Wood Fiber Fill to Reduce Airport Pavement Settlements

JAMES H. HARDCASTLE AND TERRY R. HOWARD

The Benewah County Airport runway and apron pavements, reconstructed in 1977 over an unknown thickness of peaty, silty, and clayey flood plain deposits, settled more than 2 ft at some locations during the subsequent 10-year period. In 1987, the runway was reconstructed and the original grades reestablished following the removal of up to 3.5 ft of a crushed rock ballast and up to 8 ft of the highly organic subgrade soil. These materials were replaced with a compacted lightweight wood fiber fill. The engineering properties of the wood fiber material—including its shear strength, compression, and creep properties—were determined. An analysis was performed in the design of a fill prism that imposed no net stress increase on the highly compressible subgrade soils. The objective of the design was to limit post-construction settlements to creep of the wood fiber fill and secondary compression of the subsoils. Pavement elevation changes measured 15 and 32 months after the completion of the 1987 construction indicate that although settlements are larger than predicted, the objective of preventing a new cycle of subgrade consolidation settlement was achieved and that settlements were within acceptable limits.

The Benewah County airport is located in the flood plain inside a meander bend of the St. Joe River near St. Maries, Idaho. The absence of other suitably flat terrain in this mountainous region led to the construction of the airport at this site. Because of the airport's proximity to the St. Joe River and because two sewage lagoons are also located on the flood plain, the ground water table remains essentially at or slightly above the natural ground surface throughout most of the year.

Past efforts to keep the runway surface above the surrounding ground and ground water surface levels required the use of low embankment sections. The increased stresses on the fine-grained, highly organic flood plain deposits caused by the fill and the pavement section have contributed to substantial time-dependent differential settlements.

In 1977, settlements had reached levels that required a major reconstruction of the 3,200-ft-long airport pavement. A subsurface investigation was performed prior to the reconstruction. Test borings were made to depths of 20 ft. Soils encountered in the borings were classified as MH, OH, ML, and Pt in the Unified Soil Classification System and as E-9 and E-13 in the FAA system. The geotechnical consultant recommended that a ballast material be used to establish a level profile for the runway surface and to raise the runway surface above the existing natural ground and water surfaces. The resulting embankment fill, which was up to 2 ft thick, consisted of a locally available crushed metamorphic material, with a maximum size of 3 in., laid on a sheet of geotextile. The geotextile was placed directly on the natural ground surface and was used to increase the stability of the very soft, compressible peaty subsoils during construction and to prevent intrusion of the subsoils into the ballast. The geotextile evidently performed its intended stabilizing and separation functions, and the construction was completed without incident.

Departments of Civil Engineering and Geological Engineering, University of Idaho, Moscow, Idaho 83843.

The consultant's 1977 report did not mention the magnitude of expected future settlements of the pavement. A "double-shot" bituminous treatment was recommended for the pavement surface. This treatment was recommended as being able to withstand "without major damage, the probable rutting and settling of the pavement section under aircraft loads." Because the immediate compression of the underlying soils during construction required the placement of more than anticipated thicknesses of ballast in order to achieve the planned pavement grades, fill sections containing as much as 3.5 ft of the ballast were constructed at some locations.

The serviceability of the pavement proved to be limited by the time-dependent differential settlements, occurring as a result of compression of the subsoils under the weight of the fill, rather than by traffic-associated pavement deformations. Figure 1 shows the settlements of four stations on the runway pavement centerline during the 10 years following the 1977 construction. The estimated increases in vertical effective stress produced at the four stations as a result of the 1977 construction are also shown in the figure. The curves show a fairly rapid compression (attributed to subgrade soil consolidation), followed by a continuing period of secondary compression of the organic subgrade soils. By 1987, some stations with 3 ft of ballast had settled as much as 2 ft; the pavement at these sections was again frequently covered by the seasonally high ground water table. Furthermore, by 1987, differential settlements rendered portions of the runway unsafe for aircraft

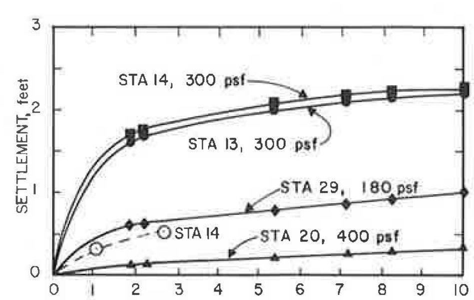

FIGURE 1 Runway pavement settlement, 1977–1987 and post-1987.

operations. Differential settlements occurred because of variations in both the ballast thickness and in the composition and thickness of the organic subgrade soils.

In 1986, the county commissioners decided to reconstruct a portion of the runway and some of the aprons using available federal assistance. Engineers were retained, and they asked for assistance in developing recommendations to eliminate future problems caused by excessive settlements of the runway pavement.

After the subsurface conditions were reviewed, as revealed in the 20-ft-deep borings made in the 1977 site investigation and in a few additional shallow test pits opened in 1987, possible measures to reduce settlements of the reconstructed portions of the runway were considered. These included (a) removing high points on the runway profile while permanently lowering the water table, (b) adding additional ballast to the portions of the runway that had settled excessively, and (c) installing a lightweight fill prior to resurfacing those areas of the runway that had settled excessively. The first two approaches would have resulted in a new cycle of consolidation settlements and a certain need for reconstruction at some future date. Because wood fiber material in the form of sawmill waste was available locally at reasonable cost ($3 per cubic yard) and because of its reportedly satisfactory performance in other projects in the region, it was decided that a lightweight fill composed of wood particles would offer a reliable and economic solution. This project tested the properties of the wood particles that were considered in the decision to use the material. An analysis was performed to arrive at a fill prism that imposed essentially no net increase in effective stress on the subgrade soils while reestablishing the runway surface at a level above the seasonally high water table.

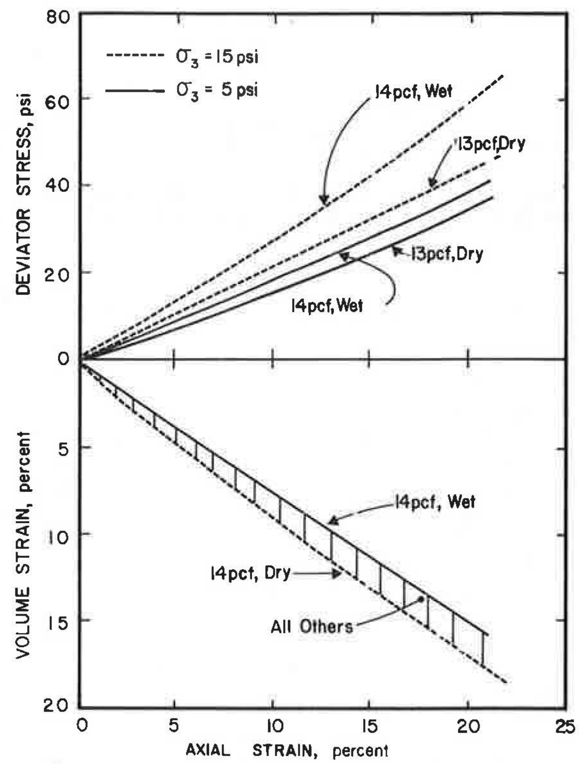

FIGURE 2 Stress-strain of wood particles compacted to T99 and T180 dry unit weights (*1*).

ENGINEERING PROPERTIES OF WOOD FIBER FILL

The properties of interest in the design of a wood fiber fill are the same as those for soils: strength, compressibility, unit weight, and compactibility. A property unique to a wood fiber fill is its resistance to decomposition with time. Each of these properties is briefly discussed.

Strength

Studies at the University of Idaho and elsewhere have shown that although the stress-strain behavior of a wide variety of wood particle types differs from that of soils, the materials are capable of developing substantial strength. Figure 2 shows the typical strain-hardening behavior of wood chips as described by Cox (*1*) on a material containing particles with a maximum size of 1 in., similar in composition to the wood particles available for the airport project. The results shown in Figure 2 were obtained in drained triaxial tests performed on 4-in.-diameter by 8-in.-high specimens tested at the initial unit weights obtainable with the standard and modified AASHTO compaction efforts. These dry units weights ranged from 13.0 to 14.0 lb/ft^3. Mohr circles and strength envelopes corresponding to 5 and 20 percent strain are shown in Figure 3. Because most of the wood fiber fill prism was to be confined in an excavation, its strength was not a critical consideration.

Compressibility

Volume changes resulting from stress increases and creep of wood particles under sustained stresses were the major concerns in the evaluation of suitability for this project. The curves of Figure 2 show that shear stresses produce significant volume reductions of the material. Relatively smaller volume decreases are produced by changes in isotropic stresses. Cox (*1*) reported coefficients of compressibility for isotropic

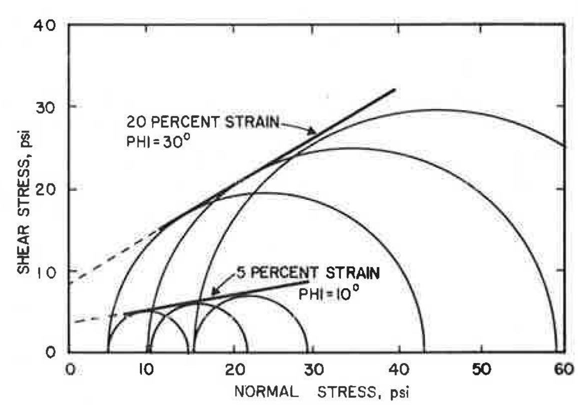

FIGURE 3 Mohr circles for wood particles (*1*).

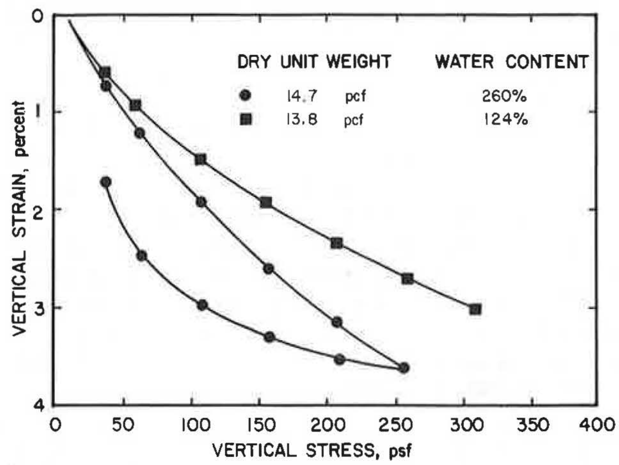

FIGURE 4 One-dimensional compression of wood particles compacted to T99 dry unit weight.

stress increases of 0.01 to 0.02 psi^{-1} for wood chips. Results of two one-dimensional compression tests performed for this project on wood particles compacted into 4-in.-diameter by 4.6-in.-high steel molds are shown in Figure 4. These results indicate that immediate thickness reductions of up to 4 percent can occur for increases in vertical stress of 360 lb/ft^2. This value correponds to a coefficient of compressibility of 0.016 psi^{-1}. Other test results were qualitatively similar irrespective of moderate differences in the moisture content of the compacted material.

The results shown in Figure 4 reflect only the immediate compression of the fibers in response to stress increases. The estimated immediate compression of the wood fiber fill prism under the weight of the pavement section and 12 in. of ballast was calculated and compensated for by appropriate additional thicknesses of fill placed during construction. A 12-in. layer of ballast was used between the pavement and the wood fiber fill in order to reduce the live load stresses from light aircraft to levels causing negligible permanent or recoverable deformations in the wood fiber fill.

Another characteristic of wood particles of concern was the possibility of relatively large amounts of creep settlements. Figure 5 shows the effects of sustained isotropic stresses on the materials tested by Cox (*1*). Cox calculated coefficients of secondary compression, C_α, of less than 0.015 units of volumetric strain per unit logarithm of time ratio. If vertical strain is taken as one-third the volumetric strain, the usual one-dimensional coefficient of secondary compression might be on the order of 0.005 strain units per 10-fold increase in time. This value is more than one would expect for coarse and some inorganic fine-grained soils, but it is substantially less than values reported for some organic clays (*2*). If the volumetric strain is considered to be a conservative upper bound and substituted directly for vertical strain, the maximum long-term settlements due to creep of an 8-ft-thick section of wood fiber fill is estimated from Figure 5 to be about 0.4 ft after 20 years.

Unit Weight and Water Content

Weight-volume relationships of the wood fiber material were important in this project for three reasons. It was necessary to determine the total and effective unit weights in order to calculate effective stresses in the soils beneath the fill, to estimate the quantity of wood fiber fill for pay purposes, and to develop a compaction specification for the material.

The dry unit weight of wood particles materials has been found to be relatively insensitive to usual variations in levels of compaction effort and compaction water content. For the wood fiber material of this project, the dry unit weight corresponding to AASHTO T99 compaction was about 14 lb/ft^3; for T180 effort, the dry unit weight was about 16 lb/ft^3. These values were also obtained by Cox (*1*) for a similar material. Schneider and Roth (*3*) and Kilian (*4*) also obtained comparable values for other types of wood particles.

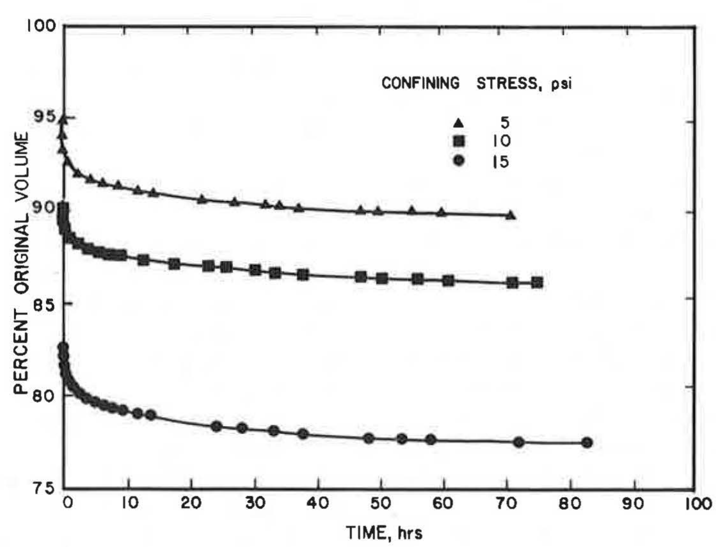

FIGURE 5 Time-dependent compression of wood particles compacted to T99 dry unit weight (*1*).

Total unit weight–water content relationships for moist wood particles are complicated by the fact that the particles absorb water. Part of the water added during or after compaction becomes part of the particle while part may remain as ordinary pore water. The water therefore consists of interparticle water, which remains in the voids between the particles like the water in coarse soils, and intraparticle water, which is absorbed into the cells of the wood. The intraparticle or absorbed water can be subdivided further into water contained in the cell walls, bound water, and the water contained in the cell cavities, free water (*5*). The bound water is the last water to be removed from the wood by oven drying. Changes in bound water content are accompanied by changes in particle volume, whereas changes in the free water content do not cause significant changes in the dimensions of the particles. Changes in free water content occur readily in response to changes in humidity and temperature, but unless the material is dried in an oven or kiln, the bound water content remains constant.

It is clear that for a material with these characteristics, pay quantities are most conveniently defined in terms of volume, either loose in the haul vehicle or as-compacted in the fill. In this project it was decided to pay for loose volume as determined by the number and volume of truckloads delivered.

The reason for using the wood fiber material in the fill was the ability to elevate the pavement grade to a level above the ground water table while imposing no net increase in stress in the highly compressible subgrade soils. It was expected that part of the wood fiber fill prism would always be below the ground water table, that is, submerged, while the remainder would be above the water table for part of the year and below the water table for part of the year. Thus it was necessary to determine the submerged or buoyant unit weight as well as the total unit weight of the material in its wet, unsubmerged condition. In both conditions the particles contain the maximum possible intraparticle water, but in the wet, unsubmerged condition, most of the interparticle water has drained from the voids.

The total unit weight corresponding to the wet, unsubmerged condition was determined using two procedures. In one procedure, the particles were compacted in the 6-in.-diameter mold at the as-received water content of 124 percent. After conpaction, the mold and its contents were soaked under a surcharge of 10 psi until constant weight was obtained. After the weight stabilized, the material was allowed to drain for a few minutes. Finally, the total unit weight and total water content were determined by weighing and oven drying (at 105°C). The procedure produced an initial compacted dry unit weight of 13.8 lb/ft^3. Unit weights and water contents after soaking and draining averaged 52 lb/ft^3 and 260 percent, respectively.

The second procedure was identical to the first except that the particles were soaked in water for a week before being compacted. The compacted dry unit weight was 14.7 lb/ft^3 at a water content of 251 percent. After further soaking, the average total unit weight and water content after draining were 53 lb/ft^3 and 261 percent, respectively. The first procedure corresponds most closely to what the particles were expected to experience in the field.

The effective unit weight of the material in the submerged condition was estimated using three procedures. In the first procedure, the dry unit weight and specific gravity of the wood substance were used to calculate the true volume of solids per bulk cubic foot of material. Using the compacted dry unit weight of 14 lb/ft^3 and a specific gravity for the wood substance of 1.53, a volume of solids equal to 0.15 ft^3 per ft^3 of material was obtained. The weight of an equal volume of water displaced by the solids is 9.4 lb/ft^3 so that the effective or buoyant unit weight of the material was calculated as 4.8 lb/ft^3. This calculation assumes that all the void spaces within the wood particles, as well as the conventional interparticle void spaces, are filled with water when the material is in the submerged condition. The value of 1.53 used for the specific gravity of the wood substance is essentially independent of the wood species (ASTM D2395-83).

The second method of calculating a submerged unit weight was based on the assumption that the absorbed water becomes part of the solid material. The specific gravity of solids is then defined as the weight of the wood substance plus the weight of the absorbed water divided by volume of the particles and the unit weight of water. A specific gravity of 1.10 was found for the soaked particles using the wet pycnometer technique. The submerged unit weight was then calculated as the difference between the weight of the "solids" in air and their weight in water. Using a measured unit weight of the soaked particles of 53 lb/ft^3, the submerged unit weight was calculated as 4.8 lb/ft^3.

The third method for determining the effective submerged unit weight was based on direct measurement of a saturated unit weight for the material. To obtain the saturated unit weight, soaked wood particles were first compacted into a 6-in.-diameter mold with a watertight base plate. The mold and its surcharged contents were then submerged in a tank and a partial vacuum was applied over the water surface. After a few days of soaking, the mold and its contents were weighed. The unit weight of water was subtracted from this measured saturated unit weight to obtain an effective (submerged) unit weight of 4.6 lb/ft^3. As shown in Figure 6, a rounded-off value of 5 lb/ft^3 was used in the stress calculations.

Compaction

Because the AASHTO impact methods do not produce unit weights as high as those readily obtainable with static compaction and because of the difficulty in measuring in situ densities of the fibrous wood material, the compaction requirement for the wood fiber fill was stated in terms of a method rather than an end result. Following precedents established by engineers of the U.S. Department of Agriculture Forest Service and state highway agencies in the region (*4,6,7*), the compaction requirement recommended was that the uncompacted material be placed in lifts not more than 1.0 ft deep and compacted by rolling the surface of each lift with a minimum of two passes of a crawler-type tractor or dozer of weight equal to or greater than that of a Caterpillar D–7. It was observed later during construction that no observable densification of the material was produced after the two passes were applied. It was also determined that the bulking factor or the ratio of loose volume to the compacted volume of the material delivered was 2.

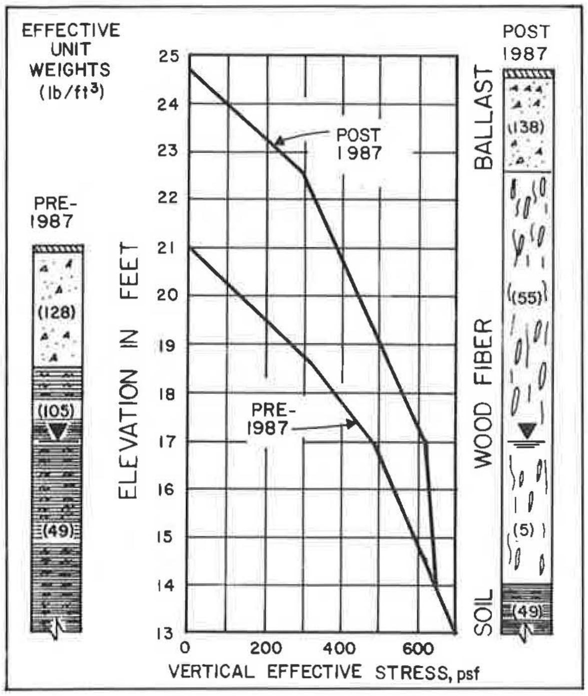

FIGURE 6 Pre- and post-1987 effective stresses at Station 14.

Permanence

Although very few quantitative data are available concerning the rate of decomposition of wood fiber fill, engineers and other observers of sawmill wood waste piles agree that except for the outer edges of the piles, very little degradation or deterioration of the material takes place within 15 years or longer (*6,8*). It has been suggested that the material seals itself as decomposition proceeds inward from the outer surfaces (*9*).

Measurements of temperature and methane gas concentration in wood particle fills in British Columbia by Smith and Coulter (*8*) indicate that anaerobic conditions develop soon after construction in fills both above and below the water table. Under anaerobic conditions, decomposition of the wood particles takes place very slowly. Development of anaerobic conditions within wood fiber fills may be enhanced by sealing the surfaces of the fill with plastic, asphaltic, or other membranes. In this project, all surfaces of the wood fiber fill were covered with at least 12 in. of a compacted, well-graded, crushed granular material both to protect the material from possible fire and to enhance the development of anaerobic conditions.

CALCULATION OF REQUIRED FILL THICKNESS

Figure 6 is an example of one of the pre- and postconstruction profiles used to calculate the required thickness of the wood fiber fill in order that there be no net effective stress increase on the subgrade soil. The figure illustrates a "worst" condition assumed possible at the particular station (Station 14+00). The condition shown assumes that the ground water table has been lowered to an elevation 4 ft below the existing ground surface (also the preconstruction pavement surface elevation) after previously having been as much as 1 ft above the existing ground elevation. The distributions of vertical effective stress shown in the figure were calculated using the moist and submerged wood particle unit weights previously described along with measured and estimated unit weights of the pavement surfacing, base, ballast, and subgrade soils. For the pavement location shown, the total thickness of wood fiber fill required was 8.6 ft. This was the maximum thickness calculated at this station for any of the assumed "reasonable" combinations of ground water levels, including the levels that existed at the time of the field explorations in 1977 and 1987. Calculations like those illustrated by Figure 6 were made at 50-ft intervals along the runway.

PREDICTED AND MEASURED SETTLEMENTS

Elevation measurements made on the runway surface 15 months after paving showed that settlements of sections containing the wood particle fill ranged between 0.05 and 0.39 ft. Settlements after 32 months ranged between 0.07 and 0.53 ft. The settlements measured at Station 14 at the location of the thickest fill are plotted as open circles on the settlement-time curve of Figure 1. These settlements are the maximum values observed at any station since the 1987 reconstruction.

The 1988 and 1990 settlement points plotted in Figure 1 reflect creep deformations of the 8-ft-thick wood fiber fill and secondary compression of the organic subgrade soils as well as consolidation of the subgrade soils. Although the observed settlement is double the predicted value of 0.24 ft, it is substantially less than the settlement that occurred at Station 14 during equal time periods following the 1977 reconstruction. It seems apparent that the use of the lightweight wood fiber fill was successful in preventing a new episode of significant consolidation settlements in the highly compressible organic subgrade soils.

CONCLUSIONS

Construction of a lightweight fill using locally available wood particles provided an economical and technically sound solution to the problem of settlements of an airport pavement constructed over soft, highly compressible organic subsoils. By using wood particles instead of conventional compacted soil fill, it was possible to elevate the pavement surface to a level up to 3 ft above the surrounding ground and water levels while imposing no net increase in effective stress on the organic subgrade soils.

Laboratory tests were used to obtain unit weights necessary for calculating required fill thicknesses. Submerged, dry, and wet effective unit weights were determined to be about 5, 14, and 55 lb/ft³, respectively. Strength and deformation parameters for design were also obtained from conventional soil mechanics tests. Compacted wood particles possess adequate strength for use in confined fills even at small strains. The material possesses substantial strength at large strains. Com-

pressibility and creep susceptibility of the wood particles used in this project were found to be comparable to levels usually observed for fine-grained soils. Stress-caused volume decreases were readily accommodated during construction. Although creep deformations could not be eliminated, the predicted settlements were considered to be within acceptable limits.

Comparison of pavement settlements measured 15 and 32 months after construction with values predicted during design indicated that the laboratory tests provided reasonably accurate design parameters and that the lighweight wood fiber fill successfully limited settlements to acceptable levels.

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