CORPS OF ENGINEERS DESIGN METHOD FOR CONCRETE BLOCK PAVEMENTS

Raymond S. Rollings

U. S. Army Engineer Waterways Experiment Station
Vicksburg, Mississippi, U.S.A.

SUMMARY
The U. S. Army Corps of Engineers has adopted a design procedure for concrete block pavements that combines their current California Bearing Ratio flexible pavement design method with an equivalent thickness to account for the block surface. Limited traffic tests indicate that this will provide a conservative design. Although the existing equivalent thickness is an effective design expediency, improvements are still needed. There is some indication that the equivalent thickness for design should vary with the tire contact area, and there is still no explicit way to evaluate the effect of block thickness and shape.

1. BACKGROUND

In the fall of 1978, the Office, Chief of Engineers, U. S. Army Corps of Engineers, directed the Waterways Experiment Station to evaluate concrete block pavements for Corps of Engineers' use. Available literature was reviewed and Corps of Engineers personnel visited a number of manufacturers and examined in-service pavements. This information was used to prepare an Engineering Technical Letter that was issued by the Office, Chief of Engineers, in April 1979 (1). The Engineering Technical Letter authorized the Corps of Engineers to use concrete block pavements for low-speed pavements and provided basic design and construction information.

In August 1979, the Waterways Experiment Station built three concrete block pavement test items over a soft clay subgrade and tested them under traffic from a 25,000-lb (11,340-kg) twin wheel, tandem axle load and a 105,000-lb (47,627-kg) military tank. This test demonstrated that the Corps of Engineers design method for block pavements was conservative and that block pavements could be designed and built to carry heavy traffic loads over a soft subgrade. Additional technical literature was reviewed as it became available, and additional block pavement sites were visited over the next few years. The Waterways Experiment Station published the information gathered during this study of block pavements as a technical report in March 1983 (2).

2. SCOPE

This paper describes the basis and method for the Corps of Engineers thickness design for concrete block pavements. Shortcomings and limitations of this design method are pointed out, and areas for further work are identified.

3. DESIGN BASIS

The primary method of block pavement failure observed in experimental and in-service pavements is rutting. This is characteristic of a flexible pavement which transmits surface loads to the subgrade through layers of varying strength and stiffness. The most common flexible pavement consists of an asphaltic concrete surface over layers of decreasing quality, usually the base and subbase over the subgrade. This is in contrast to a rigid pavement such as portland cement concrete which relies on bending of the concrete slab to transmit the loads to the subgrade.

Since block pavements transmit loads and fail like flexible pavements, modifying the existing Corps of Engineers flexible pavement design procedure appeared to be the most appropriate approach for design of block pavements. The Corps of Engineers flexible pavement design method is based on three principles. First, each layer must have sufficient strength to withstand the stresses developed by the traffic loads. Next, each layer must be compacted to a degree that ensures that the layer strength assumed in design is reached and that no densification with resulting surface settlement takes place under traffic. And finally, the materials used in each layer must meet requirements such as gradation and Atterberg limits that have been found necessary for adequate long-term performance. The difference between a concrete block-surfaced and an asphaltic concrete-surfaced flexible pavement is in the way loads are transmitted through the blocks and the asphaltic concrete. Consequently, all of the requirements in existing Corps of Engineers flexible pavement design manuals (3, 4) and guide specifications that deal with the last two principles remain unchanged.

The Corps of Engineers flexible pavement design method evaluates the strength of each layer in terms of the California Bearing Ratio (CBR). Boussinesq elastic theory is used to determine stress distribution within the pavement, and linear superposition is used to handle the effect of overlapping stresses at depth from multiple wheel loads. The empirical relation between CBR, load effects, and repetitions of load is based on the results of accelerated traffic tests conducted between 1940 and 1970 and is expressed as a cubic equation (5, 6). The traffic tests on which the CBR equation is based used a failure criterion of a 1-in. (25.4-mm) upheaval due to shearing. Consequently, pave-

ment thickness selected on the basis of the CBR equation is simply the thickness found necessary from past tests to avoid a given degree of shear failure in a material of the design CBR under the design load and repetitions.

4. MODIFICATION FOR BLOCKS

Although concrete block-surfaced and asphaltic concrete-surfaced pavements are both flexible pavements, several investigators have confirmed from pressure cell measurements that concrete block pavements appear to distribute surface loads to the base better than asphaltic concrete pavements. This superior load-distributing characteristic of block pavements should reduce the required thickness of pavement compared to an asphaltic concrete-surfaced pavement since the magnitude of stress at any point in the lower layers is reduced.

Knapton (7) compared the pressure measured under concrete paving blocks to the stresses under a conventional flexible pavement using a two-layer, elastic analytical model. From this comparison, Knapton developed his recommendation that for design the concrete block surface and sand laying course could be considered as equivalent to 6.3 in. (160 mm) of conventional asphaltic concrete and base. The Corps of Engineers adopted this suggested equivalency for use with their conventional CBR flexible pavement design method but rounded it off to 6.5 in. (165 mm) (1). No direct allowance for block thickness is made in the design calculation, but the block thickness is selected from the type and weight of vehicles that will use the pavement.

Adopting Knapton's (7) recommended design equivalency allows the Corps of Engineers to include consideration of block pavements within their existing manuals and guide specifications with only minor modifications. The three Waterways Experiment Station test items indicated that this design equivalency when combined with the Corps of Engineers CBR design method would underpredict actual performance, but it would provide a conservative design (2). A review of other potential design methods generally found that the current state of the art in design of concrete block pavements is rather primitive, and no other method appears sufficiently developed and tested to warrant adoption (2).

5. APPLICATION

The Corps of Engineers designs conventional roads, streets, and storage areas in terms of a design index. The design index of a road depends on the types of vehicles and amount of traffic that the pavement will support. Design index is defined in Table 1, and some suggested minimum concrete block thicknesses are also provided. It is now a simple matter to develop the concrete block design chart in Figure 1 by using the 6.5-in. (165-mm) equivalency and the conventional flexible pavement design chart that is published in the Army manual for flexible pavement design of roads, streets, and storage areas (3).

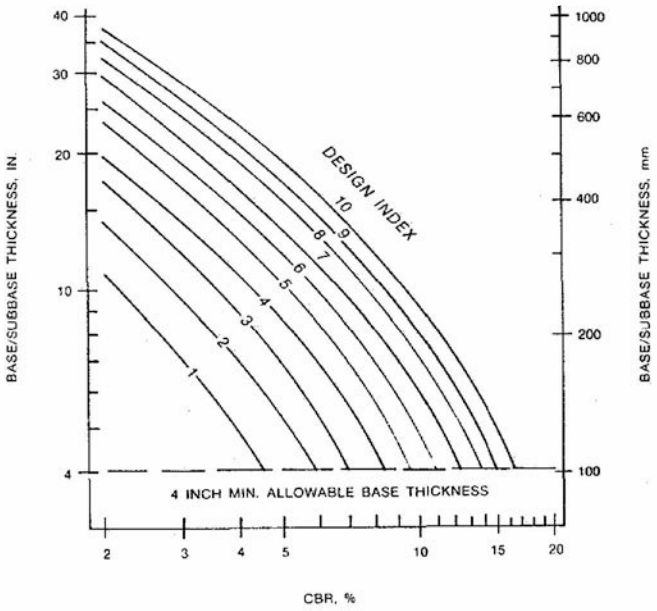


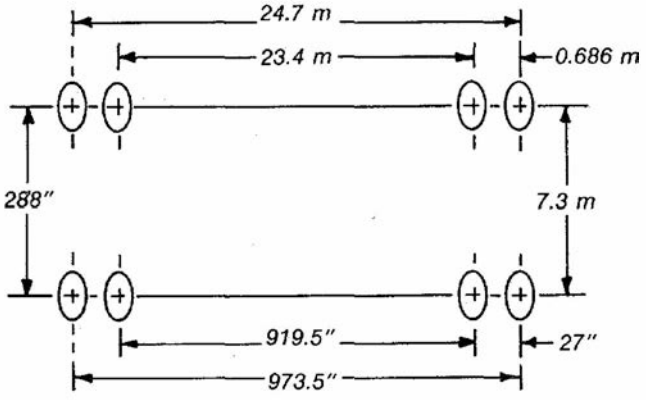
Figure 1: Concrete block pavement design curves for Army traffic design indexes

Table 1: Definition of design index

Design index	Typical traffic description*	Equivalent 18-kip single-axle loads	Suggested minimum block thickness
1	Passenger vehicles only, no trucks	3.10×10^3	60 mm
2	Up to 950 vehicles/day with up to 10% two-axle trucks	1.35×10^4	80 mm
3	Up to 2500 vehicles/day with up to 10% two-axle trucks	5.90×10^4	80 mm
4	Up to 4200 vehicles/day with up to 14% two-axle and 1% three- to five-axle trucks	2.60×10^5	80 mm
5	Up to 5800 vehicles/day with up to 14% two-axle and 1% three- to five-axle trucks	1.15×10^5	80 mm
6	Up to 5300 vehicles/day with up to 15% two-axle and 10% three- to five-axle trucks	5.00×10^6	80 mm
7	50,000-lb tracked vehicles and 30,000-lb forklifts	2.25×10^7	80 mm
8	80,000-lb tracked vehicles and 50,000-lb forklifts	1.00×10^8	80 mm
9	Up to 10 passes of 120,000-lb tracked vehicles/day	4.40×10^8	100 mm
10	Up to 100 passes of 120,000-lb tracked vehicles/day	2.00×10^9	100 mm

* Representative description only; complete description in Reference 3.

One major advantage of the Corps of Engineers CBR design method is that designs can be prepared for any type of vehicle and traffic pattern. Therefore, any type of concrete block pavement can be designed by first developing a conventional CBR design curve using the procedures published in a Waterways Experiment Station technical report (5) and then simply using the 6.5-in. (165-mm) equivalency to modify the curve for block pavements. For example, preparing a design curve for a Travelift CH1150 yard gantry with the design characteristics shown in Figure 2 would require the following steps. First an equivalent single-wheel load curve is prepared for the critical load configuration. Next the distribution of traffic and the wheel configuration are used to develop a pass-to-coverage ratio which relates the number of passes of a vehicle that are needed to apply one load repetition or coverage in the critical traffic areas of the pavement surface. For this example, the wander width of the vehicle is assumed to be 25 in. (635 mm) to represent the concentrated traffic lanes often encountered in cargo handling areas (8). The next step is to solve the CBR equation to provide a design curve relating CBR and thickness of required overlaying material for each desired level of traffic. Reference 5 describes in detail how to perform each step up to this point. Finally, 6.5 in. (165 mm) is subtracted from these curves to account for the block and sand laying course which leaves the required thickness of base and subbase needed for varying CBR values of traffic. Figure 3 shows the conventional CBR flexible pavement design curve for 50,000 passes of the Travelift CH1150 and the concrete block design curve for 200 and 50,000 passes. As can be seen, the block curves simply are displaced 6.5 in. (165 mm) from the conventional curve for any CBR value. A design example is provided as Appendix A to this paper.



GROSS WEIGHT = 223,200 LB (101,242 Kg)
SINGLE-WHEEL LOAD = 40,365 LB (179.6 KN)
TIRE INFLATION PRESSURE = 146 PSI (1007 KPa)
CONTACT AREA = 280 IN.^{2} (0.18 m^2)
PAYLOAD = 67,200 LB (30,481 Kg)

Figure 2: Design characteristics for Travelift CH1150 yard gantry

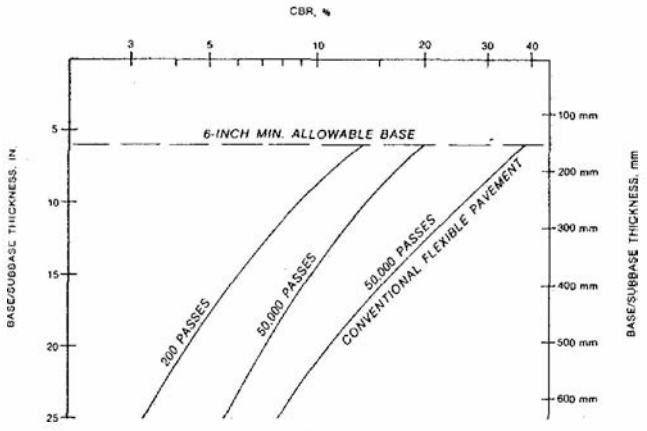


Figure 3: Conventional and concrete block design curves for CH1150 yard gantry

6. DESIGN IMPROVEMENTS

The Corps of Engineers' use of Knapton's 6.5-in. (165-mm) equivalent thickness for block pavements is an expedient design solution that provides a conservative design and that does not require major modifications to other Corps specifications such as material quality or degree of compaction. Although it is a usable interim design solution, improvements in design are still needed. Completely theoretical design approaches using elastic layer, finite difference, or finite element analytical models do not appear promising because of the difficulty of defining material properties for the block layer and because the block layer increases in stiffness under traffic. Theoretical design approaches have been proven difficult to apply to conventional pavement design and can be expected to be even more difficult to use with block pavements. The most promising immediate approaches to design improvement appear to be either continued use of equivalent thickness for the blocks or development of an empirical or semiempirical design based on carefully controlled traffic tests.

Knapton (7) based his equivalent thickness on measured pressures compared to a two-layer elastic solution to the problem. More extensive testing (9, 10) of this type generally confirmed Knapton's findings. Pressures under the block and sand layer in these tests generally are between 50 to 60 percent of the applied surface load depending on the stiffness of the underlying layers. Knapton's original assumptions concerning modular ratios and thickness of the surface layer can be avoided by using a Boussinesq solution for a circular load on an elastic half space, and this finds that the stresses at 50 to 60 percent of the surface stresses are at a depth of 1.1 to 1.3 times the radius of the loaded area. For the loading areas used by Knapton (7) and Clark (9, 10), this would correspond to a depth or effective thickness of the block surfacing between 5.3 in. (135 mm) and 7.8 in. (198 mm) roughly agreeing with Knapton's equivalency.

All of the tests run with block pavements have used contact loading areas between 62 and 113 sq in. (.040 and .073 m^2) which covers the expected

range for normal highway traffic. However, many industrial vehicles used for cargo handling will have tire contact areas much larger than this. For example, the Hyster H 620B forklift has a contact area of 224 sq in. (.144 m^2) and the LeTro Crane GC-500 has a tire contact area of 1275 sq in. (.823 m^2) (8). These larger-tired vehicles may have a different equivalency than 6.5-in. (165 mm) currently used.

Clark (10) reported that only those blocks that were in contact with the loading plate were effective in transmitting load to the base. There was apparently little or no load carried over to blocks outside of this area. If this is true in general, then the stress reduction caused by the blocks depends primarily on the number of partially loaded blocks around the circumference of the load. The area of the partially loaded blocks around a circular load can be added to the load to provide an equivalent and equal circular effective loaded area. If the radius at the loaded area changes, the difference in radius between the loaded area and effective loaded area should remain constant since the pattern of partially loaded blocks on the circumference of the load should not change when the radius of the loaded area changes. The data reported by Clark (10) can be used to calculate this constant difference in radius as 2.36 in. (60 mm) for an average of 21 tests covering different block shapes and thicknesses and different base stiffnesses. This was used in Figure 4 to show that as the diameter of the loaded area increases the effective block thickness also increases. Standard plate load tests with 30-in.-diam (762-mm) plates were run on the surface of the blocks and base course for each test item during the Waterways Experiment Station tests, and the average ratio of the block surface results to the base course results was 1.30 (2). This compares well with the value of 1.34 that would be calculated from Figure 4. A number of approximations, simplifications, and the Boussinesq stress solution were used to develop Figure 4, so tests with larger diameter plates than used in past tests are needed to confirm or reject the trend shown here.

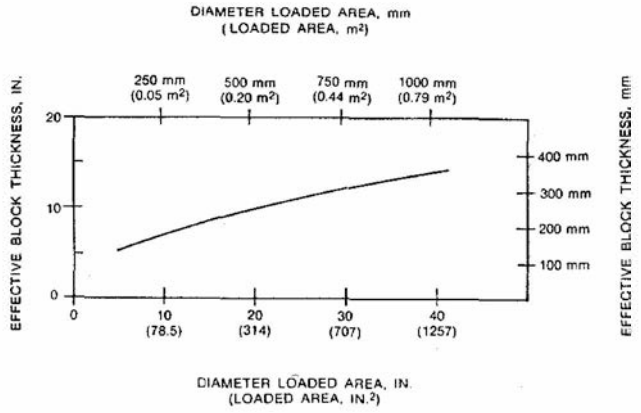


Figure 4: Influence of loaded area size on effective block thickness

Figure 5 from Reference 2 shows trafficking data reported by several investigators. There appears to be some potential for developing an empirical relation between thickness, CBR, load, and traffic levels. However, there are gaps in the data that must be filled, tests of this kind are expensive, and more work is needed to develop good usable relationships.

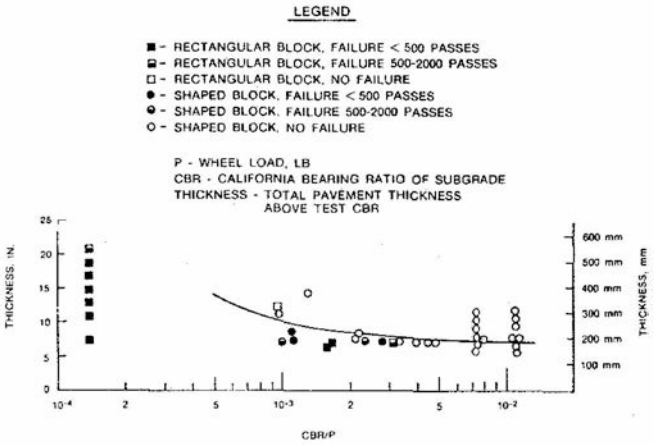


Figure 5: Performance of selected concrete block test items

Several investigators have reached different conclusions concerning the effect of block thickness and shape. At the present time information is not extensive enough to quantify these factors in a design procedure. For example, in Figure 5 most of the shaped blocks have been tested under favorable conditions such as high CBR or low load, while most of the rectangular blocks appear clustered under unfavorable conditions of low CBR or high load. This makes determining a quantitative effect of block shape impossible with the present test data.

7. CONCLUSIONS

The Corps of Engineers has adopted a simple equivalent thickness for concrete blocks that can be used with their conventional CBR flexible pavement design method. This approach provides a conservative design and requires no major changes for existing specifications and manuals. It is an effective interim approach, but more work is needed to determine if new equivalent thicknesses are needed for large contact area tires and to quantify the effect of block shape and thickness.

APPENDIX A

8. DESIGN EXAMPLE

Prepare a design for concrete block pavements for a road with a design index of 8 and for a storage area where aisles will be subjected to 50,000 passes of a CH1150 yard gantry. The subgrade has a CBR of 6 percent, and available construction materials are a sand with a design CBR of 20 percent for the subbase and a crushed stone with a design CBR of 100 percent for the base.

9. ROAD DESIGN STEPS

(1) Figure 1 requires 13 in. (330 mm) of base and subbase over 6 CBR.
(2) Reference 3 as shown in Figure 1 requires a minimum 4 in. (102 mm) base so subbase thickness will be 9 in. (228 mm) (13-4).
(3) Table 1 suggests 80 mm (3.1 in.) thick block.
(4) Final design: 80 mm (3.1 in.) block, sand laying course, 4 in. (102 mm) crushed stone base, 9 in. (228 mm) sand subbase.
(5) If cement or bituminous stabilization of the base or subbase is desired, Reference 3 provides appropriate procedures.

10. STORAGE AREA DESIGN STEPS

(1) Figure 3 requires 23.5 in. (597 mm) over a CBR of 6.
(2) Figure 3 requires 6 in. (152 mm) of base over a CBR of 20.
(3) Sand subbase thickness will be 17.5 in. (445 mm) (23.5-6.0).
(4) Because of large wheel loads, suggest 100 mm (3.9 in.) blocks and guidance of Reference 4 for minimum base thickness, base and subbase quality requirements, design for stabilizing materials with cement or bitumen, etc.
(5) Final design: 100 mm (3.9 in.) block, sand laying course, 6 in. (152 mm) of crushed stone base, 17.5 (445 mm) sand subbase.

11. REFERENCES

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