Introduction

This report covers items 1.1.1, 1.1.2, 1.1.3 and 1.1.4 of the personal services contract No. APO-91038(AR) between the Pan American Health Organization (PAHO) and Michael J. O'Rourke, Ph.D.

ITEM 1.1.1

Presented below is an itemized list of information necessary for a vulnerability analysis of water pipelines in seismic areas of Mexico. This list covers only those items related to the vulnerability of pipelines. However, if the specific system under consideration includes other seismically vulnerable elements such as hydraulic fill dams, water towers, treatment plants etc., it is recommended that these elements also be included in the vulnerability analysis.

In the past, seismic damage to water pipelines has been due to; fault crossing, liquefaction, landslides and/or seismic wave propagation. For each of these potential problems, two types of information are needed. First of all, the seismic hazard must be quantified. That is, the relative displacement, acceleration, etc likely to be imposed upon the pipeline by an earthquake must be estimated. This information tends to be probabilistic in nature and likely is available from the National Autonomous University or the Mexican equivalent of the U.S. Geological Survey. Secondly, information such as the pipes cross-sectional area and modulus of elasticity, load deformation characteristics of the surrounding soil, etc. is needed to evaluate the pipelines seismic resistance. That is, given certain physical characteristics of a pipeline and its surrounding soil, one can estimate the relative fault displacement which would cause failure of the pipeline. This information tends to be deterministic in nature.

The information needed to determine the seismic hazard and the seismic resistance for each of the four potential failure mechanisms are presented below.

A. Fault Crossing

Seismic Hazard The following information is needed for all known faults which are crossed by the pipeline

- fault type (strike-slip, normal-slip, etc.)
- direction of relative fault movement for faults with a strike-slip component (left lateral or right lateral)
- angle of fault plane with respect to vertical (if available)
- width of fault zone (if available)
- estimated earthquake magnitude with recurrence intervals of 50, 100 and 500 years for faults in question
- estimated maximum amount of relative fault displacement for recurrence intervals of 50, 100 and 500 years (this information may be generated using presently available empirical relations between relative fault displacement and earthquake magnitude)

Seismic Resistance The following information about the pipeline and its surrounding soil is needed at all fault crossing locations. It is assumed herein that the pipeline is buried. If the pipeline is not buried, requested information about the soil should be replaced with information about the spacing and frictional characteristics of the structural support for the pipeline.

- pipeline diameter, wall thickness and buried depth
- stress-strain characteristics of pipeline material
- detail of pipeline joints
- force-displacement and moment-rotation characteristics at joints in segmented pipelines (if known)
- location of pipeline joint with respect to fault (if known)
- trench or berm geometry
- unit weight and coefficient of soil pressure at rest for backfill material*[1]
- undrained shear strength and/or angle of internal friction for backfill material*

B. Liquefaction The following information is needed for all locations along the pipeline route where Remote Sensing, Seismic Hazard Maps and/or Ground Surveys indicate the potential for liquefaction.

<u>Seismic Hazard</u>

- estimated peak horizontal ground acceleration with recurrence intervals of 50, 100 and 500 years at potential liquefaction sites

<u>Seismic Resistance</u> There are three methods which one can use to determine the resistance of a soil mass to liquefaction. The following list assumes that the soil stiffness is quantified by

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[1]this information is also needed about the native soil for deep, narrow trench burials

blowcounts from a Standard Penetration Tests (SPT). However, results from seismic crosshole or downhole tests, or results from cone penetrometer test may be used in lieu of SPT blowcounts.

- location of water table
- total unit weight of soil
- blowcounts from Standard Penetration Tests
- atterberg limits
- grain size analysis

C. Landslides The following information is needed at all locations along the pipeline route where landslide hazard maps or black and white aerial photographs, possibly supplemented by infared imagery, indicate the potential for slope instability.

Seismic Hazard

- estimated peak horizontal ground acceleration with recurrence intervals of 50, 100 and 500 years at potential landslide sites.

Seismic Resistance

- location of pipeline with respect to potentially unstable slope
- resistance coefficient from conventional slope stability analysis using Bishops or other methods

D. Wave Propagation Effects

Seismic Hazard The following information is needed at a number of locations equally spaced along the pipeline route. The spacing between these locations should be about 25 km.

- peak ground velocity with recurrence intervals of 50, 100 and 500 years
- shear wave velocities as a function of depth
- type of faults (strike-slip, normal-slip, etc.) which governs the peak ground velocity (if known)
- distance from governing faults to pipeline

Seismic Resistance The following information is needed for the locations along the pipeline route mentioned above, as well as for all bends or changes in direction of the pipeline.

- pipeline diameter, wall thickness, modulus of elasticity and burial depth
- type and unit weight of backfill soil
- trench or berm geometry
- detail of pipeline joints
- force-deformation and moment-curvature characteristics of joints for segmented pipeline (if available)
- undrained shear strength and/or angle of internal friction for backfill material
- location of anchor points near bends (if any)
- bend radius

References

For an indepth description of the four potential failure mechanisms (fault crossing, liquefaction, etc.) as well as possible methods of analysis and nomenclature, the reader is referred to a pair of recent publications of the American Society of Civil Engineers (345 E 47th St., New York, NY 10017-2398)

- "Advisory Notes on Lifeline Earthquake Engineering," 1983
- "Guidelines for the Seismic Design of Oil and Gas Pipeline Systems," 1984

ITEM 1.1.2

This section contains a proposal for the conduct of a vulnerability analysis of water systems in seismic areas of Mexico and the training of key national personnel. The proposed work plan is composed of two phases with key national personnel participating in both phases. The first phase consists of an analysis of the seismic hazard and seismic resistance of the system in question. National engineers participating in this phase should be either structural engineers with a masters degree and one course in structural dynamics and/or earthquake engineering or geotechnical engineers with a masters degree and one course in soil dynamics and/or earthquake engineering. The present state of technology in lifeline earthquake engineering is such that these engineers would be able to perform certain parts of a analysis after participation in a two or three day short course.

The second phase consists of the preparation of retrofit recommendations and finally preparation of an emergency response plan. A larger group of national personnel will participate in the second phase, including personnel with responsibility for the day-to-day operation of the system. Strictly speaking, preparation of retrofit recommendations and an emergency response plan are not part of a vulnerability analysis. In simple terms, the vulnerability analysis only tells us what is likely to happen. It is strongly recommended, however, that these last two items also be included in the study so that the effects of the earthquake can be reduced by strengthing of the existing system prior to the earthquake (retrofit recommendation) and effective managing of the disaster after it occurs.

Phase I Task 1: Technical Short Course Planning

Michael O'Rourke and personnel at the Institute de Ingenieria NAUM should receive a general description of the pipeline and its route as well as general information on additional system elements such as dams, pump stations, treatment facilities, etc. After review of the material, Michael O'Rourke will be in contact with personnel at NAUM and a tentative schedule and list of speakers for the technical short course will be prepared. The following is a list of potential topics for a technical course on the seismic hazard, seismic resistance and seismic vulnerability of typical water system elements.

- quantification of seismic hazards
- wave propagation effects of buried pipeline and tunnels
- pipeline and tunnel fault crossing
- liquefaction
- equipment tie-down analysis
- seismic effects on building structures, tanks and towers
- seismically induced landslides and rock slides
- seismic effects on dams
- vulnerability analysis

Phase I Task 2: Technical Short Course and Site Visit

This task consists of a meeting between Michael O'Rourke, NAUM participants and key national personnel. The first three or four days will be devoted to the technical short course for key national personnel. Michael O'Rourke and NAUM participants will present technical information on techniques for the seismic hazard, seismic resistance and seismic vulnerability evaluation of water system elements. Appropriate reference materials (generally lecture notes, copies of technical papers, as well as ASCE Advisory Note and Guidelines) will be made available to key national personnel at this time. After the short course, the key national personnel and Michael O'Rourke will spend two or three days visiting the system in question and review the presently available information such as building plans, available soils reports, etc. Responsibility for individual elements of the analysis (i.e., seismic hazard quantification, fault-crossing, liquefaction, etc.) will be assigned to various team members and they will inspect the appropriate system components. Lists of needed additional information (such as black and white aerial photographs, laboratory tests on pipeline components, additional SPT tests, etc.) will be prepared.

Phase I Task 3: Seismic Hazard and Resistance Evaluation

During this task, the various key national personnel will use the reference material distributed at the short course to evaluate the seismic hazard and seismic resistance for their particular area of responsibility. Interim written reports from each of the national personnel will be made available to Michael O'Rourke and NAUM participants for review and comment. In addition, during this period Michael O'Rourke will spend two or three days in Mexico, reviewing progress of this task and answering questions which may arise.

Phase I Task 4: Interim Project Meeting

This task consists of a three day project meeting at which the results of task 3 will be presented by individual team members and reviewed by the group as a whole. At this point, the portions of the system which appears to be most seismically vulnerable will be identified. A national engineer or a NAUM participant will be assigned responsibility for evaluating the seismic vulnerability of the existing system as a whole.

Phase I Task 5: Vulnerability Analysis

The probability and system analysis concepts presented during portions of the technical short course will be used in this task by a national engineer or a NAUM participant to determine the seismic vulnerability of the existing system as a whole. In addition the likely repair time and repair costs for the critical elements will be considered so that the impact of loss of service upon the customers of the present system can be evaluated.

A written final report on the seismic vulnerability of the existing system will be the end product of this task.

The five tasks outlined above encompass a seismic vulnerability analysis of a water system. Although technically not part of a vulnerability analysis, it is strongly recommended that the second phase outlined below be included in the total project. This second phase involves preparation of retrofit recommendations to strengthen the existing system and preparation of an emergency response plan to effectively deal with a earthquake after it occurs.

Phase II Task 1: Emergency Response Planning Short Course

This task consists of a one or two day short course for national personnel who have responsibility for the day to day operation of the water system in question. The national personnel who participated in Phase I will make presentation to the national operators on the likely types and locations for seismic damage to the system. Michael O'Rourke and NAUM participants will present information on general techniques for preparing an emergency response plan as well as examples of existing plans for systems in the United States.

Phase II Task 2: Preparation of an Emergency Response Plan

The Mexican nationals with responsibility for the day-to-day operation of the system will prepare an emergency response plan. This plan will cover items such as primary and alternate location of headquarters, inspection of system elements after the earthquake, communication procedures in the event of loss of electrical power and/or telephone service, inventory of repair materials, mutual aid agreements with neighboring systems, etc. An interim written emergency response plan will be sent to Michael O'Rourke and NAUM participants for review and comment.

Phase II Task 3: Retrofit Recommendations

In this task, the national engineers who participated in Phase I will prepare preliminary designs and cost estimates for strengthening the most seismically vulnerable portions of the system. Note these critical elements will have been identified in Task 4 of Phase I. In some cases these retrofit measures may be fairly simple, such as the design of a small structure to prevent rock fall damage to the pipelines air rejection values or design of hold down bolts and/or seismic bracing for equipment and control panels. These plans will be sent to Michael O'Rourke and NAUM participants for review and comment. During this period, Michael O'Rourke will spend three or four days in Mexico reviewing progress of this task and participating in the Emergency Response Planning Short Course.

Phase II Task 4: Final Project Meeting

This final task consists of a one day meeting between the team members, PAHO personnel and SARH personnel with overall management responsibility for the water system in question. The three products of this study, that is the seismic vulnerability analysis, the emergency response plan and the retrofit recommendations will be presented to the PAHO/SARH people and discussed.

The fee for Michael O'Rourke's participating in the study outlined above is $12,500. This does not include travel or per diem expenses. Michael O'Rourke does not speak Spanish well enough to communicate professionally. Hence, depending upon the English speaking ability of the Mexican participants, it may be necessary to have a translator at the short courses and project meetings. The cost for such a translator in Mexico is not included in the $12,500 fee mentioned above. However, the written reports which are to be sent to Michael O'Rourke for review and commend may be written in Spanish and they will be translated locally (i.e., in New York State) at Michael O'Rourke's expense. Similarly, lecture notes for the short courses and other written communication from Michael O'Rorke will if desired, be in Spanish. The cost for this translation will also be at Michael O'Rourke's expense.

ITEM 1.1.3

In this section some pertinent aspects of the Acueducto Rio Colorado-Tijuana will be briefly reviewed and a proposed schedule for conduct at a seismic vulnerability analysis of the system will be presented.

The system starts in the Mexicali Valley and ends close to Tijuana. The aqueduct is about 70 miles in total length and is mainly composed of buried prestressed concrete pipe of 54", 60" and 72" diameters. The above ground portions of pipe are 54" diameter welded steel pipe. The system has a number of pumping stations and surge tanks, two tunnels, a dam and a water treatment plant. Concerning the seismic vulnerability of the system, two items are of note.

- The system is located very close to the U.S.-Mexican border. This allows us to use information from both Mexico and the U.S. in quantifying the seismic hazard. For example, the Laguna Salada fault which the aqueduct crosses between Mexicali and La Rumorosa was the subject of a Ph.D. dissertation in the U.S.
- A brief review of the design drawings for some of the major structures in the system indicates that seismic loads were considered for the dam, water towers, building structures, etc. However, during a site visit, it seemed that lateral earthquake loads were not considered in the design of auxiliary items such as control panels, motors,

transformers, etc. Hence, a system malfunction due to overturning of control panels at pump stations and/or the water treatment plant, or a system malfunction due to pipeline failure at a fault crossing are probably more likely during a moderate earthquake than system malfunction due to collapse of a water tower or building structure.

Figure 1 presents a proposed schedule for a seismic vulnerability analysis of the Acueducto Rio Colorado-Tijuana. This schedule is based upon the phases and tasks outlined previously.

The one month delay in Phase I between tasks 1 and 2 is to allow time for Michael O'Rourke and NAUM participants to prepare lectures and lecture notes for the technical short course. The duration of Task 3 in Phase I is almost 5 months and is based upon the probable need for laboratory tests at the NAUM on the moment-rotation characteristics of large diameter prestressed concrete pipe joints. This data is needed to determine the seismic resistance of the system's buried segmented pipelines to fault movement.

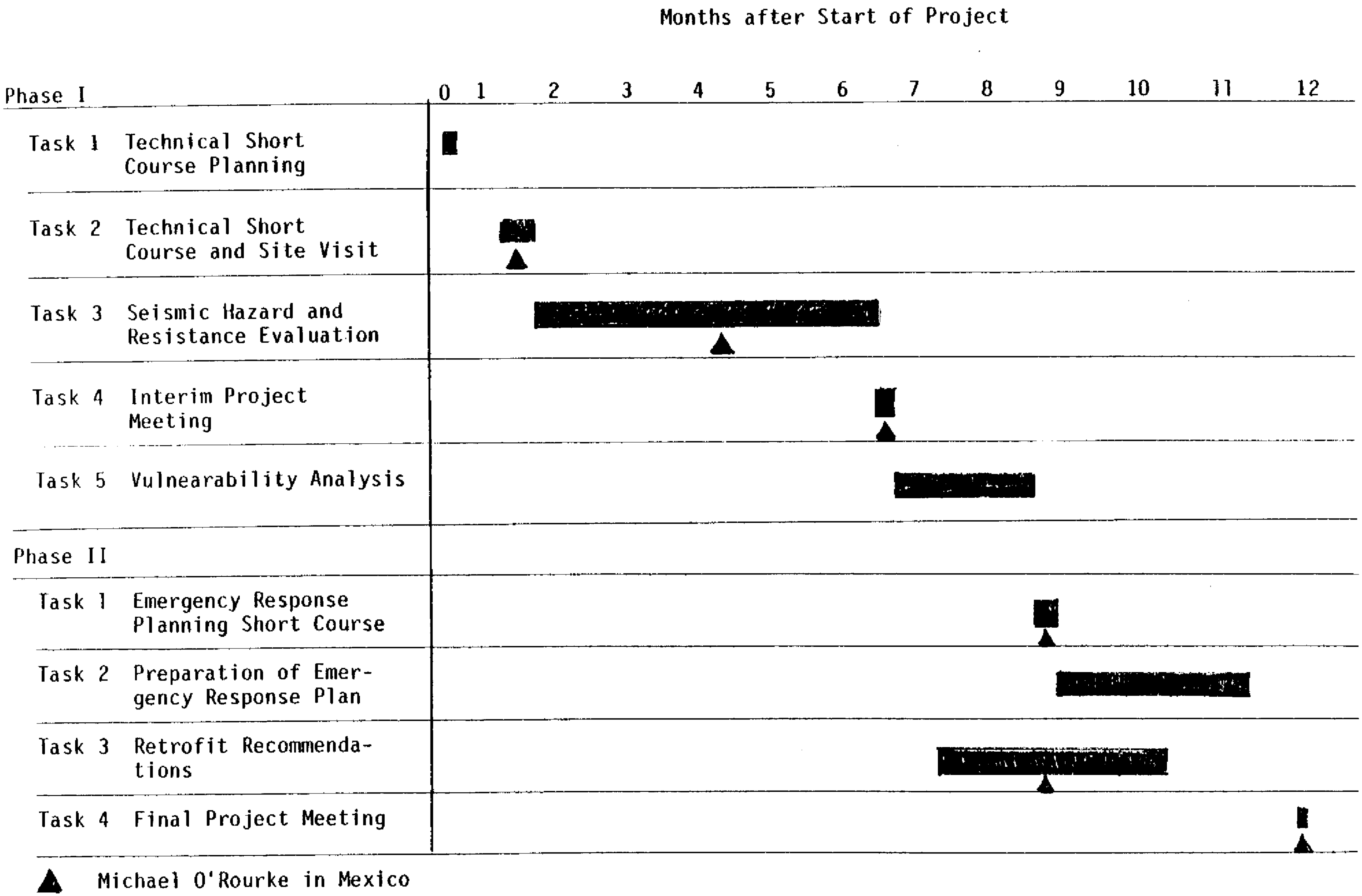

Figure 1 Proposed Schedule for Seismic Vulnerability Analysis of Acueducto Rio Colorado - Tijuana

ITEM 1.1.4

Presented below is a proposed list of participants and their areas of responsibiliies.

Technical short course lectures in Phase I:

- quantification of seismic hazard - Esteva (NAUM), O'Rourke or other NAUM participant
- wave propagation effects on buried pipeline and tunnels - O'Rourke
- pipeline and tunnel fault crossing - O'Rourke
- liquefaction - NAUM participant
- equipment tie-down analysis - Ayala (NAUM) or other NAUM participant
- seismic effects of building structures, tanks and towers - Ayala, Esteva, and/or other NAUM participant
- seismically induced landslides and rock falls - NAUM participant
- seismic effects on dams - NAUM participant
- vulnerability analysis - Gelman (NAUM)
- aerial photo interpretation for landslide potential - NAUM participant or outside expert

Seismic Hazard and Seismic Resistance Evaluation in Phase I

- seismic hazard data - Hungsberg (SARH)
- fault crossing and wave propagation effects - Flores (SARH), Aquilera (SARH) or other SARH structural or geotechnical engineer with a masters degree
- equipment tie-down, buildings, tanks and towers - SARH structural engineer with masters degree
- landslides, rock falls, and dams - Aquilera, Wong (SARH) or other SARH geotechnical engineer with a masters degree
- liquefaction - Wong, Aquilera, Flores or other SARH geotechnical engineer with a masters degree

Vulnerability Analysis in Phase I

- to be done by a SARH engineer with a background in probability, statistics and systems analysis or as an alternative by Gelman of NAUM

Emergency Response Planning Short Course Lectures in Phase II

- general techniques - Gelman and/or other NAUM participant
- existing plans in the U.S. - O'Rourke

Emergency Response Plan Preparation in Phase II

- to be done by SARH personnel with responsibility for day-to-day operation of the Acueducto Rio Colorado - Tijuana

Retrofit Recommendations in Phase II

- to be done by the SARH engineers mentioned in relation to Task 3 Phase I (seismic resistance evaluation).