# Utilization of Marginal Aggregate Materials for Secondary Road Surface Layers

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**The purpose of this study was to develop methodology and procedures for the use of marginal-quality aggregates (aggregates that do not meet existing specifications) in the construction of surface pavement layers of asphalt and portland cement concrete. This paper describes the properties of the bituminous and zero-slump mixes made from marginal aggregate materials and the testing of a specially designed test section, which consists of both flexible and rigid pavement surface layers made of marginal-quality aggregate. Also presented are construction techniques and the behavior of the marginal aggregate mixes subjected to accelerated 4.5-Mg (5-ton) military dump truck and two types of tracked vehicle traffic. Recommended properties of asphalt and portland cement concrete mixes made of marginal aggregate materials are presented to aid the engineer in constructing paved surfaces that are to be used only for limited traffic and short periods of service life.**

The cost of constructing pavements is continually rising due to increasing cost of labor, materials, and equipment. Current U.S. Army Corps of Engineers design procedures allow only the use of high-quality aggregates in asphaltic concrete (AC) and portland cement concrete (PCC) mixtures. Many military operations require paved surfaces for roads, airfields, heliports, and parking aprons, which have only limited traffic and short periods of service life. Therefore, if satisfactory AC and PCC pavement mixes can be made by using marginal materials (aggregates) that do not meet existing specifications but withstand limited traffic for short periods of service life, a considerable savings in construction cost can be realized.

To study the concept of using marginal materials in AC and PCC pavement surface layers, two specially designed test sections were constructed and subjected to accelerated test traffic. The primary test vehicle was an M51 4.5-Mg (5-ton) dump truck that was operated at gross loads of 18 583, 18 685, 19 936, and 22 114 kg (40 920, 41 145, 43 900, and 48 695 lb). A limited amount of tracked-type vehicle traffic was applied to both test sections by using an M113 armored personnel carrier and an M48A1 tank at gross weights of 8628 kg (19 000 lb) and 46 871 kg (103 210 lb), respectively.

## DESIGN AND CONSTRUCTION OF THE TEST SECTIONS

The rigid and flexible pavement test sections were designed to determine the effects of traffic during various weather conditions on the PCC and AC pavement surface mixes made of marginal materials. Both test sections were constructed of sufficient thicknesses to prevent base course or subgrade failures during the traffic period. A plan and profile of the rigid and flexible pavement test sections are shown in Figures 1 and 2, respectively.

The subgrade for both test sections was classified as a lean clay according to the Unified Soil Classification System and had a liquid limit (LL) of 34 and a plasticity index (PI) of 12. The average strength of the subgrade for the flexible pavement test sections was about 25 California bearing ratio (CBR). The base course material for the two test sections was classified as a gravelly-clayey sand that had a LL of 37 and a PI of 24. The 15-cm (6-in) thick gravelly-clayey sand base material for the flexible pavement text section was stabilized with 4 percent lime, which resulted in a strength of above 150 CBR. Plate bearing and thickness measurements made on the finished unstabilized base material for the rigid pavement test section indicate that the average K-value 15.9 kg/cm$^2$ (575 lb/in$^3$) and that the thickness was about 10.2 cm (4 in).

### Zero-Slump Concrete Mixes and Placement Procedures

A mix design for five zero-slump concrete mixes was prepared by using four different aggregate materials (designated S2, G1, G2, and G3) and type 1 portland cement. Classification data for these materials are shown in Figure 3. Mix 1 was designed according to American Concrete Institute (ACI) standard 211.13-75 by using aggregates S2 and G3 and was placed in test items 1 and 2. This mix was designed as a high-quality concrete mix and had a 28-day flexural strength of 5.17 MPa (750 lbf/in$^2$). Mixes 2-5 were designed by using the same cement factor [306.7 kg/m$^3$ (517 lb/yd$^3$)], as for mix 1. Aggregate materials G2, S2, G3, and G1 were used in mixes 2, 3, 4, and 5, respectively. Mixes 2-5 were placed in test items 3-6, respectively. Properties of the in-place mixes are shown in Table 1.

The concrete in test item 1 was placed by end dumping the mix onto the surface of the base and then spreading the mix with a motor grader. The concrete in all other test items was placed with an asphalt finisher. A 11 353-kg (25 000-lb) tandem vibratory roller was used to compact all mixes.

### AC Mixes and Placement Procedures

The primary variables in the flexible pavement's 13 test items were the asphalt content and the aggregates used in the mixes. An 85-100 penetration grade asphalt was used in all of the mixes. The AC mix placed in item 1 was a standard mix that used 1.9-cm (0.75-in) maximum-size crushed limestone minus 4.75-mm (No. 4) limestone screenings and sand filler. A gradation curve of the blended stockpile aggregates used for this bituminous mixture is shown as curve 1 in Figure 4. This gradation meets requirements for conventional bituminous concrete to be used for roads, streets, and heliports or airfields that are not subjected to fuel spillage or to traffic by aircraft that have high-pressure tires [greater than 0.69 MPa (100 lbf/in$^2$)]. The bituminous mixes placed in items 2-13 were made from either one of four basic marginal materials or blends of these materials. Classification data of each of these bituminous mix aggregates are shown in Figure 4.

The optimum asphalt contents, as determined by the Marshall design criteria for the marginal materials, appeared to be slightly high for the sand mixes. This is

**Figure 1. Layout of rigid pavement test section.**

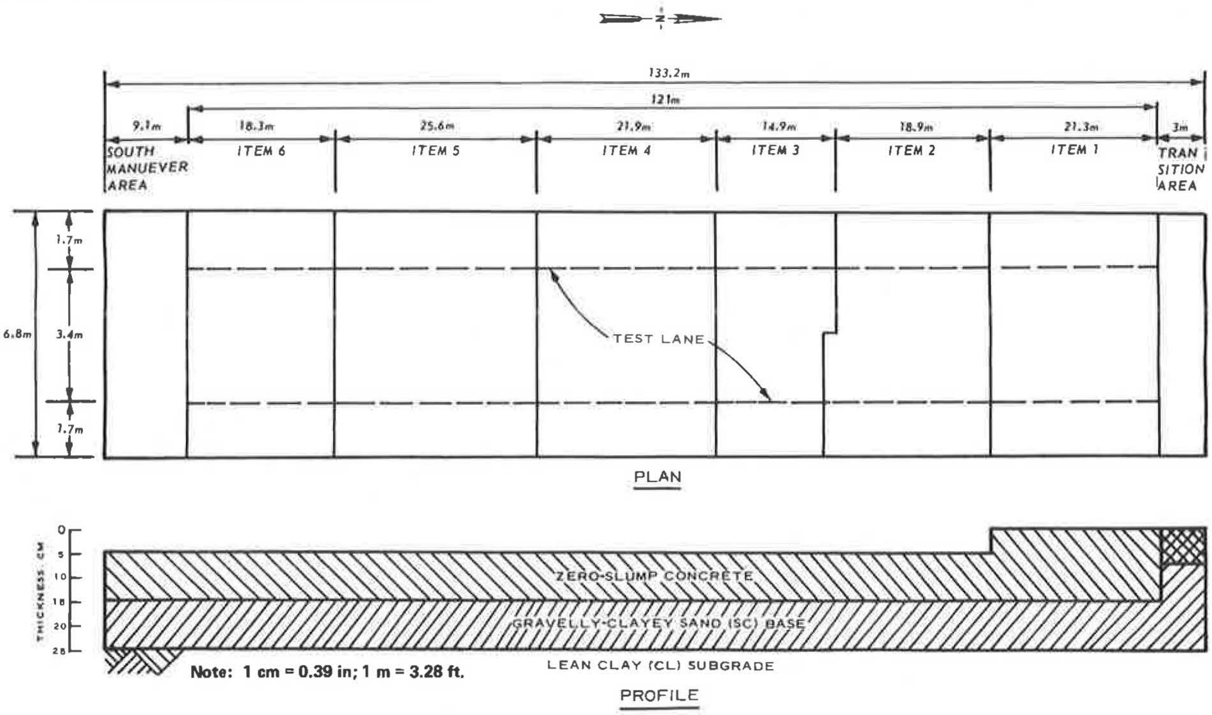
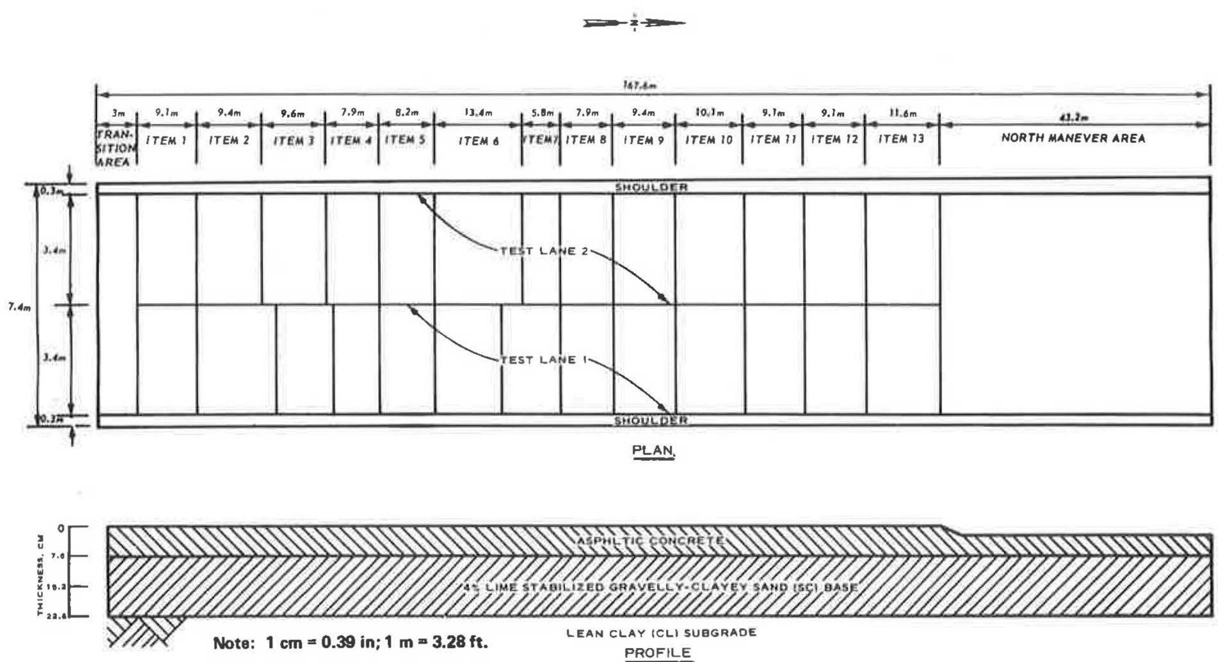


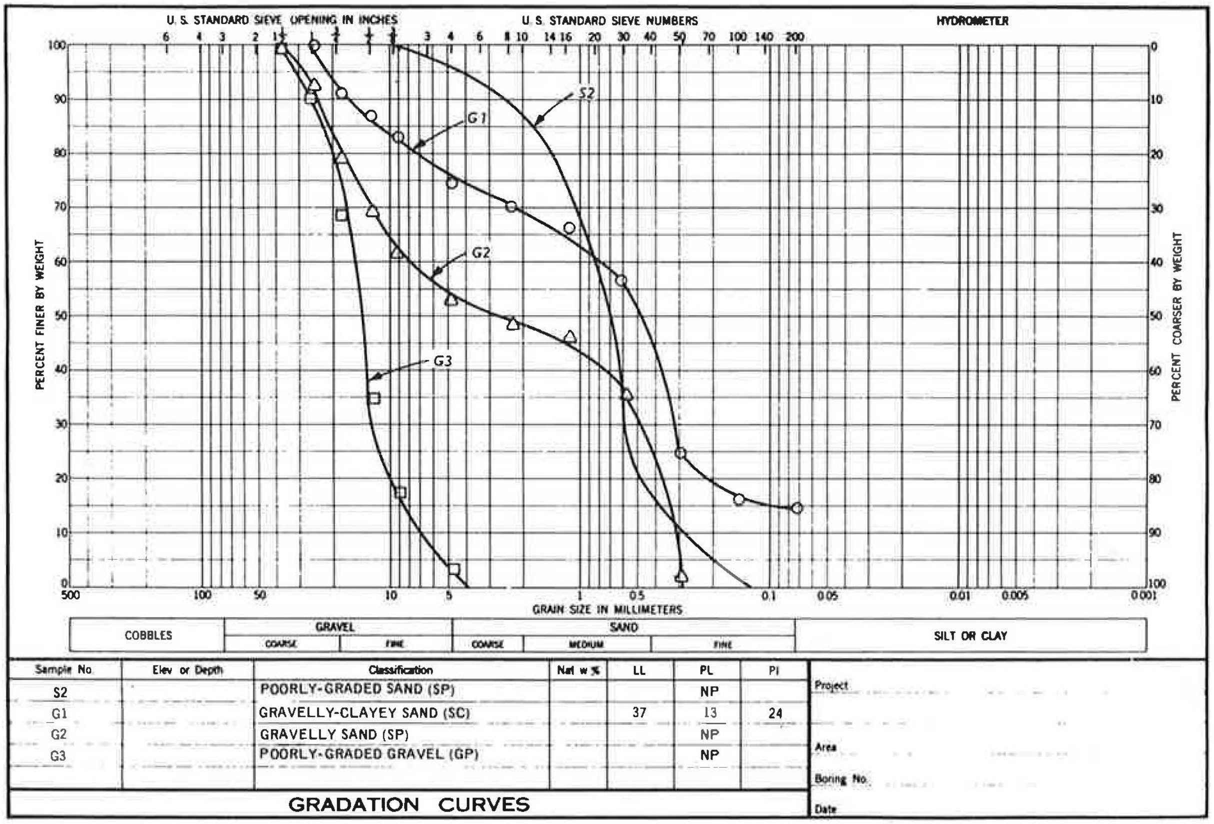

**Figure 2. Layout of flexible pavement test section.**




caused by the high percentage of voids in the mineral aggregates and the voids criteria used with the Marshall method of design. It was felt that the proper asphalt content for the sand mixes should be just enough to coat the aggregate particles plus the asphalt that would be absorbed in the aggregate pores. Therefore, the asphalt content required to provide the amount absorbed and a 6-micron film thickness based on the surface area of the aggregate were calculated for each mix. A comparison of the optimum asphalt content as determined by the Marshall design procedure and the surface area method for the various materials used in the test section plus the actual asphalt contents and resulting stabilities of the various mixes used in each of the test items is given in Table 2.

Conventional placement and compaction equipment was used during construction of the flexible pavement test section. In some instances, initial efforts to compact the mixes at normal rolling temperatures of 139°C (250°F) or higher were unsuccessful because of the low

Figure 3. Grading curves of zero-slump mix aggregates.




NOTE: 1 cm = 0.39 in.

Table 1. Properties of in-place zero-slump concrete mixes.

| Test Item | Mixture Number | Cement Factor (kg/m³) | W/C Ratio | S/A Ratio | 28-Day Field Flexural Strength (MPa) |
|---|---|---|---|---|---|
| 1 | 1 | 306.7 | 0.32 | 0.32 | 5.17 |
| 2 | 1 | 306.7 | 0.32 | 0.32 | 5.17 |
| 3 | 2 | 306.7 | 0.37 | 0.53 | 4.72 |
| 4 | 3 | 306.7 | 0.67 | 1.00 | 4.07 |
| 5 | 4 | 306.7 | 0.25 | 0.0 | 2.41 |
| 6 | 5 | 306.7 | 0.57 | 0.67 | 0.86 |

Note: 1 kg/m³ = 1.7 lb/yd³; 1 MPa = 145.04 lbf/in².

stability of the mix. Therefore, the mix was allowed to cool before rolling. The rolling temperatures of the various marginal material mixes ranged from about 72°C to 133°C (130°F to 240°F).

## PERFORMANCE OF TEST SECTIONS DURING TRAFFIC

Traffic tests were performed on one lane located in the center of the rigid pavement test section and on two separate lanes of the flexible pavement test section. Lane 1 of the flexible pavement test section was trafficked only when the pavement temperature was 44°C (80°F) or lower, and lane 2 was trafficked when the pavement temperature was 44°C (80°F) or higher.

### Rigid Pavement

The three failure conditions (initial crack, shattered slab, and complete) used for judging plain, nonreinforced rigid pavements were used to judge the performances of the zero-slump mixes during traffic. The total amount of test traffic applied to the test section is shown in Table 3.

Test results indicate that the zero-slump concrete mixes made of pit-run gravelly sand, poorly graded sand, and gravelly-clayey sand performed very well during traffic. The mixes made from these materials were placed in items 3, 4, and 6. Only slight minor cracking was observed in any of these items after traffic. However, note that the surface of item 6 tended to become slippery during wet-weather traffic. Item 6 contained the mix made from the highly plastic gravelly-clayey sand.

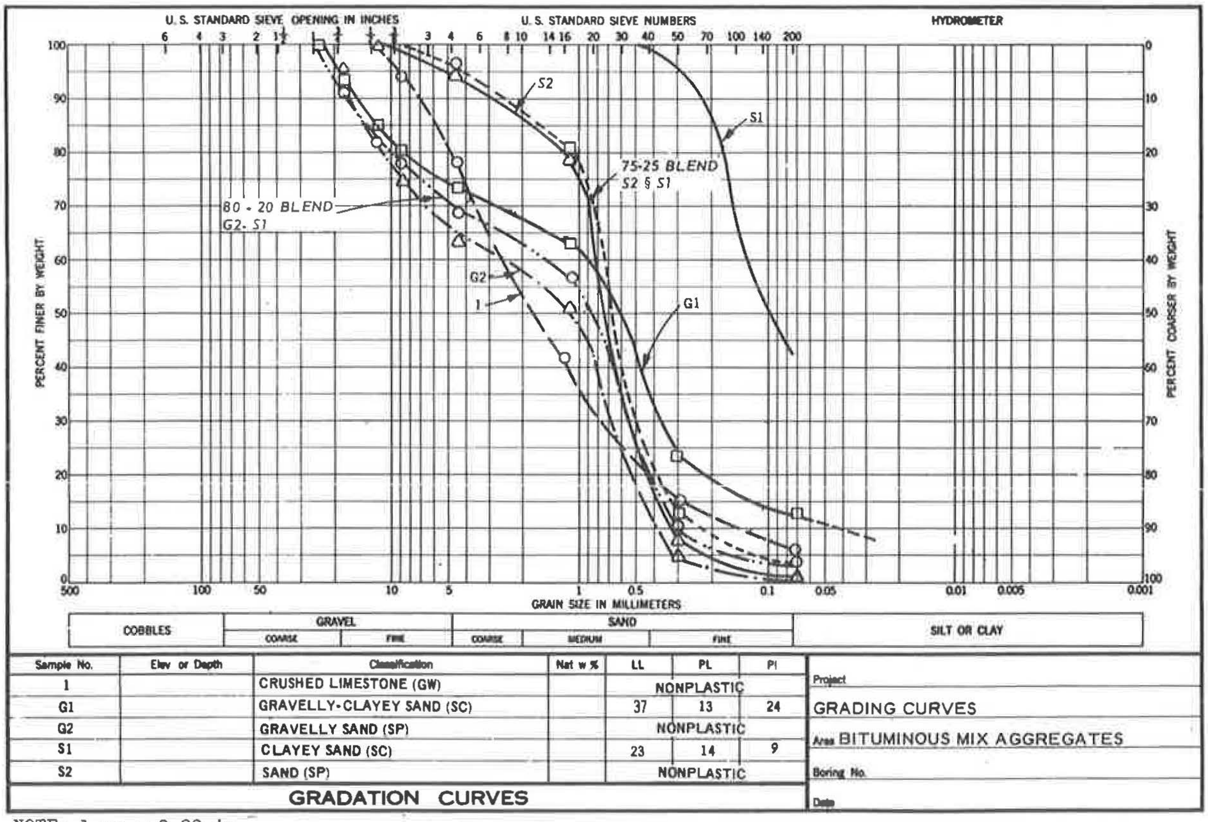
The mix made with the open-graded gravel (G3) and placed in item 5 failed because of severe raveling. Only 5390 operations were applied to this item before failure, as compared with about 125 000 operations applied to items 3, 4, and 6 without a failure.

The standard zero-slump mix placed in item 2 failed after 18 245 operations. However, it is believed that the poor behavior of this mix was caused by construction problems.

Although the placement procedures resulted in the surface of item 1 being slightly rougher than the surface of items 2-6, the riding quality of item 1 was satisfactory for truck traffic. The surface of item 1 was rougher because the mix in this item was placed by a motor grader under adverse conditions as compared with placement by an asphalt finisher in all other items.

After the M51 4.5-Mg (5-ton) dump truck traffic, track-type vehicle traffic was applied to the test section. There was no distress observed in items 1, 3, 4, and 6 after 130 operations (326 passes) of an M113 personnel

Figure 4. Grading curves of bituminous mix aggregates.



NOTE: 1 cm = 0.39 in.

Table 2. Asphalt contents and stabilities of the marginal material bituminous mixes.

| Material | Test Item | Asphalt Content (%): Optimum by Marshall Mix Design | Asphalt Content (%): By Surface Area Method | Asphalt Content (%): Used in Test Item | Stability (N) |
|---|---|---|---|---|---|
| Crushed limestone, 1 | 1 | 5.7 | 5.5 | 5.8 | 6601 |
| Gravelly sand, G2 | 2 | 7.5 | 5.0 | 7.6 | 1201 |
| | 3 | 7.5 | 5.0 | 6.7 | 721 |
| | 4 | 7.5 | 5.0 | 5.4 | 663 |
| Gravelly-clayey sand, G1 | 5 | 9.0 | 8.7 | 5.5 | 3180 |
| | 6 | 9.0 | 8.7 | 5.2 | 2976 |
| | 7 | 9.0 | 8.7 | 4.3 | 3140 |
| | 13 | 9.0 | 8.7 | 6.7 | 3069 |
| 80 percent G2 | 8 | 6.2 | 7.0 | 6.2 | 1268 |
| 20 percent S1 | 9 | 6.2 | 7.0 | 5.6 | 3011 |
| Concrete sand, S2 | 10 | 9.8 | 5.2 | 6.4 | 320 |
| 75 percent S2 | 11 | 7.8 | 7.4 | 7.4 | 894 |
| 25 percent S1 | 12 | 7.8 | 7.4 | 5.9 | 623 |

Note: 1 N = 4.4 lbf.

carrier and 50 000 operations (20 passes) of an M48A1 tank. Since items 2 and 5 were considered failed prior to track-type traffic, the performance of these items during traffic was not considered.

## Flexible Pavement

Since hot bituminous mixes are placed on base courses (a) to provide a smooth riding surface, (b) to waterproof the base against the penetration of surface water, and (c) to protect the base from the raveling effects of traffic, a test item was considered failed when any of the following conditions occurred:

1. Surface depressions of 5.1 cm (2 in) or more,
2. Surface cracking to the extent that the pavement was no longer waterproof,
3. Severe surface raveling to significant depths (for these tests, 5.1 cm or greater), or
4. Severe shoving (for these tests, resulting rut depths of 5.1 cm or more).

The total amount of test traffic applied to test lanes 1 and 2 is given in Table 4.

Test results indicate that the bituminous mixes made with the gravelly-sand aggregate (items 2-4) performed as well structurally under pneumatic-tired traffic as did the bituminous mix made with high-quality crushed

Table 3. Summary of test traffic applied to the rigid pavement test section.

| Test Vehicle | Gross Weight (kg) | Number of Passes | Equivalent 80-kN S-Axle Load Operations |
|---|---|---|---|
| M51 | 18 685 | 1750 | 27 222 |
| M51 | 22 114 | 9906 | 528 320 |
| M113 | 8 629 | 326 | 578 |
| M48A1 | 46 871 | 20 | 222 222 |

Note: 1 kg = 2.202 lb; 1 kN = 0.225 kips.

Table 4. Summary of test traffic applied to the flexible pavement test section.

| | | Lane 1 | | Lane 2 | |
|---|---|---|---|---|---|
| Test Vehicle | Gross Weight (kg) | Number of Passes | Equivalent 80-kN S-Axle Load Operations | Number of Passes | Equivalent 80-kN S-Axle Load Operations |
| M51 | 18 583 | 5008 | 63 658 | | |
| M51 | 18 685 | 1750 | 27 222 | | |
| M51 | 19 936 | 310 | 7 000 | | |
| M51 | 22 114 | 1010 | 53 867 | 8896 | 474 453 |
| M113 | 8 629 | 326 | 578 | 326 | 578 |
| M48A1 | 46 871 | 20 | 222 222 | 20 | 222 222 |

Note: 1 kg = 2.202 lb; 1 kN = 0.225 kips.

stone (item 1). However, during the traffic period, exposure of the smooth and polished surfaces of some of the larger aggregate was observed in items 2 to 4. Test items 6 and 7, which consisted of lean bituminous mixes that had asphalt contents of 5.2 and 4.3 percent, respectively, made with gravelly-clayey sand, performed unsatisfactorily because of raveling. The rate of raveling in these items increased considerably during wet-weather traffic. Test items 5 and 13, constructed with this same aggregate at asphalt contents of 5.5 and 6.7 percent, respectively, performed much better and had less raveling and rutting. These items performed satisfactorily for the entire traffic period. Substantial rutting [1.9-4.8 cm (¾-1⅞ in)] in depth developed in items 8-12 during hot-weather traffic. However, cross-section measurements show that the rutting was more pronounced in the outside wheel paths of these items than it was in the inside wheel paths. The outside wheel path was near the edge of the pavement, and the rutting was primarily caused by internal shoving, which could be eliminated by lateral containment of the mix (paving the shoulders). Although the aggregate gradation of the mixes placed in items 8 and 9 was the same and the aggregate gradation of the mixes placed in items 11 and 12 was the same, rutting was more severe in items 8 and 11 during traffic than it was in items 9 and 12. It is believed that the larger ruts that occurred in items 8 and 11 were partially caused by the higher asphalt content of the mixes placed in these items. The asphalt content of the mix placed in item 8 was 6.2 percent as compared to 5.6 percent for the mix placed in item 9, and the asphalt contents of the mixes placed in items 11 and 12 were 7.4 and 5.9 percent, respectively. A slight amount of the rutting that occurred in items 2-13 is also attributed to consolidation of the mix under traffic because in Table 4 the densities of the bituminous mixes within the wheel paths after traffic were greater than the densities of the respective mixes either prior to traffic or after traffic and between the wheel paths.

All 13 test items withstood the straight-pass-type traffic applied with the M113 and M48A1 tracked vehicles without any noticeable distress.

## CONCLUSIONS

Based on the results of laboratory and field tests performed on the marginal material mixes, the following conclusions are believed warranted:

1. The concept of using marginal materials in the making of hot bituminous AC mix and zero-slump PCC is applicable for pavements that are to be used as secondary roads, streets, parking lots, storage areas, or for relatively short-service-life pavements.
2. AC can be made from a wide range [almost any material with 100 percent passing the 3.8-cm (1.5-in) sieve to about 15 percent passing the 75-μm (No. 200) sieve] of coarse-grained soils.
3. The Marshall design procedure can be used for designing all marginal material hot bituminous mixes, except those made with sands that contain little or no fines. The surface area method should be used to design hot bituminous mixes made with sands.
4. If laboratory test facilities are not available, the asphalt content of hot bituminous mixes made with marginal-aggregate materials should range between about 5.5 and 6.5 percent.
5. The stability of a bituminous mix made from a marginal material should be 136 kg (300 lb) or greater, and the retained stability of this mix should be at least 50 percent.
6. Bituminous mixes made of highly plastic aggregate materials can be expected to ravel, especially during wet-weather traffic.
7. Highly plastic aggregate materials that are to be used in a hot bituminous mix or a zero-slump concrete mix should be thoroughly processed prior to incorporating asphalt cement or portland cement to ensure a uniform mixture.
8. The sand-aggregate ratio of a marginal material to be used in a zero-slump concrete mixture should be 25 or more.
9. Satisfactory placement of zero-slump concrete can be accomplished with a conventional base course spreader, asphalt finisher, or motor patrol.
10. Zero-slump concrete can be adequately compacted with heavy vibratory rollers.

## ACKNOWLEDGMENT

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