# The Development of Self-Propelled Machines in Illinois for Construction of Concrete Slabs Without Forms

By

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## *Introduction*

There have been many important developments in road building equipment in recent years; possibly the greatest progress has been made with earth-moving equipment. The size and mobility of earth-moving equipment have been developed to such an extent that production has been increased tremendously on the average road construction project. This has had a definite effect on the cost of road work as grading prices are actually lower today than in the earlier days of road building.

Asphalt paving equipment has changed considerably in recent years with larger hot-mix plants and the development of several efficient asphalt finishing machines that eliminate the need of hand finishing. Concrete paving equipment has also been developed to increase production and reduce the need of so much hand labor. Among some of the modern developments are the 34-E dual drum paver, concrete spreaders, surface vibrators, and the longitudinal float. These changes have made it possible to increase production and produce smoother riding surfaces.

An entirely new and different type of concrete paver or finishing machine was developed in Iowa in 1949 that incorporated the use of slip forms in lieu of staked-in-place steel forms. The machine was given wide publicity and created considerable attention at the time; however, little has been heard of this machine since that date.

Illinois was at that time facing the problem of rehabilitating many miles of old concrete pavement. We felt that such a machine might eventually simplify construction operations where it is necessary to construct full-width concrete base course at different locations to improve vertical and horizontal alignment on the existing highways. It was apparent that these projects offered an excellent opportunity for further research and development of this new and novel paving equipment. Any irregularities in the surface of the new concrete base course would not be detrimental, as they would be covered with three inches of bituminous concrete.

Realizing this opportunity, the Illinois Division of Highways felt obligated to highway engineering and industry to encourage the contractors to explore this new method of paving. With a certain amount of promotion and encouragement, the contractors responded beyond our expectations. They spent considerable sums of their own money to build self-propelled slip form pavers and subgrading machines. This equipment has now been used in several states outside of Illinois and has attracted the attention of many engineers and contractors over the country.

*Pavement Rehabilitation*

Early in the 1940's the Illinois Division of Highways started a program of rehabilitating old existing 18-foot concrete pavements by widening the slabs to 22 feet and 24 feet with concrete, then resurfacing the entire width with three inches of bituminous concrete. During the early years of this program steel forms were used to construct the 2-foot and 3-foot widths of concrete widening on each side of the old 18-foot pavements. However, this method of construction proved to be an expensive and slow process.

It was soon realized that a faster method of building the concrete widening must be used in order to complete the large program facing Illinois. To accomplish this result, the method of widening without forms being used in our neighboring State of Wisconsin was investigated. This method appeared so promising that the contractors were encouraged to develop it in Illinois. In a short time a satisfactory method was being used for this type of construction. Production was greatly increased and in one case a contractor placed more than 17,000 feet of 2-foot widening on one working day. Without its adoption it is doubtful that Illinois could have completed so many miles of widening each year. This method of placing concrete widening without forms has had a direct influence on contract costs and it has resulted in substantial savings to the state.

Many of the widening and resurfacing projects include certain locations where it is necessary to correct the vertical or horizontal alignment of the existing pavement to meet present-day standards. It is the practice at these locations to remove the old concrete pavement and construct a new concrete base 22 feet or 24 feet in width and resurface the entire project with bituminous concrete in order to have a uniform surface throughout. The lengths of these relocations vary from about one thousand feet to as much as two or three miles. Originally the contractors used regular steel pavement forms and finishing machines to construct the full-width base course. In addition to the cost of setting forms, considerable equipment had to be moved from one location to another, which was costly and this cost was reflected in the unit bid prices.

Since we had been successful in our program for widening pavement without forms it was felt that with the proper encouragement the contractors might be able to develop a method for building full-width base course without the use of forms and finishing machine. As mentioned above, the Iowa State Highway Commission had already done some experimenting with this type of construction, building one lane at a time. It was felt that even if the surface of the concrete base was not perfect it could be corrected with the bituminous concrete surface course.

With these thoughts in mind the problem was discussed with several contractors. Late in 1951 it was decided to revise our specifications to permit the construction of full-width base course without forms. Only one concession was made in the special provisions—the surface tolerance requirement was changed from ¼-inch in 10 feet to ⅜-inch in 10 feet. The requirements for the thickness of the concrete base course and the quality of the concrete were not changed.

*Development of Cable-Drawn Slip-Form Pavers*

This revision in the specifications created considerable interest among the contractors and engineers; however, it still required a certain amount of promotion on the part of the Division of Highways to convince the contractors of the benefits to be derived from the money expended by them in constructing a device to build full-width base course without forms. Early in 1952 one of our contractors decided to attempt to construct 1,004 feet of full-width

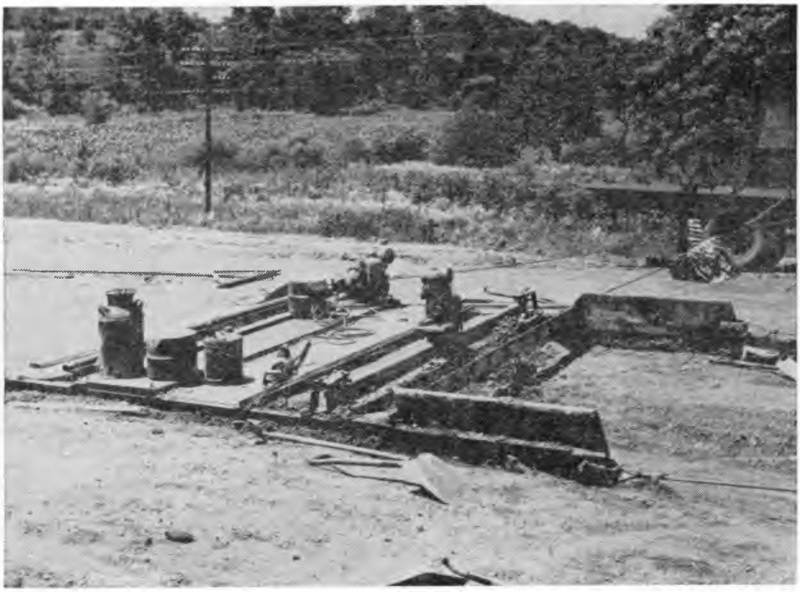

**Fig. 1. First machine developed to construct an 11-foot lane of concrete roadway without forms.**

base course involved in a grade revision without the use of forms. After considerable planning and several conferences it was decided that it would be easier to build the base course in two operations, one lane at a time. The machine as finally developed is shown in Fig. 1. The machine consisted of two runners 25 feet in length, spaced 11 feet apart, to construct the 11-foot lane of concrete. A strike-off was located near the forward part of the machine to level the concrete and form the crown of the base course. It was followed by a vibrating screed attached to the runners immediately back of the strike-off. The machine was pulled forward by a single steel cable operated from a winch on a truck. The concrete was deposited on the subgrade in front of the strikeoff and as the machine was pulled forward, it molded the concrete into a single lane of base course and did a creditable job in the first attempt to construct full-width base course without forms.

Cores taken from the concrete slab constructed in this manner proved to be of good average thickness and the quality of the concrete compared favorably with concrete finished by other methods. Following the construction of the base course, the bituminous surface was constructed and today it is impossible to locate this section of the road from general observation because it has the same appearance and riding qualities as the rest of the project.

**Fig. 2. Installation of tie bars across center line joint presented a problem with first machine.**

Several important lessons were learned from this project. The installation of the tie bars across the centerline joint presented quite a construction problem as shown in Fig. 2. The construction of the

**Fig. 3. Second machine developed. This unit was designed to construct a 22-foot course.**

**Fig. 4. A third machine was designed to construct a full-width course on super-elevated curves.**

second lane also had to be delayed until sufficient strength had been attained in the concrete placed in the first lane. It was realized from this experience that it would be more desirable to construct the full-width base course in one operation.

A second machine was built by another contractor later in the 1952 construction season. It was used on a 1,100-foot length of 22-foot width base course. This machine was similar to the first machine so far as strikeoff, vibrating screed and length of runners were concerned; however, it provided for the construction of the full-width base course in one operation. This machine was also pulled by a single cable from a winch on a truck. The contractor placed the entire length of base course within the time limit of one average working day. This machine is shown in Fig. 3. The construction of a full-width base course in one operation was proved more efficient by this machine; however, it was found that the single cable pull would not produce a straight edge alignment. It was decided that the machine should be pulled by separate cables from two winches to give better alignment control.

During 1953 two more machines were built in Illinois for the construction of full-width slabs without forms. One machine was similar to the second machine previously described except that it was pulled by two cables—one attached to the front of each slip form.

**Fig. 5. First self-propelled machine designed to construct full-width course—front view.**

The two cables as expected permitted better edge alignment control. This machine actually built 10,384 feet of base course during the 1953 construction season. On one project it was used to construct the base course on two superelevated curves, which proved to be somewhat of a problem; the operation, however, was successful. Fig. 4 shows the machine in operation.

*Development of Self-Propelled Slip-Form Pavers*

The experience gained with the cable-drawn machines confirmed our opinion that it was possible to build concrete slabs economically without forms. It was also conceded that better results and more efficient operation would be possible with a self-propelled machine; however, it was estimated that the cost of building such a machine for experimental purposes would amount to a considerable sum. It was considered doubtful that the contractors would care to make such an investment on experimental equipment.

Evidently there was a greater interest in this type of construction than we had anticipated because one contractor decided that he could and would build a self-propelled machine capable of meeting our requirements. This machine was built during the early months of 1953 and completed 3¼ miles of base course without a single mechanical failure.

**Fig. 6. Rear view of machine shown in Fig. 5, showing concrete in place.**

This self-propelled machine shown in Fig. 5 and 6 consisted of a regular concrete finishing machine with an additional vibrating screed placed between two oscillating screeds; the entire unit was mounted and attached to a pair of slip forms 30 feet in length. This unit was mounted on the inside of a power unit with two caterpillar tracks approximately eight feet in length. The heavy duty power unit was capable of propelling the slip forms forward at several slow speeds or at high traveling speeds. It could also be operated in reverse. When constructing the concrete base course, the machine operated at a speed of three feet per minute. The concrete was deposited on the subgrade in front of the machine as shown in Fig. 5, and as the machine moved forward, the concrete was struck off and the surface finished with the two oscillating screeds and the surface vibrating screed. The concrete was confined between the slip forms for a period of at least ten minutes. The machine was used successfully in placing 3.25 miles of 24-foot base course in 1953 and 3.39 miles of 22-foot base course in 1954, both having a thickness of 9 inches.

This machine actually laid as much as 1,044 feet of 24-foot base course 9 inches thick in one working day; however, there was no attempt to set a record and it was evident that the machine would take care of as much concrete as could be produced by a 34-E dual paver. The edges of the concrete slab were straight in alignment and

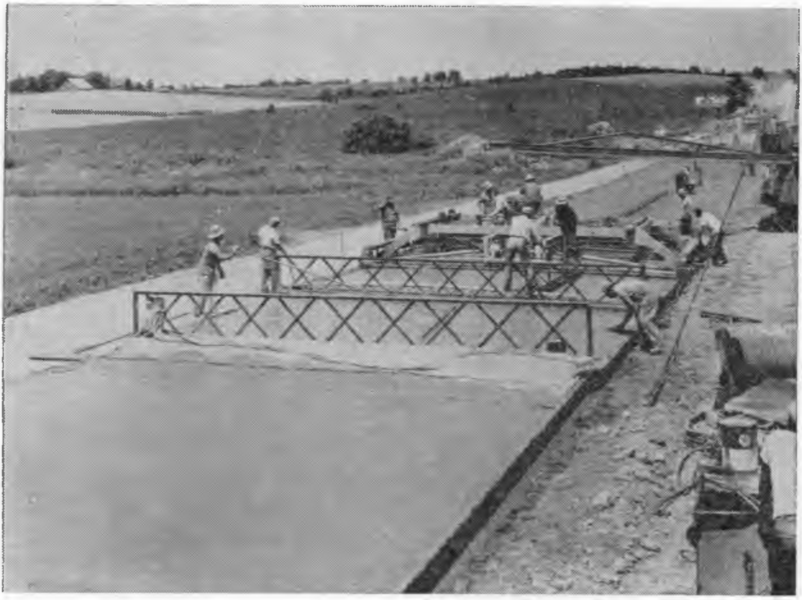

**Fig. 7. Second self-propelled machine incorporated a permanent 22-foot slip-form and a temporary 16-foot slip-form, making a total length of 38 feet.**

vertical with little evidence of slumping. The concrete slab met the surface tolerance requirement of ⅜-inch in ten feet.

The development and operation of the first self-propelled machine created considerable interest in Illinois and elsewhere. Another contractor decided that he would build a self-propelled machine incorporating his own ideas. The machine was placed in operation by this company on a contract early in 1954 to build 1.84 miles of 24-foot base course 9 inches thick. This machine is shown in Fig. 7.

This machine also utilized the basic principles of modern pavement equipment but differed in some respects from the first self-propelled machine. The supporting framework for the engine, the adjustable strike-off, the vibrating screed and the oscillating belt are mounted on permanent slip forms 22 feet in length. Temporary 16-foot slip forms are attached to the permanent slip forms, making a total length of 38 feet, thereby lengthening the time that the concrete is confined within the forms. A burlap drag which performs the final surface finishing on the slab is mounted on the steel framework which holds the ends of the slip forms in line.

The caterpillar tracks which provide the forward motion are 22 feet long and extend for the full length of the permanent slip forms. These tracks are actually a part of the slip form unit. The plate at

**Fig. 8. Heavy duty self-propelled subgrade machine developed for constructing subgrade.**

the inside edge of the caterpillar track forms the edge of the concrete slab. The tracks travel on the subgrade adjacent to the concrete slab and this portion of the subgrade is finished as accurately as though steel forms were to be placed. This accurately prepared subgrade permits the machine to hold a regular and true profile for the upper edge of the concrete slab.

In 1955, this contractor built several new machines incorporating a number of improvements. The machines are heavier in design and are adjustable to 20, 22 and 24-foot widths and will construct concrete slabs having thicknesses of 7, 8, 9 and 10 inches. Tamper bars and internal tube vibrators have been mounted on the front of the machine to consolidate the concrete. A front view of this machine is shown in Fig. 9, and Fig. 10 shows the back view of the equipment and the finished base course. The machine was remodeled again in 1956 by adding a hydraulic strike-off to the front of the machine. The strike-off spreads the concrete at a uniform elevation ahead of the front screed. The machine can be operated at several speeds; however, a speed of approximately 2½ feet per minute appears to give the best results.

*Development of Self-Propelled Subgrade Machines*

One of the problems which faced this type of construction was an economical and accurate method of building the subgrade. Realiz-

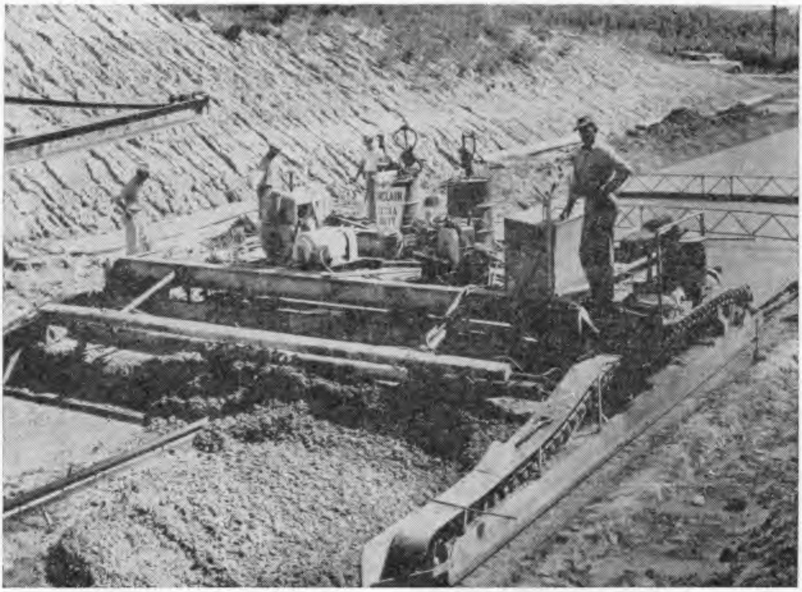

**Fig. 9. Front view of new improved paver adjustable to 20-, 22-, and 24-foot widths and capable of constructing concrete slabs 7, 8, 9, and 10 inches thick.**

ing this, one contractor developed the heavy duty self-propelled subgrade machine shown in Fig. 8. The machine operates on caterpillar tracks and it consists of a transverse cutting blade set to cut the subgrade to the proper crown and profile. Another contractor converted a conventional power subgrader for this purpose by replacing the wheels with caterpillar treads and using chain drives to propel the machine. A front and back view of this equipment is shown in Figs. 11 and 12.

The subgrade on which the tracks of the machine travel is accurately hand finished to the proper elevation. As the subgrade machine moves forward, it cuts the subgrade to the true elevation. When the paving machine, which also has caterpillar treads, moves over the same path, a uniform thickness of concrete slab is produced. The surplus subgrade material is carried to the shoulder by a conveyor belt. The machines construct an accurate uniform subgrade requiring almost no hand work. The self-propelled machines were a big improvement over the mechanically-drawn templet previously used in this type of construction. When the contractors exercised reasonable care in preparing the subgrade, the amount of overrun in concrete was reduced to less than 5 per cent of the theoretical quantity.

**Fig. 10. Rear view of machine shown in Fig. 9. Here the finished base course is shown.**

*Surface Variations*

In order to encourage this type of construction, our specifications for base course were revised by increasing the permissible surface variation from ¼-inch in 10 feet to ⅜-inch. We now feel that base course constructed with a slip form paver can be built to ¼-inch tolerance, so we have recently changed back to that requirement. The following data were taken from projects which permitted a ⅜-inch variation:

*Number of Variations*

| *Length* | *⅛-inch* | *¼-inch* | *⅜-inch* |
|---|---|---|---|
| 1300 ft. | 10 | 4 | 0 |
| 650 ft. | 5 | 1 | 0 |
| 2050 ft. | 26 | 7 | 0 |
| 2850 ft. | 24 | 7 | 0 |
| 2875 ft. | 28 | 7 | 0 |
| 3349 ft. | 182 | 44 | 5 |
| 9900 ft. | 97 | 32 | 3 |

*Core Strengths*

As mentioned in the first part of this paper; cores have been taken from the finished concrete clabs on a number of projects and

**Fig. 11. Front view of another type of subgrader on which wheels were replaced with tracks and chain drives used to propel the machine.**

the quality of the concrete compares favorably with concrete finished by other methods. We have run a number of compression tests on these cores and the following are some of the results:

| *Number of Cores* | *Age* | *Average Strength* |
|---|---|---|
| 16 | 20 to 28 days | 4168 psi. |
| 35 | 4 months | 4515 psi. |
| 14 | 5 months | 5367 psi. |
| 13 | 6 months | 5658 psi. |
| 17 | 10 months | 6060 psi. |

The concrete used to construct the base course conformed to the following composition and consistency limits:

Cement used per cubic yard ........................................5.6 to 5.8 bags
Water used per bag of cement .............................4.9 to 5.3 gallons
Slump ....................................................................1½ to 2 inches
Air content ...........................................................3 to 5 per cent
Coarse aggregate furnished in two sizes.

*Costs*

Complete cost data are not available; however, our estimating department has made a tentative analysis of one project. In con-

**Fig. 12. Rear view of Fig. 11.**

structing this project, which consisted of 6.1 miles of 24-foot 9-inch thick base, the contractor used 23 men and two foremen on the subgrading and paving operations. The equipment consisted of a 34E dual drum mixer, self-propelled subgrade machine, self-propelled slip form paving machine, motor patrol, one pneumatic roller, one steel-tired roller, two water trucks, and two service trucks. An average of 120 lineal feet of concrete slab was laid per hour on this project and the best day's run was 1,525 feet. The common labor rate was $2.10 per hour and the computed labor cost (excluding plant batching and hauling costs) was found to be $0.20 per square yard.

*Conclusions*

The fact that the contractors are willing to finance the building of their machines certainly indicates that the new type of construction is more economical than conventional methods. The machines are capable of laying full-width slabs which are uniform in thickness and have straight edge alignment. The edges stand vertically with very little slumping. Compression tests made on cores removed from the base course indicate strengths comparable to concrete placed by other methods. It is possible to lay concrete slabs without forms meeting a surface tolerance of ¼ inch in 10 feet. With further development of this machine, it may be possible to meet the requirements of ⅛ inch in 10 feet which is specified for concrete pavements.

Much has been accomplished through the effort of the Division of Highways to stimulate interest among the contractors to develop the new equipment. A total of 24.9 miles of concrete slabs has been completed by this method on state projects during the last five consecutive seasons. It is felt that the new equipment has passed beyond the experimental stage and is now in the development stage.

Engineers of other states have become interested in this equipment for building finished concrete pavements. Iowa and Colorado completed a considerable mileage of finished concrete pavements with this equipment in 1956 and plan to build more in 1957.