Innovating with Shotcrete

Shotcrete not only gets the job done, but its economy can get you the job

by Merlyn Isaak and Chris Zynda

Properly designed and conscientiously constructed, shotcrete can offer the best of all possible worlds to that most versatile of construction materials — concrete. The four projects profiled here illustrate not only that shotcrete gets the job done, but that its economy gives you a bid that can get you the job in the first place. Three of the four projects were originally designed for cast-in-place concrete, but shotcrete leveraged economy and schedule by reducing formwork costs and by incorporating the shotcrete forms into the structures. The fourth project was a seismic upgrade involving difficult shooting conditions: heavy and congested reinforcing steel and extremely tight shrinkage tolerances. The four projects described are:

Hilton Convention Center Hotel, San Jose, California — The basement walls were originally designed as cast-in-place concrete. A shotcrete system not only saved the cost of cast-in-place concrete formwork, but provided framing for future tenant improvements. The project included shooting a large water reservoir for the fire-protection system.

Capitol Square, Sacramento, California — Shotcrete innovation helped this general contractor win the bid, replacing a scheme based on very large precast panels to be cast off-site, which would have presented major logistical problems.

Hewlett Packard Building, Palo Alto, California — The basement walls were originally designed as cast-in-place concrete. Shotcreting allowed substantial savings in both form costs and construction time, which translated to project schedule gains.

Stanford University Graduate School of Business, Palo Alto, California — This substantial seismic upgrade project involved adding major new shear-resisting elements in an existing concrete framed building. It was notable because of large and congested reinforcement that had to be accommodated and encased.

Many factors were common to all four projects:

1. The wet-mix process was used (a small amount of dry-process was used for overhead elements on the Stanford University project).
2. Design strength equalled 4000 psi.
3. Material had a slump of 2 ± 1 in. (51 ± 25 mm), and was delivered to the jobsites in ready-mix trucks.
4. Cement content was approximately 660 lb/yd^3 (390 kg/m^3).
5. Tall and thick walls (up to 40 ft [12 m] high and 24 in. [610 mm] thick) with heavy reinforcement.
6. Taut high-tensile-strength wire (gaging wire) was used on all projects to control size, shape, and thickness of walls and any structural elements.

Hilton Hotel

Project scope

This project called for subterranean/basement enclosure walls for a 17-story steel frame structure, varying from 9¼ to 12 in. (235 to 305 mm) thick, and averaging 14 ft (4.2 m) high with two curtains of reinforcing steel. An interior water tank, 20 ft wide x 80 ft long x 14 ft high (6 x 24 x 4 m), with 10 in. (254 mm) thick walls, used as a reservoir for the fire protection system, was also included. All elements were designed originally for cast-in-place concrete.

Shotcrete advantages/innovation

The south wall was designed only 12 to 18 in. (305 to 457 mm) from adjacent existing convention center wall. Since this wall could only be shot from inside, a backside form was constructed of water-resistant gypsum board (greenboard) over metal studs that were braced against the convention center wall with removable kickers. Upon completion of the wall (including curing), the kickers were removed and the backside form wall was left in place. The inside space adjacent to this wall consisted primarily of a loading dock area, requiring only a float finish suitable for painting.

The excavation permitted shooting the west and north walls from the outside. Again, the wall was formed using greenboard with metal studs, this time braced with temporary wood braces. Once the shotcrete was cured, the temporary braces were removed and the metal stud wall was left in place to be used for finishing the interior space.

The east wall, including the ramp wall, was formed with MDO (faced) plywood for a finish equivalent to cast-in-place concrete minus form-tie holes.

The subterranean water tank was situated so that some of the structural steel columns had to be encased. Shotcrete considerably simplified and speeded the encasement process by eliminating most of the forming.

Other special features

The congested reinforcement was a major problem. A test panel simulating one of the more difficult situations (six #9 bars in each face of a 2 ft-6 in. [0.75 m] deep beam; see Fig. 1) shot, then dissected by the project inspector prior to final set, indicated no voids or pockets.

Miscellaneous details

Approximately 700 yd^3 (535 m^3) of 4000-psi (28-MPa) shotcrete were used. Mix design (wet-mix process) included 593 lb/yd^3 (352 kg/m^3) of Type II cement; 65 lb/yd^3 (39 kg/m^3) fly ash; 896 lb/yd^3 (532 kg/m^3) saturated surface dry (SSD) coarse aggregate (⅜ in. [9.5 mm] pea gravel); 2034 lb/yd^3 (1207 kg/m^3) SSD fine aggregate (sand); and 325 lb/yd^3 (192 kg/m^3) water. Water reducing/retarding (ASTM C 494 Types B and D) and air entraining (ASTM C 260) admixtures were used, and a liquid membrane was used for curing.

Capitol Square

Project scope

This was a rehabilitation/revision, including partial demolition, of an existing four-level parking garage to allow construction of a high-rise office building on part of the site (see Fig. 2).

Due to on-site space and schedule restrictions, the new walls were originally designed as concrete panels 9¼ in. thick, 40 ft high, and 11 ft-6 in. wide (235 mm x 12 x 3.5 m) to be precast offsite. They were to have numerous welded joint details for panel-to-panel and panel-to-existing floor connections. The formidable logistics involved for casting, shipping, handling, and erecting such large precast panels caused the successful bidding contractor to look at alternatives. One of these was using shotcrete, which eventually gave them the edge to win the contract.

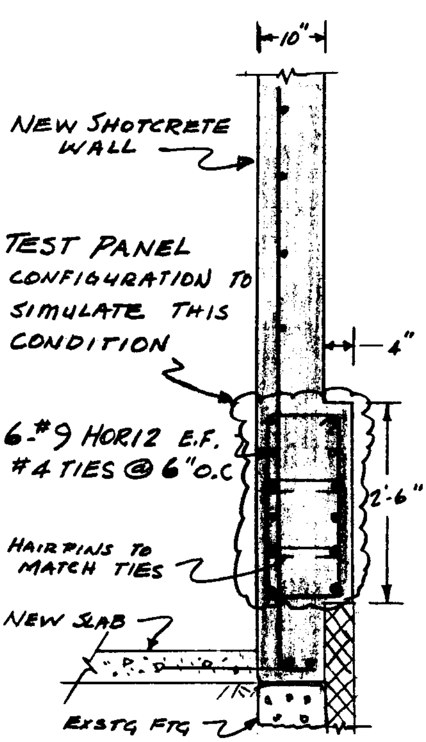

Fig. 1 — Schematic drawing of test panel for Hilton Hotel project.

Shotcrete advantages/innovation

Because some of the space adjacent to the new walls inside the existing structure on the lower floor was going to be converted to retail, office, and storage, the shotcrete scheme incorporated the backing (form) walls into the lower 16 ft (5 m) of the structure in those areas. The backing form was constructed of greenboard over metal studs, with the metal studs on the commercial side. Subsequently, the framing became the support for the new wall covering in the commercial space, thus saving the cost of form materials and form stripping.

The balance of the upper portion of these walls was shot against conventional plywood, which was removed after shotcrete curing.

Using shotcrete eliminated all the welded panel-to-panel joints, and also permitted a less costly attachment of new concrete walls to the existing floor, incorporating existing slab rebar lapped with new rebar into new shotcrete.

Other features

The reinforcement pattern originally designed for the precast panels was retained in the shotcrete version (#4 bars at 10 in. [254 mm] horizontal and #4 bars at 16 in. (406 mm) vertical on each face).

Miscellaneous details

Approximately 540 yd^3 (413 m^3) of 4000-psi (28-MPa) shotcrete were used. Mix design (wet-mix process) included 560 lb/yd^3 (332 kg/m^3) of Type II cement; 98 lb/yd^3 (58 kg/m^3) fly ash; 875 lb/yd^3 (519 kg/m^3) SSD coarse aggregate; 1864 lb/yd^3 (1106 kg/m^3) SSD fine aggregate; and 333 lb/yd^3 (198 kg/m^3) water. Water reducing (ASTM C 494 Type A) and air entraining (ASTM C 260) admixtures were used, and a liquid membrane was used for curing.

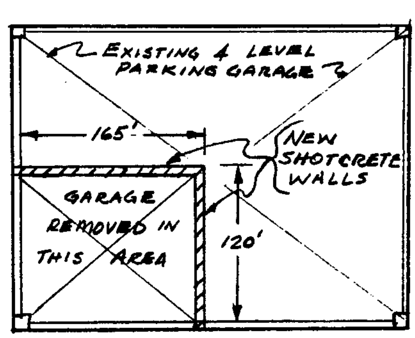

Fig. 2 — Site plan for Capitol Square project; not to scale.

Hewlett Packard

Project scope

This electronics design and manufacturing building has a footprint of approximately 25,000 ft^2 (2320 m^2), with the entire first floor (basement) below grade. The below-grade walls, typically 18 to 24 in. (457 to 610 mm) thick and 24 to 26 ft (7.3 to 7.9 m) high, with a total surface area of 18,000 ft^2 (1672 m^2), were originally designed for cast-in-place concrete.

Shotcrete advantage/innovation

Shotcreting reduced the total wall form surface by one-half, required less forming material due to the nonexistent hydrostatic head, and reduced the form stripping time by one-half. Form simplification gained valuable schedule time for the contractor on this fast-track project.

Site excavation allowed shotcrete to be shot from the outside against form-ply plywood, thus providing a finish comparable to cast-in-place concrete on the inside. A single-waler system was used for forming, and whenever possible on forms adjacent to future cast-in-place concrete elements (i.e. columns, beams, and slabs above), a row of snap-ties was imbedded in the shotcrete with the head projecting approximately 4¼ in. (108 mm) outside the formed side to help form the cast-in-place concrete elements. This greatly expedited the contractor's subsequent forming operations.

Other features

Because of size and spacing (two curtains, one with #9 bars at 6 in. [152 mm] on center, the other with #4 bars at 12 in. [305 mm] on center), one of the early concerns was achieving total encasement of the rebar. Preconstruction test panels simulating wall conditions were shot (below, top) The Capitol Square project included two 40 ft high, 9¼ in. thick wall sections totalling 285 ft in width. (middle) The color difference in this completed wall is a result of finishing technique only. For architectural reasons, the top 4 ft received a "green-float" finish, while the rest got only a wood float finish.

(above) One wall for the Hilton Convention Center Hotel was shot against greenboard and a metal stud form, which was left in place. Limited space against the adjacent wall would have made conventional forming for cast-in-place concrete extremely difficult.

(left) Shotcreting in progress amid heavy reinforcement for the Hewlett Packard Building. (above) The formed side of shotcrete walls shows columns blocked out with stayform. The adjacent embedded snap ties will be used to help form cast-in-place columns.

and later cored, showing no pockets or voids. Furthermore, upon stripping the forms from the structure after curing, no pockets or voids were visible in the entire surface. Daily in-process quality-control test panels for each change in nozzleman and/or each 600 ft² (56 m²) of wall/day further emphasized the importance of quality control.

The concrete columns that were designed integrally with the wall were blocked out using "stayform" (expanded metal mesh) during shotcreting and subsequently cast-in-place because rebar congestion and column depth would not permit a viable shotcreting application. Using stayform proved extremely advantageous because of ease of fabrication and placement, especially around reinforcing steel that was continuous from the wall and into and through the column. An additional advantage was that stayform could be left in place, eliminating form stripping, which also simplified forming the columns for cast-in-place concrete.

Production averaged about 70 to 80 yd³ (54 to 61 m³) per day, shooting the full thickness of the wall between designated column lines in 4 ft (1.2 m) high lifts, up to a level of approximately three-quarters of the total wall height on a given day. This necessitated a construction joint consisting of a 45-deg slope for the full thickness of the wall. Overspraying and cleaning this joint behind two curtains of rebar added some labor hours that could have been avoided or substantially reduced by better planning to avoid the joint. If a joint becomes unavoidable on future projects, we will recommend a horizontal chamfer strip at the top of the 45-deg slope with kraft paper applied to protect the form above the chamfer from the overspray. The paper would be removed at the start of the next day's shooting.

Miscellaneous details

Approximately 1000 yd³ (765 m³) of 4000-psi (28-MPa) shotcrete were used. Mix design (wet-mix process) included 593 lb/yd³ (352 kg/m³) of Type II cement; 65 lb/yd³ (39 kg/m³) fly ash; 896 lb/yd³ (532 kg/m³) SSD coarse aggregate (⅜ in. [9.5 mm] pea gravel); 2034 lb/yd³ (1207 kg/m³) SSD fine aggregate; and 325 lb/yd³ (193 kg/m³) water. Water reducing/retarding (ASTM C 494 Types B and D) and air entraining (ASTM C 240) admixtures were used; slump was 2 ± 1 in. (51 ± 25 mm). Exterior surfaces were travel-finished to receive waterproofing, and curing was by snugly covering the shotcrete surface with a polyethylene sheet.

Stanford University Graduate School of Business

Project scope

This was a seismic upgrade of an existing concrete shearwall building, strengthened by thickening existing shearwalls and adding new ones. Wall thicknesses varied from 18 to 22 in. (457 to 559 mm), with heavy reinforcement.

Where new shotcrete shearwalls were used to augment existing walls, specifications called for roughening all existing surfaces.

Preconstruction test panels were specified that would simulate a worst-case scenario with respect to reinforcement congestion and also to simulate the closure at the top of the new wall where it meets the beam above. Specifications limited the gap between the top of the wall and overhead beam at closure to 1/16 in. (1.6 mm) after final set of the shotcrete. The test panels were also used to prequalify three nozzlemen, each of whom shot one panel.

Extensive coring from front, back, top, and sides, including cutting through rebar, showed no pockets or voids in the panels.

Shotcrete advantage

This project might not have been economically feasible without using shotcrete. Shooting against existing walls essentially eliminated forming costs.

Other aspects

The shooting sequence was critical; due to the wall thickness, slipouts occurred if the rate was too fast. To minimize the plastic shrinkage gap at the wall tops, walls were shot to within approximately 6 in. (152 mm) of the top and allowed to take initial set before shooting the final 6 in. Similarly, the rodmen had to allow about 45 minutes after shooting before striking off the surface.

In some locations, closing the final gap at the top of the wall was complicated by the extent of prior roughening of the existing overhead surfaces. Roughening had been done using bush hammers to achieve a roughness amplitude of ± ¼ in. (6 mm), and because "rougher usually is better," in some locations the amplitude was probably closer to ½ to ¾ in. (13 to 19 mm). But since the previously roughened overhead surface is horizontal, the projections essentially deflected the new shotcrete particles downward, creating minor pockets at the interface/closure joint. Cores were taken at several locations along these joints and, though relatively minor in both size and frequency, the voids were extensive enough to require filling with pressure-injected epoxy. In subsequent areas, roughening was limited to sand blasting, which eliminated the need for epoxy-grouting.

Because of the size of bars and close spacing required, the structural engineer specified swedged couplers on rebar joints to eliminate laps that would have further complicated the shotcrete nozzlemen's ability to achieve total encasement of the reinforcement.

Daily in-process quality-control test panels were shot. In addition, cores were periodically taken from the structure at random locations.

Miscellaneous details

Approximately 900 yd³ (689 m³) of 4000-psi (28-MPa) shotcrete were used during Phase I and II. Mix design (wet-mix process) included 558 lb/yd³ (331 kg/m³) of Type II cement; 100 lb/yd³ (59 kg/m³) pozzolan; 1000 lb/yd³ (593 kg/m³) SSD coarse aggregate (ASTM C 33, size 8 pea gravel); 1937 lb/yd³ (1149 kg/m³) SSD fine aggregate; and 317 lb/yd³ (188 kg/m³) water. A water reducing/retarding admixture (ASTM C 494 Type D) was used; slump was 2 ± 1 in. (51 ± 25 mm). Curing was by snugly covering the shotcrete surface with a polyethylene sheet.

Summary and recommendations

For structural projects such as these, the importance of experienced, qualified personnel cannot be overstated. Documenting that experience, unfortunately, is often overlooked by all involved. This

(above) "Worst-case" simulation test panel for Stanford University project incorporated a simulated concrete soffit. (right) Completed in-fill section of wall.

documentation is critical for nozzlemen in particular to avoid disqualification, which can make the difference between working and not working for both the nozzleman and the contractor. This is a shared responsibility; thus nozzleman and contractor both should keep adequate records of all work performed.

The shotcrete contractor's record-keeping must be thorough, accurate, and detailed enough to substantiate qualifications. A list of submittals for a new project should typically include:

- A brief history of the company, its size, major equipment, type of work, and qualifications of personnel (especially nozzlemen).
- A list of recent similar projects, their size, and names and phone numbers of key potential reference contacts.
- Proposed shotcrete mix design.
- Documentation for mix design ingredients and their properties, where appropriate.
- Material safety data sheets.
- History of some previous similar shotcrete test reports.
- Test panel details (with examples from past projects where similar and applicable).
- Proposed curing procedures.
- Proposed form systems, including preliminary shop drawings where applicable.

For most projects, we recommend a schematic plan outlining the shooting sequence that takes into account scaffold staging, wall thickness, production rates, maximum rates of buildup, construction joints, etc. Simply stated: Too thick, too high, too fast causes problems.

In our experience, using MDO plywood does not gain enough in surface quality or re-use of forms to justify the additional cost.

Shotcrete:	Concrete Structures Associated, Santa Clara, Calif.
Hilton Convention Center Hotel:	
General Contractor:	Devcon Construction, Milpitas, Calif.
Structural Engineer:	Erkel/Greenfield & Assoc., Los Angeles, Calif.
Readymix Supplier:	Central Concrete, San Jose, Calif.
Capitol Square:	
General Contractor:	Hensel Phelps Construction Co., Sacramento, Calif.
Structural Engineer:	Buehler & Buehler, Sacramento, Calif.
Readymix Supplier:	A. Tiechert & Son, Sacramento, Calif.
Hewlett Packard Building 25:	
General Contractor:	Rudolph & Sletten, Foster City, Calif.
Structural Engineer:	Industrial Design Corporation, Portland, Ore.
Readymix Supplier:	Central Concrete, San Jose, Calif.
Stanford University, Graduate School of Business:	
General Contractor:	R. C. Benson, Mountain View, Calif.
Structural Engineers:	Rutherford & Chekene, San Francisco, Calif.
Readymix Supplier:	Graniterock Co., San Jose and Redwood City, Calif.

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