CONSTRUCTION OF A PREFABRICATED HIGHWAY TEST SECTION

Lorys J. Larson, South Dakota State University; and
Wayne R. Haug, State Highway Commission of Kansas

A unique section of highway is being tested under regular traffic conditions on the US-14 bypass near Brookings, South Dakota. It consists of a 900-ft stretch of two-lane highway constructed of precast, prestressed concrete panels 6 ft wide, 24 ft long, and $4^1/_2$ in. thick. The panels are overlaid with a bituminous mat that ranges in thickness from 3 in. at the centerline to $1^1/_2$ in. at the edges. The prefabricated panels are designed to replace conventional pavement more than 10 in. thick that may be required for the heavier loads of the future. Evaluation of structural performance is continuing and will be made available at a later date. This paper is a brief account of the procedures utilized in the construction of this test section. A cost summary is also included showing that this type of pavement costs about $15 per sq yd. The cost is not competitive with current conventional pavements. However, the precast, prestressed concrete panel concept was visualized as a possible solution for future highway loads that may require increased thickness for conventional pavements. At that time, this type of prefabricated highway could become economically feasible.

•BECAUSE of the increase in heavy-truck traffic, stronger pavements are needed to carry the increasing wheel loads. This has resulted in the development of thicker pavements that cost more. In some parts of the country the aggregates needed for such pavements are scarce, which makes it necessary to transport the aggregates over long distances to the construction site. Long haul transportation increases the pavement cost further; therefore, it is necessary to investigate other methods of construction.

During the past three decades, research has resulted in the development of prestressed concrete pavements that are composed of concrete prestressed with high-strength steel (1, 2, 3, 4, 5, 6). As a result of prestressing, both the high compressive strength of the concrete and the high tensile strength of the steel are utilized. Through utilization of the compressive strength, the prestressed concrete slab can be thinner yet have the same load-carrying capability as ordinary concrete pavement. Such a reduction in thickness means a saving in aggregate as well as a possible saving in construction time. As the size of vehicle loads increases, the use of prestressed concrete pavements should become economically competitive with current methods of construction.

In 1962, the Civil Engineering Department at South Dakota State University, in cooperation with the South Dakota Department of Highways and the U.S. Department of Transportation, Federal Highway Administration, initiated a study to determine the suitability of precast, prestressed concrete panels for use in highway pavements.

In 1962, Gorsuch (7) constructed a laboratory test to determine the structural behavior of precast, prestressed concrete panels. He used half-scale test panels 12 ft long, 2 ft wide, and 2 in. thick. The panels were laid in a transverse direction and were post-tensioned in the logitudinal direction. From a structural standpoint, the panel sections held promise for use in highway pavements.

Further laboratory testing was made by Kruse (8) in 1966 to evaluate the feasibility of using prestressed and post-tensioned concrete panels and to make recommendations for possible field studies. The test panels were each 24 ft long, 4 ft wide, and $4^1/_2$ in.

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thick. These panels were pretensioned in the longitudinal direction by five steel cables, each of which was $^3/_8$ in. in diameter. Each cable consisted of 7-wire steel strands. The panels were also post-tensioned in the transverse direction. A repetitive wheel loading was used. This study showed that the pavement ($4^1/_2$ in. thick) was structurally adequate for heavy-duty highway service and that pumping of the subgrade was a principal factor. Kruse suggested that further laboratory studies be made with heavier loads under adverse conditions that would be conducive to subgrade pumping. The suggested field studies included the testing of the precast panels, direction of pretensioning, expansion joints, distance between joints, total panel movement, subgrade friction, and the investigation of methods by which the panels are transported and handled.

In 1967, a study was conducted by Jacoby (9) dealing with thermal expansion and contraction in a pavement consisting of prestressed concrete panels. This study was divided into a laboratory study and a small-scale field test section. Half-scale panels were used in the laboratory study, whereas full-scale panels were used in the field study. The field study panels were 24 ft long, 6 ft wide, and $4^1/_2$ in. thick. Nine 7-wire steel strands ($^3/_8$ in. in diameter each) were used to develop a prestress of 350 psi in the longitudinal direction. No prestress was used in the transverse direction. The 96- by 24-ft field test section was located near the South Dakota Department of Highways' maintenance yards near Brookings, South Dakota. It was subjected to highway department vehicles moving at speeds of less than 25 mph.

The findings of the studies at South Dakota State University have resulted in the continued study of a special test section constructed with prestressed concrete pavement panels overlaid with asphalt concrete and located on the US-14 bypass north of Brookings, South Dakota, adjacent to South Dakota State University.

The present paper is a brief account of the construction procedures and costs involved in the construction of the precast, prestressed composite pavement test section now in public use near Brookings, South Dakota. Research now in progress involves a 5-year study of the cost and performance of this pavement under actual traffic conditions. The study began in 1967 for the South Dakota Department of Highways in cooperation with the U.S. Department of Transportation, Federal Highway Administration.

PANEL ARRANGEMENT AND CONFIGURATION

The 900-ft long by 24-ft wide test section was divided into two parts. In the east part of the test section (504 ft), the panels were laid in the longitudinal direction; in the west part (396 ft), the panels were place in the transverse direction (Fig. 1).

After consideration of design loadings and lifting stresses, it was found that lifting and handling stresses were critical. Accordingly, all panels were designed to accommodate the stresses while holding the panel thickness to the considered minimum of $4^1/_2$ in.

Four steel loops were precast into the panels for lifting and handling. For each panel, the loops were located 5 ft from each end and 1 ft from the side. The stresses, which resulted 5 ft from each end due to lifting, were 612 psi of compression at the top of the panels and 196 psi of compression at the bottom.

The panels were constructed at Gage Brothers Concrete Company in Sioux Falls, South Dakota. All panels were 24 ft long, 6 ft wide, and $4^1/_2$ in. thick with the exception of 4 end panels that were 12 ft long, 6 ft wide, and $4^1/_2$ in. thick. A uniform prestress of 405 psi was obtained in the longitudinal direction by using ten $^3/_8$ in. diameter, 7-wire steel strands, high-strength steel cables having a yield stress of 270,000 psi. The panels were all reinforced in the transverse direction with No. 3 reinforcing bars spaced at 1-ft centers (Fig. 2).

Tapered grout keyways were constructed on all adjoining sides of the panels. These were subsequently filled with portland cement mortar grout to provide a shear transfer from one panel to another (Fig. 3).

For the east portion of the test section, the panels were constructed with protruding reinforcing bars that provided for a welded connection (primarily for holding the panels in place during construction) at a distance of 6 ft from the panel ends. At these points, access for welding was furnished by widening the grout keyway 2 in. for a distance of 4 in. (Fig. 3).

Figure 1. Test section plan.

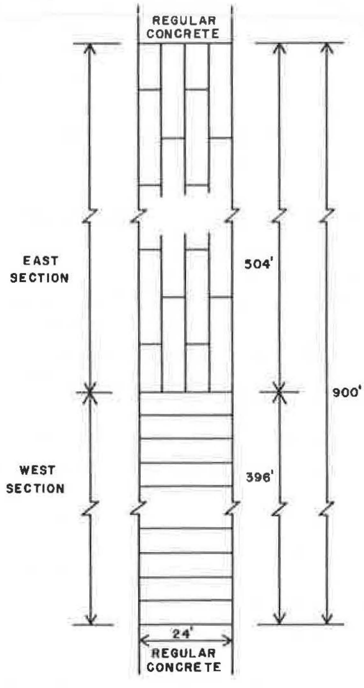


Figure 2. Typical panel details.

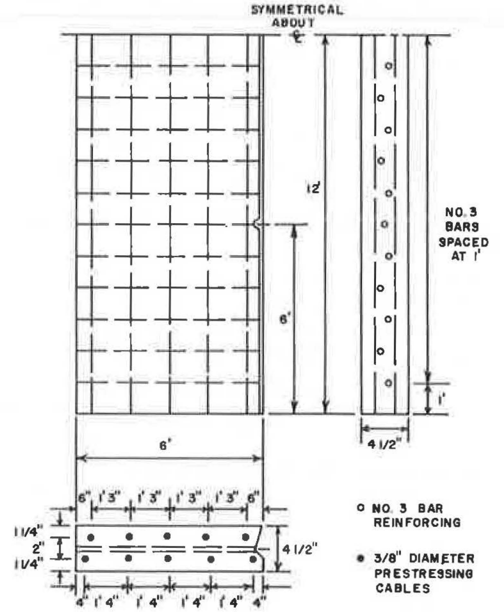
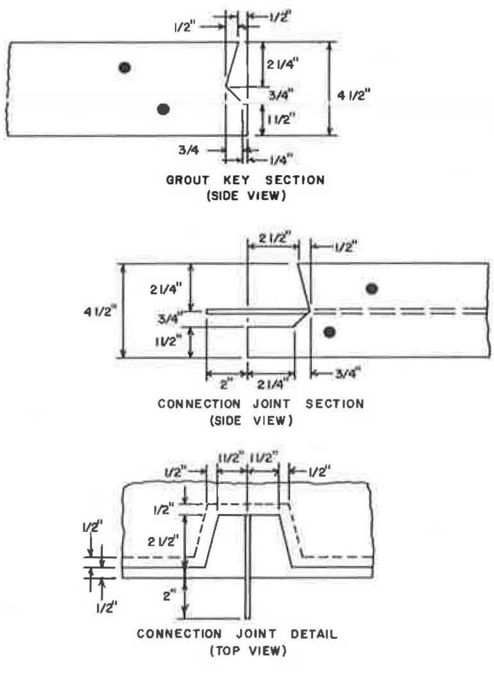


Figure 3. Grout key and connection joint sections.



The panels for the west portion of the test section were designed without the welded connections between the panels.

SUBGRADE PREPARATION

The subgrade was constructed by undercutting through cut sections and shallow fill sections, 3 ft below the proposed earth subgrade, to ensure that there was a minimum fill height of 3 ft. The subgrade embankment was compacted to 8- to 10-in. lifts to meet specified moisture and density criteria by using sandy silt fill material from a nearby borrow pit. Crushed gravel subbase was then added and compacted to produce the necessary transverse slope and thickness, with a 3-in. minimum thickness provided at the centerline after fine grading.

An autograder was used to fine grade the base course to the correct elevation. The base course and subbase were then compacted with a pneumatic self-propelled roller, and the paver track forms were installed at the correct elevation.

Prior to placing the precast panels, a ½-in. layer of bedding sand was added. A tail blade, operating on track forms, leveled the bedding sand and established the correct elevation.

A typical cross section of the finished pavement is shown in Figure 4.

PLACEMENT OF PANELS

The panels, which had been transported to the construction site by trucks, were unloaded on the shoulder of the road by a hydraulic crane. The panels were lifted by using the four steel loops that were precast into each panel. Before the panels were laid in place on the highway, a bond breaker (RC 250 asphalt) was applied along one edge of the panels to prevent the grout (placed in the joints later) from bonding along one edge of the keyway.

The placement of the panels began at the east end of the site, where they were placed in the longitudinal direction (Fig. 5). The track forms were utilized for alignment. The panels were later connected by welding together the steel reinforcing bars provided at each connection point.

The panels in the west section of the test site were placed in the transverse direction (Fig. 6). These panels were not provided with welded connections.

After the panels had been placed on the base course, the steel loops, which were used in handling, were burned off with an acetylene torch. Wooden planks were then placed on the in-place panels, and a vibrator type of roller was used to ensure that the panels were firmly placed in the bedding sand.

Initially, the contractor attempted to use an air-pressure grout machine to fill the grout keyways; however, this machine proved inadequate, and a piston-driven grout machine was used to complete the grouting operation. Immediately after the grouting had been completed, the panel assembly was covered with polyethylene for curing.

A tack coat of RC 70 asphalt was applied prior to covering the panels with a Class G asphaltic concrete mat. Mat thickness ranged from 3 in. at the center of the roadway to 1½ in. at the edges. The mat provided a crown for the highway as well as a smooth riding surface.

A summary of equipment, labor, and material costs of the test section is given in Table 1.

CONVENTIONAL CONCRETE PAVEMENT COSTS

Current construction costs of conventional pavements were obtained from several states within the same geographical area (Table 2). These states were chosen because they had similar climatic and terrain features. Construction methods and practices were about the same throughout the area. The costs cited are averages and refer to portland cement concrete pavements 24 ft wide. The cost per square yard varied from $5.21 for nonreinforced pavement to $7.89 for continuously reinforced pavement. The cost of earthwork, subgrade, or base construction is not included because it does not vary with type of pavement used.

Figure 4. Fine grading the subbase.

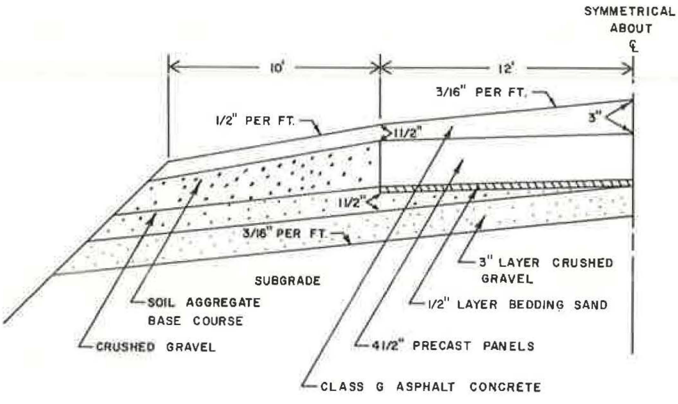


Figure 5. Placing panels in the east section.

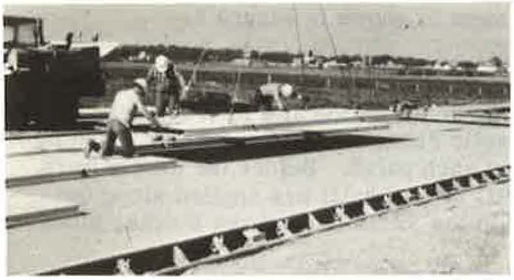


Figure 6. Placing panels in the west section.

Table 1. Test section costs.

Item	Equipment Rental (dollars)	Equipment[a] (dollars)	Equipment Total (dollars)	Labor (dollars)	Material (dollars)	Total (dollars)	Total Cost Per Square Yard (dollars)
Precast panels	–	–	–	–	32,698.00	32,698.00	13.62
Transportation	1,262.13	412.60	1,674.73	305.73	–	1,980.49	0.83
Unloading panels	324.68	244.23	568.91	132.44	–	701.32	0.29
Fine grading subbase	414.60	–	414.60	167.63	–	582.23	0.24
Bedding sand	552.91	64.35	617.26	326.35	126.90	1,070.51	0.45
Placing panels	752.82	186.83	939.65	534.62	–	1,476.27	0.62
Grouting panels	2,940.29	238.96	3,179.25	536.84	343.35	4,059.44	1.69
Asphalt mat	–	–	–	–	2,232.24	2,230.24	0.93
Total	6,247.43	1,146.97	7,394.40	2,003.61	35,400.49	44,798.50	18.67

[a]Equipment on project but not in use.

Table 2. Conventional concrete pavement costs.

State	Year	Type of Reinforcement	Pavement Thickness (in.)	Cost Per Square Yard (dollars)
South Dakota	1968	Nonreinforced	8	6.50
North Dakota	1966	Continuously reinforced	7	6.65
North Dakota	1967	Continuously reinforced	8	6.55
Wyoming	1968	Nonreinforced	8	5.53
Minnesota	1968	Reinforced	9	6.30
Iowa	1968	Nonreinforced	8	5.21
Iowa	1968	Reinforced	10	7.89
Iowa	1968	Continuously reinforced	8	7.20

CONSTRUCTION PROCEDURES AND COSTS

The 1967-1968 cost of the precast, prestressed concrete pavement is considerably higher than that listed for conventional pavement construction. However, it is believed that the $18.67 per sq yd cost of the prefabricated test section can be appreciably reduced. Mass production and familiarity with this type of highway construction would materially reduce overall construction costs. Because this is a new type of construction, considerable time was spent by personnel in learning the technique of placing the panels. Similarly, the cost of unloading the panels at the site could be reduced if an experienced crew were used to move the panels directly from the trucks to their placement on the highway. This would eliminate dual handling.

Costly experimentation with two types of grouting machines resulted in unnecessary expense to the contractor. Proper planning and experience with this type of operation could reduce grouting equipment costs by as much as $1.00 per sq yd.

The contractor made excellent use of the paver track forms to reduce the time and cost of construction. The forms were used by the tail blade to smooth the bedding sand and to obtain the correct elevation after the base course had been fine graded with the autograder. The forms also served to confine the bedding sand, and they were used as alignment guides during placement operations.

The panels could be produced at central casting yards on a year-round basis with quality control, which would provide concrete of high durability. The precast panels could then be trucked to places having weather conditions that might not be suitable for conventional pavement construction. This flexibility could have the same effect as lengthening the construction season.

The asphalt mat provides a smooth riding surface as well as a protective covering over the concrete panels and joints. Reflection cracking prevails over the panel joints during the winter months; however, these tend to seal themselves with the advent of warmer weather.

If a section of this pavement needs repair, the panels can be removed and replaced with new panels in a short period of time, thus lowering maintenance costs.

Conventional pavements are being constructed with greater thicknesses to carry the increasing loads required of current highways. Thus, greater quantities of high-quality aggregates are required. As a result, good aggregates are becoming scarce, and their price continues to rise, which makes conventional pavements increasingly more expensive.

It is felt that the total cost of this pavement could be reduced to somewhat less than $15.00 per sq yd. This figure is still not competitive with the current price of conventional 7- to 10-in. thick pavements. However, the type of pavement under consideration was visualized for use with heavy loads of the future that may require conventional pavements of 15 in. or more in thickness. Under these requirements, the precast panels would become economically competitive.

In addition to highway pavement use, precast, prestressed concrete panels could be stockpiled and used in the construction of parking lots and driveways. The U.S. Corps of Engineers has also expressed interest in the use of this type of panel for boat landing ramps.

CONCLUSIONS

This investigation to date has produced the following conclusions:

1. With increased expreience and the development of new construction techniques, the cost per unit area for precast, prestressed concrete composite pavement could be reduced to a price somewhat below $15.00 per sq yd.
2. The use of central casting yards would result in quality production in fabricating the concrete panels.
3. Precast, prestressed concrete panels could be placed during weather conditions that are not conducive to the placing of conventional pavements, thus lengthening the construction season.
4. As aggregates become more scarce, the precast panel system should become more competitive with conventional pavements.

5. As the thicknesses of conventional pavements increase because of heavier loads in the future, this type of precast panel construction would become more feasible.

6. Precast panels could be used for construction of parking lots, driveways, and boat landing ramps.

7. Subject to structural performance, precast, prestressed concrete composite pavement suggests a possible solution for future highway construction.

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