1.0 INTRODUCTION

The American Lifelines Alliance (ALA) was formed in 1998 under a cooperative agreement between the American Society of Civil Engineers (ASCE) and the Federal Emergency Management Agency (FEMA). In 2001, ALA requested George A. Antaki, P.E., to prepare a guide for the seismic design of new piping systems, and the seismic retrofit of existing, operating systems in critical facilities.

1.1 Project Objective

The purpose of this guide is to

- Provide comprehensive, yet easy to follow guidance for the seismic design of piping systems in essential facilities such as power plants, chemical process facilities, oil and gas pipelines and terminals, and post-earthquake critical institutions such as hospitals.
- Compile and describe in a single document the steps and techniques necessary for the seismic qualification of new or existing above ground piping systems, based on current analytical and dynamic testing technology, as well as experience from the behavior of piping systems in actual earthquakes.
- Propose a seismic qualification standard, to be submitted to the American Society of Mechanical Engineers, ASME, for consideration as the basis for a B31 standard.

1.2 Project Scope

The guide addresses the seismic design of piping systems or the retrofit of existing piping systems. The purpose of seismic design or retrofit is to assure that in case of earthquake, the piping system will perform its intended function: position retention (the pipe would not fall), leak tightness (the pipe would not leak), or operability (the piping system would deliver and regulate flow).

This Guide applies to above ground piping systems, which - except for seismic design – otherwise comply with the provisions of the ASME B31 pressure piping codes for materials, design, fabrication, examination and testing. For buried piping and pipelines, the reader is referred to an earlier ALA report "Guidelines for the Design of Buried Steel Pipe", July 2001.

Piping systems may be seismically designed or retrofitted for any one of several reasons:

(1) Public and worker safety; for example, assuring the leak tightness of process piping containing toxic materials, or cooling water supply to a heat exchanger controlling the temperature of an exothermic or explosive mixture.

(2) Environmental protection; for example, assuring the integrity of a hazardous liquid pipeline or oil terminal in an environmentally sensitive area.

(3) Protection of capital assets; for example, assuring the integrity of costly systems at a chemical or power plant.

(4) Vital post-earthquake function; for example, assuring the supply and distribution of critical gases in a hospital, or the fuel supply to an emergency diesel-generator.

(5) Compliance with regulatory requirements.

This guide does not address the seismic design and retrofit of nuclear power plant piping systems, which are explicitly prescribed by the US Nuclear Regulatory Commission, and codified in ASME Boiler & Pressure Vessel Code, Section III, Division1, Nuclear Components.

1.3 Notations

A_C = area of base of 45^o concrete cone emanating from anchor bolt tip, in^2
a = lateral uniform acceleration, g's dL= change in length, in
a_P = component amplification factor (1.0 to 2.5)
dT = temperature change, ^{o}F
E = weld joint efficiency factor
c = corrosion allowance, in
D = pipe outer diameter, in
d = maximum displacement at impact, in
d = swing amplitude, in
d_s = static displacement of elastic member due to its own weight, in
d_{st} = static displacement due to weight plus the weight of the falling body, lb
E = Young's modulus, psi
F = maximum permitted load applied to the system, lb
F_{LAC} = limit analysis collapse load, lb
F_P = horizontal load, lb
F_{PAC} = plastic analysis collapse load, lb
F_{PI} = plastic instability load, lb
f = natural frequency, Hz
f_a = swing frequency, Hz
f_C' = concrete strength, psi
g = gravity, 386 in/sec^2
H = height of falling interaction, in
H = height from support-vessel attachment to vessel's center of gravity, in
h = height of structure
h = height of free fall, in
I = importance factor (1.0 or 1.5)
I = moment of inertia, in^4
K = total global stiffness of vessel assembly, lb/in
K_V = vessel stiffness, lb/in
K_L = total stiffness of support legs, lb/in
k = anchor bolt factor

k = stiffness of elastic member, referenced to point of impact, lb/in
L = length, in
L_T = span length from ASME B31.1 Table 121.5
N = number of cycles to fatigue failure
n = actual number of fatigue cycles
NEP = non-exceedance probability
P = design pressure, psi
P = impact force, lb
P_b = primary bending stress, psi
P_C = tensile capacity of anchor bolt, lb
P_N = nominal tensile capacity of anchor bolt, lb
P_L = primary general or local membrane stress, psi
P_m = primary membrane stress, psi
P_{max} = maximum primary stress intensity at any location, psi
P_N = nominal pullout strength, lb
P_U = mean measured strength of concrete anchor bolt, lb
R = resultant response
R = radius of the zone of influence, in
R_{EW} = east-west response
R_{NS} = north-south response
R_V = vertical response
R_i = response in mode i
r = exceedance probability = 1 – NEP
R_P = component response modification factor (1.0 to 5.0)
RP = return period, years
S = allowable stress defined in B31.1 or B31.3 for the material and design temperature, psi
S_a = spectral acceleration at frequency f_a, in/sec^2
S_S = short period acceleration (IBC), g
S_1 = 1 sec acceleration (IBC), g
S_{DS} = design spectral response acceleration at short period (IBC), g
S_{D1} = design spectral response acceleration at 1 second (IBC), g
S_U = minimum ultimate strength of the material, psi
T = minimum wall thickness required by code, in
T = exposure period, years
T = average primary shear across a section loaded in pure sheer, psi
V_C = shear capacity of anchor bolt, lb
V_N = nominal shear capacity of anchor bolt, lb
V_H = horizontal spectral velocity, in/sec
V_V = vertical spectral velocity, in/sec
W = weight, lb
W = weight of falling body, lb
W_b = weight of elastic member, lb
X_{ij} = concrete anchor penalty factor for tension
$x(t)$ = displacement as a function of time t, in
Y_{ij} = concrete anchor penalty factor for shear
y = temperature correction factor, 0.4 below 900^{o}F.

z = height of attachment to structure

α = coefficient of thermal expansion, $1/^{o}F$
σ = maximum bending stress, psi
σ = standard deviation of measured strength of anchor bolts, lb
Δ = deflection at mid-span, in
Φ = strength reducton factor [ACI 349]
ω = circular frequency, rad/sec
ω_D = damped circular frequency, rad/sec
ζ = damping, %