Vacuum-Dewatered Concrete

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The vacuum dewatering process is a technology which effectively produces a zero slump high-strength concrete using fresh concrete with a high water-cement ratio.

Vacuum dewatering involves the following steps (Fig. 1):

1. Concrete is placed in forms.
2. The concrete is consolidated with standard probe vibrators.
3. The placement area is struck off and further consolidated with a vibrating screed.
4. Filter pads are placed on the level surface.
5. A suction mat is placed over the filter pad and sealed carefully around all the edges.
6. The placement area is vacuum dewatered.
7. The suction mat and filter pads are removed and the surface is immediately mechanically floated.
8. The surface is then final finished with a power trowel.

Vacuum dewatering compacts the concrete so tightly that a man can walk across the fresh concrete immediately after it has been vacuum treated and leave only shallow footprints. From the point of concrete placement to completion of surface finish, it usually takes 2½ hr, depending upon the surface finish desired and the weather.

Several testing organizations have reported increased compressive strengths, flexural strengths, and wear resistance.

Vacuum treatment of concrete was invented in the United States by K. P. Billner in 1935. Billner obtained a patent which included the principle and various practical applications of vacuum dewatering. Vacuum dewatering was used in the U.S. in the '40s and '50s, with some success on projects such as the construction of Shasta Dam in California, and the Pentagon Building in Washington, D.C. At that time the vacuum dewatering equipment was expensive, heavy, and complicated to use. Also, Billner promoted vacuum dewatering as a panacea for concrete construction, which it was not, and prematurely forced this new technology into areas of application where it performed poorly. For these reasons, U.S. concrete contractors eventually rejected vacuum dewatering as a viable construction technique.

Keywords: concrete construction; concrete finishing (fresh concrete); concrete slabs; mix proportioning; troweling; vacuum-treated concrete; water-cement ratio; water content (of freshly mixed concrete).

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Interest in vacuum dewatering was renewed several years ago in Scandinavia because of two things:
1. Based on Billner's earlier work, the vacuum dewatering equipment has been developed to the point where it is much cheaper and easier to use.
2. Vacuum dewatering can justify its use based upon time savings alone, and the improved strength qualities have been deemphasized (even though they do exist)." 

Today, vacuum dewatering is used throughout Europe, especially in Sweden where approximately 50 percent of all concrete floors are vacuum treated. Interest in vacuum dewatering has, therefore, been renewed in the U.S., for this technology appears to hold some real advantages.

**Mechanics of the vacuum process**

Concrete is vacuum treated in the following way:

1. Filter pads are placed over the fresh concrete.
2. A suction mat is placed over the filter pad, with a hose connecting the suction mat to a vacuum pump.
3. The vacuum pump is operated for several minutes, depending upon the thickness of the concrete slab.

The extracted water carries a small amount of cement and fine particles towards the surface, causing two things:
1. A higher concentration of cement fines at the top surface of the concrete slab (Fig. 2).
2. The extracted water carries away 0.2 to 0.5 percent of the cement fines. (The purpose of the filter pad is to minimize the loss of cement fines.)

The vacuum dewatering process and the mechanical finishing that
immediately follows, both change the equivalent capillary radius of the cement paste. The vacuum de-
watering lowers the water-cement ratio, and the power troweling increases the specific surface of the cement particles by grinding. Both procedures reduce the value of the capillary radius. The lower capillary radius of the fresh cement paste results in a lower capillary radius of the hardened cement paste, and therefore reduces the thermal and moisture gradient in the concrete slab. The result is increased density, strength, frost resistance, and decreased absorption, abrasion, and shrinkage.

It is important to note that the vacuum process cannot remove more water than is needed for the hydration of cement.

**“How-to”**

**Proper mix proportions**

The vacuum treatment process does not work for every type of concrete (which is probably why the technology failed in Bilinner’s time). There are 4 factors which affect the suitability of concrete for vacuum dewatering:

1. Cement content
2. Initial water content
3. Cement grinding fineness
4. Admixtures

**Cement content** — The vacuum process increases the concentration of cement fines near the top surface of the concrete slab. As the amount of cement fines is increased, the capillary radius decreases which therefore slows the dewatering process. If there is an excessive amount of fines (passing 100 to 200 mesh sieves) near the top surface when dewatering, a hard, thin layer of mortar will develop at the top surface causing the lower portion of the concrete slab to be insufficiently dewatered. This false compaction is called “crusting.” When crusting occurs, the hard layer on the top surface will break when it is stepped on.

To assure the dewatering process achieves good depth penetration, it is critical to use a MAXIMUM CEMENT CONTENT OF 590 LB/CU YD (350 KG/M³).

**Initial water content** — Regardless of the initial water content, the remaining water content of freshly placed concrete after vacuum dewatering is generally the same. But the fluid consistency of a high-initial-water-content concrete will allow more cement fines to migrate to the top surface during the vacuum process, which can lead to crusting. By using water-reducing admixtures and lowering the cement content of the mix, it is possible to improve the suitability of concrete for vacuum dewatering without changing the consistency or strength.

**Fig. 3 — Portable vacuum-treatment device.**
Therefore, it is recommended that the fresh concrete have a MAXIMUM SLUMP OF 5 IN. (127 MM).

Cement grinding fineness — Rapid-hardened portland cement has a higher grinding fineness than ordinary portland cement, and as the grinding fineness increases, the effectiveness of vacuum dewatering decreases.1

Therefore, it is recommended to always USE LESS CEMENT AS THE CEMENT’S GRINDING FINENESS INCREASES.1

Admixtures — Admixtures do not significantly affect vacuum treatment, but it is recommended to LIMIT AIR ENRAINTMENT TO 5%.4

A particular concrete mix proportion should first be tested for its suitability to vacuum treatment at the batch plant. A portable vacuum treatment device (Fig. 3) can be used to test a gallon of freshly-mixed concrete (either at the plant or the site). The device dewater the concrete on a small scale and gives a good correlation to full-scale vacuum treatment by measuring the amount of extracted water.

Equipment and crew

The equipment consists of the following:

1. Filter pads are 4 ft (1.2 m) wide and are available in rolls up to 100 ft (30 m) (Fig. 4).
2. A typical suction mat is 20 ft (6.1 m) wide and ranges in length from 10 to 23 ft (3.1-7 m), weighing from 53 to 130 lb (24-59 kg) respectively (Fig. 5).
3. The suction hose is typically 1½ in. (38 mm) in diameter (Fig. 5).
4. A typical vacuum pump (Fig. 1) weighs 250 lb (113 kg) and can produce sufficient vacuum for an 800 sq ft (74 m²) area.2

A contractor can buy all of the necessary start up equipment for approximately $12,000, which includes the pump, suction hose, filter pads, and 2 suction mats (covering 800 sq ft (74 m²)).2

A typical concrete crew can learn the vacuum dewatering techniques in 2 days.2 Two finishers can handle the mats and the pump (if union regulations allow), and assuming an average concrete floor construction crew, approximately 6000 sq ft (557 m²) of floor can be placed, vacuum dewatered, and finished in a day.5

Preliminary measures

1. The maximum vacuum penetration is generally 6-12 in. (152-305 mm).1
2. Mechanical and electrical piping stubs must be kept below floor level.4
3. The minimum temperature of fresh concrete in place should be 50 F (10 C).

Placement of fresh concrete

1. Concrete slabs greater than 4 in. (102 mm) in thickness should

Fig. 4 — Placing 4 ft (1.2 m) wide filter pads.

Fig. 5 — Typical suction mat and hose.

Fig. 6 — Slabs 4 in. (102 mm) thick or greater should be consolidated with standard probe vibrators.
be consolidated with standard probe vibrators (Fig. 6).

2. The freshly-placed concrete must be struck off higher (2 percent of the designed slab thickness) than the intended finish floor elevation to compensate for the compaction of the slab during dewatering (Fig. 7).

**Dewatering**

1. **Placing the pads** — The filter pads should overlap each other (Fig. 8) by 8 in. (203 mm). The top suction mat extends 4 in. (102 mm) outside the filter pads on all sides to insure a good seal (Fig. 9). The seal is extremely important to guarantee that a sufficient vacuum is developed and evenly distributed over the concrete surface.

2. **Running the pump** — The sooner the vacuum process begins, the better, even though waiting up to 1 1/2 hr does not significantly affect the results. One vacuum pump can supply suction to 2 mats simultaneously. The pump should reach 80 percent of full vacuum in a few minutes. It is important to note that a 50 percent vacuum applied for a long time will not give as good a result as a 95 percent vacuum applied for a short time. The pump should be run approximately 4 minutes for each 1 in. (25 mm) of concrete thickness.

3. **Removing the pads** — The top cover can be removed after rolling one edge of the mat toward the center to break the vacuum (Fig. 10). Breaking the vacuum causes an immediate pressure differential which forces standing water on the filter pads back through the filter hose and through the pump. The other side of the mat should then be rolled toward the center while the pump is running to remove all of the standing water. With both sides of the suction mat rolled to the middle, the mat can be picked up and moved to the next section (Fig. 8). The top cover should overlap the previous vacuum-treated section by 12 in. (305 mm). The top cover will only seal against fresh concrete, and not against hard concrete.

**Finishing**

A vacuum-treated surface is too hard for manual finishing. Power finishing should be started immediately after the suction mat is removed. On the first finishing pass, a power trowel should be used, fitted with either a planing disc or floating blades (Fig. 11). This removes the high spots and irregularities left on the surface after vacuum treatment (Fig. 12). For a smoother surface, the concrete surface can be power troweled with polishing blades a few hours after the planing operation. A polished concrete surface can usually be achieved within 4 hr of fresh concrete placement.

Curing procedures for vacuum-treated concrete are the same as for regular portland cement concrete, but curing should begin as soon as possible.

**Results**

Test results indicate that vacuum dewatering of concrete reduces the porosity of a concrete mix, and therefore increases the concrete’s wear resistance (Fig. 13) and impermeability. These tests reported that a concrete surface, vacuum treated and power-trowel finished, showed an increased wear resistance of 1 1/2 to 2 1/2 times that of nonvacuum-treated concrete. Other tests reported that the impermeability of vacuum-treated concrete was 70 percent greater than that of normal nonvacuum-treated concrete.

These results would at first seem contradictory to results reported by Malinowski and Wenander in 1975, which showed that the volume of extracted water after vacuum dewatering was generally larger than the volume reduction of the treated concrete. Since no external air enters the concrete, the volume differential would supposedly be the result of increased air pore volume, therefore increased porosity. There is no question that the vacuum treatment process induces a migration of cement fines towards the top...
surface of the concrete slab and therefore an increase in density along the top surface. This explains the observed increases in wear resistance and impermeability. Vacuum dewatering's effect on the porosity of the middle and bottom parts of the slab is still open to question. Whatever the effect is on porosity below the top surface, vacuum dewatering does not appear to have an adverse effect on strength. Indeed, test results show very high early compressive strengths in the top part of the slab, and 28 day strength gains of 20 to 40 percent over standard nonvacuum-treated concrete. Also, the 2-day strength of vacuum-dewatered concrete is generally greater than the 5-day strength of nonvacuum-treated concrete of the same mix.

The observed strength gain from the vacuum treatment and its use in structural design is still subject to question. Malinowski concluded that the relationship between concrete strength and water-cement ratio can be used for vacuum-dewatered concrete, but because of the supposed increase in porosity, a more correct relationship should be drawn between strength and the water-plus-air/cement ratio.

Applications

1. Any application that requires high wear resistance and impermeability.

2. The early strength development can be useful for construction of suspended slabs in buildings and tilt-up construction (Fig. 14).

3. A vacuum-treated concrete topping placed on a previously set base improves the bond between the topping and the base, due to the vacuum-induced pressure at the interface of the topping and base, and because of the reduced shrinkage of the topping.

4. Joint spacing can be increased in floor slabs because vacuum dewatering reduces shrinkage.

5. In Saudi Arabia, the vacuum treatment process is used to minimize the crusting problem encountered in that country's severely hot climate.

Vacuum dewatering of vertical surfaces was recently used during the construction of 6 concrete bridge piers near Copenhagen, Denmark (Fig. 15). The Danish Highway Authorities specified that the piers be vacuum dewatered from 6 1/2 ft (2 m) under sea level to 10 ft (3 m) above. The total form surface dewatered was 807 sq ft (75 m²). The nominal strength of the concrete was 5072 psi (35 MPa), but the vacuum dewatering process increased the strength to 7971 psi (55 MPa) in the outer 6 in. (152 mm) of the pier. The height of the form was 17.4 ft (5.3 m). It took 3 hr to place the concrete, and 3 hr for vacuum treatment. Dewatering started 30 min after the first concrete placement.
Conclusions

1. Vacuum dewatering produces high quality floors that have excellent wear resistance, impermeability, and strength.
2. Vacuum dewatering greatly reduces the dead time between placement of concrete and finishing. A 6 in. (152 mm) slab can be walked on in 30 min.
3. The various steps in a vacuum dewatering process overlap so that one step can be started before the previous one is finished. This means increased control over the different steps of placement and finishing.
4. The high-early-strength achieved with vacuum-dewatered concrete allows early removal of shoring and formwork and reduces the odds of accidental damage and/or vandalism to freshly placed floors.

Vacuum dewatering has been tested by many laboratories and has proven itself on a large number of projects in Europe. In Norway, the government authorities require that all new bridge decks be vacuum dewatered.

In spite of the evidence, vacuum dewatering’s acceptance and use in North America is marginal at this point. Vacuum dewatering has been used by the U.S. Bureau of Reclamation and the U.S. Army Corps of Engineers, but there is very little documentation in the literature on the use and performance of vacuum-treated concrete.

It appears that vacuum dewatering is a cost-effective construction technique based upon its improved qualities of wear resistance, impermeability, and time spent at the site. There is not yet enough documentation to substantiate the reduction of concrete slab thicknesses because of vacuum dewatering’s effect on high-early-strengths and overall strength gain. The questions concerning porosity and strength development will have to be fully answered in the research literature before full acceptance of vacuum dewatering by government and private industry.

Fig. 13 — Wear resistance of regular portland cement concrete (left) versus that for vacuum-treated concrete (right).

References


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Fig. 14 — Vacuum treatment can speed construction of tilt-up panels.

Fig. 15 — Concrete bridge piers were vacuum treated in Denmark.