Regular straightedging followed the vibrating screed. Passes of several aluminum or magnesium straightedges in sequence flattened the slab across its width.

Quality control to achieve a superflat floor

A description of the necessary interactions between the concrete supplier, the construction companies and the floor flatness monitor

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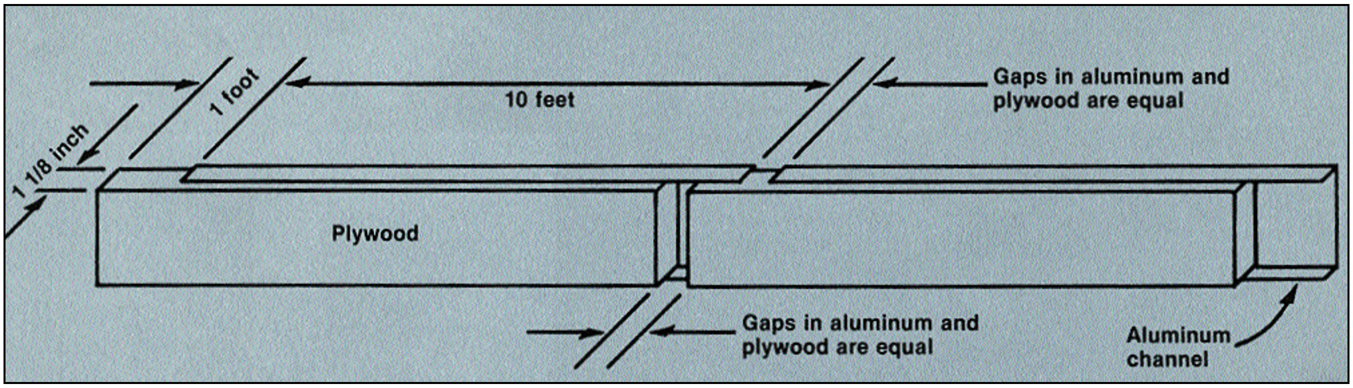
Higher costs for transporting goods have resulted in more regional warehouses being built. But the increased costs of commercial land and the need to reduce forklift travel time have created a demand for high-rack warehouses that use space more productively. Floors in such facilities must be extremely flat to permit adequate forklift speeds without the danger of material falling off pallets while being stored or retrieved.

These are the reasons the Pic 'N' Save Corporation, a large retail chain in the Southwest, selected a superflat floor system. They found it would cost more to build a 1.2-million-square-foot conventional warehouse than an 800-thousand-square-foot building that contained 600 thousand square feet of superflat floor. Such a warehouse allows wire-guided 40-foot-high forklifts to store and retrieve at 7 miles per hour without incident.

After much research and consulting between the owner and The Edward W. Face Company, floor flatness consultants, one of the most coordinated and controlled concrete installations in Southern California was set into motion. The Oltmans Construction Company was selected as the general contractor well in advance of the project start. Preparations began two years prior to construction. The company visited successful superflat installations in two different states and then made a trial run of its own in a tilt-up warehouse where no superflat floor was needed. Special forming placing and finishing procedures were used. Halfway through this trial floor placement, the floor flatness consulting and monitoring company was called to measure the floor with a profilograph machine. While the floor was very good, it didn't measure up to the requirements



Forms specially designed by general contractor contributed to flatness. The design included interlocking of units for continuity of elevation of the top. Spaces between butted ends kept sections from buckling due to the effect of temperature on aluminum or the effect of humidity on plywood. Tops of forms were checked frequently for accuracy of elevation.

that would be needed for high-bay narrow-aisle storage at Pic 'N' Save. During the ensuing year of investigations the general contracting company found that its own construction methods had to be replaced by those recommended by the floor flatness consulting company. The general contractor put together a construction team in which the general contractor installed bulkheads, placed concrete, cured the finished floor and stripped concrete. D & K Flooring Company was responsible for all finishing operations after the concrete was in place and Conrock Co. supplied the concrete.

Unique features

It is recommended that installation of superflat floors be done under an established roof structure. Because this building was to be a tilt-up structure, however, no roof could be erected before floor construction so the weather offered continual placement challenges to the constructors. They experienced an average temperature range of 40° F, winds up to 15 mph, air moisture varying from 20 percent relative humidity to heavy rain and almost every combination of temperature, wind and humidity.

The rules say: "use 12 to 15 men to install 4000 square feet per day." However, the floor finishing company completed over 8300 square feet per day with 10 men for the first three days, then increased output to over 15,000 square feet per day with two 10-man crews for the remainder of the job.

Biggest and fastest

To date this floor in Rancho Cucamonga, California stands as both the largest and most rapidly built superflat concrete warehouse floor. It was by quality control that this team made that achievement on their first attempt.

Formwork

Bulkhead forms were set by the general contractor one day before placing concrete. The subgrade required compaction to 100 percent of maximum density. Forms were installed at the rate of three bays per day—one 590 feet long and two shorter ones of 212 feet each. Form heights were checked four separate times by transit to a tolerance of $\frac{1}{32}$ inch at 6-foot intervals. On the day the concrete was placed forms were checked just before placement, after the concrete was straightedged the second time, and after finishing was completed.

Bulkhead form sections consisting of an aluminum channel face with plywood insert for nailing were devised by the general contractor (see figure). The components were staggered so that individual sections could be easily aligned and overlapped. To allow for $\frac{1}{8}$ to $\frac{1}{4}$ inch expansion and contraction, ends were not butted. Typical temperature differences during the day affected form movements. In the morning when it was cool and damp, the wood absorbed moisture and expanded while the metal contracted. In the afternoon with high temperatures and low humidity, the wood shrank and the metal expanded. Preparations for concreting were completed by placing a special perforated plastic sheeting on the subgrade and setting the reinforcement.

If necessary, the forms were cleaned with a grinder after each use to remove any hardened concrete adhering to the top of the aluminum channel (see cover photo). This helped to eliminate surface irregularities in the concrete caused by roughness on the form edges, which supported vibrating screeds and metal straightedges used in the finishing operations.

Concrete and delivery

The concrete mix proportions were selected with the intent of achieving the most uniform time of setting. Proportions used early in the project are shown in the table. Two of the company's batch plants would have been able to deliver concrete for superflat construction, but to reduce possible variations only one was used. Only the 12-cu-

QUANTITIES FOR 1 CUBIC YARD OF CONCRETE	
Required strength	4000 psi
Slump	4 inches
Type II cement	564 pounds
Coarse aggregate (Gravel)	
1½-inch	520 pounds
1-inch	1484 pounds
Sand	1221 pounds
Water, design	300 pounds (36.0 gallons)
Water, maximum	300 pounds (36.0 gallons)

bic-yard booster mixers owned by the company could be used to deliver a 10-cubic-yard load. One load was batched every 5 minutes, which gave each of the two crews 10 minutes to place the concrete. With a 30-minute travel time, the average time required to deliver and fully discharge was 50 minutes.

The quality control operations of the supplier involved many people to meet the required 4 ± ½-inch slump with no more than 10 gallons of water added per load at the jobsite. Aggregates sent to the batch plant were either freshly produced or taken from a sprinkler-dampened stockpile. A second batchman was stationed at the plant to monitor incoming materials and also visually check the loads after mixing in the yard.

When a truck arrived at the job, it went to a centrally located control point where a laboratory technician from the concrete supplier was stationed. He checked the slump, added water up to the allowable amount if necessary, and then directed the truck to one of the placing crews. Communication between the job and batch plant was maintained by a two-way radio installed in the laboratory pickup truck. If a delay or breakdown of any sort occurred, the communication system functioned so that no concrete was lost.

The general contractor had carefully planned ahead to take care of any concrete that for any reason was unusable for superflat work. This was used in less critical footings that were held open on another part of the job. The floor finishing contractor was also organized to handle problems. If one of the crews broke down, truck deliveries from the plant were immediately shut off and trucks enroute were redirected to the remaining crew. If the batch plant broke down, each crew went through a staged slowdown so no cold joints would occur. Communication between the finishers and supplier was the key to good quality control.

Placing and finishing

The essence of this kind of floor finishing operation is to monitor each day the flatness of the previous day's placement and then to modify the new day's operations in the light of the previous day's experience and the expected effect of the new day's weather. Larry Littlejohn, of D & K Flooring explains "superflat floor construction is not a procedure, but an experience"—his way of describing how the contractor may live closely with what is happening and feel his way on the basis of changing circumstances and weather.

The team installed an average of 340 cubic yards of superflat floor concrete per day. Placement usually began at 6 A.M. and finishing was completed at least by 2 P.M., 8 hours later.

A placing and finishing sequence

The following steps might be typical, though they were continually changed in response to daily floor flatness measurements and job conditions. This repeatedly led to adjustments in techniques of placing and finishing, timing of operations, spacing between straightedges, and sequence of operations.

1. Placement by chute from truck mixer
2. Light tamping of floor edges only
3. Vibrating screed used with two shovel men working ahead of it and one behind
4. Straightedging with a special aluminum or magnesium straightedge following 10 feet behind the vibrating screed, used in a side-to-side sawing motion while being drawn forward
5. Edges cleaned with hand trowel, a procedure used throughout the operation to provide a clean working surface on the tops of the forms
6. Excess concrete removed from high spots with a concrete rake and shovel and used to fill low spots
7. Form edges cleaned and second straightedging operation done 20

Highway straightedging followed the power troweling. This kind of straightedge moved across the slab to flatten the surface longitudinally. Each pass of the straightedge overlapped the previous pass for continuity. Each highway straightedge was slightly longer than the preceding one so that the slab was made increasingly flat.

Profilograph renders daily verdicts and thereby helps define the next day's procedural strategy. Modifications of procedures were continually made in response to the trend in flatness, the weather, and other job conditions.

feet behind the first

8. Form edges cleaned and third straightedging operation done 30 to 40 feet behind the second, while excess concrete was removed with a special squeegee

9. A 10-foot highway straightedge, drawn across the width of the slab, overlapping each stroke halfway

10. Delay in time

11. First power trowel run back and forth *lengthwise*

12. A 12-foot highway straightedge drawn across width of slab

13. A 16-foot highway straightedge drawn across width of slab

14. Delay in time

15. Second power trowel run across *width* of slab

16. Third power trowel run *lengthwise* to polish surface

17. Application of curing compound

This sequence was fine-tuned as the project proceeded. The procedures produced the best results with very little correction by grinding. Several other techniques used early in the job proved to be counterproductive to subsequent operations, such as using a power float after the first straightedging. Power floating created a ridge-and-valley effect that couldn't be cut down with subsequent straightedgings, so it was discontinued.

It was interesting that within this process each of the two crews expressed its own style in accomplishing the same end results. Finishers had to be very flexible in their timing of operations in response to the changing weather. The quality control each crew exercised was based on its familiarity with the subtle ways concrete behaves in different situations.

Measurement and correction

Each day's work was usually measured for flatness in the late afternoon after the curing compound had completely dried. Close cooperation between the floor flatness monitoring company and the general contractor and the floor finishing company made each day's placement a learning experience. The experimental techniques used in the early stages of the project were carefully noted and then checked against the profilograph readings. The finishers' confidence in the profilograph machine was earned. Areas that the machine indicated as needing minor grinding were areas that could not be visually detected or found with use of a 4-foot straightedge to be out of tolerance. When a 2-foot straightedge was used, the exact point could be easily found.

The few corrections that were needed were made with a water-cooled diamond grinding disk. The responsibility was that of the floor finishing company. Necessary grinding was usually done early in the period of concrete strength development to minimize the grinding time.

Acknowledgments

Special thanks to Bob Roy and John Schwind of Oltmans Construction Company and Larry Littlejohn of D & K Concrete Flooring without whose cooperation this article would not have been possible.

Credits

Owner: Pic 'N' Save Corporation, Carson, California

General contractor and floor bulkheads and placement: Oltmans Construction Company, Monterey Park, California

Floor finishing: D & K Flooring Company, Anaheim, California

Floor flatness consultants and monitors: The Edward W. Face Company, Norfolk, Virginia

Concrete supplier: Conrock Company, Los Angeles, California

PUBLICATION #C840291