y	283A	A36		STRUT	1
701CCR452	70	180	Y	283A	A36		STRUT	1
701CCR456	70	040	Y	283A	A36		STRUT	1
701CCR469	70	100	Y	283A	A36		STRUT	1
701CCR471	70	100	Y	283A	A36		STRUT	1
701CCR473	70	100	Y	283	A36		STRUT	1
701CCR528	70	160	Y	283A	A36		STRUT	1
701CCR551	70	180	Y	283A	A36		STRUT	1
701CCR553	70	180	Y	283A	A36		STRUT	1

# U-BOLT EVALUATION SUMMARY BY SYSTEM NUMBER
CF=UBOLT8

SUPP ID	SYS NO	PIPE DIAM	TRAP	U-BOLT CAT NO	U-BOLT MATERIAL	BP NSP NO	TYPE STRUT	LC
701CCR556	70	180	Y	283A	A36		STRUT	1
701CCR562	70	180	Y	283A	A36		STRUT	1
701CCR585	70	080	Y	283A	A36		STRUT	1
701CCR594	70	180	Y	283A	A36		STRUT	1
701CCR601	70	180	Y	283A	A36		STRUT	1
701CCR605	70	180	Y	283A	A36		STRUT	1
701CCR621	70	180	Y	6502	A36		STRUT	1
701CCR637	70	080		283A	A36		STRUT	1
701CCR640	70	080	Y	283A	A36		STRUT	1
701CCR648	70	080	Y	283A	A36		STRUT	1
701CCR649	70	080	Y	283A	A36		STRUT	1
701CCR672	70	180	Y	283A	A36		STRUT	1
701CCR675	70	180		283A	A36		STRUT	1
701CCR692	70	180		6500	A36		STRUT	1
701CCR694	70	180	Y	SP26487	A193 GRB	SP26487	STRUT	1
701CCR725	70	120	Y	283A	A36		STRUT	1
701CCR731	70	120	Y	283A	A36		STRUT	1
701CCR732	70	120	Y	283A	A36		STRUT	1
701CCR734	70	120	Y	283A	A36		STRUT	1
701CCR753	70	080		283A	A36		STRUT	1
701CCR754	70	080		283A	A36		STRUT	1
701CCR757	70	080		283A	A36		STRUT	1
701CCR758	70	160	Y	6502	A36		STRUT	1
701CCR761	70	160	Y	283A	A36		STRUT	1
701CCR765	70	080	Y	283A	A36		STRUT	1
701CCR776	70	180	Y	SP6500	A36		STRUT	1
701CCR779	70	180	Y	SP6500	A36		STRUT	1
702CCR022	70	030	Y	283A	A36		STRUT	1
702CCR031	70	080	Y	283A	A36		STRUT	1
** Subtotal **								76

U-BOLT EVALUATION SUMMARY BY SYSTEM NUMBER
CF=UBOLT8

SUPP ID	SYS NO	PIPE DIAM	TRAP	U-BOLT CAT NO	U-BOLT MATERIAL	BP NSP NO	TYPE STRUT	LC
** SYSTEM NUMBER 72								
47A43705008	72	100		6502	A36		STRUT	1
721CSR003	72	100		6502	A36		SNUBBER	1
721CSR013	72	100		283A	A36		SNUBBER	1
721CSR031	72	100	Y	283A	A36		STRUT	1
721CSR093	72	060		6502	A36		STRUT	1
721CSR115	72	100	Y	SP283	A36		STRUT	1
721CSR117	72	100	Y	283A	A36		STRUT	1
721CSR124	72	100	Y	283A	A36		STRUT	1
** Subtotal **								
								8
** SYSTEM NUMBER 74								
174007	74	140	Y	SP26466	A193 GRB	SP26466	SNUBBER	1
174008	74	140	Y	SP26437	A193 GRB	SP26437	SNUBBER	1
174020	74	140	Y	SP26467	A193 GRB	SP26467	SNUBBER	1
741RHRR003	74	080	Y	6502	A36		STRUT	1
741RHRR004	74	080	Y	283A	A36		STRUT	1
741RHRR006	74	080	Y	6502	A36		SNUBBER	1
741RHRR017	74	080	Y	283A	A36		STRUT	1
741RHRR063	74	080		SP26380	A193 GRB	SP26380	STRUT	1
741RHRR101	74	080		283	A36		STRUT	1
741RHRR190	74	020	Y	283A	A36		SNUBBER	1
741RHRR192	74	020	Y	283A	A36		SNUBBER	1
741RHRR194	74	020	Y	283A	A36		SNUBBER	1
741RHRR196	74	020	Y	283A	A36		SNUBBER	1
741RHRR197	74	020	Y	283A	A36		SNUBBER	1
741RHRR231	74	080	Y	283A	A36		STRUT	1
** Subtotal **								
								15

U-BOLT EVALUATION SUMMARY BY SYSTEM NUMBER
CF=UBOLT8

SUPP ID	SYS NO	PIPE DIAM	TRAP	U-BOLT CAT NO	U-BOLT MATERIAL	BP NSP NO	TYPE STRUT	LC
** SYSTEM NUMBER 77								
47A56004088	77	040		283	A36		STRUT	1
** Subtotal **								
								1
** SYSTEM NUMBER 78								
781FPCR021	78	010	Y	283	A36		SNUBBER	1
781FPCR047	78	080		6502	A36		STRUT	1
781FPCR049	78	100		283	A36		STRUT	1
781FPCR074	78	080		6502	A36		STRUT	1
** Subtotal **								
								4
*** Total ***								
								335

APPENDIX B

BELLEVILLE WASHER DESIGN

APPENDIX B

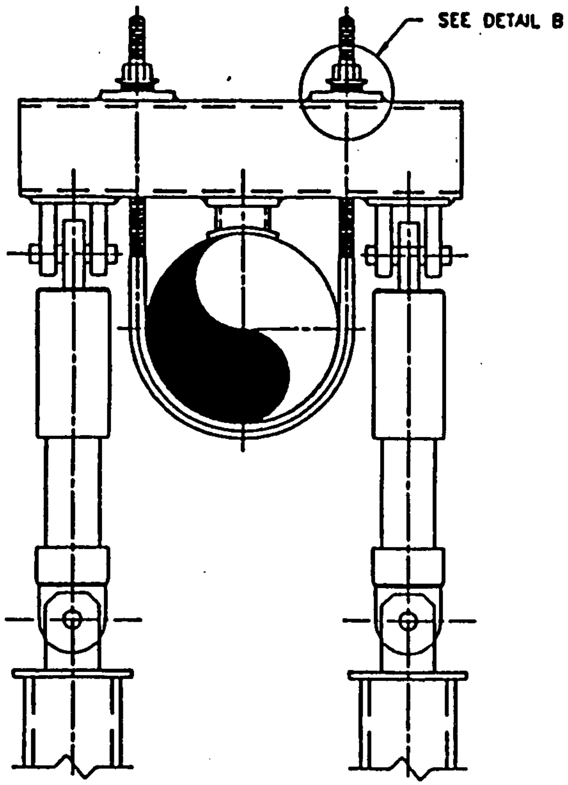
Details A & B show the proposed enhanced design where Belleville Disc Springs assure that the required tension in the U-bolt is maintained under all operating modes of the piping system.

This is accomplished by the compression of Belleville Disc Springs to a predetermined load height. The number of discs in parallel apply a force commensurate with the tension required. For example: in the picture shown, the restraining design force on each leg is assured to be 4,500 [lb] from the National Disc Spring Catalog, (Ref. 7) disc number AM 502526, having an ID of 1.0 [in] and OD of 1.970 [in], will exert a force of 1540 lbs when compressed to half of its free height. Three springs in parallel will apply a force of 3 x 1540 [lb] or 4,620 [lb]. The spring package design consists of three discs in parallel and 4 sets in series which produces a stack free height of 1.4041 [in]. The series arrangement (4 gaps) allows a total deflection of 4 x .0558 = 0.2232 [in]. Therefore, the set height requires that the spring package be deflected 0.11 [in].

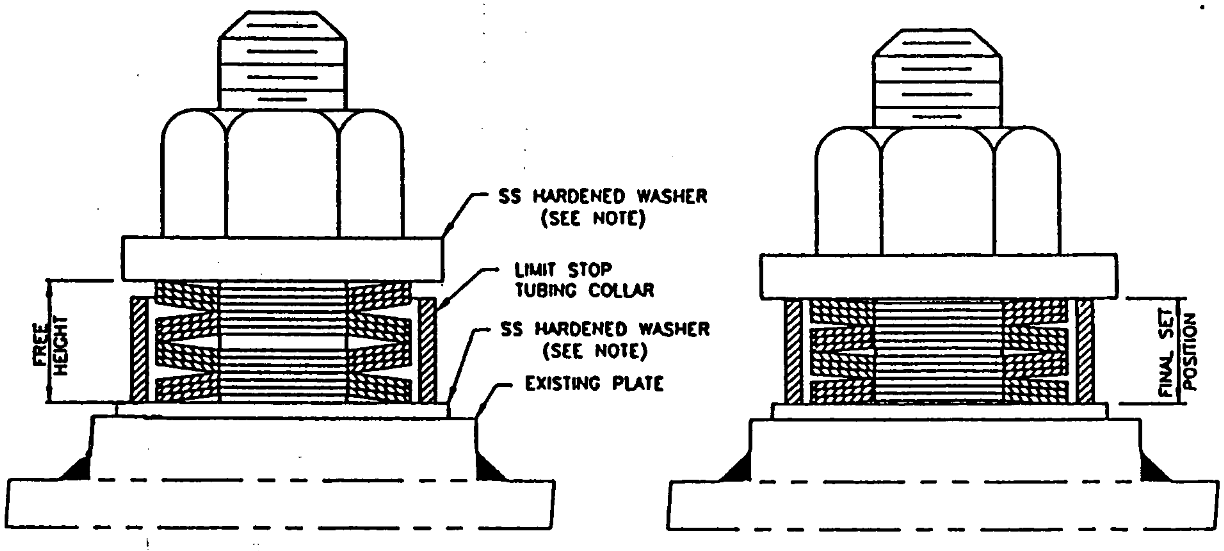
To achieve the correct loaded deflection, a machined collar, cut from tubing to a set height of (1.4041-0.11) = 1.29 inches for the above example is placed around the stack to provide a limit stop when the restraint structure is subjected to any imposed thermal, seismic, or other anticipated design loads.

Relaxation losses in preload will be virtually eliminated because they will be controlled by the spring rate at the Belleville Disc Springs.

MODIFIED DESIGN OF U-BOLT ASSEMBLY



DETAIL A
(SCALE 3/4" = 1'-0")



INSTALLED POSITION
PRIOR TO SPRING COMPRESSION

FINAL COMPRESSED POSITION

NOTE: 17-7 PRECIPITATION HARDENED (PH) STAINLESS STEEL, HEAT TREATED TO ROCKWELL C40-48 HARDNESS.

DETAIL B
(SCALE 1" = 1")

EBASCO SERVICES INCORPORATED

PROJECT:

TENNESSEE VALLEY AUTHORITY
WATTS BAR NUCLEAR PLANT