STEEL FIBROUS CONCRETE FOR AIRPORT PAVEMENTS

Frazier Parker, Jr.
Soils and Pavements Laboratory, U.S. Army Engineer Waterways Experiment Station
Vicksburg, Mississippi and
John L. Rice
Pavement Design and Construction Standards
Federal Aviation Administration
Washington, D.C.

INTRODUCTION

In the past several years, considerable interest has been generated in the use of steel fibrous concrete for pavements. Steel fibrous concrete is a composite material consisting of a concrete matrix containing a random dispersion of small steel fibers. The introduction of the fibers imparts to the concrete matrix certain characteristics, such as resistance to spalling, the ability to sustain load after initial cracking, and the ability to keep cracks tightly closed, which improve its performance compared to plain or conventionally reinforced concrete pavement.

This paper contains a discussion of the properties of steel fibrous concrete, procedures for designing and constructing steel fibrous concrete airport pavements, and applications on airports.

DESIGN CONSIDERATIONS

Engineering Properties of Steel Fibrous Concrete

The introduction of ductile, high-strength steel fibers in the concrete matrix alters the properties of the concrete by compensating for its low tensile strength and low ductility, thereby enhancing its mechanical and physical properties. A state-of-the-art report (1), prepared by Committee 544 of the American Concrete Institute, contains a treatment of the mechanics of fiber strengthening and a discussion of the properties of fibrous concrete. In this report, reference is made to a number of studies on the properties of fibrous concrete.

In analysis of the load-deformation response of steel fibrous concrete there is a tendency to compare its properties to those of plain concrete, and to attribute all observed differences in the response to the presence and quantity of fibers. While the post-cracking response may be directly attributed to the fibers, comparisons of strength and stiffness must be qualified by considering differences in other properties of the concrete such as mixture proportions, cement factor, water-cement ratio, and workability of the plastic concrete.

Steel fibrous concrete mixtures will, in general, contain more cement, contain smaller coarse aggregate, have a higher ratio of fine aggregate to coarse aggregate, and have a higher water-cement ratio than plain, paving concrete mixtures. Higher cement contents, fine aggregate contents, and water-cement ratios are needed to provide paste to coat the fibers and to ensure workability of the mixture which is inherently harsher than mixtures without fibers. It is important to note that each of these will also result in higher strength. A more detailed discussion of mix design considerations will be presented later. However, when comparing properties of plain and steel fibrous concrete it is important to remember that the mixes are different, and that some of the differences in material properties may be attributed to factors other than the presence of steel fibers.

Load-deflection curves for plain and steel fibrous concrete beams are illustrated in Fig. 1. Plain concrete is a relatively brittle material, and its load-deflection curve is essentially linear up to the ultimate load. On the other hand, the load-deflection curve for the steel fibrous concrete is linear up to the load referred to as "first crack" (or proportional limit) load. Past this load, the load-deflection relationship becomes nonlinear. An ultimate load is achieved, after which the relationship between the load

and deflection would become dependent on the type test being performed. In a controlled strain test the load would decrease as the deflection increased. For plain concrete, once a crack is initiated it will propagate for the entire depth of the beam resulting in a catastrophic failure. For steel fibrous concrete, additional load is required for a crack to propagate and complete failure to occur. The additional energy is required to debond the fibers (they do not fracture) and pull the beam apart.

Toughness is one property which is directly related to the presence of fibers. Toughness is a measure of the ability of a material to absorb energy, and is an indication of the resistance against crack propagation. A measure of the toughness of a material is the area under the stress-strain curve. Considering Fig. 1, the relative toughness of plain concrete and steel fibrous concrete is illustrated by the areas under the load-deflection curves. The plain concrete has a smaller ultimate load, but even if the ultimate strength were the same as the steel fibrous concrete, the toughness would be much less. The toughness is also directly related to the amount of fibers in a mixture. Although strength, workability, and other properties change with changes in fiber content, there is a direct relationship between the material toughness and fiber content.

In a comparison of the strength of plain and steel fibrous concrete, several qualifications must be made. Referring to Fig. 1, several strength values are defined. The first crack (proportional limit) strength of steel fibrous concrete is analogous to the ultimate strength of plain concrete, while the ultimate strength of the steel fibrous concrete is developed only after some plastic deformations occur. Part of the increase in first crack strength can be attributed to the presence of the fibers, but part of it is due to the higher cement content. The increase in the ultimate strength can be directly related to the presence of the fibers, but should not be attributed solely to the fibers, since mixes without fibers can be produced which will have comparable strength. Tests conducted by the Portland Cement Association (2) illustrate this relationship, and also show the relationships between strength (ultimate and first crack), water-cement ratio, workability as measured by the slump, and fiber content. In this study, fiber content and cement content were varied and it was possible to isolate the effects of cement content and fiber content on strength. By keeping workability constant, strengths were obtained for mixes without fibers which were as high or, in certain cases, higher than some of the mixes with fibers.

The modulus of elasticity of steel fibrous concrete is basically the same as that of plain concrete composed of the similar ingredients, although some investigators have shown a slight decrease. With respect to Fig. 1, this indicates that the initial straight-line portions of the load-deflection curves have basically the same slope. This, in turn, means that within the linear range the ductility is basically the same. However, on the basis of the total response, steel fibrous concrete is a more ductile material, and the increase in ductility can be directly related to the presence and quantity of the fibers.

Other miscellaneous properties of steel fibrous concrete, such as spall resistance, impact and dynamic strength, abrasion resistance, and fatigue strength, are directly related to the presence and quantity of steel fibers. Spall and impact resistance have been demonstrated through dynamic and explosive loading tests (3 and 4). Repeated load beam tests (5) have demonstrated that there is an increase in fatigue strength with increasing fiber content. However, increases in fatigue strength have been for concrete with large fiber contents, and the results are inconclusive for fiber contents (2 percent or less by volume) which can be mixed and placed in the field.

Design Parameters

The observed performance of steel fibrous concrete pavements (6) has been similar to plain concrete pavements in many respects. The basic stress manifestation is cracking, attributed to the repeated applications of tensile stresses in the pavement slabs. As a result, the basic design parameter is the same as it is for plain concrete; i.e., tensile stress in the slab. The required slab thickness is determined as that necessary to limit the tensile stress in the slab to such a level that fatigue cracking will not occur until after the pavement has received the design number of stress repetitions (analogous to coverages). In keeping with usual conventions (selected for ease in constructing design curves), the fatigue or performance criteria for steel fibrous concrete, extracted from Reference 6, are shown in Fig. 2 in terms of a ratio of the required thickness to the standard thickness of plain concrete. The standard thickness of plain concrete is for 5000 coverages, and is that thickness necessary to limit the ratio of the

flexural strength of the concrete to the tensile stress in the slab to a value of 1.3. The required thickness of steel fibrous concrete for any traffic volume may be found by determining the required standard thickness of plain concrete and multiplying this thickness by the appropriate factor from Fig. 2.

To determine the standard thickness, the strength of steel fibrous concrete used is the ultimate flexural strength. Since steel fibrous concrete normally has higher strengths than plain concrete, thinner standard thicknesses will be obtained. This, combined with the smaller thickness ratios, results in smaller required thicknesses for steel fibrous concrete than for plain concrete for similar design conditions.

The improved performance may be attributed to the mechanical properties of steel fibrous concrete. The critical stress in pavement slabs is assumed to exist in the bottom of the slab. When the fatigue strength of the concrete is exceeded a crack will occur. Even for plain concrete pavement slabs, the crack will not immediately propagate to the surface, but requires additional energy before this propagation will occur. This required energy is supplied by additional repetitions of load and/or changes in temperatures. For steel fibrous concrete pavements, the level of stress required to induce the cracking and the energy requirements or number of load applications required for the crack to propagate to the surface will be higher than those for plain concrete pavements.

After the cracks reach the surface, or for situations where the loading causes critical tensile stress in the top of the slab, the fibers will prevent the cracks from opening up and propagating horizontally. The fibers across the cracks, being stiffer than the concrete, reduce the stress concentrations at the ends of cracks and thereby prevent them from propagating. Fig. 3 illustrates the discrete cracking that initially develops in steel fibrous concrete pavements. Additional load repetitions are necessary to produce the energy required to debond the fibers, allowing the cracks to open up and propagate further. Fig. 4 illustrates three cracks at various stages of development. Crack 1 is in an early stage of development and is not visible through the layer of paint, whereas crack 2 has developed to the point where it is visible at several locations. Crack 3 is in an advanced stage of development, having opened up considerably, and would be detrimental to the performance of the pavement. Several repetitions of the load are required for a crack to progress from the condition illustrated by crack 1 to the condition illustrated by crack 3. For plain concrete pavements, the progression is much more rapid; therefore, for identical conditions of concrete and foundation strength, thickness, and induced stress, a steel fibrous concrete will withstand more repetitions of load before the cracks begin to have a detrimental effect on the performance of the pavement.

The improved resistance to spalling of steel fibrous concrete is evident from the behavior of pavements. Failure of plain or conventionally reinforced concrete pavements is often characterized by spalling along cracks and joints. This may lead to a decrease in the riding quality of the pavement, an increase in the rate of deterioration of the pavement, and for airfield pavements, possible foreign object damage to equipment. Cracks and joints in steel fibrous concrete pavements do not spall as they do in plain concrete, even when loaded well past what would be considered failed conditions. Rather, the edges tend to ravel or become abraded as illustrated in Fig. 5, which shows the condition of cracks in a completely failed pavement.

Since the required thickness for steel fibrous concrete will be considerably less than that for plain concrete, the pavement will be more flexible. The deflections experienced by steel fibrous concrete pavements will be greater than those for equivalent plain concrete pavements, and can lead to failure of the underlying material. Criteria have been proposed for controlling deflection in steel fibrous concrete pavement. These criteria were intended to minimize the possibility of pumping, densification or shear in the underlying material, or loss of load transfer across joints. Only a few data points are available, and, as a consequence, it was necessary to use data from plain and reinforced pavements to develop relationships between elastic deflection and pavement performance. It was assumed that the trends shown by the data for the plain and reinforced pavements would hold for fibrous concrete pavement. The curve shown in Fig. 6 (6) was drawn through the data points for steel fibrous concrete parallel to a curve for plain and reinforced pavements. The relationship shown in Fig. 6 does not reflect limiting or maximum vertical deflections which the foundation material could have withstood. Rather, it indicates deflections which proved to be acceptable for the entire pavement system.

Design Procedure

The criteria described in the previous section have been assimilated into a design procedure for steel fibrous concrete (6). Thickness is determined based on the limiting stress criteria, and the thickness thus determined is checked against the deflection criteria. The thickness must meet both criteria to be acceptable.

The design procedure is contained in a series of charts for each aircraft type. An example of charts for the stress criteria is shown in Fig. 7 (6). This design chart is for the L-1011 aircraft. Parameters needed for application of the charts are the concrete flexural strength (7), modulus of soil reaction k (8), gross aircraft design weight, and design traffic in terms of annual departures. Thickness is determined by entering with flexural strength and proceeding through the chart as illustrated by the dashed lines.

The thickness thus determined must be checked to determine if the limiting deflection criteria are met. This is accomplished by computing the deflection with a chart similar to the one for the L-1011 aircraft contained in Fig. 8 (6). The deflection is determined by entering with thickness and proceeding through the chart as illustrated by the dashed lines. If the computed deflection exceeds the allowable deflection, as shown in Table 1, the slab thickness must be increased until the computed deflection is less than or equal to the limiting deflection, or a new design must be initiated with new design parameters.

Table 1

Limiting Elastic Deflections for Civil Airports (6)

Traffic Volume Annual Departures	Limiting Elastic Deflection in.
1,200	0.060
3,000	0.055
6,000	0.050
15,000	0.050
25,000	0.050

As a result of the increased tensile strength of steel fibrous concrete, it is possible to increase joint spacings. The maximum spacing for longitudinal joints should be 25 ft. The maximum transverse joint spacing should be 50 ft. For thicknesses greater than 6 in., larger transverse joint spacings may be acceptable provided dowels are included to ensure alignment and load transfer, and compression seals are used to ensure a sealed joint. Joint spacings larger than 50 ft should only be permitted after it has been proven, on the job, that intermediate transverse cracking will not develop.

Procedures have been developed for determining thickness requirements for steel fibrous concrete overlays of flexible pavement and partially bonded or unbonded overlays of rigid pavement. While only partially bonded overlays have been tested, the procedure for unbonded overlays was extrapolated from this procedure by assuming that the performance of unbonded overlays will be similar to the performance of unbonded plain concrete overlays.

It is recommended that overlays of flexible pavement be designed as a slab on grade by considering the flexible pavement as a base course. The maximum value to be used as the design subgrade modulus should not exceed 500 pci.

The thickness of partially bonded overlays of rigid pavement can be determined from the equation

$$h_o = (0.75) \sqrt[1.4]{h_d^{1.4} - C\left[\left(\frac{h_d}{h_{db}}\right) h_e\right]^{1.4}} \qquad (1)$$

where

h_o = required thickness of the steel fibrous concrete overlay, in.

h_d = required thickness of an equivalent single slab of plain concrete having a flexural strength equal to the flexural strength of the steel fibrous concrete used for the overlay, in.

h_{db} = required thickness of an equivalent single slab of plain concrete having a flexural strength equal to the flexural strength of the concrete in the existing pavement, in.

h_e = thickness of the existing pavement, in.

C = coefficient describing the condition of the existing pavement

It is recommended that the thickness of unbonded overlays be determined from the equation

$$h_o = (0.75)\sqrt{h_d^2 - C\left[\left(\frac{h_d}{h_{db}}\right) h_e\right]^2} \qquad (2)$$

where the variables are as identified above. The minimum recommended thickness for either type overlay is 4 in.

Joints in partially bonded steel fibrous concrete overlays should coincide with joints in the base pavement; however, when the transverse contraction joint spacing in the base pavement is 15 ft or less, every other joint in the overlay may be eliminated. It is not necessary for joints to be over similar joints. Longitudinal contraction joints in the base pavement may be spanned in partially bonded overlays. Longitudinal construction joints in partially bonded overlays should be matched with longitudinal construction joints in the base pavement.

For unbonded overlays, it is unnecessary for the joints to coincide with joints in the base pavement. Longitudinal construction joints in unbonded fibrous concrete overlays should be either doweled or keyed-and-tied. Longitudinal construction joints in partially bonded overlays should be doweled.

CONSTRUCTION CONSIDERATIONS

Mix Design

Previously, the general characteristics of steel fibrous concrete mixtures were enumerated. It was noted that part of the increased strength of steel fibrous concrete was due to the fibers, but that part of the higher strength was due to the higher cement content. Mixture workability was also discussed and it was noted that the introduction of fibers drastically decreases mixture workability. By removing the fibers from a steel fibrous concrete mixture and reducing the water content (thus reducing the water-cement ratio) to maintain a constant workability, the resulting material would have strength greater than normal paving quality concrete. In the remainder of this section, quantitative details of steel fibrous concrete mix design will be considered.

The surface area to volume ratio of the steel fibers requires a large amount of paste to coat the fibers and aggregate. The shape of the fibers also requires an increase in the paste content, to ensure that the fibers are properly dispersed in order to avoid harsh mixes which are difficult to place. Cement contents from 550 to 950 lb per cubic yard have been used with water-cement ratios between 0.4 and 0.6.

The size, type, and volume of fibers will influence other parameters in the mix. The following are two general rules regarding the influence of fibers:

a. An increase in fiber content results in increased strength and decreased workability. Experience has shown that fiber contents in excess of 2 percent by volume are difficult to mix and place in the field.

b. An increased fiber aspect ratio (length to diameter or equivalent diameter) results in increased strength and decreased workability. For proper mixing, the maximum aspect ratio should be about 100.

There are presently only a few sizes of fiber commercially available. Therefore, the usual procedure is to select a type of fiber and then design the mixture by trading off strength for economy and workability. The most commonly used fibers are 1 in. long and are either round in cross section (0.016 in. in diameter) or rectangular (0.010 by 0.022 in.). A 0.025-in.-diam by 2-1/2-in.-long round fiber has had limited use, as have some of the more exotic types such as Duoform fibers which have a variable (round-rectangular) cross section.

In addition to variations in fiber type and content, there are the normal parameters such as cement and water content, aggregate proportions, etc., which can be varied in a mix design. The procedures for optimizing a fibrous concrete mix for preselected materials are similar to those used for plain concrete. A trial mix is selected based on experience, and then the constituents are adjusted to produce the desired properties. Several mixes which have been used are shown in Table 2.

Table 2

Typical Steel Fibrous Concrete Mixes

Material	Saturated Surface Dry Batch Weight lb
Mix I	
Cement (Type I)	846
Fine aggregate (natural sand)	1700 (70%)
Coarse aggregate (3/8-in. maximum-size natural gravel)	738 (30%)
Fibers (round, 1 in. long by 16 mils in diameter)	250 (2%)
Water	390
Air-entraining agent (5% air)	--
Mix II	
Cement (Type I)	517
Fly ash	225
Fine aggregate (natural sand)	1525 (55%)
Coarse aggregate (3/4-in. maximum-size crushed limestone)	1200 (45%)
Fibers (rectangular, 1 in. by 10 by 22 mils)	200 (1-1/2%)
Water	275
Air-entraining agent (4% air)	--
Set-retarding admixture	--
Mix III	
Cement (Type IP)	822
Fine aggregate (natural sand)	1593 (60%)
Coarse aggregate (3/8-in. maximum-size natural gravel)	1014 (40%)
Fibers (Duoform, 3/4-in. long)	115 (1%)
Water	325
Air-entraining agent (5% air)	--

Mix I resulted in slumps of about 4 in. and was used for manually constructed test pavements.

Mix II resulted in slumps of about 2 in. and was used for slip-formed 4- and 6-in.-thick overlays.

Mix III resulted in slumps of about 4 in. and was used for manually constructed test pavements.

Some general characteristics of steel fibrous concrete mixtures which have been used for pavements are as follows:

a. For pavement applications, maximum-size coarse aggregate has been varied between 3/8 and 3/4 in., with the 3/8-in. size used predominately.

b. The percentage of coarse aggregate (of the total aggregate content) can be varied. The percentage has generally varied from 25 to 40 percent for pavement application.

c. The composition of the cementitious constituent can be varied. Specifically, fly ash or other pozzolans can be substituted for portland cement to provide the necessary paste. The substitution of a pozzolan decreases the rate of strength gain.

d. Admixtures for air entrainment, water reduction, and set control have been used, and conventional procedures regarding their use should be followed.

The typical values and mixtures should be considered only as guidelines, and before any construction is started, a thorough mix design should be conducted with available material in order to select a workable mix which will yield the desired strength.

Concrete Production

Concrete production involves two basic processes: batching and mixing. The inclusion of fibers adds one additional ingredient which must be handled during batching operations. Fibers require handling techniques and equipment which are different from those used for aggregate, cementitious materials, or liquids. During mixing, there is a tendency for balls or clumps of fibers to form (or they may already be formed and not be broken up during mixing).

Manual procedures have been used for introducing the fibers into the batching operation. Fibers are presently shipped in boxes of about 1-cu-ft volume containing from 40 to 80 lb of fiber. This method is not an efficient way to ship the fibers since a cubic foot of steel weighs about 490 lb. With this packaging procedure, additional labor is required for handling because of the wasted space. However, the need for weighing is eliminated and not as much effort is required to disperse the fibers as would be required if they were packed more efficiently.

In the batching operation, fibers are generally handled as aggregate, but care must be taken when the fibers are required to pass through a constriction since they have a tendency to bridge over an opening. Efforts should also be made to disperse the fibers as much as possible and to achieve as much preblending of the fibers with the aggregate as possible prior to mixing.

Several procedures have been used successfully for ready-mix operations. The most successful method has been to place the fibers onto a belt or through a chute carrying the aggregate to the mixing drum. With this procedure, the fibers and aggregate are preblended before entering the mixing drum. This preblending helps to minimize balling. Cement and water are added after the fibers and aggregate have been charged. Another procedure that has been used is to introduce the aggregate into the mixing drum followed by the fibers and then the cement and water. When fibers are introduced, an effort should be made to achieve as much dispersal as possible.

For central batch operations, the most successful method that has been used is that of feeding the fibers onto a belt that deposits the fibers onto the charging belt of the central-mix plant. A number of methods for placing the fibers onto the first belt have been tried. The most successful has been to manually place the fibers directly onto the belt. A hopper with a vibrating screen has been used during the construction of a number of projects. Fibers are placed in the hopper and are dispersed through the screen as they drop onto the charging belt. As with ready-mix operations, regulation of the flow of the aggregate so that the fibers and aggregate are preblended before entering the mixing drum minimizes the formation of fiber balls.

Bulk-handling techniques for introducing fibers during batching operations have not been developed. Fiber and equipment manufacturers are currently developing equipment and techniques for shipping and handling large quantities of fibers. The extent of this

development will depend on the large-scale application of fibrous concrete, and vice versa the use of large quantities of fibrous concrete will depend on the ability to efficiently handle large volumes of fibers.

Mixing action should be as vigorous as possible to break up any balls or clumps of fibers that formed during batching or that are tending to form during mixing. Mixing time requirements are essentially the same as for plain concrete. However, overmixing should be avoided since the fibers tend to ball up and the balls tend to grow as mixing is continued. When transit-mix trucks are used, special precautions should be taken to prevent overmixing and to prevent fiber ball formation as the mixer operates at agitating speed.

Concrete Placement

Steel fibrous concrete can be placed with conventional paving equipment. Hand methods, bridge-deck machines, form-riding pavers, and slip-form pavers have been successfully used to construct pavements. Because of the harshness of steel fibrous concrete, it is more difficult to handle. There is a tendency to increase the water content in order to increase workability. However, as with plain concrete, the water content should be kept as low as possible. With central-mix facilities and modern slip-form paving trains, steel fibrous concrete with slump as low as 1 in. has been placed successfully in thicknesses as small as 4 in. Slabs 2 and 3 in. thick have been successfully placed with slip-form pavers, but higher slump concrete was used. Thin slabs (2 to 3 in. thick) have been placed with manual procedures and bridge-deck finishing machines. For these placements, slumps ranging from 3 to 6 in. have been required. The slump required for proper placement will depend on the slab thickness and the equipment used. Thin slabs placed with manual procedures will require higher slump concrete than thicker slabs placed with modern paving equipment. The equipment used for transporting and spreading the concrete will also affect the slump required.

When transit-mix trucks are used, it will be necessary to use concrete with at least a 3-in. slump for proper discharge. Because of its harshness, it is difficult and sometimes impossible to discharge steel fibrous concrete with slumps less than about 3 in. When mechanical spreaders are used, lower slump concrete can be used than is possible when manual techniques are used.

The pavement surface can be finished with conventional techniques. Because of the high cement content of the concrete, the surface usually finishes easily. A burlap drag cannot be used for surface texturing since the fibers stick in the burlap and cause tearing of the surface. Transverse texturing with a stiff bristle brush or a wire comb has been successful. The presence of the fibers causes no problems and the resulting texture appears to be no different from that obtained for plain concrete.

FIELD APPLICATIONS ON AIRPORTS

In the first two sections the properties of steel fibrous concrete and the development of design and construction procedures were discussed. In this section it is intended to demonstrate how the material has evolved into a practical pavement construction material by getting out of the laboratory and into practical use. Laboratory mixing and placing are performed under nearly ideal conditions and the suitability of conventional paving equipment and techniques to handle fibrous concrete was in question.

Tampa, Florida

The first field placement on an airport was made in February 1972. The placement consisted of a 6-in.-thick overlay, 175 ft long and 75 ft wide, and a 4-in.-thick overlay, 50 ft square. The placement was made on a taxiway which consisted of a 12-in.-thick plain concrete with a 3-in. limerock base over an E-3 sand subgrade. The primary objective of the Tampa job was to determine if steel fibrous concrete could be placed using conventional paving equipment.

The 6-in.-thick overlay was constructed in three 25-ft-wide paving lanes. The longitudinal construction joints matched the joints in the base pavement. No transverse joints were provided in the overlay pavement. The overlay spanned one expansion joint and five transverse contraction joints. A butt-type construction joint with no load transfer devices was used between each paving lane.

The 4-in.-thick overlay was placed in two 25-ft-wide paving lanes such that the paving lanes straddled the longitudinal construction joints in the base pavement. No transverse joints were constructed in the overlay so each lane spanned one transverse contraction joint. The longitudinal construction joint was a butt type with no provision for load transfer. Plan and section drawings of the placement are shown in Fig. 9.

The Tampa placement demonstrated that steel fibrous concrete could be produced and placed with conventional construction techniques. The major problem encountered at Tampa was with the handling of the fibers. The fibers were loaded onto a conveyor belt by hand and represented the most difficult phase of the project. Construction of the overlays with a slip-form paver was satisfactory. Transverse finishing with a stiff bristle broom furnished an acceptable surface texture. Curing was accomplished by application of conventional curing compound. Performance to date has been reasonable. Some reflection cracking has occurred in both overlays.

New York City, New York

The second installation was made at John F. Kennedy Airport, New York, in May 1974. Three small placements were made. The largest placement of the three was on the 22 end of runway 4L-22R and was 170 by 120 ft of 5-in.-thick steel fibrous concrete. The placement was made on a bituminous overlay of a rigid pavement. The next largest placement was made on a taxiway and consisted of an 8-1/2-in.-thick slab, 650 sq yd in area, over an existing flexible pavement. The smallest placement was a 5-in.-thick buried slab, 150 sq yd in area. This installation was intended to solve a problem the airport had been having with shoving caused by aircraft turning off the taxiway onto the runway.

The material used at Kennedy was produced in ready-mix trucks. The fibers were dispersed with a vibratory screen and then fed into the ready-mix trucks for mixing. The material had a slump ranging from 3 to 4 in. All areas were formed and placed with conventional equipment. Considerable problems were encountered with fiber clumping, slow production, and low flexural strengths. Initially, the FAA decided to disallow payment of Federal funds for the fibrous concrete slabs because the specified flexural strength was not met. However, one year later, this decision was reversed based on the excellent performance of the pavements. This placement seemed to indicate a need to examine flexural strength test requirements for steel fibrous concrete.

Reno, Nevada

During May and June 1975, a rather large placement, 23,000 sq yd, of steel fibrous concrete was made at Reno International Airport. The placement consisted of a 4-in.-thick bonded overlay of an existing 11-in.-thick rigid pavement. The placement was made on the terminal parking apron. An overlay was needed to strengthen the existing pavement for future use by DC-10 and L-1011 aircraft and to correct a severe surface scaling condition. Overlaying the apron presented a problem in that only 4 to 5 in. of headroom were available due to the need to provide drainage away from the terminal building. The only available alternatives were to remove and replace the existing pavement or to overlay with steel fibrous concrete. Steel fibrous concrete provided the necessary strength with only a 4-in. thickness.

Steel fibrous concrete was produced in a conventional batch plant with two special modifications added to handle the fibers. Fibers were emptied onto a vibrating screen with openings about 3 in. wide to initially break up any large clumps of fibers. One man was positioned by the vibrating screen with a rake to break up larger clumps of fibers. The vibrating screen emptied the fibers onto a conveyor belt which carried the fibers to the top of a second fiber dispersal device. The second dispersal device consisted of a pipe, about 24 in. in diameter, with a vertical rotating shaft with blades attached. The shaft rotated at about 2000 rpm and the fibers were dispersed by the action of the blades. The fibers were dropped onto the aggregate charging belt and the process was conventional from that point. A schematic of the fiber handling process is shown in Fig. 10. Mixing was accomplished with ready-mix trucks enroute to the site. Fly ash was added to the mixture from a separate silo.

The existing pavement was cleaned by high-pressure water and coated with grout to achieve bond between the existing pavement and the overlay. Steel side forms were used to form the overlay. The concrete was deposited directly in front of a Blaw Knox spreader from

the ready-mix trucks. Two Clary screeds followed the spreader and finishers floated the surface. Texturing was done by hand using a wire comb. Curing compound was used to cure the overlay.

Some problems were encountered at Reno with plastic shrinkage cracks. This was attributed to the high winds and low humidity which existed at the time of placement. Plastic shrinkage cracking would probably have occurred in plain concrete also. The overlay has experienced considerable shrinkage cracking and loss of bond. The overlay slabs are curling more than would be anticipated for a 4-in. thickness. Thus far most of the cracks are being held closed by the fibers.

Las Vegas, Nevada

The largest application of steel fibrous concrete on an airport was at McCarran International Airport, Las Vegas, Nevada, where 60,000 sq yd of a transient aircraft parking apron was overlaid. The overlay pavement is 6 in. thick. The existing pavement is a 13-in. flexible pavement resting on a caliche subgrade. The existing pavement was badly cracked and the decision to use steel fibrous concrete was based largely on the expectation that reflection cracking would be practically eliminated. The placement was made in February 1976. The concrete was produced in a central mixing plant. A 6-cu-yd mixer was used to mix 3-cu-yd batches. The small batches provided thorough mixing and minimized fiber clumping. The fibers were dispersed with a vibrating screen only; the second dispersion device used at Reno was not used at Las Vegas. The conveyor belts were arranged so that no 90-deg turns were encountered and this helped avoid fiber clumping. The concrete was hauled to the site in end dump trucks and placed with a slip-form paver. Paving lanes were 25 ft wide and contraction joints 50 ft apart. The material was placed with a slump of 2-1/2 in. and finished with a stiff broom.

Future Applications

The authors feel that steel fibrous concrete, as a pavement construction material, will have application in special circumstances. The material costs at least twice as much as plain concrete and is thus usually competitive only in special applications. Steel fibrous concrete is eligible for use on Federally funded civil airport and military airfield applications on a case-by-case basis. More experience is needed in fiber handling as the hand labor required is expensive and time-consuming. A definitive test for strength is needed as the post-crack behavior of the material makes flexural testing difficult to interpret. Placement and texturing can be accomplished readily with conventional paving equipment and techniques.

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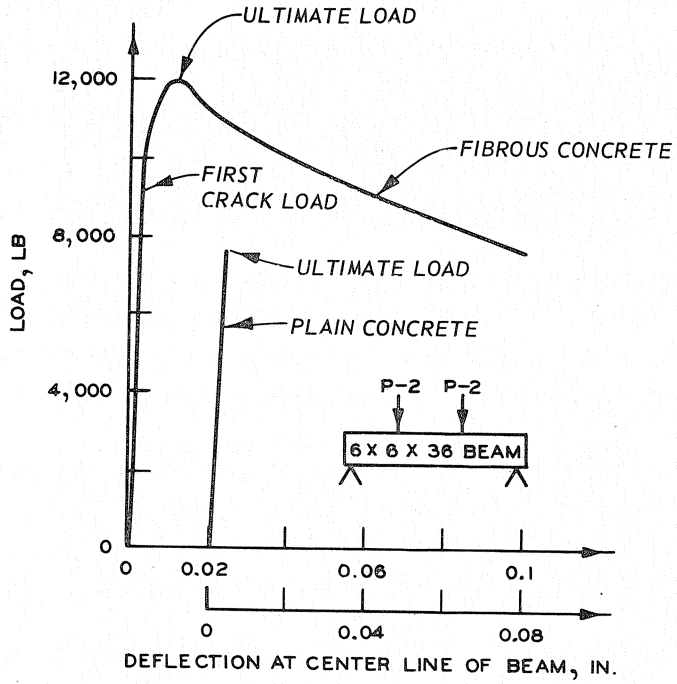


Fig. 1.--Typical load-deflection curves for a steel fibrous concrete and a plain concrete beam

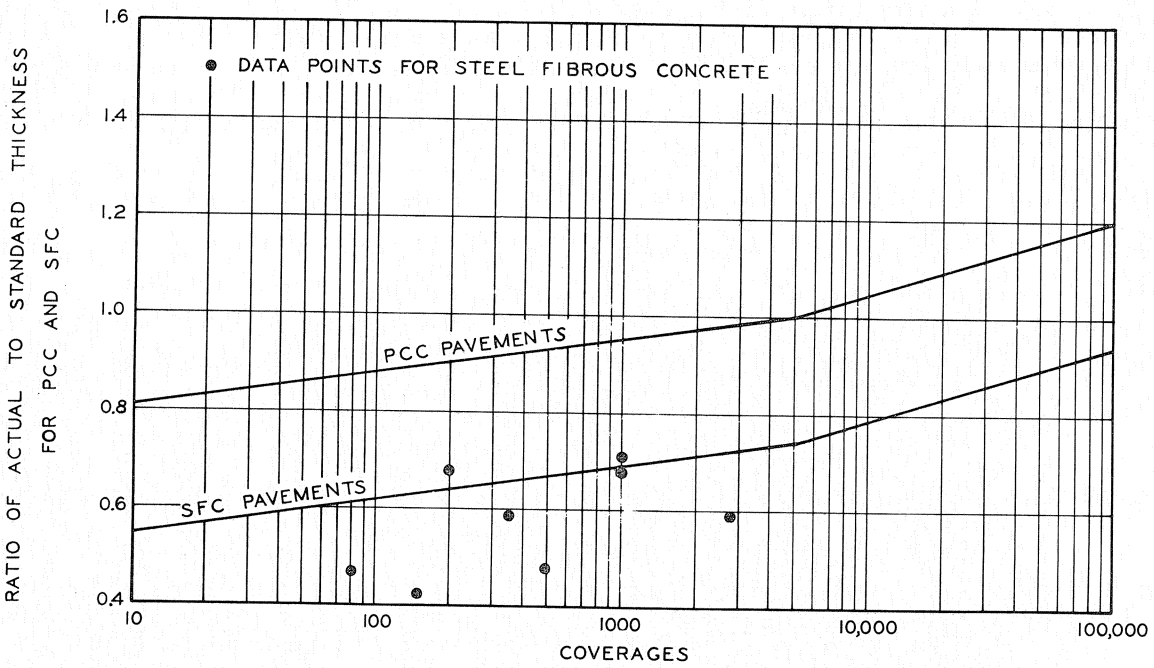


Fig. 2.--Performance criteria for steel fibrous concrete pavements based on first crack failure criteria (6)

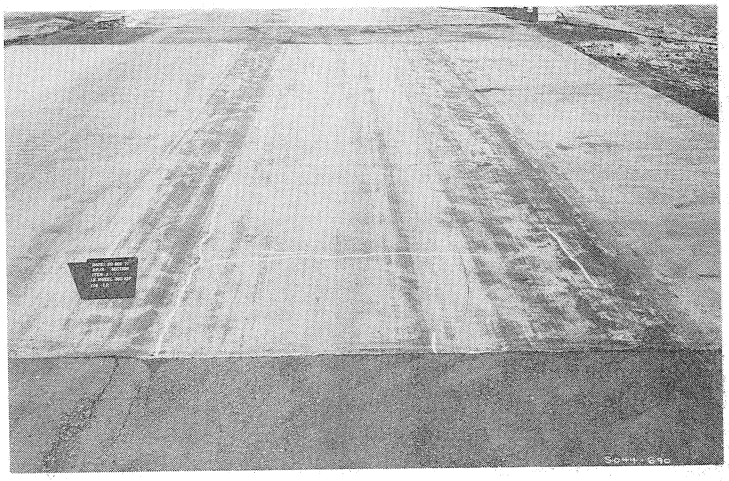


Fig. 3.--Example of discrete cracks that initially form in steel fibrous concrete pavement

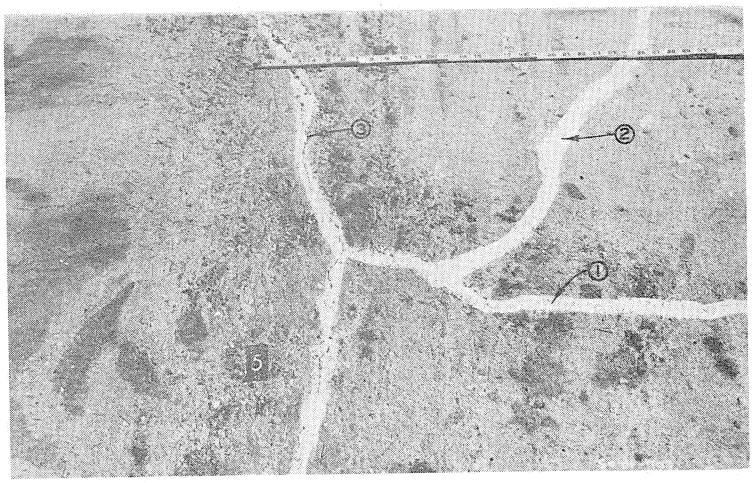


Fig. 4.--Typical cracks that develop in steel fibrous concrete pavements with traffic

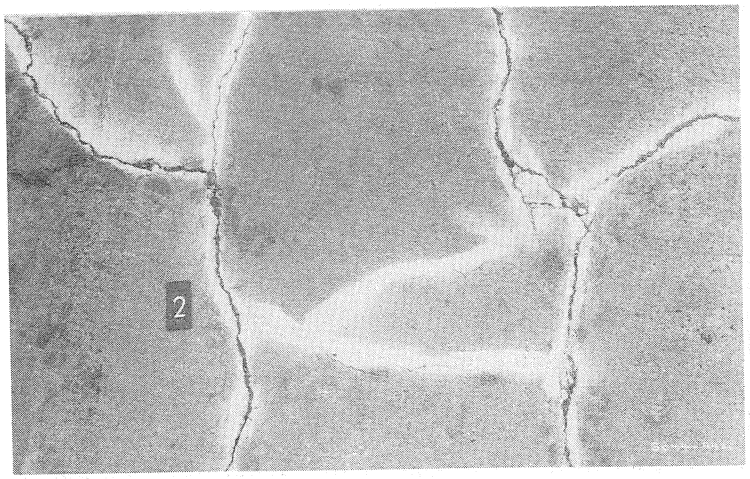


Fig. 5.--Example of cracks in completely failed steel fibrous concrete pavement

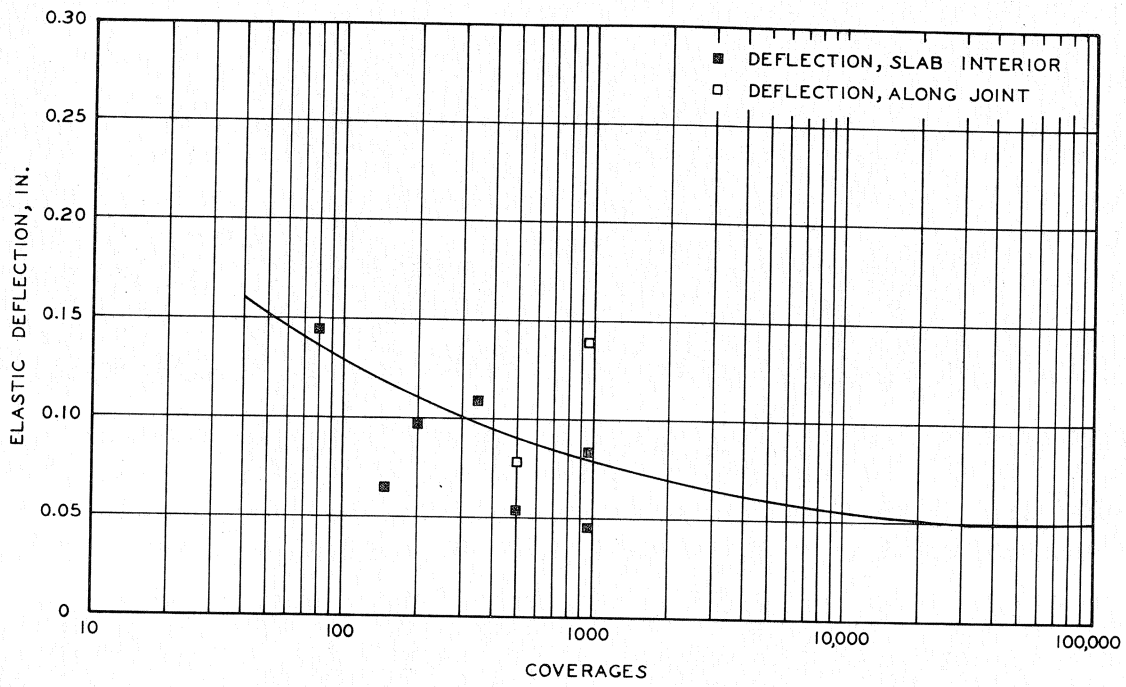


Fig. 6.--Limiting vertical deflection criteria for steel fibrous concrete pavements (6)

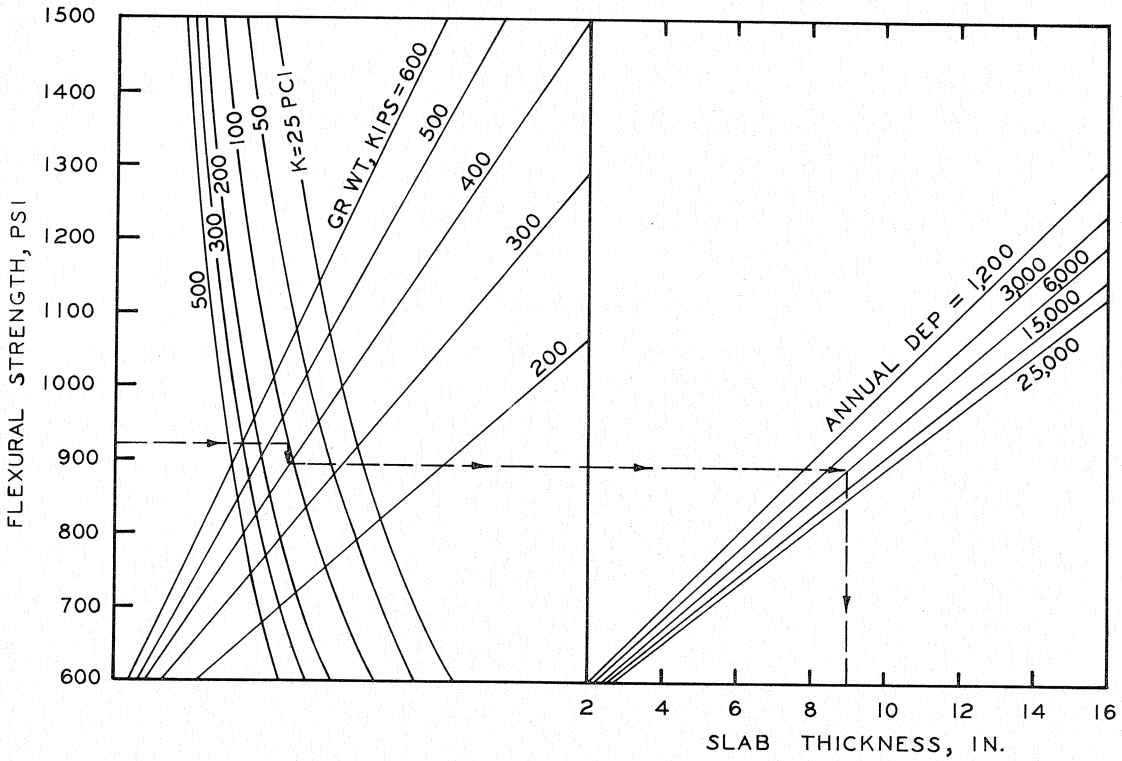


Fig. 7.--Steel fibrous concrete pavement design curve for L-1011 aircraft on critical pavement areas

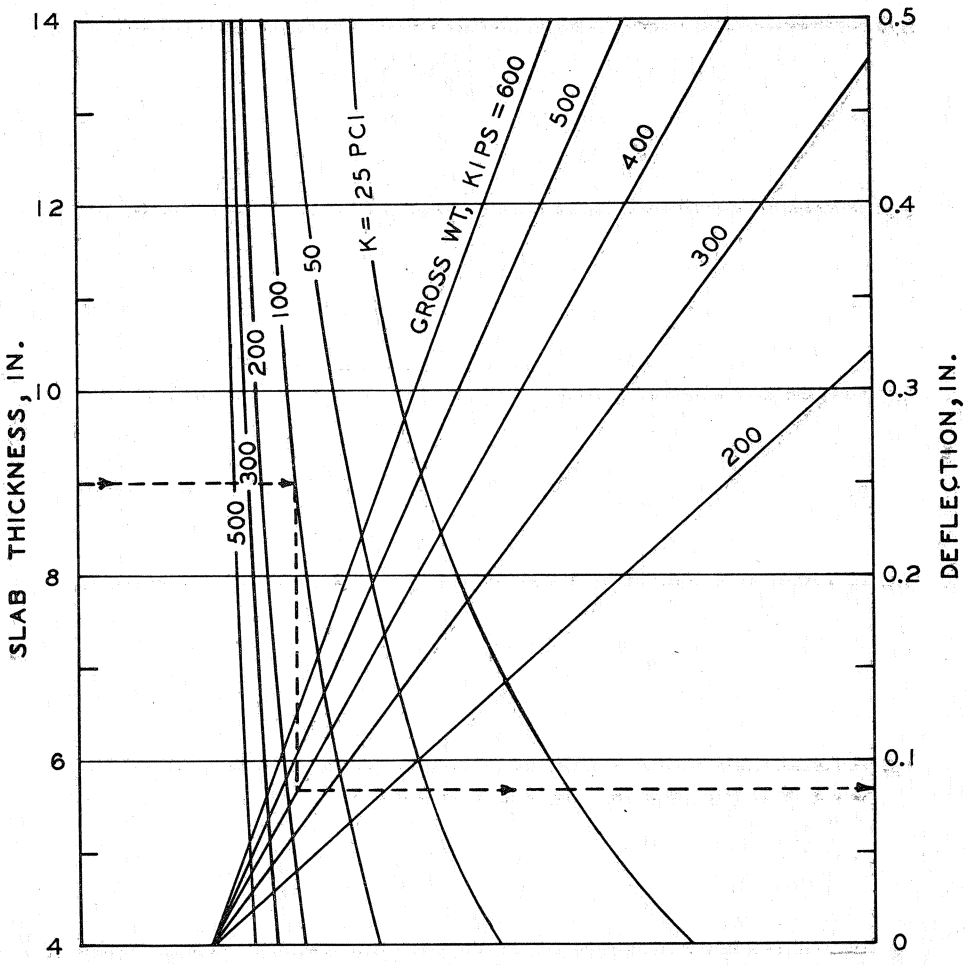


Fig. 8.--Chart for computation of elastic vertical slab deflection for L-1011 aircraft

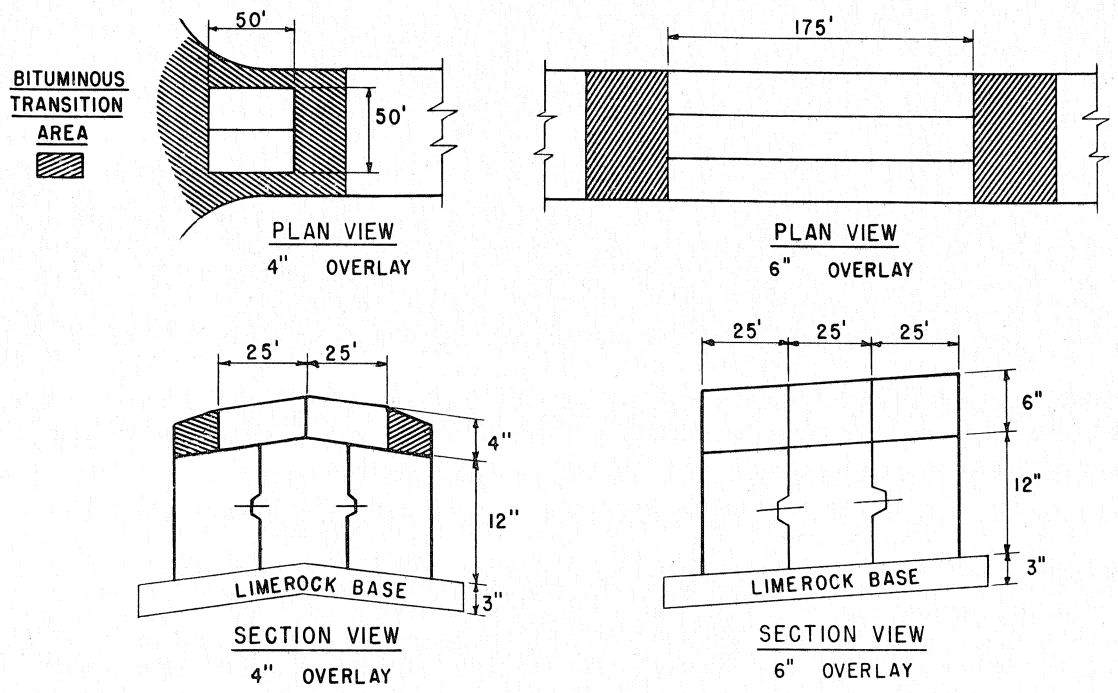


Fig. 9. Layout for Tampa overlay test items

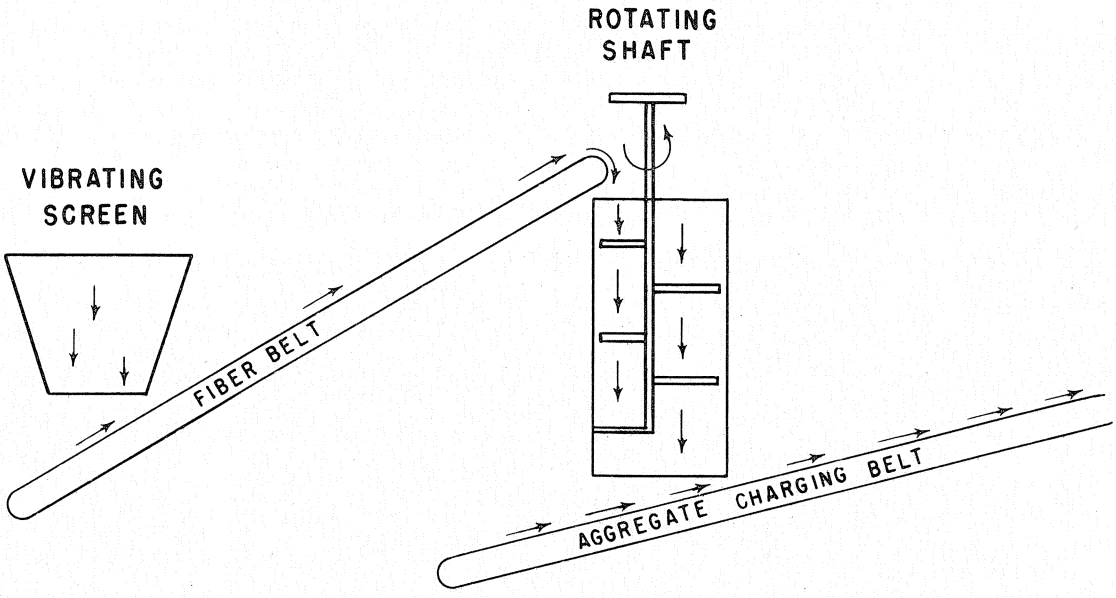


Fig. 10.--Schematic of fiber handling process - Reno, Nevada