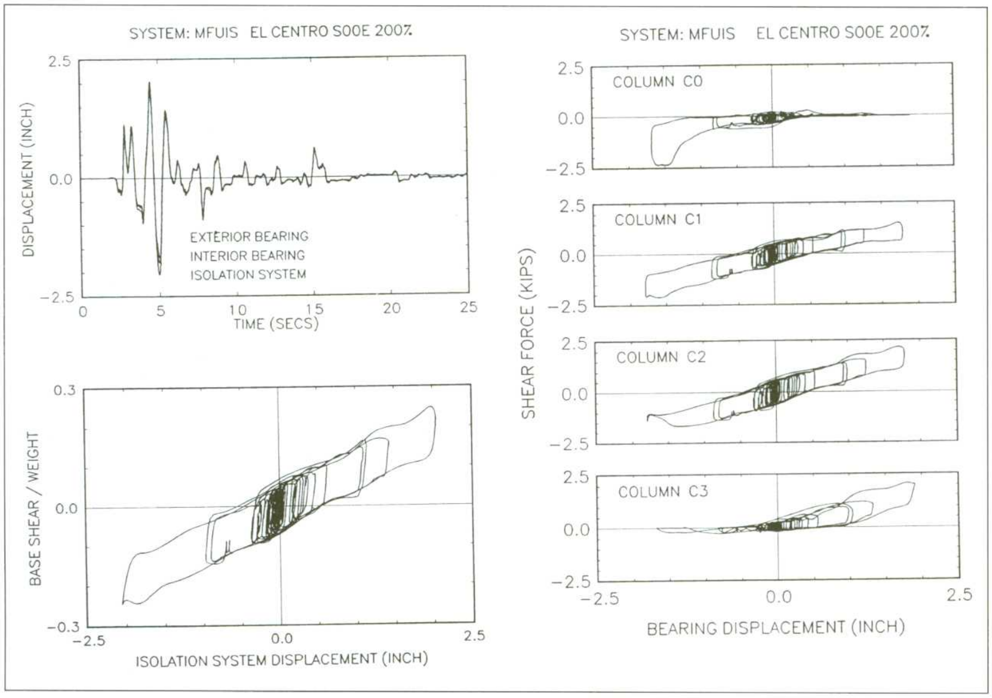


Figure 4
Response of Isolation System in El Centro 200% Test.

U.S. Court of Appeals Buildings, San Francisco

The U.S. Court of Appeals building in San Francisco is an early example of American Renaissance Style and is the only such example in the western United States. Constructed in 1905, it features granite exterior walls, marble columns and statues, hand-painted murals and mosaic tile floors. Figure 5 shows the ornate interior and exterior of the building.

The building has plan dimensions of 95 m by 81 m and overall height of 25 m above street level. It consists of a full basement, four floors and two mezzanines. Its weight is approximately 57,000 metric tons. The courthouse survived the great San Francisco earthquake of 1906, but was damaged in the 1989 Loma Prieta earthquake. Damage to the interior tile walls, which formed part of the lateral load resisting system, significantly reduced its seismic resistance. The owner, the General Services Administration, closed the building while investigating retrofitting methods. Seismic isolation was selected over conventional retrofitting schemes because it afforded the greatest degree of seismic protection, had the least impact on the building's historic and architectural character and had the least life-cycle cost.

The FPS system was selected based on cost and technical merit. The technical reasons for the selection of the FPS system have been its extensive testing, its low profile, which allowed installation without cutting away part of the foundation's wood pilings, and its unique construction, which minimized transmission of overturning moment to the footings and averted additional reinforcement of the footings.

The in-

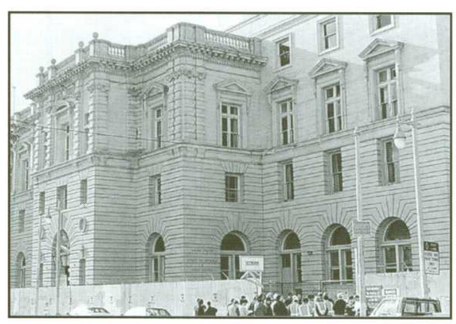


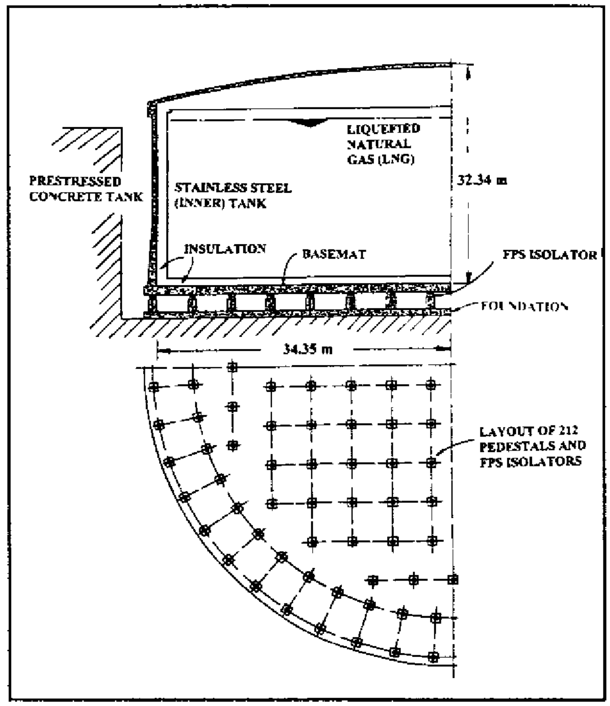
Figure 5
View of U.S. Court of Appeals Building in San Francisco.

stallation of the isolation system was completed in July 1994 It consists of 256 FPS bearings, having a radius of curvature of 1880 mm and displacement capacity of 350 mm. Eight different bearing types carry load in the range of 450 to 5350 kN. Dynamic analyses were performed with the computer program 3D-BASIS (see 3D-BASIS: Computer Program Series for Nonlinear Dynamic Analysis of Three-Dimensional Base Isolated Structures in this volume.)

Liquefied Natural Gas Storage Tanks, Greece

Liquefied Natural Gas (LNG) storage tanks represent critical facilities. Plant-operational and safety aspects dictate designs of these tanks with full containment, as illustrated in figure 6. An inner stainless steel tank contains LNG at cryogenic temperature of about -160°C Approximately 1 m thick insulation surrounds the inner tank. A prestressed concrete outer tank is built around the inner tank and insulation for containing the LNG in the case of rupture of the inner tank, to protect the inner tank against missile or aircraft impact. and to provide support for the insulation and piping systems.

The design of LNG storage tanks is primarily controlled by hydrostatic stresses. LNG has unit weight just less than half that of water. Prior to commissioning, LNG storage tanks are filled with water for testing. This loading condition induces hydrostatic stresses which are larger than the combined hydrostatic stresses caused by LNG fill and hydrodynamic stresses due to moderate seismic excitation. However, above a certain level, seismic loadings begin to become the dominant loading condition. This has been the case for the LNG storage tanks in Greece. Rather than modifying the tank geometry, providing anchorage and accepting yielding of the tank in strong seismic excitation - a situation which may cause inelastic buckling or "elephant foot" buckling - the tanks were designed with an isolation system, which



■ **Figure 6**
Configuration of Isolated LNG Storage Tanks in Greece.

can reduce the seismic forces to a level that hydrotesting becomes the dominant loading case.

The two LNG storage tanks are currently under construction on the Revithoussa island, which is located near Athens. Both are of the same geometry with an inner tank diameter of 65.7 m and height of 22.5 m. The outer tank has a diameter of 68.7 m and height of 32 3 m. The tanks are positioned in excavated pits 24 m deep and 75 m in diameter. The partial burial is for reasons of aesthetics and is not intended for containment. Figure 6 illustrates the tank construction.

The author is a senior consultant to the owner, responsible for the isolation system and inner tank design and quality assurance of the isolation system. In the preliminary design phase, he developed alternative seismic isolation designs and, together with Professor Andrei Reinhorn and Graduate Student P. Tsopelas, developed the computer program 3D-BASIS-ME for use in the final analysis. In January 1994, the FPS isolation system was selected for the project. The design called for 212 bearings per tank on top of concrete pedestals as illustrated in figure 6. The bearing design is nearly identical to the largest size FPS bearing of the U.S. Court of Appeals building. Fabrication of the bearings began in April 1994 in San Francisco. Installation is scheduled for early 1995.

Conclusion

NCEER and Earthquake Protection Systems cooperated on the experimental and analytical study of the FPS seismic isolation system. The system has been rigorously studied over a period of five years and the results have been promptly disseminated to the engineering community. The system has since been selected for the seismic isolation of two major structures, the U.S. Court of Appeals building in San Francisco and liquefied natural gas storage tanks in Greece.

Personnel and Institutions

The primary collaborators were Professors Michael Constantinou and Andrei Reinhorn of the University at Buffalo for NCEER and Dr. Victor Zayas for Earthquake Protection Systems, Inc. The work was carried out by University at Buffalo graduate students Anoop Mokha, T.M. Al-Hussaini and P. Tsopelas.

Publications

Mokha, A., Constantinou, M.C. and Reinhorn, A.M , "Teflon Bearings in Aseismic Base Isolation Experimental Studies and Mathematical Modeling," Technical Report NCEER-88-0038, National Center for Earthquake Engineering Research, Buffalo, N Y., 1988

Mokha, A., Constantinou, M C. and Reinhorn, A.M., "Sliding Isolated Structures Experiments and Mathematical Modeling", Proceedings, 1989 ASME PVP Conference, Hawaii, July 1989, Vol 181, pp. 101-106

Mokha, A., Constantinou, M.C and Reinhorn, A.M., "Teflon Bearings in Base Isolation. Part 1 Testing," Journal of Structural Engineering, ASCE, Vol. 116, No. 2, 1990, pp. 438-454.

Mokha, A., Constantinou, M.C. and Reinhorn, A M., "Teflon Bearings in Base Isolation Part 2. Modeling," Journal of Structural Engineering, ASCE, Vol. 116, No. 2, 1990, pp. 455-474.

Mokha, A., Constantinou, M C. and Reinhorn, A M., "Experimental and Analytical Study of Earthquake Response of a Sliding Isolation System with a Spherical Surface," Technical Report NCEER-90-0020, National Center for Earthquake Engineering Research, Buffalo, N.Y., 1990.

Mokha, A , Constantinou, M.C. and Reinhorn, A.M., "Further Results on the Frictional Properties of Teflon Bearings," Journal of Structural Engineering, ASCE, Vol 117, No. 2, 1991, pp. 622-626.

Mokha, A., Constantinou, M.C., Reinhorn, A M., and Zayas, V, "Experimental Study of Friction Pendulum Isolation System", Journal of Structural Engineering, ASCE, Vol. 117, No. 4, 1991, pp 1203-1219.

Theodossiou, D., and Constantinou, M.C , "Evaluation of SEAOC Design Requirements for Sliding Isolated Structures," Technical Report NCEER-91-0015, National Center for Earthquake Engineering Research, Buffalo, N Y., 1991.

Tsopelas, P., Nagarajaiah, S., Constantinou, M.C and Reinhorn, A M "3-D-BASIS-M: Nonlinear Dynamic Analysis of Multiple Building Base Isolated Structures," Technical Report NCEER-91-0014, National Center for Earthquake Engineering Research, Buffalo, N.Y. 1991

Soong, T.T. and Constantinou, M.C , "Base Isolation and Active Control Technology-Case Studies in the U.S.A.," Proceedings, IDNDR International Symposium on Earthquake Disaster Reduction Technology, Building Research Institute, Ministry of Construction, Tsukuba, Japan, December 1992.

Mokha, A., Constantinou, M.C. and Reinhorn, A M., "Verification of Friction Model of Teflon Bearings Under Triaxial Load," Journal of Structural Engineering, ASCE, Vol 119, No 1, 1993, pp 240-261.

Constantinou M C , Winters, C.W and Theodossiou, D , "Evaluation of SEAOC/UBC Analysis Procedures Part 2. Flexible Superstructure," Proceedings, ATC-17-1-Seminar on Seismic Isolation, Passive Energy Dissipation, and Active Control, March 1993, San Francisco, CA.

Winters, C.W. and Constantinou, M , "Evaluation of Static and Response Spectrum Analysis Procedures of SEAOC/UBC for Seismic Isolated Structures," Technical Report NCEER-93-0004, National Center for Earthquake Engineering Research, Buffalo, N Y, 1993

Tsopelas, P., Nagarajaiah, S., Constantinou, M.C., and Reinhorn, A.M., "Nonlinear Dynamic, Analysis of Multiple Building Base Isolated Structures," J Computers and Structures, Vol. 50, No. 1., 1994, pp. 47-57.

Al-Hussaini, T.M., Zayas, V.A. and Constantinou, M.C., "Seismic Isolation of Multi-Story Frame Structures Using Spherical Sliding Isolation Systems," Technical Report NCEER-94-0007, National Center for Earthquake Engineering Research, Buffalo, N.Y., 1994

Tsopelas, P.C., Constantinou, M.C., and Reinhorn, A.M. "3-D BASIS-ME Computer Program for the Nonlinear Analysis of Seismically Isolated Single and Multiple Building Structures and Liquid Storage Tanks," Technical Report NCEER-94-0010, National Center for Earthquake Engineering Research, Buffalo, N.Y., 1994.