SCIENTIFIC AND ENGINEERING INFORMATION NEEDS FOR REDUCING EARTHQUAKE HAZARDS TO WATER AND SEWER LIFELINES

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Water and sewer facilities are complex systems involving all engineering disciplines. The design, construction, and retrofitting of these systems has been under study for some years, beginning intensively in this country after the 1971 San Fernando earthquake. A reasonably current overview of the state of the art in this field was included in *Advisory Notes on Lifeline Earthquake Engineering*, published by the American Society of Civil Engineers (ASCE) in 1983.

This listing of the scientific and engineering information needs has been developed as part of a project by the Building Seismic Safety Council (BSSC) involving the development for the Federal Emergency Management Agency (FEMA) of an action plan for the abatement of seismic hazards to lifelines. As part of this project issue papers were prepared on a variety of lifeline topics and a workshop was held. The authors who prepared papers on various aspect of water and sewer lifelines were Donald H. Babbitt, Donald B. Ballantyne, Martin Jaffe,[1] LeVal Lund, James E. McCarty,[1] Michael J. O'Rourke, Lawrence D. Reaveley, Charles H. Trautmann, and Leon Wang and Eiichi Kuribayashi.

In order to simplify the discussion of needs and reduce duplication and confusion, the scientific and engineering needs are grouped here, somewhat arbitrarily, into four categories:

- Performance of existing systems during earthquakes
- Analysis and design tools
- Equipment and material development
- Design codes or standards

The suggestions or recommendations of the paper authors also are summarized below under the same categories. Where duplication occurs, the recommendations have been combined; further, some have not been included if this author believes that the information is already available or not germane.

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[1]See Volume 6 of the proceedings for papers on political, social, economic, legal, and regulatory issues affecting water and sewer lifelines by these authors and others.

Many suggestions or recommendations apply to lifelines as a whole, not just to water and sewer. Further, the issue paper authors offered suggestions and recommendations that applied directly to the action plan and are covered in that document.

PERFORMANCE OF EXISTING SYSTEMS DURING EARTHQUAKES

There are many shortcomings in the knowledge of water and sewer lifeline performance under actual earthquake conditions. Most information has resulted from examination of facilities after an earthquake and, accordingly, is haphazard and incomplete. It is much less extensive than the same type of information available for structures where observation is easier, the area extent is much less, and strong-motion instrumentation has been installed and operated during actual earthquakes. To fill this need for additional information on performance all the water and sewer issue paper authors proposed studies or research. This writer believes the following items cover essentially all the suggestions made under this category.

Strong-Motion Instrumentation

General Information Nationwide

To check the results of analyses, develop attenuation relationships and increase the knowledge of lifeline facility responses, more complete and extensive information on earthquake shaking is needed. Strong-motion programs similar to that in California are needed throughout the country in areas where earthquakes are expected to occur with some regularity. This is a general recommendation applicable to all lifelines as well as all structures in general. (See the papers by Babbitt, Lund, and Wang and Kuribayashi.)

Fault Identification and Fault/Site Attention

Identification of active (capable) faults and improved knowledge of fault-to-site attenuation is essential to continued advance of seismic design. Current efforts should be continued at the present level or increased. This particularly applies to the area east of the Rocky Mountains. This also is a general recommendation applying to all earthquake knowledge needs. (See the paper by Babbitt.)

Performance of Specific Components

Strong-Motion Instrumentation on Pipelines

Observation data on the relative displacement and strain of the soil surrounding pipelines is needed to confirm design considerations for buried pipelines. This data should be developed in connection with strong-motion array networks so that it may be correlated with free field ground motion characteristics. (See the papers by Lund and Wang and Kuribayashi.)

Strong-Motion Measurements on Storage Structures

Data on the behavior of tanks subject to earthquakes by instrumentation of tanks in seismically active areas are needed to assess the adequacy of analytical procedures, to help guide future analytical development, and to determine needs to analytical testing. (See the paper by Lund.)

Pipelines in Soil Liquefaction Environment

Improved analytical/empirical methods for prediction of pipeline response in soil subject to liquefaction are needed. (See the papers by M. O'Rourke and Wang and Kuribayashi.)

Joint Resistance Characteristics

Force-displacement and moment-rotation information on all types of pipe joints is needed to supplement the incomplete information available for some existing pipe elements. The needed information should include performance during actual or simulated (shaking table) earthquakes and laboratory tests under controlled conditions. (See papers by M. O'Rourke and Wang and Kuribayashi.)

Seismic Effects on Equipment

More complete information on the seismic resistance of equipment (i.e., pumps, motors, switchgear, presses, hoists, clarifier mechanisms, etc.) used in lifeline facilities is needed to guide utilities, designers, and builders in the selection and installation of such equipment. (See the paper by Ballantyne.)

Geotechnical Unknowns

Data on Soil Strain Related to Pipelines

A more complete understanding of dynamic soil resistance characteristics as related to seismic response of buried pipelines is essential to the eventual development of a seismic design code for buried pipelines. This should include information on dynamic axial soil resistance under a snaking environment and dynamic lateral soil resistance under liquefaction environment as well as static axial and lateral resistance for fault movement. (See the paper by Wang and Kuribayashi.)

Ground Strain and Curvature at Transition Zones

There is a need for information on the ground strain and curvature environment at transition zones from soft soil to firm soil or rock. Most previous work has focused on amplification or deamplification at transition zones, but information directed specifically at horizontal ground strain at these zones is important in assessing the vulnerability analysis of existing systems. This item is a general need applying to most earth structures. (See the paper by M. O'Rourke.)

ANALYSIS AND DESIGN TOOLS

Earth Structures

Refine Dynamic Analysis and Input

More field work is necessary to refine or redirect the dynamic analysis and input data now being used and to develop knowledge of such important effects as how soils generate and dissipate pore pressures during and after earthquakes. Backfiguring performance of structures during actual earthquakes is vital to this effort. This item is also a general need applicable to most earth structures. (See the paper by Babbitt.)

Dynamic vs. Static Analysis for Embankment and Soil Dams

Studies are needed to establish if there are dependable correlations between static and dynamic analyses, particularly where there is no serious loss of soil strength or cracking of concrete during earthquake shaking. (See the paper by Babbitt.)

Develop an Improved Standard Penetration Test

Research is needed to standardize or replace the Standard Penetration Test. It is, in reality, rarely a standard test; yet, it has a significant effect on the results of dynamic analysis. This suggestion will require general agreement by a broad representative group of the geotechnical engineering community to be successfully pursued and implemented. This item also would apply to other types of lifelines. (See the paper by Babbitt.)

Improved Techniques for Densifying Existing Structures

Better techniques are needed for densifying potentially liquefiable soils, particularly those under existing structures. The current techniques available are very expensive and sensitive to the soil types being treated. This item is a general need applying to earth structures. (See the paper by Babbitt.)

Pipelines and Conduits

Quantify Soil Strain at the Soil-Pipe Interface

Observed data from existing earthquakes and laboratory tests need to be developed to confirm the assumptions on which the current analysis of buried pipelines is based. The popular assumption that the pipe moves exactly with the soil surrounding it needs to be confirmed or modified to reflect what actually occurs. (See the paper by Wang and Kuribayashi.)

Analysis Method for Bends and Junctions

There is need for methods to analyze the behavior at bends and junctions of buried segmented pipelines for seismic wave propagation effects. This should include or at least consider the nonlinear nature as well as the variability of system parameters. (See the paper by M. O'Rourke.)

Techniques for Increasing Redundancy

There is a need for research on techniques to increase the redundancy of new and existing water and sewer systems. Quantitative measures of system redundancy need to be established as well as methods for identifying which new interconnections would be most effective. (See the papers by M. O'Rourke and Trautmann.)

Application of Expert System Techniques to Models

Development of the application of expert system techniques to water and sewer system hydraulic models is needed. This will permit fast solution of emergency system management problems and guide decision making for repair, retrofitting, and increasing system redundancy. (See the paper by Trautmann.)

Tanks, Basins, and Vaults

Buckling Analysis for Steel Tanks

A better understanding is needed of the buckling of the walls of steel tanks under dynamic conditions of loading and of the effect of such buckling on the overall integrity of the tank. Both experimental and analytical studies are needed to define dynamic buckling sufficiently well that the design process can take it into account. (See the paper by Lund.)

Analysis and Design for Unanchored Tanks

Research is needed to improve the present methods of analysis and design of tanks that are not anchored at their base. An improved analysis procedure needs to be developed that properly accounts for the effects of sliding and uplifting of the base and that reproduces, with a reasonable degree of accuracy, the complex nonlinear response mechanisms that experimental laboratory programs have revealed. (See paper by Lund.)

Refine Liquid Sloshing Analysis for Nonlinearity

In evaluating the effects of liquid sloshing, the amplitudes of motion at the free surface of the liquid are considered to be sufficiently small that the response is linear. The influence of multiple short- and long-period liquid sloshing should be investigated, particularly as it affects the integrity of the tank (shell and roof) and appurtenances. Study of the Mexico City experience to determine if the sloshing period is close to the natural period of the site may throw light on this question. If the two periods are similar, the resulting response application should be determined. If this influence is found to be significant, a procedure for including it in the design should be developed. (See the paper by Lund.)

Method for Evaluating Response to Vertical Excitation

A rational method is needed for evaluating the response of tanks to vertical excitation. Design of tanks normally neglects or approximates the effect of the vertical component of ground shaking. Except for some exploratory studies, this problem has not attracted the attention it deserves. (See the paper by Lund.)

Procedures for Retrofitting Existing Tanks and Basins

Simple cost-effective methods need to be developed for retrofitting existing storage tanks and treatment basins that are found to be deficient in seismic resistance. A first step would involve development of low-cost modifications that a utility could apply as part of its regular or everyday maintenance program. The second step would be development of modifications of moderate cost that would increase the seismic resistance of a tank against collapse. (See the paper by Lund.)

EQUIPMENT AND MATERIAL DEVELOPMENT

New or Improved Flexible-Restrained Pipeline Joints

Improved types of pipeline joints are needed to allow larger displacement and absorb more energy during seismic shaking, liquefaction, and fault movement. Irrespective of the type of seismic hazard (i.e., fault crossing, wave propagation, etc.), the joints in segmented buried pipelines are the elements that suffer damage. An improved joint needs to be flexible but also restrained and able to accommodate, without leakage, significant rotation and longitudinal movement between two pipe segments. (See the paper by Wang and Kuribayashi.)

Improved Connections for Piping to Structure

Research is needed on inlet-outlet piping for storage tanks, treatment basins, and other massive structures. These are vulnerable points where there have been many failures during earthquakes. The investigation should include tests, both field and laboratory, on existing methods of connection such as bellows joints, flexible ball joints, combinations of sleeve type joints, offsets and angle fittings, etc. The program should quantify the performance of existing methods and develop new or improved systems that can be depended upon to perform adequately under specified conditions. (See the papers by Ballantyne and Lund.)

Improved Expansion, Contraction, and Construction Joints

Expansion, contraction and construction joints in concrete structures are vulnerable to damage and failure during earthquakes, particularly when the reinforcing steel does not extend through the joint. Under earthquake shaking, the opposed faces of the joint tend to pound together, often damaging the water stop, if any, and spalling the concrete. This particularly occurs when the mass on the two sides of the joint are significantly different or a change of alignment occurs. The investigation should include both field and laboratory tests and should quantify performance of the various methods now used to construct such joints as well as develop improved designs. (See the papers by Ballantyne and Lund.)

Reduced-Cost Seismic-Resistant Equipment

There is a need for more seismically resistant equipment at competitive prices. It is proposed that a program be instituted to perform shaking-table testing on a line of standard equipment. This could include motors, pumps, hoists, presses, mixers, scrapers, compressors, and any other equipment used in water and sewer facilities. Equipment weaknesses could be identified and the design could likely be improved at nominal costs. To be successful, this work should involve joint efforts by equipment/material manufacturers and academia/consulting engineers. (See the paper by Ballantyne.)

DESIGN CODES OR STANDARDS

Aseismic Design Code for Water and Sewer Systems

The long range goal for abatement of seismic hazards for water and sewer systems should be the development of a design code or design standard. In order to develop such a standard, further research on ground motion characteristics, pipeline response behavior under a liquefaction environment, and basic dynamic soil and joint resistance characteristics should be carried out as described above. Work on the ground strain environment at transition zones and on the behavior of bends and junctions is also needed before the standard is developed. This code or standard should probably be a separate effort from the development of standards for design of treatment, pump and well facilities. (See the papers by M. O'Rourke, Trautmann, and Wang and Kuribayashi.)

Design Manual for Treatment, Pumping, and Well Facilities

A manual of practice or standard should be developed for the design of treatment, pumping and well facilities for seismic hazards. This manual development should have input from across the industry including utility representatives, academia, consulting engineers, equipment and material suppliers. It is believed that sufficient scientific and engineering information is available to begin the preparation of such a manual in the immediate future. (See the paper by Ballantyne.)