Compaction of a Graded Crushed-stone Base Course

Compactage d'une Couche de Base en Pierre Concassée de Bonne Granulométrie

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Summary

This paper describes the results of field compaction tests on two cohesionless graded crushed-stone base courses. The purpose of the tests was to determine the degree of compaction necessary to resist the detrimental effects of a large number of wheel-load repetitions of very heavy military aircraft. The test sections simulated, on a field scale, the laboratory compaction test. The materials were placed at a range of water contents and subjected to varying numbers of repetitions with a heavy rubber-tyred roller. The sections were then surfaced and subjected to simulated traffic of a heavy aircraft.

Plots of water content *versus* density were developed for laboratory compactive efforts and for various coverages of the rubber-tyred roller and the simulated airplane traffic.

The tests show that base-course materials of this type should be compacted at the highest practicable water content, which is literally a 'flushed' condition. Also, 32 coverages of the heavy rubber-tyred roller, applied while the material was in the 'flushed' condition, produced densities which were substantially adequate for the simulated airplane traffic.

Sommaire

Cette communication présente le résultat d'essais de compactage en chantier de deux couches de fondation en pierre concassée de bonne granulométrie mais sans cohésion. Le but de ces essais était de déterminer le degré de compactage nécessaire pour éviter les effets nocifs d'un grand nombre de passages d'avions militaires très lourds.

Les essais *in situ* représentaient, à l'échelle du chantier, ceux de laboratoire. Les matériaux étaient placés avec des teneurs en eau différentes et étaient soumis à des nombres de passages variables d'un rouleau pneumatique lourd. Les sections furent ensuite recouvertes d'un tapis de roulement et exposées au trafic représentant la circulation d'avions lourds. Des abaques furent dressés, qui indiquent les densités sèches observées en fonction des teneurs en eau et du nombre des passages du rouleau pneumatique ou de la circulation des avions. Les essais indiquent que les matériaux de cette nature utilisés en couche de base doivent être compactés à une teneur en eau aussi élevée que possible, qui est littéralement un état détrempé. Il a aussi été démontré que, pour les points du revêtement soumis 32 fois au passage du rouleau à pneus, le matériau était détrempé, les densités obtenues étaient sensiblement suffisantes pour une circulation représentant celle des avions.

The current bomber-type aircraft used by the U.S. Air Force is equipped with tyres that are inflated to high tyre pressures and is capable of carrying heavy loads. The tyre load on the B-47 aircraft is 50,000 lb., and the inflation pressure is approximately 200 lb./sq. in. The aircraft is operated on taxiways and taxilanes on aprons so that the traffic is channelled along very narrow paths; the area subjected to this traffic therefore receives greater repetitions of load than where traffic is distributed over a wider area. The combination of heavy load, high tyre pressure, and large number of repetitions requires that the elements of flexible pavements be compacted to very high densities to prevent further compaction under traffic.

Results of compaction studies on subgrade materials conducted at the Waterways Experiment Station have previously been presented (U.S. WATERWAYS EXPERIMENT STATION, 1954; TURNBULL and FOSTER, 1956; TURNBULL, 1950; TURNBULL, JOHNSON and MAXWELL, 1949). This paper describes the results of studies conducted on graded crushed-stone base courses to determine the means of compacting base courses to the high densities required in airfields that are subjected to heavy loads and high tyre pressures.

These studies were conducted by the Corps of Engineers' Flexible Pavement Laboratory at the Waterways Experiment Station as a part of the overall investigational programme of the Office, Chief of Engineers for developing design criteria for pavements for the U.S. Air Force. The study was monitored by T. B. Pringle and F. B. Hennion of the Office, Chief of Engineers, and was conducted under the supervision of the authors. Engineers directly responsible for the work were O. B. Ray and C. D. Burns.

The scope of the work consisted of simulating, on a field scale, the laboratory compaction test on two gradations of a base-course material. The materials were placed at a range of moisture contents from air-dry to essentially saturated, and subjected to varying numbers of coverages of a heavily loaded rubber-tyred roller. Samples were taken to develop moisture-density curves for the various compactive efforts. To determine if the densities obtained would be satisfactory under airplane traffic, the section was surfaced and subjected to simulated airplane traffic with a heavy wheel load. Density samples of the base-course materials were taken to show the effect of the simulated traffic.

Materials and Equipment

Base-course material—The base-course material was a high-quality crushed limestone aggregate obtained from a commercial quarry near Franklin, Tennessee. The wear in the Los Angeles abrasion test, ASTM C-131, is 25 per cent. The fines are non-plastic. The material was purchased in three sizes, 1½ to ¾ in., ¾ in. to No. 4, and minus No. 4 sieve, and blended on a paved area to meet the gradations shown in Fig. 1.* The gradation of the ¾ in. maximum size was purposely controlled to duplicate the gradation that would be obtained in the laboratory by processing the 1½ in. maximum-size material by the Corps of Engineers' procedure (scalp on ¾ in. screen and replace scalped material with equal weight of material between ¾ in. and No. 4 screens). Results of laboratory compaction tests at three different compactive efforts are shown in Figs. 2 and 3.

Roller—The rubber-tyred roller used in these tests consists of a trailer-type load box mounted on two sets of dual wheels abreast which are free to oscillate. The wheels are equally spaced in the load box to assure uniformity of coverages. The roller was loaded to 100,000 lb. gross load (25,000 lb. per tyre), and the tyres were inflated to 90 lb./sq. in. The compactive effort applied by the tractor which towed the roller was small compared to that applied by the roller.

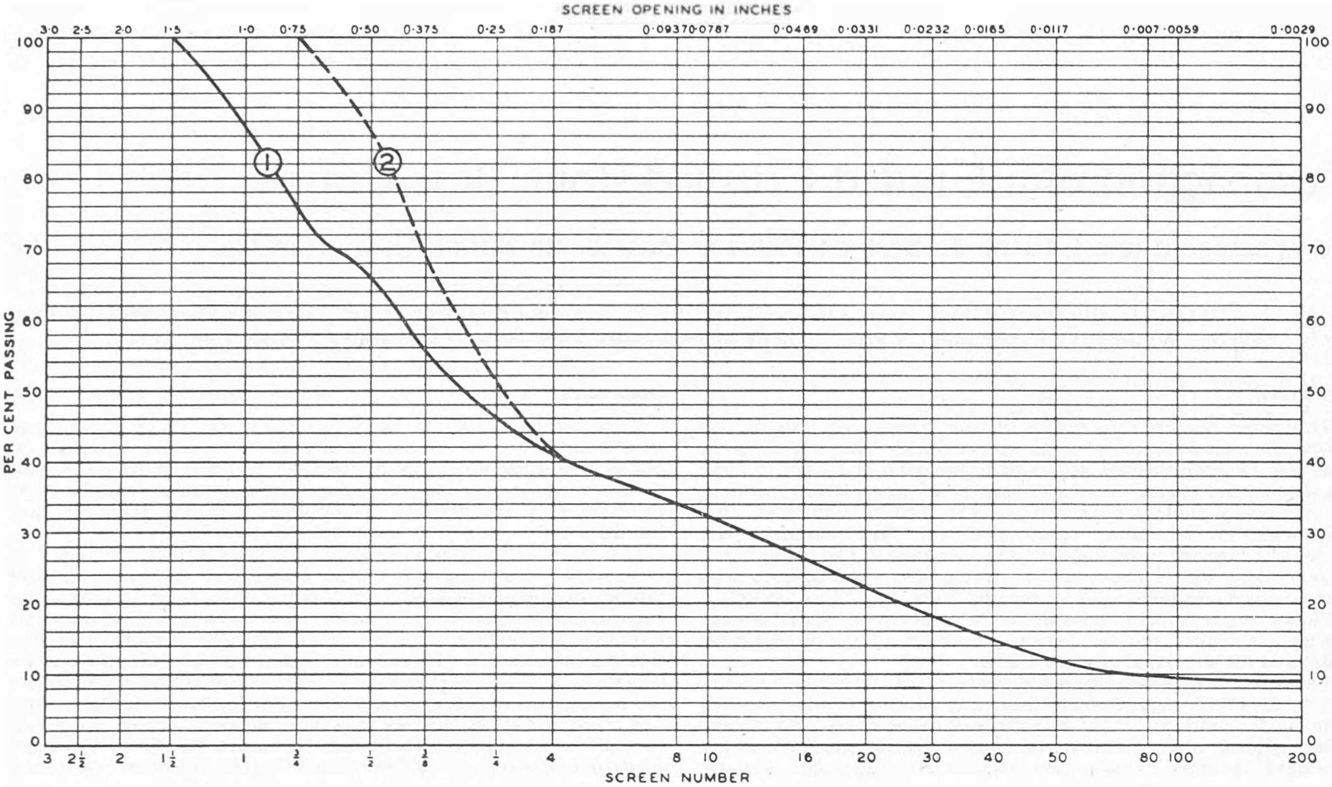


Fig. 1 Gradation of graded crushed limestone base course material
Granulométrie d'une sous-couche en calcaire concassé de bonne granulométrie

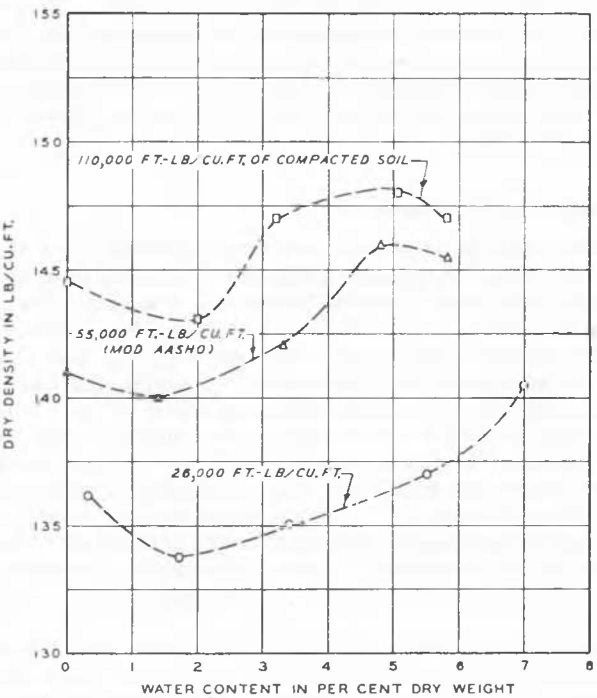


Fig. 2 Laboratory compactage data (graded crushed limestone base course ¾ in. maximum size)
Résultats de compactage en laboratoire (sous-couche en calcaire concassé de bonne granulométrie—Dimension maximum ¾ in.)

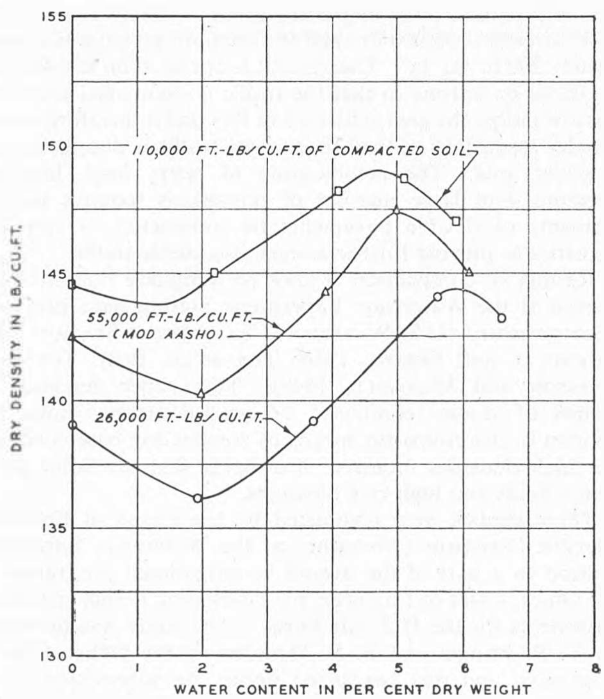


Fig. 3 Laboratory compactage data (graded crushed limestone base course 1½ in. maximum size)
Résultats de compactage en laboratoire (sous-couche en calcaire concassé de bonne granulométrie—Dimension maximum 1½ in.)

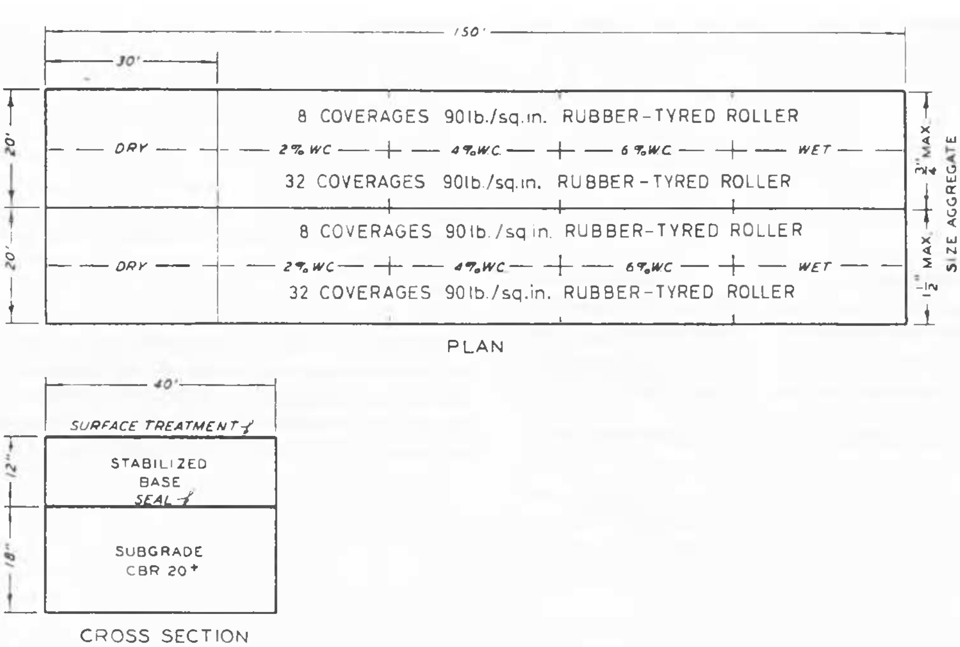


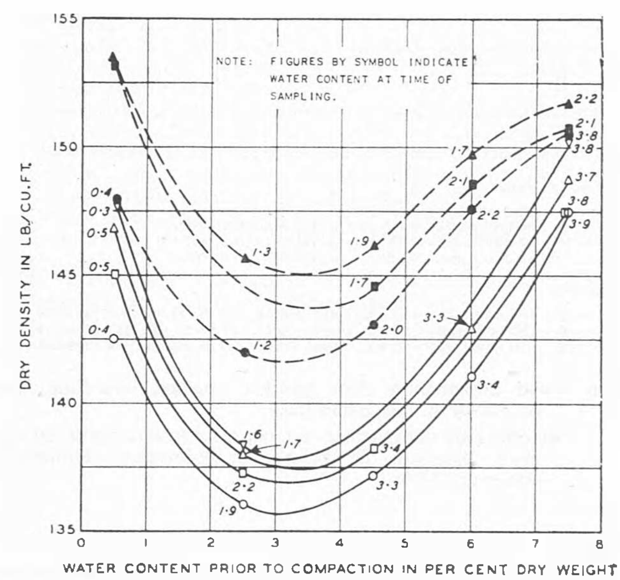
Fig. 4 Layout of graded crushed limestone base course
Mise en place d'une sous-couche en calcaire concassé de bonne granulométrie

Tests

Test section—Fig. 4 is a layout of the section constructed for these tests. The section was 40 ft. wide by 150 ft. long, and was divided into 20 by 150 ft. subsections for the 1½ and ¾ in. maximum-size aggregates. Each subsection was further divided into two lanes, one for application of eight coverages and the other for application of 32 coverages of the rubber-tyred roller. The section was divided longitudinally into five units for varying amounts of water ranging from air-dry to a 'flushed' condition. The section was constructed on a lean clay subgrade which had been purposely compacted on the dry side of optimum to give a firm surface. The subgrade was sealed with a membrane of asphalt cement so that water applied to the crushed stone would not affect the subgrade. The intent was to construct a subgrade with adequate strength so that it would not be a factor in the analysis of test results. Settlement plates set on the surface of the subgrade showed, as had been planned, that no settlement occurred in the subgrade; therefore, the subgrade was not a factor in the analysis of these tests.

Placing and rolling—The aggregates used in the study were thoroughly blended to obtain a uniform gradation. Material for the dry sections was processed to the air-dried condition; the remainder was sprinkled to bring the moisture content to about 2 per cent to minimize segregation during handling. Material was then picked up with a bucket loader and hauled to the test section in trucks. Spreading was accomplished with a bituminous paving finisher in three lifts to give a 4 in. compacted thickness of each. Segregation was a serious problem in the air-dried, but was no problem in the others. Following spreading, water was added to wetter units, as required, to bring them to the desired moisture content before rolling. Each layer was compacted with the prescribed number of coverages (see Fig. 4) with the rubber-tyred roller. Water was drained from, and was forced out of, the material during the rolling, particularly in the wetter sections, so that the actual moisture content during rolling is not known. However, in the wettest section, the amount of water that was present during the rolling was sufficient to maintain a 'flushed' condition. No noticeable rutting, shoving, or sponginess occurred in any units, and uniform compaction was obtained.

Test made—Moisture content, density and CBR tests were made on the top lift of the eight-coverage lane at the end of rolling and on the top lift of the other lane after 16, 24 and 32 coverages. Density tests were made with the sand-displacement method using a device designed by R. R. Proctor that



Construction data

○——○ 8 coverages—90 lb./sq. in. rubber-tyred roller
□——□ 16 coverages—90 lb./sq. in. rubber-tyred roller
△——△ 24 coverages—90 lb./sq. in. rubber-tyred roller
▽——▽ 32 coverages—90 lb./sq. in. rubber-tyred roller

Traffic data

●——● 72 coverages—50 kip, single wheel, 200 lb./sq. in. tyre pressure
■——■ 250 coverages—50 kip, single wheel, 200 lb./sq. in. tyre pressure
▲——▲ 500 coverages—50 kip, single wheel 200 lb./sq. in. tyre pressure

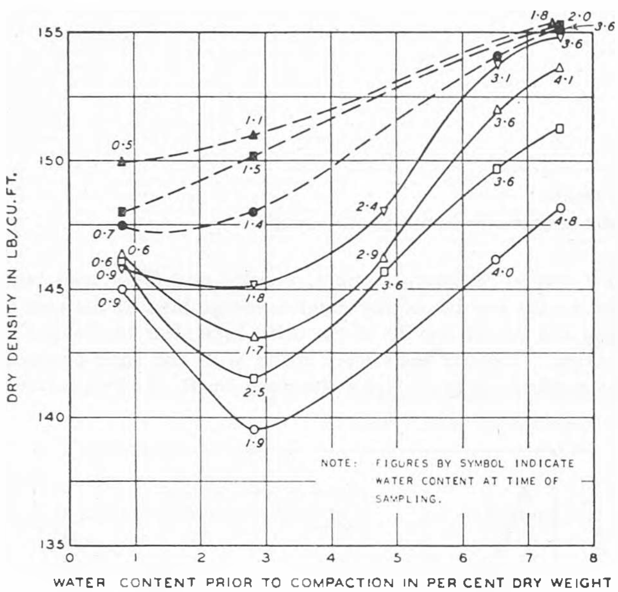
Fig. 5 Field compactage data (graded crushed limestone base course ¾ in. maximum size)
Résultats de compactage sur chantier (sous-couche en calcaire concassé de bonne granulométrie—Dimension maximum ¾ in.)

permits calibration of the sand each time it is used. Tests were made in triplicate. Results are plotted in Figs. 5 and 6.

Surfacing—The wearing surface was restricted to a thin asphalt covering so that it would not enter as a material factor in the analysis of behaviour of the base courses. Before the wearing course was applied, the surface of the base was primed with 0·27 gal./sq. yd. of RC–2 cutback asphalt. After a three-day curing period, a double-surface treatment wearing course was applied as follows:

Layer	*Bitumen*	*Chips*
Bottom	0·4 gal./sq. yd. AC–15 (150 penetration asphalt cement)	30 lb./sq. yd. coarse limestone chips
Top	0·4 gal./sq. yd. AC–15 (150 penetration asphalt cement)	20 lb./sq. yd. fine limestone chips

Each layer of chips was rolled with a 10 ton steel-wheel roller.



Construction data

○——○ 8 coverages—90 lb./sq. in. rubber-tyred roller
□——□ 16 coverages—90 lb./sq. in. rubber-tyred roller
△——△ 24 coverages—90 lb./sq. in. rubber-tyred roller
▽——▽ 32 coverages—90 lb./sq. in. rubber-tyred roller

Traffic data

●——● 100 coverages—50 kip, single wheel, 200 lb./sq. in. tyre pressure
■——■ 250 coverages—50 kip, single wheel, 200 lb./sq. in. tyre pressure
▲——▲ 500 coverages—50 kip, single wheel, 200 lb./sq. in. tyre pressure

Fig. 6 Field compaction data (graded crushed limestone base course $1\frac{1}{2}$ in. maximum size)

Résultats de compactage sur chantier (sous-couche en calcaire concassé de bonne granulométrie—Dimension maximum $1\frac{1}{2}$ in.)

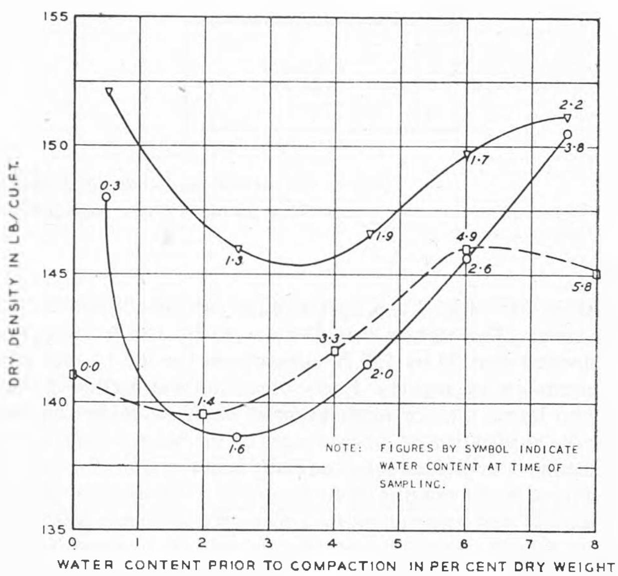
Traffic

Traffic lanes were 10 ft. wide and located so that half the lane was in the area subjected to eight coverages of the rubber-tyred roller and half in the area subjected to 32 coverages. Traffic applied with the runway load test cart which has been described previously (Foster, 1949). The cart was loaded to 50,000 lb. and equipped with a single 56 × 16 in. airplane tyre inflated to 200 lb./sq. in. This resulted in a ground contact area of approximately 270 sq. in. The test cart was operated back and forth the length of the test lanes and was shifted laterally to give uniform coverage across the lane. Traffic was continued to 500 coverages. Moisture content, density and CBR tests were made after 72, 250 and 500 coverages. Results are plotted in Figs. 5 and 6.

Discussion

Figs. 5 and 6 are plots of density *versus* water content for the $1\frac{1}{2}$ and $\frac{3}{4}$ in. maximum-size material, respectively. Curves developed by the rubber-tyred roller in both the 8- and 32-coverage lanes are shown, but curves developed by the simulated airplane traffic are shown for only the 32-coverage lane because the data for the 8-coverage lane are nearly the same. The water content plotted is that prior to compaction, as some loss of water occurred during compaction and between compaction and sampling. Water contents at the time of sampling are noted in the plot.

Figs. 7 and 8 show comparisons of field and laboratory compaction curves. The shapes of the curves developed by field compaction are similar to the laboratory curves and both are typical of those for cohesionless materials. Compaction curves for cohesionless materials are characterized by a fairly high density for the air-dried conditions, low densities at low



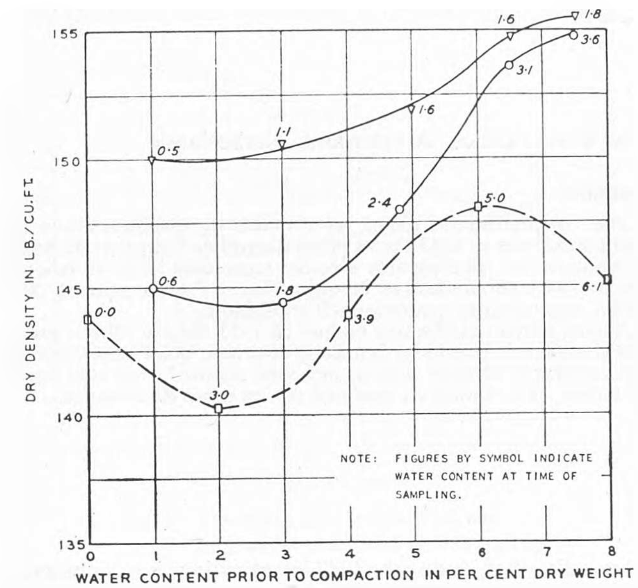
□ Laboratory modified Aasho—6 in. steam mould
○ Field—32 coverages—90 lb./sq. in. rubber-tyred roller
▽ Field—after 500 coverages—50 kip, single wheel, 200 lb./sq. in. tyre pressure

Fig. 7 Comparison of field and laboratory compaction data (graded crushed limestone base course $\frac{3}{4}$ in. maximum size)

Comparaison des résultats de compactage en laboratoire et sur chantier (sous-couche en calcaire concassé de bonne granulométrie—Dimension maximum $\frac{3}{4}$ in.)

water contents, frequently called the 'bulking' water content, and high densities at the high water contents. The laboratory curves show a small decrease in density at the highest water content, which is not shown in the field curves. The air-dried condition is generally not practicable for field construction, but it is practicable to maintain the material in a 'flushed' condition during the compaction process. The term 'flushed' as used in this case refers to a water content approaching that used in compacting waterbound macadams. If adequate measures have been taken to protect the underlying sub-base and subgrade, close control of the water will not be necessary and the 'flushed' condition can be achieved simply by applying an excess of water. If large quantities are used, *ad hoc* drainage will be required during construction to dispose of the water that drains through the base course. However, where excess water will damage the underlying layers, it is possible to achieve high densities by compaction at a water content just dry of the 'flushed' condition and accomplish the desired result with very little excess water draining through the base course.

It should be noted that the spread of densities obtained by the two field compactive efforts shown in Figs. 7 and 8 between the 'bulking' water content (2 to 3 per cent) and the 'flushed' condition (6 to 7 per cent) was from 6 to 12 lb./cu. ft.; therefore, it is obvious that it is necessary to maintain a high moisture content during compaction to get the greatest densification.



□ Laboratory modified Aasho—6 in. diam. mould
○ Field—32 coverages—90 lb./sq. in. rubber-tyred roller
▽ Field—after 500 coverages—50 kip, single wheel, 200 lb./sq. in. tyre pressure

Fig. 8 Comparison of field and laboratory compaction data (graded crushed limestone base course 1½ in. maximum size)

Comparaison des résultats de compaction en laboratoire et sur chantier (sous-couche en calcaire concassé de bonne granulométrie—Dimension 1½ in.)

The effect of compactive effort is clearly shown, as the density at any water content increases with an increase in compactive effort. The increase ranged from 3 to 7 lb. with the exception of the air-dried condition for the 1½ in. maximum size which showed a negligible increase in density with increased coverages.

Where the base course had been compacted with 32 coverages of the rubber-tyred roller in a flushed condition, the subsequent application of 500 coverages of simulated airplane traffic produced very little increase in density, which was in the order of 1 to 2 lb./cu. ft. However, where the material had been placed at intermediate water contents and rolled with a lesser number of coverages, a significant increase in density (approximately 4 to 7 lb./cu. ft.) occurred during simulated airplane traffic. These data indicate that crushed-stone base-course materials for heavy duty military airfields should be compacted at the highest practicable moisture content with a fairly high number of repetitions of the rubber-tyred roller.

The field densities of the material with a ¾ in. maximum size were generally lower by 2 to 5 lb. than those of the material with 1½ in. maximum size. Also, the ¾ in. maximum-size aggregate showed more tendency to bulk at the intermediate moisture contents than the 1½ in. maximum-size aggregate. Both were satisfactory under traffic when adequately compacted. The 1½ in. maximum-size material would generally be more economical from the standpoint of crushing costs, but the ¾ in. maximum size may be needed, especially in the top lifts of a base course, in order to meet necessary grades and smoothness requirements.

Conclusions

On the basis of the studies conducted, the following conclusions are believed warranted.

(a) Cohesionless, graded crushed-stone base courses should be placed and compacted at the highest practicable water content, usually a 'flushed' condition.

(b) Application of 32 coverages with the heavy rubber-tyred roller produced densities at the highest moisture content (near saturation) which were substantially adequate for traffic of a heavy airplane wheel load.

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