Stacy Park Reservoir Seismic Retrofit

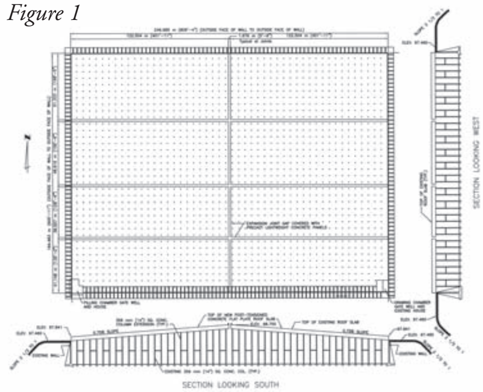
City of St. Louis, Missouri

By Duane L. Siegfried, P.E., S.E. & Amir A. Arab, P.E.

The Stacy Park Reservoir Seismic Retrofit and Horner & Shifrin, Inc. (St. Louis, MO) were presented on Outstanding Project Award (Buildings Under $5M in Construction Value) in the NCSEA 2003 Excellence in Structural Engineering Awards program.

The Stacy Park Reservoir is the primary source of potable water in the City of St. Louis, Missouri. The 600 by 800 by 35-feet deep Reservoir was constructed in 1926 on a hill that provides the pressure needed for distribution in the City. The reservoir features below-grade perimeter concrete buttressed retaining walls, 1,680 interior concrete columns, and a concrete floor and roof slab. In the 1980's, the original concrete roof slab was replaced with post-tensioned concrete slabs. The new roof slab was divided into 8 independent plates to permit temperature movements (see Figure 1). Neither the old roof slab nor the new was tied to the perimeter walls.

Figure 1



The City commissioned a Seismic Vulnerability study by Theiss & Associates in 1992 that identified the Reservoir as a critical disaster recovery element, and one that would suffer severe damage in a strong earthquake. Nearby faults include the New Madrid Fault in southern Missouri and the Wabash Valley Fault in Illinois. As a result of that study, Horner & Shifrin, Inc. was commissioned in 1999 to retrofit the reservoir for seismic loads.

FEMA publication 273 was used as the guide for establishing the performance criteria, recurrence interval, and material behavior for the seismic retrofit. In 1999 this document was relatively new to the Engineering community, and was the result of seven years of development. In consultation with the City, with the guidance of FEMA 273, it was decided the goal for the retrofit would be the "Immediate Occupancy" level of service. This level of service requires all elements of the reservoir to operate within the elastic range, quite a goal for a tall, slender, and brittle structure. It was also decided to retrofit for the 2500 year earthquake, commonly referred to as the Maximum Considered Earthquake, which had a maximum ground acceleration of 0.26g.

Our preliminary design study determined the 1,680 columns were the main vulnerability. These columns are 14 inches square and 35 feet tall, and are braced at mid-height by rigid frame concrete beams (10-inch x 12-inch) in groups of four columns (forming a four column box in plan view). The column deflection prior to retrofit for the 2500 year earthquake was estimated to be 3.1 inches, resulting in flexure and shear failure. The concrete roof slab was divided into eight separate plates with no interconnection, thereby prohibiting diaphragm action. The retrofit had to permit expansion and contraction of these plates. Retrofitting each column and beam was cost prohibitive. Several retrofit strategies were investigated, and two were carried through a schematic design phase: interior shear walls; and a passive seismic damping system installed on the exterior of the reservoir.

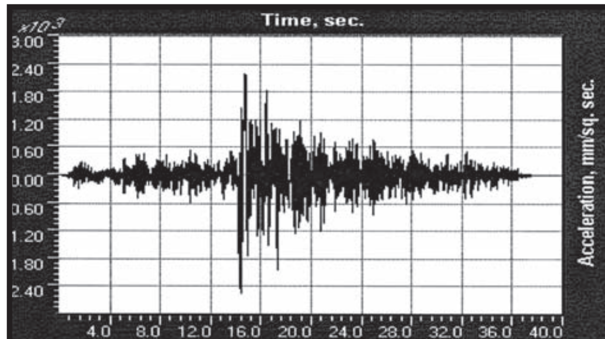


Figure 2

The interior shear wall alternate required that the reservoir be taken out of service for at least 18 months. This would require the addition of pumping capacity in the potable water system, and a temporary reservoir. Another drawback of shear walls is the possibility that they would create "dead zones" in the water flow through the reservoir, leading to a decrease in water quality. The shear wall alternate was found to be feasible and the cost was estimated at $7,000,000.

The exterior passive damping alternate was also found to be feasible. Passive Dampers were arranged to transfer the seismic loads across the plate expansion joints, to the exterior retaining walls, finally resisted by the passive soil pressure. This design required the development of synthetic Time Histories for the faults

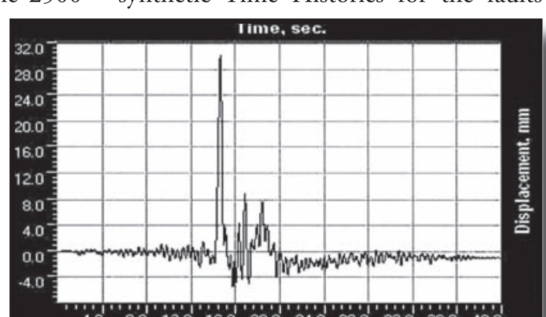


Figure 3

involved. Mr. J.P. Singh, with assistance from the Memphis EERI, provided 6 scaled time histories (see Figure 2). This structural system was non-linear and was analyzed with SAP 2000NL. A range of boundary conditions were analyzed to model the variations in passive soil stiffness, column and wall base fixity, and material properties (see Figure 3). These models were then run with varying coefficients for the non-linear passive dampers to select the optimal coefficients for the damper equation $F = CV^a$ (see Figures 4 and 5 for the schematic analytic models). Based on our analysis, lower values of alpha resulted in better incremental performance (lower column deflections with less resulting damper force). Manufacturing limitations prevent values of alpha lower than 0.3 from being cost effective. As retrofitted, the column deflection was calculated as 1.1 inches, compared to our target of 1.63 inches, or 0.004 times the column height (see Figure 2). The damper alternate bids were well below the project budget at $3,000,000.■

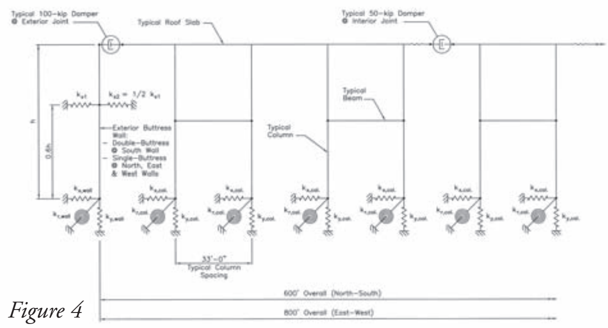
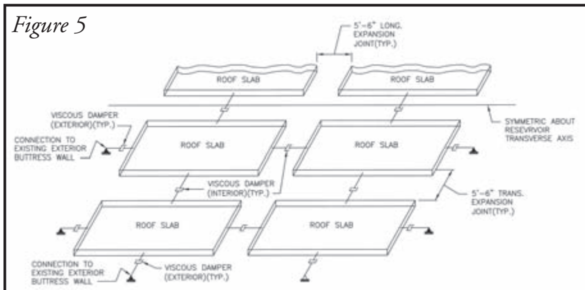


Figure 4

Figure 5



Duane L. Siegfried, Associate Manager of Structural Engineering, Horner & Shifrin, Inc., holds both B.S.C.E. and M.S. degrees and has been responsible for the structural design of buildings, bridges, and navigation structures.

Amir A. Arab, Structural Project Engineer with Horner & Shifrin, Inc. and Guest Lecturer at Southern Illinois University – Edwardsville, has been involved in the structural design of bridges, and buildings with a specialty in finite element analysis.

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Software:

SAP 2000NL by Computers & Structures, Inc., Berkely, CA

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Hollis Riggins Construction Company, St. Louis, MO

Taylor Devices, North Tonawanda, NY

Gate City Steel, St. Louis, Mo.

G&M Steel Fabrication, Crystal City, MO

Collins & Herman, St. Louis, MO

Boyd Contracting, St. Louis, MO

Apex Contracting, Valley Park, MO

Acme Erectors, St. Louis, MO

Cardinal Rebar, St. Louis, MO

Brekenridge Materials, St. Louis, MO

Schaefer-Meyer Seed-Sod Division I, Inc., St. Charles, MO

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