LIFELINE EARTHQUAKE ENGINEERING

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ence contained 26 technical sessions, including plenary sessions, that provided an overview of global philosophies and a panel discussion on lifeline earthquake engineering.

The conference was organized and convened by ASCE under the direction of the Technical Council on Lifeline Earthquake Engineering. The Conference Organizing Committee included the following persons:

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The Organizing Committee extends special thanks for the financial support and cooperation of the National Science Foundation, the Federal Emergency Management Agency, and the Civil Engineering Department of the University of California at Los Angeles.

Each of the papers included in the *Proceedings* has been accepted for publication by the Proceedings Editor. All papers are eligible for discussion in the appropriate journals of ASCE. All papers are eligible for ASCE awards.

Michael A. Cassaro
Editor

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LIFELINE EARTHQUAKE ENGINEERING
AT THE TURN OF THE CENTURY

by

W. J. Hall, Honorary Member ASCE*

INTRODUCTION AND BACKGROUND

The author considers it a singular honor to be the first recipient of the C. Martin Duke Award under the auspices of the Technical Council on Lifeline Earthquake Engineering (TCLEE) of the American Society of Civil Engineers (ASCE), and takes this opportunity to thank all those who made it possible.

The author knew Martin Duke, and admired his vision, leadership and perseverance in working to establish this council. It had been apparent in many of the earlier earthquakes, about which Martin Duke wrote summary papers, as for example the 1957 Mexican Earthquake and the 1960 Chilean Earthquakes, that lifelines of various types were subject to damage in the same manner as buildings. Moreover he was acutely aware of the vital importance of lifelines to the personal well being of the public as well as to the sustaining infrastructure required by society today. The 1964 Alaskan Earthquake, which has been accorded the most detailed documentation of damage to date, confirmed without doubt to the world the vulnerability of lifelines, and the effect of damage to lifelines on the population and general well being of society.

The occurrence of the 1971 San Fernando Earthquake in the Los Angeles area provided the final motivation for Martin Duke to work in earnest for establishment of a group within ASCE devoted to the study of lifelines. Martin Duke was a man of many accomplishments as outlined in his biography. The author's remembrances of Martin

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Duke are many, but most importantly his genuine interest in people and their activities, his vision and leadership, and the ability to inspire others to achieve beyond their dreams. These are the hallmarks of a true leader.

Within a broad definition lifelines can be defined as those utilities, facilities, structures and equipment that make up much, but not all, of the fabric of our infrastructure, whether it be in a rural or urban setting. The field of lifeline earthquake engineering can be subdivided generally into the subject areas listed below.

Electric Power and Communications
Gas and Liquid Fuels
Transportation
Water and Sewage

In addition there are other important aspects of study and concern surrounding the field of lifeline earthquake engineering, and in most respects these are of equal importance. A limited list of these topics includes the following.

Seismic Risk
Political, Economic, and Social Issues
Legal and Regulatory Issues
Engineering and Medical Services
Education

Some lifelines should be able to function immediately after an earthquake (sometimes during an earthquake) to facilitate search and rescue, and to support emergency services. There are other classes of facilities that should be able to be repaired and put back in service relatively quickly in order to provide for the movement of goods and services required for population sustenance, and for post earthquake reconstruction. As a result of urbanization many lifeline systems have become extremely large and complex, and detailed considerations of reliability and redundancy are mandatory in assessing preparedness, especially in terms of having assurance that the systems can be made to function immediately after an earthquake disaster.

There is a special class of facilities, often included with lifeline descriptions and containing some overlap, that must remain operational before, during and after an earthquake, namely police and fire services, communications, emergency rescue services, and medical and hospital facilities. Such facilities often are termed "critical facilities," and should receive special

design attention to be sure that they possess the ability to withstand earthquake effects in the manner desired.

As might be surmised the list of items in our infrastructure that could fall under the foregoing classification umbrella is immense; this fact alone points up why governmental and private sector leaders should make an assessment of just how prepared they are, or should be, in the event of an earthquake. At this time, following the 1989 Loma Prieta Earthquake, the Seismic Safety Commission of California is engaged in just such an activity for California state-wide governmental agencies. The Veterans Administration embarked on a successful upgrading effort for its hospitals immediately after the 1971 San Fernando Earthquake. Only recently has the federal government begun embarking on such a plan for its buildings and facilities. Many private firms in turn have elected to conduct earthquake-based physical vulnerability studies to help assure that their employees work in a safe environment, to protect their investment and economic viability, and to help ensure protection of the environment.

With these brief introductory observations the next logical step is to examine the origin and purposes of TCLEE.

STATUS OF LIFELINE EARTHQUAKE ENGINEERING

The first definitive published papers on the subject of lifelines were written by Martin Duke and his colleagues (Refs. 5, 6, 7, and 10) at about the time TCLEE was being formed. The Technical Council on Lifeline Earthquake Engineering was founded by ASCE on July 15, 1974. The purpose, as noted in the 1975 ASCE Official Register (and even today) is as follows: "To establish the means by which the civil engineering profession can undertake a comprehensive role in elevating the state of the art of lifeline earthquake engineering. The present technology is dangerously underdeveloped, no major organization is committed to the problem area, and the Society's goals and structure correspond uniquely with the dimensions of the problem."

For purposes of official record the makeup of the Executive Committee of TCLEE from its inception to the present is given in Table 1. Since these listings are not easily obtained, for purposes of historical record the listing has been prepared in some detail. This roster is interesting in terms of examining the range of professionals who have played a role in moving the field

TABLE 1

TECHNICAL COUNCIL ON EARTHQUAKE ENGINEERING

EXECUTIVE COMMITTEES

(TCLEE Founded in 1974)

1975	C. M. Duke (Chairman), R. V. Whitman, R. Sosa, B. A. Lewis, L. L. R. Crandall*
1976	R. V. Whitman (Chairman), B. A. Lewis, V. A. Smoots (S), C. M. Duke, J. E. McCarty, L. L. R. Crandall*
1977	B. A. Lewis (Chairman), J. E. McCarty, V. A. Smoots (S), C. Martin Duke, N. M. Newmark, L. L. L. R. Crandall*
1978	J. E. McCarty (Chairman), N. M. Newmark, V. A. Smoots (S), B. A. Lewis, M. W. Dowd, L. LR. Crandall*
1979	N. M. Newmark (Chairman), M. W. Dowd, A. S. Veletsos (S), V. A. Smoots, J. E. McCarty, B. A. Lewis*
1980	M. W. Dowd (Chairman), V. A. Smoots, D. J. Nyman (S), N. M. Newmark, W. F. Anton, B. A. Lewis*
1981	V. A. Smoots (Chairman), W. F. Anton, D. J. Nyman (S), M. W. Dowd, N. M. Newmark, W. J. Hall, B. A. Lewis*
1982	W. F. Anton (Chairman), W. J. Hall, D. J. Nyman (S), L. V. Lund, V. A. Smoots, B. A. Lewis*
1983	W. J. Hall (Chairman), L. V. Lund, D. K. Ostrom (S), W. F. Anton, D. J. Nyman, J. E. McCarty*
1984	L. V. Lund (Chairman), D. J. Nyman, D. K. Ostrom (S), O. W. Steinhardt, W. J. Hall, J. E. McCarty*
1985	D. J. Nyman (Chairman), O. W. Steinhardt, D. K. Ostrom (S), J. Isenberg, L. V. Lund, M. W. Dowd*
1986	O. W. Steinhardt (Chairman), J. Isenberg, J. D. Cooper (S), D. K. Ostrom, D. J. Nyman, M. W. Dowd*
1987	J. Isenberg (Chairman), D. K. Ostrom, D. B. Ford (S), J. D. Cooper, O. W. Steinhardt, M. W. Dowd*
1988	D. K. Ostrom (Chairman), J. D. Cooper, R. T. Eguchi (S), D. B. Ford, J. Isenberg, M. W. Dowd*
1989	J. D. Cooper (Chairman), D. B. Ford, A. J. Schiff (S), D. K. Ostrom, R. T. Eguchi, L. V. Lund*
1990	D. B. Ford (Chairman), R. T. Eguchi, M. A. Cassaro (S), J. D. Cooper, D. B. Ford, L. V. Lund*
1991	R. T. Eguchi (Chairman), A. J. Schiff, D. B. Ballantyne (S), M. A. Cassaro, D. B. Ford, L. V. Lund*

Notes: (S) denotes Secretary, * denotes Management Group Contact Member to its present state. One hastens to add, however, that the list represents but a small portion of those many dedicated engineers and scientists who have contributed so greatly to the field of lifeline earthquake engineering. To everyone, including those assembled here today, I thank you for your efforts. This TCLEE activity is evidence of what can be accomplished by a dedicated group of individuals who possess vision. In the years ahead there is much additional and valuable effort that remains to be undertaken, as shall become evident later herein.

Each year the members of TCLEE present and publish papers on many different aspects of lifeline earthquake engineering, under auspices of the various ASCE activities. Many participate in workshops and short courses. Some of the papers appear in the journals of the society, some in articles in Civil Engineering, and much of the work has been summarized in reports and guideline documents available from ASCE. A list of these documents as published by ASCE over the years is presented in Table 2.

The major lifeline activities of the profession are focused in the Technical Council on Lifeline Earthquake Engineering, ASCE, and carried out through the active committee structure which is reformed from time to time. The details of this committee structure are contained in the ASCE Official Register. Some other ASCE Divisions handle various aspects of lifeline activities from time to time as may be appropriate, and these activities have led to some significant contributions as well.

The members of TCLEE, as would be expected, are active in other organizations, a principal one being the Earthquake Engineering Research Institute (EERI) where many outstanding contributions to the lifeline earthquake engineering field may be found in their various publications, educational programs and workshops. One of the largest technical summary endeavors in lifeline earthquake engineering in recent years was sponsored by the U. S. Federal Emergency Management Agency (FEMA) and conducted by the Building Seismic Safety Commission (BSSC) in 1987 (Ref. 2); as might be expected, ASCE TCLEE members played a major role in the preparation of those documents.

Lifeline design and research activities are prevalent in other organizations in the United States as well, for example in the American Society of Mechanical Engineers (ASME). In other countries throughout the world, as we shall learn from the other keynote addresses presented at this conference, a number of professional

TABLE 2

PUBLICATIONS ISSUED UNDER AUSPICES OF THE

TECHNICAL COUNCIL ON EARTHQUAKE ENGINEERING

AMERICAN SOCIETY OF CIVIL ENGINEERS

Advisory Notes on Lifeline Earthquake Engineering (1983)

Annotated Bibliography on Lifeline Earthquake Engineering (1980)

The Current State of Knowledge of Lifeline Earthquake Engineering (1977)

Guidelines for the Seismic Design of Oil and Gas Pipeline Systems (1984)

Lifeline Earthquake Engineering Performance, Design and Construction (1984)

Lifeline Earthquake Engineering: The Current State of Knowledge (1981)

Lifeline Seismic Risk Analysis -- Case Studies (1986)

The Mexico Earthquakes 1985: Factors Involved and Lessons Learned (1987)

Recent Lifeline Seismic Risk Studies (1990)

Seismic Design and Construction of Complex Civil Engineering Systems (1988)

Seismic Evaluation of Lifeline Systems -- Case Studies (1986) organizations and societies are active in this area and carry out major activities. Many important contributions in lifeline earthquake engineering appear in the proceedings of international conferences, including the proceedings of the World Conference on Earthquake Engineering. In the immediate years ahead we can expect to see additional international activities in this area focused through the evolving programs associated with the International Decade on Natural Disaster Reduction (IDNDR); ASCE activities in this case are coordinated directly by a committee on Natural Disaster Reduction.

ADVANCES IN LIFELINE EARTHQUAKE ENGINEERING

Advances in lifeline earthquake engineering have followed slightly behind those of the earthquake engineering field generally, for it has been necessary first to undertake the basic work in geotechnical engineering, soil dynamics, structural dynamics, etc., as a basis for technical developments in lifeline earthquake engineering. As the populations of the world (along with urbanization) have increased during the 20th Century, as our understanding of the processes leading to earthquakes and their effects has improved, and as we have observed and learned from earthquakes, it has been possible to make many advances in earthquake engineering, including lifelines. The principal advances might be categorized as arising from a better understanding of the following topics, clearly not an all-inclusive listing.

Fault source studies
Measures of energy -- magnitudes
Prediction studies
Attenuation of motions
Earthquake motion effects
(acceleration, velocity, displacement)
Response and design spectra characterization
Liquefaction, slope stability, and ground spreading
Zonation approaches
Soil-structure interaction
Post-earthquake investigations
Probabilistic hazard assessment
Risk analysis
Building code advances
Social and economic investigations
Preparedness studies
Insurance studies
Education

The research that lead to these advances was sponsored and undertaken by a broad group of physical and social scientists, engineers and others. There were many driving "forces" that lead to these rapid advances over the past two decades. Among them was the U. S. Government Earthquake Hazard Reduction Act of 1977 which in a limited form is still in effect today. Coupled with that was the work necessitated by large energy projects (for example, nuclear power plants, offshore platforms and large pipelines) where the importance in terms of public safety, the environment, and the desire to protect investment mandated seismic design and special construction. Also, it had become obvious from seismic events throughout the world that emergency and critical facilities generally needed upgrading especially in high seismic hazard zones.

The results of the research conducted by universities, private corporations and their institutes, non-profit research laboratories, and governmental laboratories and agencies has been made available in various forms, namely reports, guideline documents, and codes and standards. Today it is difficult to locate some of the cognizant materials, although repositories at Berkeley, CA, California Institute of Technology, Pasadena, CA, and The State University of New York (SUNY) Buffalo, NY will make searches, which can quite helpful. Periodically it is necessary to take stock of the "state-of-the-art" and three such examples are provided by Refs. 1, 2, and 4.

Professional Responsibility and Ethics -- A great deal of the improvements in professional practice in the earthquake engineering field, and especially in lifelines, have occurred through a "learning from earthquakes" process, which incidentally has been formalized by the Earthquake Engineering Research Institute with sponsorship by the National Science Foundation (NSF), and through studies of the Applied Technology Council (ATC). As a part of such endeavors, of which there are many conducted by a host of groups and individuals, many engineers, scientists and others are able to observe the results of "good" and "not so good" design and construction processes, some of recent origin and some quite old. Those individuals reporting on such observations carry a heavy responsibility to report on their observations in a manner consistent with high professional standards and ethics.

OBSERVATIONS ON DESIGN PRACTICE AND OPTIONS

It seems appropriate to make a few brief observations about some facets of design practice that may be of interest to others, especially to indicate the breadth of the technical endeavors involved with lifeline engineering. For purposes of illustration the author is restricting his observations to the field of gas and liquid fuel lifelines. Similar observations, equally comprehensive, could be made for any other lifeline area.

By way of review and background, the seismic design of a major fuel (energy bearing) pipeline involves a whole host of activities, ranging from establishment of the project (normally based on perceived or actual market need), financing, selection and procurement of right-of-way, pump station and terminal siting, facility, pipe and equipment procurement, and the obtaining of a multitude of local, state and federal permits; such activity requires the professional efforts of many diverse disciplines. A major block of effort is connected with planning and design to preclude any major effect on the environment.

On a major project this activity is normally followed by geological and seismological studies, the development of design criteria for seismic effects as well as for normal loadings, and preliminary system design. The geotechnical effort involves design of the site, including foundation design with attention to liquefaction, slope stability and related factors.

In the case of the structural/mechanical seismic design for aboveground facilities (pump stations, compressors, heat exchangers, communication modules, computers, motor controls, transformers, control consoles, etc.) the seismic design involves evaluating the item to be sure that the item and its supports can withstand the appropriate inertial forces in conjunction with other loadings, can accommodate relative displacement, and that it is anchored appropriately.

Several modes of pipeline placement, some connected with special large projects, are presented in Fig. 1. In contrast to what might be deduced from the figure, most pipelines are below ground for aesthetic, convenience, functional, and safety reasons.

Inertial effects rarely have any significant effect on below-ground items unless they are mounted within or on another item. Ground motions (including relative displacements) and loss of support (including ground instability) are the primary seismic factors of design concern. In addition, the designer must be cognizant of changes in "system stiffness" during the design process. In all the cases just cited the seismic effects must be appropriately combined with the other normal (including possible overload) conditions, in the light of applicable

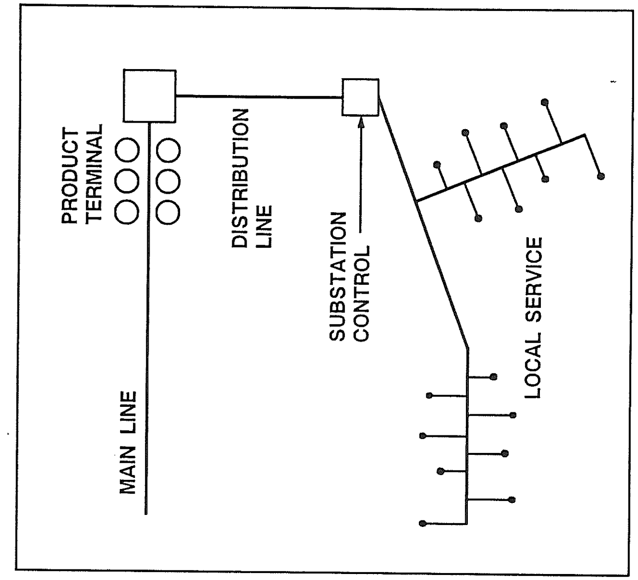

FIG. 2 SCHEMATIC OF PRODUCT DISTRIBUTION SYSTEM

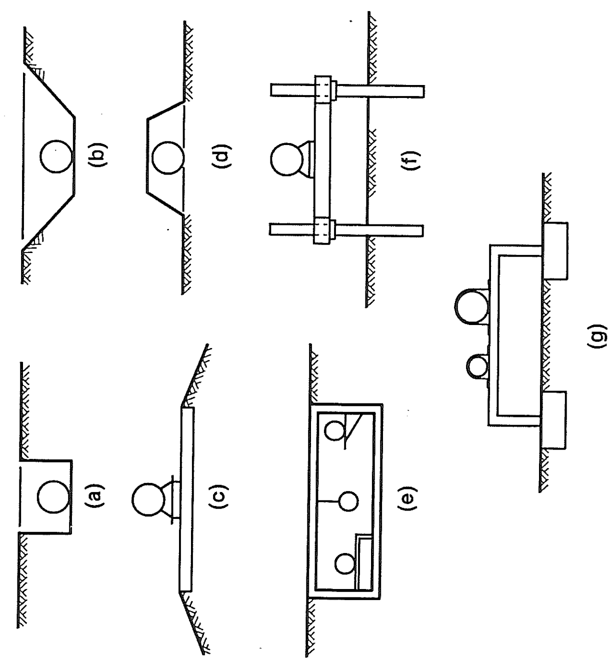

FIG. 1 PIPING CONFIGURATIONS

codes and standards, as well as the construction mode, and with environmental issues in mind. Specifically in the case of pipelines careful consideration must be given to the pipeline strain limits and the propensity for wrinkling or buckling under the various design loading and distortional conditions.

Obviously, engineering assessment of the major applicable effects, and the appropriate combining of effects, as they may affect the performance is a major part of the design process. Examples of external and internal effects referred to include dead loads, live loads of many kinds including pressure, thermal effects, induced seismic loadings, wind loading effects, and distortional (associated with relative displacement or ground spreading), fault crossing, and buoyancy effects. Engineering attention also should be given to long term effects, as for example possible corrosion, valve performance after years of operation, and instrumentation reliability.

Considering the approximations inherent in seismic criteria, dynamic analysis, and design, uncertainties in loadings must be balanced against the resistance provided to withstand these loadings. Also, the experienced designer must make some assessment of the reserve margin of strength to assure that the local detail and total system design is adequate should there be some degree of overload, i.e. for conditions not precisely in line with the design criteria. Rarely will the "loading" or "combined loadings" be precisely as predicted; however, the design process should be structured so as mitigate any surprises. Finally, all of this effort is of little or no avail if the materials employed in construction, the details, and the construction techniques are not of high quality.

At the other extreme, the design of a local distribution system (Fig. 2), including service connections to homes, businesses and factories, is handled in a more direct yet carefully controlled manner, with attention to burial conditions, valving and controls. Of importance are such matters as safety in the household, and provision for relative ease of modification and repair as required. The investment in the local distribution system may involve large sums of money as well.

In both cases it is possible that in later years it might be ascertained that the seismic hazard was greater than originally envisioned and safety considerations, or protection of investment, calls for some action. At that

point the owner has several options, namely do nothing (unwise under most circumstances, but occasionally in some cases deemed to be the proper course of action), take action to upgrade the strength in some manner if economically plausible and even possible, or take steps to enhance safety in some manner (for example, enhanced control through area isolation by valving on feeder lines).

In the case of a major pipeline one might elect to increase the number of isolation valves, strengthen some equipment items, select and arrange for a redundant routing system, or undertake upgrading of operational procedures (Refs. 8 and 9). In the case of the distribution system, especially in a highly seismic area, the decision may be to install automatic shut-off valves in all homes and at selected locations in the supply lines, although any of these actions needs to be carefully thought through as to every possible ramification, including social, economic and legal considerations, not to mention relighting costs in the case of gas service.

In light of the developments in recent years, and in cases where significant investment of resources takes place, a probabilistic risk assessment can be helpful, especially if the results are carefully presented and interpreted with the final decision body in mind. The public perception of risk is becoming difficult to gage, especially in those cases where there seems to be a built in tolerance to casualty statistics (Ref. 3), something that needs to be examined in the light of lifeline systems. More specifically, effort needs to be devoted to finding ways to present the results of such studies in a manner readily and easily understood by the engineering profession at large, as well as the lay public.

A well executed risk analysis can serve several useful purposes. It can indicate the weak links (areas of uncertainty) in a system and thereby help to focus attention on an important entity of the system in terms of possible upgrading or replacement. Also, it may aid in the decision process as to whether or not any changes should be made in the system, or lead to the decision to accept the public risk, environmental damage, and the economic loss associated with a significant earthquake. These decisions in all cases require careful consideration of public and employee safety.

SUGGESTIONS FOR FUTURE ACTIVITY

There is much yet to be done in terms of lifeline earthquake engineering and related activities. Among the items that might be addressed are the following, again using oil and gas pipelines as an example in some cases. The list could be expanded greatly if all lifeline areas are included.

Prepare technical guideline material that can be updated regularly for each of the various major lifelines topics, with subsection manuals as appropriate. These documents should not be substitutes for codes and standards, but should provide suggestions for design, analysis, construction practice, and improved maintenance procedures. The increasing cost of new systems served to emphasize attention of "life-extension" matters. At the same time they should be rich source documents for understanding the behavior of such lifelines, and thereby for criteria development.

Among the various technical activities there should be developed additional material on desired performance and potential fragility criteria. In the pipeline area, for example, a great deal of additional work needs to be undertaken on allowable pipe strain criteria as related to desired performance. Another lifeline topic needing attention is that of fire; earthquakes and fire go together.

Since public safety issues are becoming more important in everyday design, attempt to address these matters in a manner that will be of value to the public at large, the owner and/or manager of the system, as well as the designer and constructor. Similarly address pertinent environmental matters for each lifeline system, especially cost-effective provisions that will enhance protection of the environment.

Develop instrumentation for monitoring performance under normal and possible anticipated overload conditions, as well as instrumentation or other devices that can be employed to assess damage after an earthquake. In another vein, what "high tech" instrumentation and materials can be adapted readily to lifeline systems.

Prepare educational material that supplements the technical guideline material. The goal is to get the designer/analyst to "think" lifeline earthquake engineering as part of his/her normal professional practice. Similar material should be prepared for the owner and management. In the long term such an

approach will lead to a better overall quality facility, one that operates more efficiently and reliably and at the same time reduces liability considerations.

For certain classes of lifeline systems (especially gas, water, sewage and power) prepare appropriate educational material for the lay public. This material might be part of a larger package incorporating preparedness and post-earthquake recovery activities. Present recommendations that are simple and practical. Also, make the literature readily available and easy to obtain.

Work on new techniques for carrying out, interpreting, and presenting the results of risk studies as outlined earlier in this paper.

The roles of "vision" and "challenge" are still with us in this field. Indeed there is plenty to do so let us get on with the tasks. Truly I am honored by this award. Thank you.

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   Volume 4. Papers on Power Lifelines
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LIFELINE EARTHQUAKE ENGINEERING IN JAPAN A STATE-OF-THE-ART

Tsuneo KATAYAMA[1]

ABSTRACT

This is a subjective state-of-the-art report on the lifeline earthquake engineering in Japan. Beginning from the difference between civil engineering and building engineering in Japan, the paper briefly describes the evolution in the said field since early 70's. Depicted are the importance of and the lessons from the 1978 Miyagi-ken-oki earthquake in the Japanese lifeline earthquake engineering. Conservatism is one of the most notable characteristics in the earthquake-resistant design in Japan. It is stressed that good maintenance of lifelines in the ordinary times is by itself the most effective preparedness effort, and that this notion is beginning to be understood especially by large lifeline utilities.

INTRODUCTION

In writing a state-of-the-art report, the reviewer often faces two contradictory queries. At one hand, such a paper is considered to be more objective than subjective, meaning that one should summarize what has been and is going on in the particular field of interest by getting rid of one's personal feelings and opinions as much as possible. On the other hand, unless the reviewer expresses his/her subjective views, the report tends to become dreary and flat.

I have decided to incorporate my subjective opinions in this paper more than other reviewers might do. This, however, seems to have made this state-of-the-art paper rather an unusual one without a list of many references. I would like to include some of the efforts being made by Japanese utilities, which are not always directly aimed at seismic

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