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# TENNESSEE VALLEY AUTHORITY

## Division of Engineering Design

**PLANT:** WATTS BAR NUCLEAR PLANT

**Design Criteria**
**For**

SEISMICALLY QUALIFIED BURIED PIPING SYSTEMS

**Design Criteria No:** WB-DC-40-31.5

**Issue Date:** May 23, 1972

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# DESIGN CRITERIA COORDINATION LOG

Plant: WATTS BAR NUCLEAR PLANT

Design Criteria No: WB-DC-40-31.5

Design Criteria For: SEISMICALLY QUALIFIED BURIED PIPING SYSTEMS

Revision: 1

R - Denotes review

A - Denotes approval

| Engineering Support Branches | | | | | | | | Nuclear Projects Design | | | | | | | | Fossil, Hydro, & Special Projects Design and Architectural Support Branch | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| MEB | | EEB | | CEB | | NEB | | Design Project Manager | | | | | | R: JCS | A: [illegible] | | | | |
| R | A | R | A | R | A | R | A | Mechanical | | | | Electrical | | Civil | | R | A | R | A |
| | | | | | | | | R | A | R | A | R | A | | | | | | |
| | | | | EDM | EOM | | | | | | | | | | | | | | |
| | | | | | DRD | | | | | | | | | | | | | | |
| | | | | | WAE | | | JJN | [illegible] | | | | | | | | | | |
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TVA

# REVISION LOG

Title: SEISMICALLY QUALIFIED BURIED PIPING SYSTEMS

WB-DC-40-31.5

| Revision No. | DESCRIPTION OF REVISION | Date Approved |
|---|---|---|
| 1 | a. Section 1.0, changed word "guide" to "criteria."<br>b. Added section 2.2.6 to take into account axial stresses induced in piping. This revision will not be noted on each line.<br>c. Revised section 3.0 to indicate effective edition of ASME code that is applicable for piping analysis.<br>d. Revised section 4.0 to add references 4.4 through 4.14. | 1/13/83 |

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## 1.0 SCOPE

This document establishes criteria for seismic design and analysis of nuclear safety related buried piping systems. These criteria shall ensure that the system will withstand, without disrupting service, the ground accelerations imposed on the system by a safe shutdown earthquake. Where there is a conflict between this criteria and the detailed specifications, the detailed specifications shall govern. (1)

## 2.0 PROCEDURE

The primary emphasis in the seismic design of a buried piping system is to show through analysis that the system incorportes adequate flexibility to permit differential movement without damage, or sufficient strength in the pipe to exceed the soil strength.

### 2.1 Design

2.1.1 No section of pipe shall be severed to install a flexible coupling without an analysis to show that the stresses in the pipe exceed code allowables, and that the coupling is necessary to relieve strains resulting from differential movement.

2.1.2 Option 1: If the analysis of the piping system indicates a necessity for flexibility at the penetration, the preferable design is to protect the pipe with an oversize opening in the structure and a flexible guard pipe as shown in Figure 2.1.2-1 If additional protection, support, or flexibility is required, a guard box should be considered.

The flexible guard pipe consists of two flexible couplings and a section of oversize pipe. The guard pipe must be large enough to provide adequate clearance to permit one joint to move with the structure and one with the soil without contacting the process pipe. One end of the guard pipe is mounted in the structure to be penetrated and the other end is attached to the process pipe, with one coupling near the structure and the other near the attachment to the process pipe. Inside the structure, the process pipe must be supported with spring hangers for a minimum distance which varies with pipe diameter. At the penetration into the structure, additional flexibility, if required, may be provided the buried piping by a guard box. If used, one end of the guard box shall be supported on and butt against the structure, but shall not be attached to the structure. The box design shall provide adequate clearance to permit movement of the structure, pipe, and box without contacting the pipe.

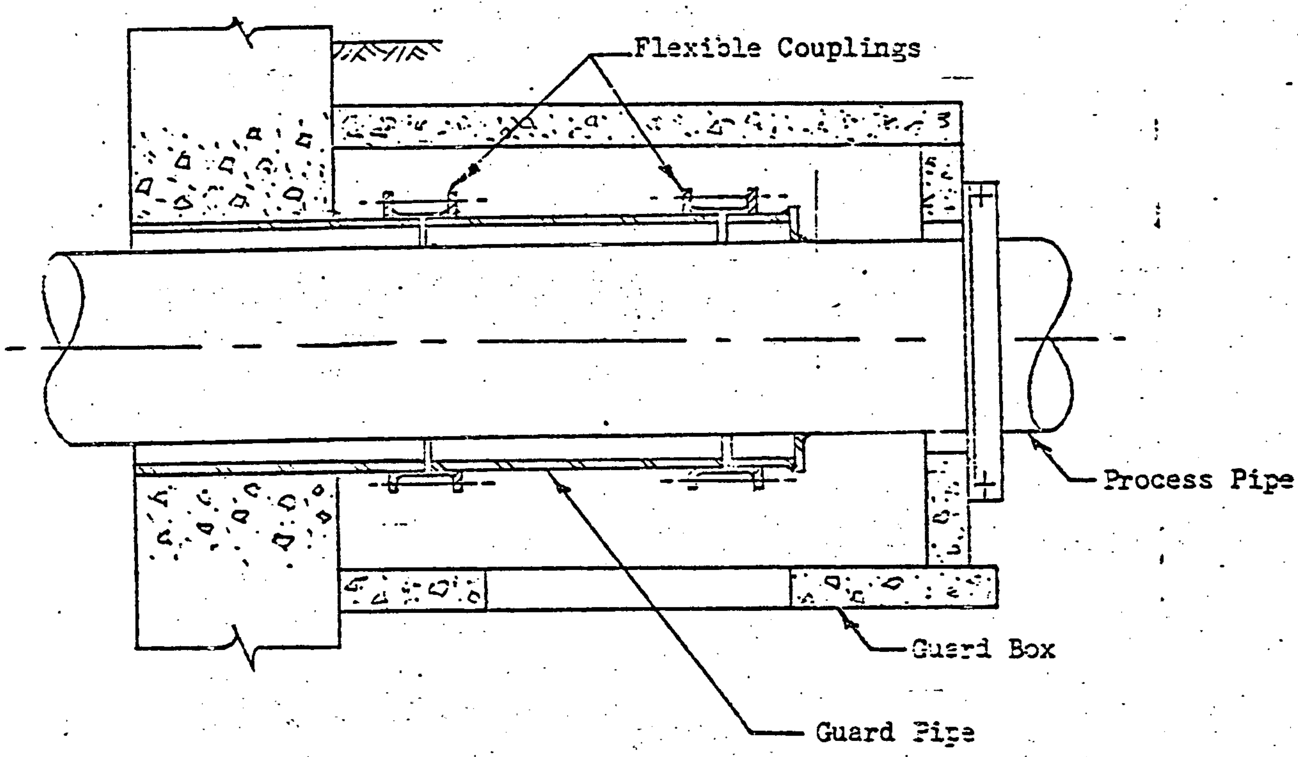



Figure 2.1.2-1

2.1.3 Option 2: If Option 1 is not usable for a particular piping system design, Option 2 may be used. At the penetration into the structure, protect the buried piping from differential movement of the soil and structure by a guard box and flexible coupling as shown in Figure 2.1.3-1.

The guard box shall be supported on and butt against the structure, but not be attached to the structure. Locate one coupling near the structure and one near the soil end of the guard box. Design the box to provide adequate clearance to permit one joint to move with the structure and one with the soil without contacting the pipe. This method has the advantage of providing maximum flexibility and deflection in a limited area; however, the pipe is severed to install the coupling and is weakened longitudinally. This requires either a harness across the coupling to maintain longitudinal structural integrity, or that the severed pipe be securely anchored in the structure to resist the longitudinal force created by the pipe pressure. Pipelines having their intake from or dicharge into an open reservoir or channel normally do not require longitudinal containment at the flexible couplings.

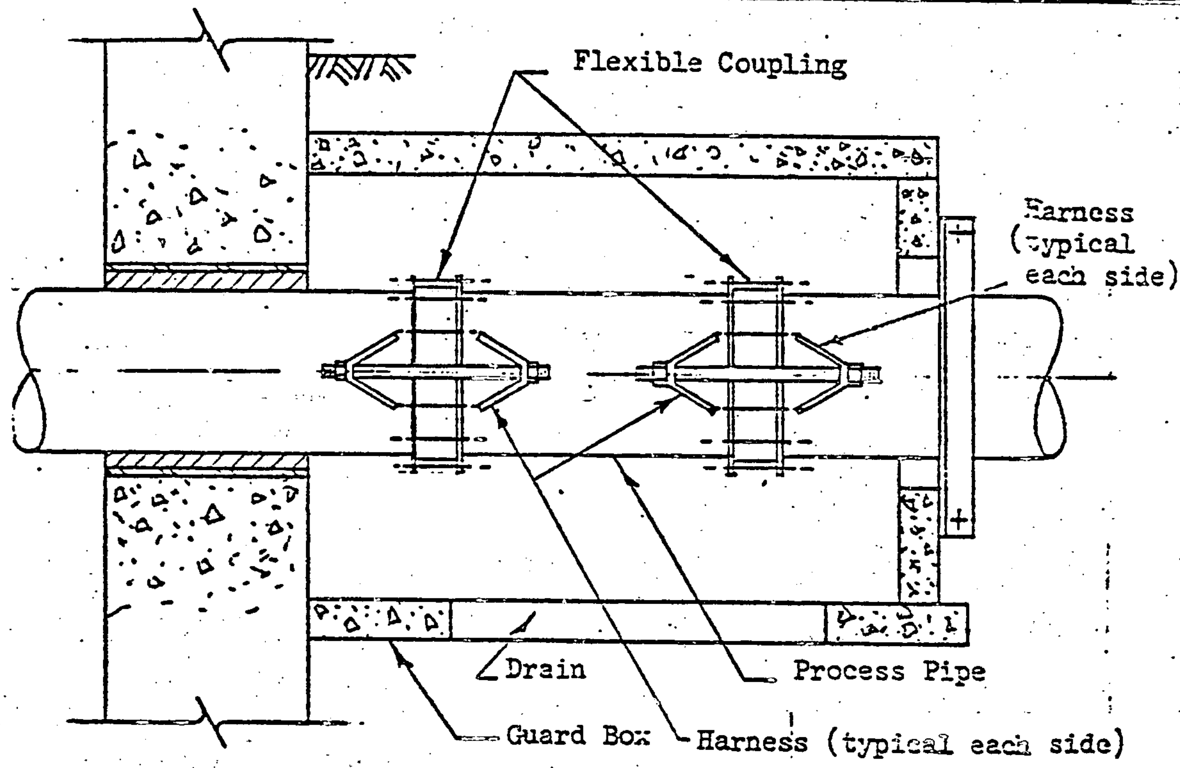
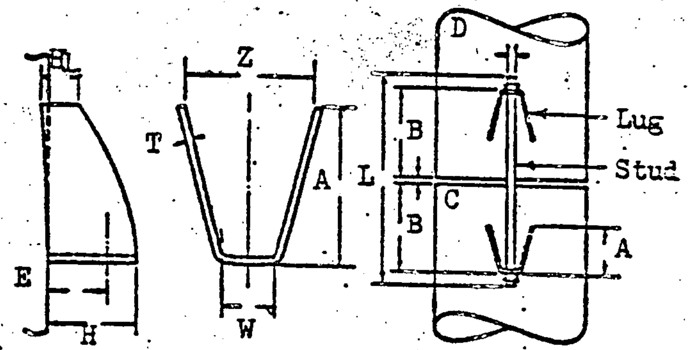



Figure 2.1.3-1

Table 2.1.3-1 provides the design criteria for an acceptable harness for pipe of 14- through 24-inch diameter and pressures to 150 lb/in$^2$. For larger pipe, or pressure, a complete design and stress analysis shall be required for each application.




| Pipe Dia | Wall | Max. Press. | A | W | Z | T | H | E | H1 | D | Hole Dia |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 14 | 0.375 | 150 | 9-1/4 | 1-7/8 | 5-1/2 | 3/8 | 4 | 2-11/16 | 2 | 1 | 1-1/8 |
| 16 | 0.375 | 150 | 10-5/8 | 1-7/8 | 6-1/2 | 3/8 | 4 | 2-13/16 | 2 | 1 | 1-1/8 |
| 18 | 0.375 | 150 | 12 | 2-3/8 | 7-1/8 | 1/2 | 4-3/8 | 3 | 2-1/4 | 1-1/4 | 1-3/8 |
| 20 | 0.375 | 150 | 13-3/8 | 2-3/8 | 8-1/4 | 1/2 | 4-3/8 | 3-1/8 | 2-1/4 | 1-1/4 | 1-3/8 |
| 24 | 0.375 | 150 | 16 | 2-7/8 | 10 | 1/2 | 5 | 3-7/16 | 2-1/4 | 1-1/2 | 1-5/8 |

Table 2.1.3-1

The stud sizes are based on the use of two heat-treated studs with a minimum yield of 70,000 psi. The lug design is based on a material conforming to SA 285, Grade C, or equal.

2.1.4 The depth of the buried piping shall be maintained at a minimum throughout the design.

2.1.5 Where practical, underground piping in the field shall be routed to avoid unstable ground and shall not pass from natural ground into a fill area. In areas, such as adjacent to buildings where underground piping systems must traverse the interface between native soil and engineering fill, an analysis must be made. This analysis shall include calculations to determine: (1) if the pipe has sufficient strength to bridge between the building and virgin soil, and support the soil above the pipe without exceeding the allowable strength of the material; or (2) if the pipe has sufficient strength to exceed the soil bearing strength and thereby redistribute the pipe loads without exceeding the code allowable. If the analysis shows that the pipe stresses are excessive, one of the preceding methods of installing flexible couplings may be used, or a beam may be designed to bridge across the fill area and support the pipe.

## 2.2 Analysis

2.2.1 All nuclear safety related buried piping must be analyzed using either the methods shown below or other current dynamic seismic analytical methods, and must comply to ASME Boiler and Pressure Vessel Code, Section III.

2.2.2 A dynamic seismic analysis of underground piping can be performed using the Engineering Data System computer program and appropriate seismic response spectrum of the soil. The analysis requires that the pipe be modeled with a series of fictitious members representing soil stiffness. Spacing of these fictitious members should be at each of the lumped mass points and there should be one spring member in the lateral and vertical direction at each such point. The fictitious member should consist of unit lengths, unit modulus of elasticity, and the area should be equal to the tributary soil stiffness, K. The tributary soil stiffness for each spring can be calculated as follows:

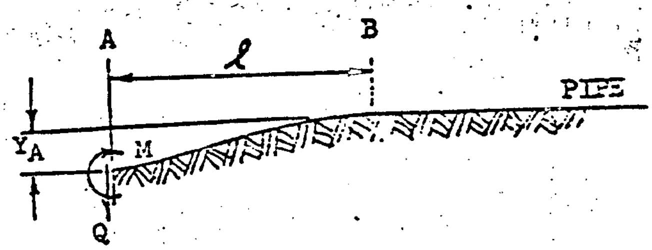
$$K = \frac{E\,D\,L}{0.37(1-\mu^2)\sqrt{D\,L}}$$

Where:

$E$ = Dynamic modulus of soil, $lb/in^2$
$D$ = Outside diameter of pipe, inches
$\mu$ = Poisson's ratio for soil
$L$ = Tributary length of pipe to the point under consideration. Approximately equal to the distance between fictitious points.

2.2.3 If a suitable anchor is not provided at the point where the pipe penetrates the structure, the dynamic seismic analysis must be continued inside the structure to a suitable location for terminating the analysis. This approach is mandatory in order to ensure that the stress levels in the pipe and pipe support structure do not exceed the allowables specified by the ASME Boiler and Pressure Vessel Code, Section III. However, when analyzing the pipe inside the structure, the soil may be considered an anchor and the pipe analysis terminated at that point.

2.2.4 Pipe stresses due to the relative movement of the soil and the building, whether they are caused by seismic deflections or by settlement of the soil, must be calculated, and combined with those stresses resulting from seismic ground deformation. These stresses may be calculated from the following values for shear and moment:




$Y_A$ = Building deflection, in.
$\ell$ = Affected length of pipe, in.
$A$ = Penetration into structure
$Q$ = Shear force in pipe, lb
$M_A$ = Bending moment in pipe, in.-lb
$\phi_A$ = Slope in pipe at penetration, radians
$\phi_B$ = Slope in pipe at end of affected length, radians

Assume:

$$\phi_A \text{ and } \phi_B = 0$$

Then:

$$M_A = \frac{0.498\, Q}{\lambda}$$

$$Q = \frac{0.988\, Y_A\, K}{\lambda}$$

For:

$$K = D\, K_o \text{ and}$$

$$\lambda = \sqrt[4]{\frac{K}{4\, E\, I}}$$

Where:

$K_o$ = Modulus of foundation, lb/in$^3$.
D = Outside diameter of pipe, in.
E = Young's modulus of pipe material, lb/in$^2$.
I = Moment of inertia of pipe, in$^4$.

2.2.5 An alternate, simplified method of hand calculating the pipe stress due to a seismic disturbance may be used. This analysis will be conservative and will provide the maximum earthquake response and maximum bending stress in the pipe. If the pipe stress exceeds the allowable stress using this method, the more exact analysis described in paragraph 2.2.2 must be used.

The soil is considered to be a horizontal 1-layer system which responds to the earthquake by moving in a continuous sinusoidal plane wave and supported by a second layer or base material. The top layer is assumed to pick up accelerations from the base material.

Utilizing the average values for the shear wave velocity and density for the top layers, the ground deformation pattern in terms of wave length and amplitude is determined. The buried pipes are assumed to deform along with the surrounding soil layers. Since no shearing between the pipe and soil is considered to occur, no relative displacement between the soil and the lines is considered.

$$V_{ST} = \frac{\sum V_S h'}{h}$$

Where:

$V_{ST}$ = Average shear velocity in the top layers of soil, ft/s
$V_S$ = Shear velocity in each layer of soil, ft/s
$h'$ = Depth of each layer of soil, ft
$h$ = Total depth of top layers of soil, ft

The fundamental period of the single layer is calculated from the following equation:

$$T = \frac{4h}{V_{ST}}$$

If the depth of the soil layer varies over the distance traversed by the buried pipe, both cases, for maximum and minimum depths, must be considered and results summarized.

The dynamic magnification factor for a single-layered undamped system is calculated from the equation:

$$DAF = \frac{\rho_B V_{SB}}{\rho_T V_{ST}}$$

Where:

DAF = Dynamic amplification factor for the soil layer
$\rho_B$ = Density of the base rock, $lb/ft^3$
$\rho_T$ = Average density of the soil layer, $lb/ft^3$
$V_{SB}$ = Shear wave velocity in the base rock, ft/s
$V_{ST}$ = Shear wave velocity in the soil layer, ft/s

$$\text{Displacement} = \left(\frac{T}{2\pi}\right)^2 \times \text{Accel}$$

Where:

Accel = % G x g
g = Local acceleration of gravity, $ft/s^2$
% G = Value for the appropriate period from the SSE seismic response curve for the base rock, $ft/s^2$

The value of the "wave length" is calculated using:

$$\text{Wave length (per cycle)} = V_{ST}\, T$$

Then using the above data, calculate the bending moment resulting from the seismic disturbance. The buried pipe must follow the soil and deform to a sine wave distortion. The maximum bending moment is given by:

$$M = \frac{\pi^2 EIA}{L^2}$$

Where:

M = Maximum bending moment, ft-lb
E = Modulus of the pipe, $lb/in^2$.
I = Moment of inertia of the pipe, $in^4$.
A = Maximum amplitude (displacement x DAF), ft
L = One-half the wave length, in.

The corresponding bending stress is obtained by dividing the moment by the section modulus of the pipe.

Combining the above bending stress with the bending stress from paragraph 2.2.4 provides the maximum stress in the pipe. This stress level will occur in the pipe at the wall of the penetrated structure. The pressure stress must be combined with the above stresses to determine the primary stress.

### 2.2.6 Axial Stresses

Maximum axial stresses induced in long slender buried members, due to propagating seismic compression and shear waves, may be determined in the following ways depending on the assumptions made.

Following the method of Newmark (References 4.8 and 4.9), Yeh (Reference 4.11), and Kuesel (Reference 4.10), which assumes the soil is linearly elastic and homogenous, slender beam theory, and the buried member deforms with the surrounding soil (this implies the strain in the soil equals the strain in the member), the maximum axial stresses are given by:

$$\sigma_a = \pm EV_p/C_p \text{ (due to axial compression wave)}$$

and

$$\sigma_a = \pm EV_s/2C_s \text{ (due to oblique shear wave)}$$

Where:

$E$ = Young's modulus of buried member
$V_p$ = Maximum particle velocity of soil due to compression wave
$V_s$ = Maximum particle velocity of soil due to oblique shear wave
$C_p$ = Compressional wave velocity of soil
$C_s$ = Shear wave velocity of soil

However, in the case of a straight structural member embedded in soil, the transfer of soil strain as axial strain into the member depends on the end-bearing of the member against the soil and the frictional resistance between the member surface and the soil. At the ends of a long straight element, frictional resistance will develop for some length, an embedment length, along which the member will displace relative to the surrounding soil because of strain incompatibility between the soil and member. Shah and Chu (Reference 4.12) calculate this embedment length as:

$$l_m = \frac{\varepsilon_m AE}{f} = \frac{\sigma_a A}{f} = \frac{F_{max}}{f}$$

Where:

$l_m$ = Maximum slippage length
$\varepsilon_m$ = Maximum strain in the member (calculated according to Yeh)
$A$ = Cross-sectional area of member
$E$ = Young's modulus for the member
$f$ = Frictional force per unit length of member
$\sigma_a$ = Maximum axial stress in member (calculated according to Yeh)
$F_{max}$ = Maximum axial force in member (calculated according to Yeh)

Thus, if the element is relatively short (the length of the element is less than twice the maximum slippage length), the maximum strain, and hence stress, is always less than that computed by Newmark or Yeh.

Considering the frictional resistance at the member and soil interface as a limiting rate of strain (or stress) transfer and the sinusoidal nature of the seismic waves, a reduced maximum axial strain, stress, or force may be calculated for the member.

Sakurai and Takahashi (Reference 4.14) presents empirical relationships based on observations and measurements on three kinds of pipe lines during the Matsusbiro earthquakes. Their conclusions are:

(1) For small earthquakes, the deformations of the pipe are the same as for the soil. (This would imply the maximum force as calculated by Newmark and Yeh or Shah and Chu apply).

(2) For large earthquakes, the axial deformations in the pipe are less than those in the soil. In this case, the upper bound of strain for straight pipe is:

$$\varepsilon_u = \frac{C_o L}{4EA_o} = \frac{C_o VT}{4EA_o}$$

Where:

$C_o$ = Frictional force per unit lengths of pipe
$L$ = Wave length
$A_o$ = Cross-sectional area of pipe
$E$ = Young's modulus of pipe
$V$ = Velocity of seismic wave (compressional, shear, Love, Rayleigh)
$T$ = Period of ground movement
$\varepsilon_u$ = Strain in the pipe

Reordering the equation yields:

$$F_{max} = \varepsilon_u EA_o = \frac{C_o L}{4}$$

Or that the maximum axial force, $F_{max}$, in the pipe is equal to one-fourth of the wave length times the frictional resistance of the pipe-soil interface. This $F_{max}$ may also be used in Shah and Chu's method to determine an equivalent embedment length. Generally, the operating basis and safe shutdown earthquakes are "large" earthquakes causing slippage at the member-soil interface.

These axial forces are applied to the piping system to determine the effect on straight sections and at elbows using procedures developed by Shah and Chu, and Goodling (4.15).

## 3.0 ALLOWABLE STRESS LEVEL

The piping shall be analyzed to the requirements of the 1974 edition of the ASME Section III, Division I Code. (1) (1)

## 4.0 REFERENCES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4.15. Goodling, E. C., "Flexibility Analysis of Buried Piping," Joint ASME/CSME Pressure Vessels and Piping Conference, Montreal, Canada, June 25-30, 1978. (1) (1) (1)