Constructing a Superflat Concrete Floor Slab

by Don Gehring

Table 1 – Floor dimensions for F_{min} 100

	Wheel or axle separation (in.)	Elevation difference (in.)	Rate of change per foot (in.)
Transverse	42/46	0.068	0.039
Longitudinal	60	0.084	0.040
Longitudinal	12	0.031	0.032

Owner:	Freightliner Corporation Portland, Oregon
Structural Engineers:	Moffatt, Nichol & Bonney, Inc. Portland, Oregon
Concrete Flooring Consultant:	Edward W. Face Co. Norfolk, Virginia
General Contractor:	Seabold Construction Co. Portland, Oregon
Concrete Subcontractor:	Terry J. Fricks, Inc. Fort Worth, Texas
Concrete Supplier:	Reno-Sparks Redi-Mix Reno, Nevada
Testing Laboratory:	Lab-Sea Inc., Sparks, Nevada

Teamwork, craftsmanship, and experience combined to make a recently-constructed warehouse floor slab twice as flat as was specified.

The floor was constructed for the new Freightliner Mercedes-Benz 148,000 ft^2 (13,750m^2) distribution center in Stead (Reno), Nevada. The warehouse will expand the firm's parts stockpiling and distribution system into the southwest. The new structure, similar to one constructed earlier in Chicago, is a very narrow aisle (VNA) facility.

Criteria for the effective operation of a VNA warehouse are:

-A flat floor over which VNA vehicles (VNAV) (fork lifts) can operate at optimum speed safely, with minimal vibration and maximum productivity.

-A level floor, to enable the VNAV to load the racks (24 ft[7.3m] high or more) within an envelope, or vertical clearance, of only 1/4 in. (6.4mm).

The problem

An engineer in Freightliner's Portland, Oregon, office, which had responsibility for the Nevada warehouse, recalled difficulties in meeting the VNAV criteria for the Chicago warehouse. To avert similar problems, the Edward W. Face Company, developers of the F-number system for measuring floor flatness and levelness, was retained as consultant on the project.

The solution

The floor consultant made design recommendations and proposed construction techniques that would assure superflat (F_{min} 100) floors would be achieved. F_{min} 100 converts to the absolute floor slab dimensions shown in Table 1, and these pertain to the VNAV's 'view' of the floor,

Table 2 – Mix proportions for slab base and topping

		Base	Topping
Cement	(lb/yd^3)	564	752
Coarse aggregate	(lb/yd^3)	1729	2000
Fine aggregate	(lb/yd^3)	1321	1000
w/c		0.40	0.42
Slump	(in.)	3	4

since they show elevation differences along the exact track the vehicle will travel up and down the narrow aisles.

The floor consultant developed and built the Differential Floor Profileograph, a device that tracks along the path of the VNAV, with its wheels and axles set to match the VNAV's exactly, and thus measure the slab from the vehicle's viewpoint. The measurements are shown as a trace on a paper tape, the length of the tape being proportional to the distance travelled.

Slab design

All elements in the slab design-mixes, dimensions and detailing-were the result of discussions between the owner, floor consultant, structural engineer, general contractor, and testing laboratory. The basic structure selected was a 5 in. (127mm) thick post-tensioned base slab topped with an integral 1 in. (25.4 mm) thick topping of 3/8 in. (9.5mm) traprock aggregate, for a hard wearing surface. Concrete for the base slab was to have a compressive strength of 3,000 psi (20.7 MPa). After close study of local (Reno) aggregates and the shrinkage problems often incurred there, the mix proportions shown in Table 2 were selected for the base slab and topping.

The warehouse area was divided into twenty-one 12 ft (3.65m) wide slabs, with the 12 ft (3.65 m) dimension being used also to space transverse sawcut joints in the 90,000 ft^2 (8,360 m^2) slab that was non-superflat and non-reinforced. The post-tensioned, unjointed, 275 ft (84 m) long (average) superflat slabs were expected to be (and were) crack-free, despite the significant shrinkage that was expected and which did occur.

The construction procedures and techniques recommended by the consultant were essential to the successful construction of the superflat floor. The concrete sub-contractor had prior experience with superflat slabs, which meant that the consultant did not have to conduct the indoctrination and training usually given to concrete workers new to the superflat concept. Even so, the subcontractors crews did place some of the non-superflat slabs first as a rehearsal for the more critical superflat work.

After the base course was struck off one inch below the forms and had partially set up, the surface was broomed to insure adequate bond with the top course.

Preparation for concrete placement

Before the concrete was placed, 6 in. (152.4mm) of flex base (a road base material) was placed and compacted for the entire floor area of the warehouse. A vibrating roller was used to achieve 95 percent compaction.

The first step in preparing for base course placement was the setting of forms, obviously critical because levelness starts with accuracy here. Sections of 2x8 wood were cut to 6 in. (152.4 mm) and planed prior to setting, then checked to zero tolerance using a high quality optical transit. After elevation and alignment were approved, the forms were secured in place by metal pins and anchored against horizontal thrust by wooden braces. Final check for imperfections was made by sighting under a 20 ft (6 m) long metal straightedge, with any high spots being planed manually, using an electric hand plane.

The polyethylene slip sheeting was then unrolled and placed. This served to reduce sub-grade drag and thus reduce crack-causing stresses to a minimum. The slip sheeting was perforated to prevent moisture being entrapped, thus reducing any tendency of the slab to curl.

To effect load transfer and continuity of alignment across the longitudinal joints between the 275 ft (84 m) long slabs, 3/4 in. (19 mm) dowels were set into the forms at 12 in. (305 mm) centers. They were held rigidly in place, to prevent movement during concrete placement. Each dowel was padded along its protruding sides in order, once encased in the slab, to permit horizontal differential movement of the slabs relative to each other without setting up crack-producing stresses.

With the formwork in place, #4 (13 mm diameter) bars were set transversely and 3 in. (76 mm) high on 3 ft (9.1 m) centers over the full length of the slab. Over these supporting carrier bars, and tied to them, were laid out the five post tensioning tendons that would stress the 275 ft (84 m) long slab.

(The non-superflat slabs were non-reinforced, except for 3/4 in. [19 mm] dowels, placed in baskets, at the 12 ft [3.65 m] spaced, sawed control joints.)

Concrete placement

For the first group of slabs (1,3,5, etc), concrete for the low slump, 5 in. (127 mm) thick base course was placed directly into the forms from the ready-mix trucks. But for intermediate slabs (2,4,6, etc), the concrete was delivered by Georgia buggies, this being the only wheeled traffic permitted on the adjacent, newly cast slabs.

The base course was stuck off to its 5 in. (127 mm) depth by vibratory screed.

The top course, placed 20 to 60 minutes after the base couse, ws struck off with a vibrating screed, which also improved the bond between the courses.

Immediately after placement and strike-off of the base course came placement of the topping. The 'window of opportunity' here was critical, with the topping needing to be placed, for complete integration with the base, anywhere between 20 to 60 minutes after base placement. This was strictly a judgment call, depending upon factors like temperature and humidity, which underscores the need for experienced craftsmen and close, skilled supervision. (Superflat floor slabs might be said to call for art and intuition, as well as science.)

The concrete subcontractor elected to perform an optional step at this critical juncture. To be absolutely sure that the topping is integral with the base (a must for the superflat floor to function effectively and without future separation), the surface of the freshly-placed base mix was broomed to help assure bonding. This step had to be fitted into the critical period of 20 to 60 minutes after base placement.

Because the topping mix was highly specialized and called for close control, it was mixed on site, under cover of the already roofed-over warehouse. Here, on a raised platform, the cement was stock-piled, aggregates were delivered to the two portable mixers by wheel barrow, and the mixers discharged the concrete into buggies for delivery to the placement site.

Finishing

Following initial strike-off and two transverse strike-offs, the surface was power floated then given another transverse strike-off.

The first step after placement was vibratory strike-off, this operation also helping to improve the bond between base and topping. After strike-off (another judgment call based on experience) came two hand transverse strike-offs using magnesium straightedges. Then followed power floating, which was followed by yet another transverse strike-off, then another power troweling, followed by cutting and filling the concrete surface using the highway straightedge.

At this point, even the casual observer would note the differences between superflat and ordinary slab construction. The use and re-use of the highway straightedge is on of them. When and how to use the highway straightedge is a real judgment call. Using it at the wrong time, in the wrong way, will cause a lot of problems.

'Re-straightening' sums it up- the purposeful reapplication of the straightedge time and again as required to be absolutely sure that you are not straying from the all-critical level established by the forms or the previously placed slabs- and doing it before the concrete sets up. The final quality of the floor depends in large part upon the skill of the craftsman handling the highway straightedge. As stated in an article by William Phelan in the January, 1989 issue of Concrete Construction:

"Flatness (the F_F value) is primarily affected by finishing operations after striking off. To meet many flatness requirements, finishers must restraighten or cut and fill the top surface of the concrete while it's still plastic. The best tool for this is a 10 ft (3 m) or 12 ft (3.7 m) highway straightedge...used repeatedly during the finishing process. By substituting a highway straightedge for a bull float in the finishing operations, finishers can increase F_F values by 30 to 50 percent."

Hand working the edge of the slab with a magnesium straightedge is another skilled finishing operation essential to producing high quality superflat floors.

On the Freightliner warehouse project in Nevada, power troweling accompanied the screeding and restraightening and, once again, when and how this is done is a matter of experience. The concrete subcontractor troweled in two directions, followed by more troweling, changing in number and sequence and pattern, depending upon conditions. Obviously, skill, experience, and craftsmanship are essential ingredients for successful superflat slabs.

Another finishing step at the Freightliner job further emphasizes the need for skilled finishers: hand working of the slab edge. Here, the finisher, using a 4 ft. (1.2m) long straightedge, his vision, and a feel for superior craftsmanship, carefully worked the critical edge areas to guarantee level and straightness, by wiping out any dips and swales.

The all-important macro-smooth, super-hard finish called for on the VNA superflat slabs was the purpose of the final finishing operation. And this, especially, had to be perfectly timed: too soon might damage the surface; too late and the sheen called for would be missed. With blades set

Repeated cutting and filling the concrete surface with a highway straightedge, combined with power troweling, is essential to producing superflat floors.

When cracking compliance of the superflat slabs, the Profileograph wheels are set to match the wheelbase of the forklifts that will operate in the warehouse.

at their maximum angle and running at high speed, the blades heat up and evaporate any final drops of moisture remaining on the surface, and impart nearly molecular particles of steel to it, thus darkening the surface and

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the constantly changing conditions. It also prevented mistakes from going unnoticed and being carried from slab to slab. As a result of the rapid feedback of slab profile information, extremely flat floors were produced in the non-superflat areas.

Productivity

The concrete subcontractor's crew of 8 carpenters, 10 finishers, 6 laborers and 4 iron workers took 20 days to form all the slabs in the warehouse, place polyethylene slip sheeting and reinforcing steel, and place, finish, and cure the concrete for the base and topping of the 148,000 ft^2 (13,750 m^2) of superflat and non-superflat floors. This crew was about the same size as the subcontractor used for conventional slab work. However, with the exacting, precise work required, especially for forming and finishing, placement size was cut by one half to one third. This reduction in productivity translates into labor costs for superflat work 50 to 100 percent greater than for conventional slab work.

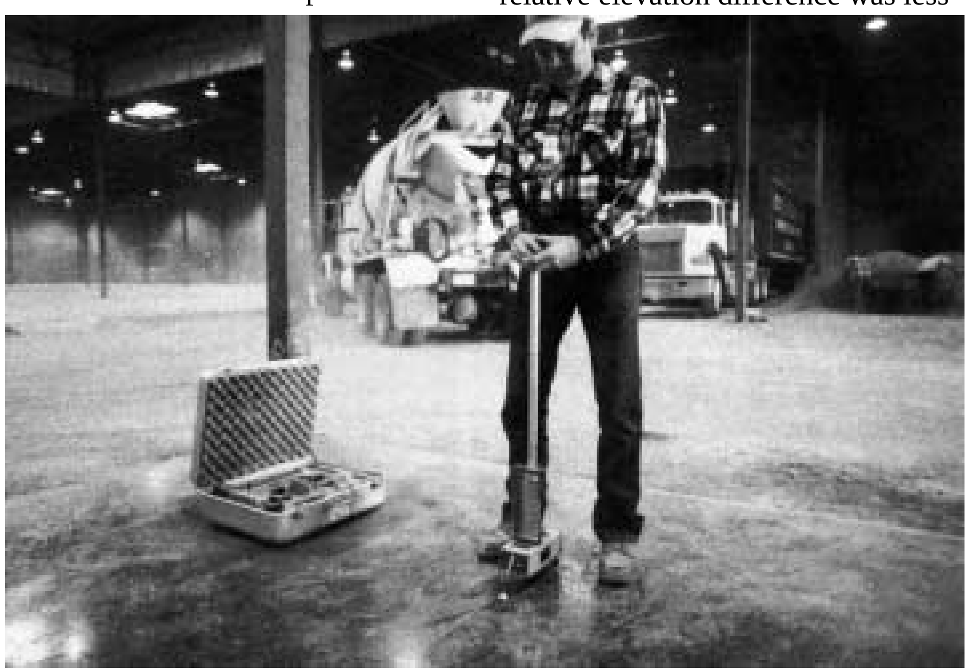
Flattest warehouse floor?

As revealed by the Profileograph and the Dipstick, the floor constructed for the new Freightliner warehouse in Reno may be one of the flattest warehouse floors ever built. This includes even the non-superflat slabs that will be used for office, storage, and other non-critical uses. These were specified at a modest F_F 35 and F_L 27, but achieved F_F 109 and F_L 104. The flooring consultant commented that these slabs exceeded the specified flatness requirements by a greater margin than any other floors he had ever measured.

For the 50,000 ft^2(4,645m^2) of superflat slabs, the Profileograph revealed equally good news. All of the slabs were exceptionally flat, not one requiring corrective grinding (which sometimes has been necessary on superflat work). The tapes of VNA slabs disclosed that the floor exceeded the specified flatness/levelness requirements (F_{min} 100) by a greater margin than the flooring consultant had ever before measured for an entire floor.

The tape's tracing showed that only one aisle was out-of-tolerance, for a distance of 6 ft (1.8 m). Since the out-of-tolerance, amount was only about 0.010 in. (0.25mm), it was agreed that no correction would be required, and the slab was accepted as placed. The rest of the floor was comfortably within the F_{min} 100 requirements.

For one slab (Number 15) the amplitude of the inked tracing for relative elevation difference was less



The non-superflat slabs were measured for compliance with the specified F-numbers by taking readings with a Dipstick the morning after placement.