

# **Lifelines 2022**

## **1971 San Fernando Earthquake and Lifeline Infrastructure**

Selected Papers from the Lifelines 2022 Conference

Online

31 January – 11 February 2022

### **Editors:**

**Craig A. Davis**

**Kent Yu**

**Ertugrul Taciroglu**

ISBN: 978-1-7138-6367-0

**Printed from e-media with permission by:**

Curran Associates, Inc.  
57 Morehouse Lane  
Red Hook, NY 12571



**Some format issues inherent in the e-media version may also appear in this print version.**

Copyright© (2022) by American Society of Civil Engineers  
All rights reserved.

Printed with permission by Curran Associates, Inc. (2023)

For permission requests, please contact American Society of Civil Engineers  
at the address below.

American Society of Civil Engineers  
1801 Alexander Bell Drive  
Reston, VA 20191  
USA

Phone: (800) 548-2723  
Fax: (703) 295-6333

[www.asce.org](http://www.asce.org)

**Additional copies of this publication are available from:**

Curran Associates, Inc.  
57 Morehouse Lane  
Red Hook, NY 12571 USA  
Phone: 845-758-0400  
Fax: 845-758-2633  
Email: [curran@proceedings.com](mailto:curran@proceedings.com)  
Web: [www.proceedings.com](http://www.proceedings.com)

# Contents

## *The 1971 San Fernando Earthquake*

<b>Research Review Summary of the San Fernando Earthquake .....</b>	<b>1</b>
Murathan Saygılı, Doğukan Yıkılmaz, and Onur Behzat Tokdemir	
<b>Van Norman Complex Retrospective Risk Evaluation: Assessing the San Fernando Dam Performance during the San Fernando Earthquake.....</b>	<b>13</b>
Martin W. McCann Jr., Jinal Jainesh Mehta, Craig A. Davis, and David L. Freyberg	
<b>Upper San Fernando Dam Construction Methods and Implications on the Modeling of Its Seismic Performance .....</b>	<b>25</b>
Craig A. Davis, Jean-Pierre Bardet, and Jianping Hu	
<b>Lessons Learned from the Observed Seismic Settlement at the Jensen Filtration Plant in the San Fernando Earthquake .....</b>	<b>37</b>
Robert Pyke	
<b>Caltrans Seismic Retrofit Program after the 1971 San Fernando Earthquake.....</b>	<b>48</b>
Mark Yashinsky, Tom Ostrom, Fadel Alameddine, and Toorak Zokaie	

## *Plenary Keynote Presentation*

<b>Measures for Enhancement of Earthquake Resilience of Waterfront Energy Industries.....</b>	<b>61</b>
M. Hamada	

## *Communication and Electric Power*

<b>Experimental and Numerical Investigation of Submarine Telecommunication Cable Responses to Earthquake-Induced Seabed Movements.....</b>	<b>71</b>
Xiaogang Qin, Cuiwei Fu, and Yu Wang	
<b>Seismic Analysis and Design of Offshore High-Voltage Cable in Young Bay Mud for M7.8 Earthquake on the San Andreas Fault.....</b>	<b>82</b>
Vladimir Calugaru, Ahmed Nisar, Christopher Hitchcock, Eric Fujisaki, Henry Ho, and Brian Low	
<b>A Key to Community Earthquake Resilience Is Neglected.....</b>	<b>91</b>
Anshel J. Schiff	

*Gas and Liquid Fuels*

- Preliminary National-Scale Seismic Risk Assessment of Natural Gas Pipelines in the United States.....99**  
N. Simon Kwong, Kishor S. Jaiswal, Nicolas Luco, Jack W. Baker,  
and Kristin A. Ludwig
- Evaluation of Flooding Potential on Gas Pipelines in Tulare County, California.....111**  
Milad Ketabdar, Mehrshad Ketabdar, Karineh Gregorian, and Soheil Oruji
- Seismic Design of Pipeline Considering Pressure and Tensile Properties.....121**  
Nobuhisa Suzuki and Takekazu Arakawa

*Transportation: Roads and Railroads*

- An Integrative Framework to Measure the Impacts of Earthquake-Induced Landslides on Transportation Network Mobility and Accessibility .....133**  
Shangjia Dong, Haizhong Wang, Michael J. Olsen, Andre R. Barbosa,  
and Michael D. Bunn
- Evaluation of Equivalent SDOF Method for Nonlinear Dynamic Response Analysis of Railway or Highway Embankments.....143**  
K. Sakai and Y. Muroso
- Functional Damage and Recovery of Highway Networks in Major Earthquake Disasters in Japan.....154**  
Nobuoto Nojima and Hiroki Kato
- Risk Management System for Road Networks Exposed to Natural Hazards .....166**  
Alondra Chamorro, Tomás Echaveguren, Eduardo Allen, Marta Contreras,  
Pablo Cartes, Manuel Contreras, Gustavo Jimenez, Carlos Pattillo,  
Hernán De Solminihac, José Vargas, Joaquín Dagá, and Felipe Baratta

*Transportation: Bridges*

- Development of the Passive Damper System Realizing the Negative Stiffness Control.....178**  
A. Toyooka and O. Kouchiyama
- Deployment of Sustainable Practices Using Lightweight Aggregates for Bridge Infrastructure .....187**  
Fariborz M. Tehrani
- Seismic Fragility Assessment of Seismic Isolated Bridges in Cold Climates.....198**  
A. H. M. Muntasir Billah and Asif Iqbal

<b>Study on Self-Centering Seismic Isolation at the Bottom of Fixed Pier in Continuous Bridge .....</b>	<b>210</b>
Fang Rong	

<b>Assessing Direct and Indirect Long-Term Economic Impacts from Earthquakes to the US National Bridge Inventory .....</b>	<b>223</b>
Kishor S. Jaiswal, N. Simon Kwong, Doug Bausch, David J. Wald, Kuo-Wan Lin, Sharon Yen, Jerry (Jia-Dzwan) Shen, and Jeffrey Ger	

<b>Assessing Cost Efficacy of the Caltrans Phase I and Phase II Bridge Retrofit Program.....</b>	<b>235</b>
Charles Huyck and ZhengHui Hu	

*Transportation: Ports*

<b>Seismic Response of Container Cranes and Effects on Wharf Response and Crane Structure Performance.....</b>	<b>246</b>
Erik Soderberg, Derrick Lind, and Di Liu	

<b>Numerical Assessment of the Contribution of Liquefaction and Directivity on the Seismic Displacement of a Quay Wall during the 2014 Cephalonia, Greece, Earthquakes .....</b>	<b>256</b>
George Zalachoris, Dimitrios Zekkos, Adda Athanasopoulos-Zekkos, Nikos Gerolymos, and Yiannis Tsiapas	

*Transportation: Subways*

<b>Nonlinear Seismic Response and Damage Analysis of a Prefabricated Subway Station Structure .....</b>	<b>267</b>
Lianjin Tao, Cheng Shi, Peng Ding, Shang Wu, Sicheng Li, and Linkun Huang	

<b>Historical Progression of Los Angeles Metro Seismic Design Criteria.....</b>	<b>281</b>
Martin B. Hudson, Geoffrey R. Martin, and Androush Danielians	

<b>Seismic Design of Los Angeles Underground Transit Stations .....</b>	<b>297</b>
Martin B. Hudson, S. H. Jason Choi, William H. Hansmire, and Kenneth S. Hudson	

<b>Seismic Design Approach for Underground Structures of Los Angeles Metro Regional Connector Transit Corridor Project .....</b>	<b>308</b>
S. H. Jason Choi, William H. Hansmire, Zsolt Horvath, and Carlos Herranz	

*Water and Wastewater*

<b>Functional Damage of Water Supply Systems due to Power Outages during Recent Natural Disasters in Japan .....</b>	<b>322</b>
Yoshihisa Maruyama and Shigeru Nagata	

<b>Deterministic Optimization Model for Budget Allocation to Seismic Risk Mitigation for Water Distribution System.....</b>	<b>329</b>
Elnaz Peyghaleh and Tarek Alkhrdaji	
<b>Enhancing Chances for Water to Cross the San Andreas Fault in the Elizabeth Tunnel.....</b>	<b>344</b>
Jeffrey R. Keaton	
<b>Earthquake Response, Vulnerability Assessment, and Rehabilitation of Water Conveyance Tunnels in High Seismic Hazard Regions: Whitewater Tunnel No. 2 Seismic Resilience Study .....</b>	<b>356</b>
Kingsley C. Ozegbe	
<b>Seismic Resilience of the Colorado River Aqueduct Casa Loma Siphon: A Century of Evolution .....</b>	<b>369</b>
Tao Peng and Cathy Chau	
<b>Design of Metropolitan Water District’s Replacement of Casa Loma Siphon Barrel No. 1 Project, San Jacinto, California.....</b>	<b>381</b>
Darren Baune, Justin Davidson, Tim Taylor, Mike Dadik, Mahmoud Hachem, Roger Parra, Robert Givler, Ross Hartleb, Cathy Chau, and Tao Peng	
<b>Seismic Resilience in Design of New Water Supply Systems: A Natural Disaster Resilience Framework Informed by Lessons Learned from the 2011 Tohoku Earthquake and Tsunami Crisis .....</b>	<b>392</b>
Michael J. Britch	
<b>A Seismic Fragility Framework for Earth Dams.....</b>	<b>405</b>
Ellen M. Rathje and Jingwen He	
<b>Comparative Study on Seismic Performance Analysis Methods of Water Distribution Systems .....</b>	<b>416</b>
Benwei Hou, Xitao Ma, Liyun Li, and Can Ren	
<b>Quantifying Earthquake Hazards to Lifeline Systems at a Regional Scale with a Study of the Los Angeles Water System Pipeline Network .....</b>	<b>428</b>
Kenneth S. Hudson, Martin B. Hudson, Jianping Hu, Alek Harounian, and Marshall Lew	
<b>Regional-Scale Seismic Vulnerability Assessment of Medium-Sized Water and Wastewater Systems .....</b>	<b>440</b>
Jenny Taing, Ahmed Nisar, Christopher S. Hitchcock, Matthew Bates, and Richard Blackmun	

<b>Vulnerability Assessment of Portland Water System in an M9 Cascadia Subduction Zone Earthquake .....</b>	<b>448</b>
Ahmed Nisar, Ryan M. Nelson, Christopher Hitchcock, Vladimir Calugaru, and Michael W. Greenfield	
<b>Seismic Resilience: Orange County Sanitation District Is Planning for 2030 and beyond through a Risk-Based Evaluation of Their Process Facilities .....</b>	<b>456</b>
Don Cutler, Chris Conkle, Doug Lanning, James Doering, Chris Hunt, and Ahmed Nisar	
<b>Assessment of the Seismic Vulnerability, Risk, and Resilience of Water Systems of Four Municipalities in Mexico City .....</b>	<b>467</b>
A. Gustavo Ayala and Marco A. Escamilla	
<b>Hetch-Hetchy Water Supply Reliability across Sunol Valley .....</b>	<b>478</b>
Nikolay Doumbalsi, Annie Li, and Ahmed Nisar	
<i>Water and Wastewater Pipelines</i>	
<b>Effects of Ground Strain and Pipeline Orientation on Pipeline Damage during Earthquakes .....</b>	<b>489</b>
Selcuk Toprak, Engin Nacaroglu, Muhammet Ceylan, and T. D. O'Rourke	
<b>Seismic-Resistant Pipeline Design: Parametric Study of Axial Connection Force Capacity .....</b>	<b>500</b>
Hailey-Rae Rose, Brad P. Wham, Shideh Dashti, and Abbie B. Liel	
<b>Multistep Pipe-Soil Interaction Analysis That Accounts for Liquefied Residual Soil Strength .....</b>	<b>515</b>
Yuxin (Wolfe) Lang, Geoffrey Bee, Rajiv Joiya, and Todd LaVielle	
<b>Seismic Vulnerability Assessment of Wastewater Pipelines .....</b>	<b>525</b>
Ronald T. Eguchi, Zhenghui Hu, Yajie Lee, William P. Graf, and Steven Nebozuk	
<b>Seismic Resiliency Evaluation of a Structural Cured-in-Place Pipe Liner for Water Mains .....</b>	<b>537</b>
Martin Bureau and Thomas Denis O'Rourke	
<b>Three-Dimensional Numerical Modeling and Full-Scale Tests of Cured-in-Place Pipe .....</b>	<b>548</b>
C. Argyrou, T. D. O'Rourke, J. E. Strait, and M. N. Bureau	
<b>Fault Rupture of Pipeline with Cured-in-Place Pipe .....</b>	<b>559</b>
T. D. O'Rourke, M. N. Bureau, B. Berger, B. Wham, and J. Strait	

<b>Seismic Performance Assessment of Water Pipes Retrofit with Corrosion–Protection–Liner Technology .....</b>	<b>569</b>
Zilan Zhong, Jinqiang Li, Yabo Zhang, and Benwei Hou	
<b>Seismic Resilience of Carbon Fiber Reinforced Polymer Renewed Riveted Steel Pipe Using Finite Element Modeling .....</b>	<b>582</b>
Ali Alavi and Graham Bell	
<b>A Novel Steel Pipe Joint for Enhancing Pipeline Seismic Resilience I: Development and Validation.....</b>	<b>592</b>
Spyros A. Karamanos, Brent D. Keil, Richard D. Mielke, Fritz Gobler, Gregory Lucier, Gregory C. Sarvanis, Giannoula Chatzopoulou, and Dimitris Fappas	
<b>Verification of the Applicable Range of Large Diameters in the Design Formula of Buried Pipelines Undergoing Fault Displacement .....</b>	<b>601</b>
Nobuhiro Hasegawa, Yusuke Ono, Junji Kiyono, and Takanobu Suzuki	
<b>Study on SPF Application for Ground Settlement .....</b>	<b>613</b>
H. Nakazono, N. Hasegawa, and K. Taniguchi	
<b>Study of Analysis Method on Behavior of Seismic Type Ductile Iron Pipes Considering Decrease of Ground Stiffness in Embankment Failure .....</b>	<b>621</b>
Koichi Morimoto, Masakatsu Miyajima, and Masato Imagawa	
<b>Damage Mechanism of Large-Diameter Ductile Iron Pipes Used to Supply Water during the 2018 Earthquake in Osaka, Japan.....</b>	<b>633</b>
Yasuko Kuwata and Hiromi Sakurai	
<b>Effectiveness of Water Supply Pipeline Systems Using Ductile Iron Pipes and Seismic Resistant Joints against Heavy Rain and Typhoon Disasters in Japan.....</b>	<b>644</b>
Fusanori Miura, Takeshi Hara, Toshio Toshima, and Akira Miyamoto	
<b>Lifeline Infrastructure Systems for Your Water Supply, Transmission, and Distribution Systems: A Step-Wise Approach to the Design and Construction of Seismic-Resistant Pipe, Fittings, Valves, and Fire Hydrants.....</b>	<b>654</b>
Maury D. Gaston	
<b>Contaminant Migration from Polymer Pipes to Drinking Water under High Temperature Wildfire Exposure.....</b>	<b>666</b>
Erica C. Fischer, Brad P. Wham, and Amy Metz	



<b>Utility-Academic Collaborative Partnership to Test, Evaluate, and Install an Innovative Seismic Pipeline Replacement Solution .....</b>	<b>677</b>
Brad P. Wham, David H. Katzev, Cory R. Innotic, and Jessica L. Ramos	
<b>Design Method of Pipeline in Shield Tunnel against Fault Displacement .....</b>	<b>688</b>
Keita Oda, Shogo Kaneko, and Shozo Kishi	
<b>The Design Approach to the Cross-Harbour Pipeline, Wellington, New Zealand .....</b>	<b>698</b>
Gareth Cowles, Hayden Pipe, and Ioannis Antonopoulos	
<b>Geotechnical Challenges in the Cross-Harbour Pipeline, Wellington, New Zealand .....</b>	<b>706</b>
Ioannis Antonopoulos, Ken Clapcott, Hayden Pipe, and Gareth Cowles	
<b>Seismic Reliability Assessment of Buried Pipelines Subjected to Significant Permanent Ground Deformations in an M9 Cascadia Subduction Zone Earthquake .....</b>	<b>716</b>
Vladimir Calugaru, Ahmed Nisar, Christopher Hitchcock, Michael W. Greenfield, and Ryan M. Nelson	
<b>Seismic Response of Pipelines from Multi-Point Shaking Table Tests .....</b>	<b>727</b>
J. Y. Han, M. H. El Naggar, Z. K. Guo, L. Y. Li, B. W. Hou, and X. L. Du	
<b>Nonlinear 3D Dynamic SSI Analyses of a Caisson Wall to Protect Filter Outlet Conduit at Diemer Plant in Yorba Linda, California .....</b>	<b>739</b>
Mohsen Beikae	

### *Critical Facilities*

<b>Reducing Extreme Flooding Loads on Essential Facilities via Elevated Structures.....</b>	<b>755</b>
Anis Hasanpour and Denis Istrati	
<b>Multi-Hazard Seismic Risk Assessment of a Cooling Water Delivery System .....</b>	<b>767</b>
Mohamed M. Talaat and Philip S. Hashimoto	

### *Infrastructure System Resilience and Interdependencies*

<b>Assessing Lifeline Interdependencies and Restoration Performance in San Francisco Using Qualitative Methods.....</b>	<b>782</b>
Laurie A. Johnson and Danielle H. Mieler	
<b>Using Global Variance-Based Sensitivity Analysis to Prioritize Bridge Retrofits for Low-Probability, High-Cost Earthquakes .....</b>	<b>797</b>
Gitanjali Bhattacharjee and Jack W. Baker	

<b>Building Seismic Resilience into a Regional Water System .....</b>	<b>809</b>
Albert J. Rodriguez	
<b>Probabilistic Seismic Risk Evaluation of the City of Los Angeles Water System Pipeline Network.....</b>	<b>819</b>
Yajie Lee, Zhenghui Hu, Jianping Hu, Alek Harounian, Martin B. Hudson, Kenneth S. Hudson, and Ronald T. Eguchi	
<b>Seismic Maintenance of Water Pipe Networks Using Stochastic Combinatorial Optimization.....</b>	<b>833</b>
B. Pudasaini and S. M. Shahandashti	
<b>Agents of Change for Resilient Infrastructure.....</b>	<b>844</b>
T. D. O'Rourke	
<b>Next Generation Hazard Resilient Infrastructure.....</b>	<b>854</b>
T. D. O'Rourke, B. Wham, B. Berger, C. Argyrou, and J. E. Strait	
<b>Impact of CyberShake on Risk Assessments for Distributed Infrastructure Systems .....</b>	<b>869</b>
Yajie Lee, Christine Goulet, Zhenghui Hu, and Ronald T. Eguchi	
<b>Resilience of Water Distribution Network: Enhanced Recovery Assisted by Artificial Intelligence (AI) Considering Dynamic Water Demand Change .....</b>	<b>880</b>
Xudong Fan and Xiong (Bill) Yu	
<b>Probabilistic Resilience Distance Measures and Application to Rural Power Distribution System.....</b>	<b>892</b>
Prativa Sharma and ZhiQiang Chen	
<b>Overview of a Framework to Engineer Infrastructure Resilience through Assessment, Management, and Governance.....</b>	<b>901</b>
Craig A. Davis, Bilal Ayyub, Sue McNeil, Kiyoshi Kobayashi, Hirokazu Tatano, Masamitsu Onishi, Yoshikazu Takahashi, Riki Honda, John van de Lindt, and Toshio Koike	
<b>Systemic Seismic Vulnerability and Risk Assessment of Urban Infrastructure and Utility Systems.....</b>	<b>914</b>
A. Poudel, S. Argyroudis, D. Ptilakis, and K. Ptilakis	
<b>Evaluating the Importance of Interdependent Civil Infrastructure System Components for Disaster Resilience of Community Housing.....</b>	<b>927</b>
Nikola Blagojević, Nathalie Lauber, Max Didier, and Božidar Stojadinović	

*Debris Removal*

**Evaluating the Impact of Equipment Selection on Debris Removal and Dependent Lifeline Infrastructure Recovery .....938**

Joseph Louis, Akash Vijay, Haizhong Wang, and Daniel Cox

**Managing Debris Clearance from Road Transportation Networks after Earthquakes .....948**

Alessandro Cardoni, Sebastiano Marasco, Marco Domaneschi, and Gian Paolo Cimellaro