# DEVELOPMENT OF TEST PROCEDURES AND METHODS OF MIXING OF STEEL FIBROUS CONCRETE

by

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# ABSTRACT

Steel fibrous concrete was designed, batched, and tested in the laboratory to identify and to resolve any problems that might be encountered with this material. The results of this study show that quality concrete can be produced using five sacks of Type III portland cement, three equivalent sacks of fly ash and 160 pounds of 1-inch long by 0.01 x 0.022-inch steel fibers per cubic yard of concrete. The quality of both the fresh and hardened concrete can be measured with the standard test methods and apparatus. This report also discusses the selection and handling of steel fibers, quality assurance tests for fly ash, and the useful physical characteristics of fibrous concrete.

# SUMMARY

This research was performed to identify problems and develop procedures in the use of steel fibrous concrete. Special safety measures had to be taken in handling the steel fibers because of their needle-like shape and tendency to spring. The optimum steel fiber content was determined to be 160 pounds for a mix containing five sacks of cement and three sacks of fly ash.

Test results indicated that quality steel fibrous concrete could be produced which was significantly higher in strength than that expected of a comparable plain air entrained concrete. Although some modifications are needed in mixing procedures for the concrete, the standard test methods and apparatus can be used to determine and control the quality of the concrete.

# IMPLEMENTATION

Fibrous concrete was determined to have a number of qualities that make it superior to normal concrete for a patching and overlay material. Although it was learned that the fibers resist the penetration of a shovel, raking and mechanical vibration can efficiently place the concrete. Curing is accomplished in the normal manner.

The concrete has excellent flexural strength very soon after final set because of the interlocking action of the fibers and mortar. With the use of Type III portland cement, the rate of hydration is increased to the point that traffic could be released in three days under normal conditions. The use of fly ash improves the plasticity of the fresh concrete and decreases the amount of drying shrinkage.

It was found that with some modification in the mix design, sequence of adding materials, and mixing procedure that quality fibrous concrete could be produced in the field. Some training of personnel in the handling of fibrous concrete is suggested before the actual field placement.

It is recommended that current standard design procedures be extended to include the use of fibrous concrete and to allow the use of fly ash as cementitious fines in structural concrete.

# I. SUBJECT

The incorporation of steel fiber material (Figs. 1, 2, 3 and 4) into portland cement concrete is a relatively new concept.[1] Recent studies[2] have investigated the use of fiberglass, nylon, steel, brass-coated steel, and other types of fiber. Many different shapes and lengths of these have been tried with varying degrees of success. Steel fibers were selected for the subject research as the most appropriate for highway patching and overlaying.

Research reports indicated that the addition of fly ash prevented the reduction in workability caused by fibers in the mix. An optimum amount was cited as three sacks of fly ash to five sacks of portland cement. This was the basis for the subject mix design.

It is obvious that the mix design, sequence of adding materials, and certain concreting techniques may differ from regular concrete production. But when properly designed, mixed and handled, the resulting concrete is giving excellent service in pilot tests. It is the unique problems encountered with this material and the special techniques required that are of primary interest to this investigation. Proper distribution of the fibers intermixed evenly with the aggregates and paste will give the qualities desired in hardened concrete. See Figure 5.

To provide the background leading to this study, the following pilot tests and projects using fibrous concrete are listed:

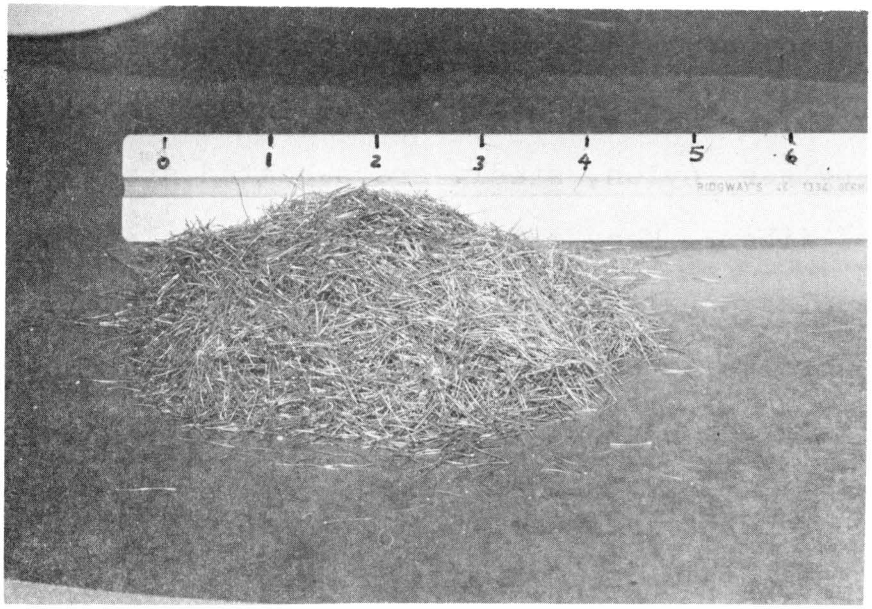


Figure 1 Steel fibers, 1 x 0.010 x 0.022-inch, are manufactured by United States Steel Corporation. These non-magnetized fibers are called "Fibercon."

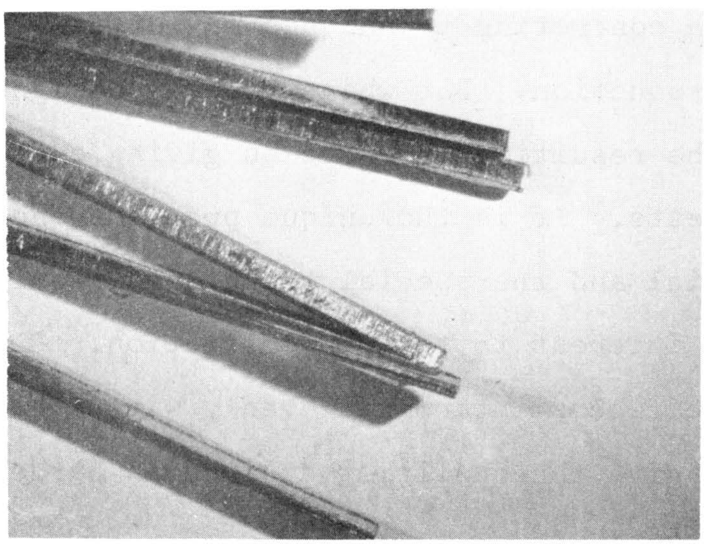

Figure 2 A close-up view of steel fibers showing a light roughness on the surfaces indicating a better bonding than a smooth surface. (Mag. 7.5X)

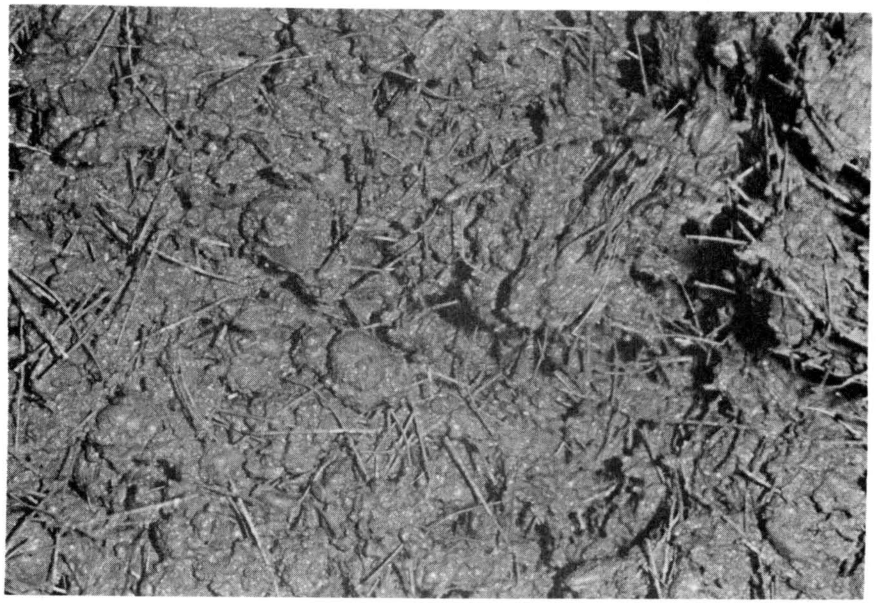

Figure 3 Plastic concrete with evenly distributed steel fibers. (3/4 actual size)

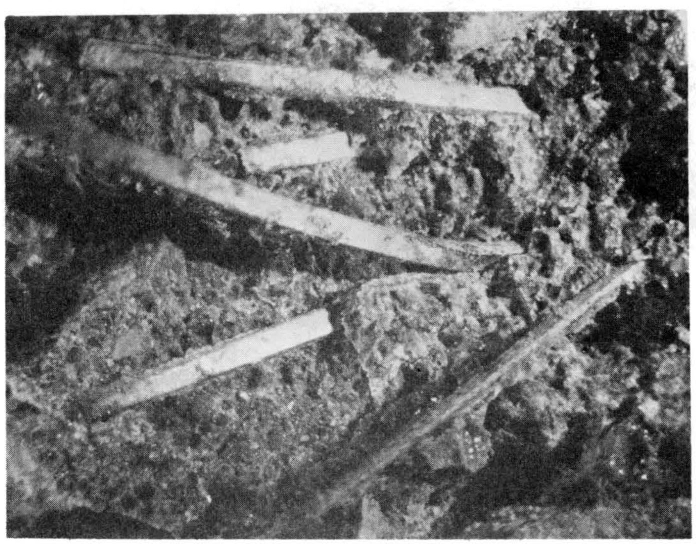

Figure 4 A close-up of the steel fibers in the concrete mixture. (Mag. 7.5X)

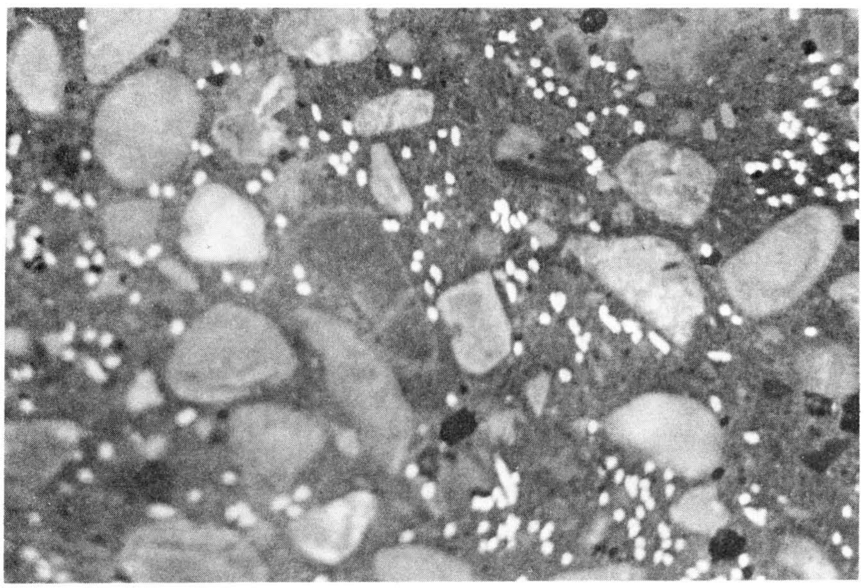

Figure 5 A cross section of a test beam specimen that shows a good distribution of steel fibers. (Mag. 1.5X)

A. The Construction Engineering Research Laboratory in Champaign, Illinois cosponsored with the U.S. Corps of Engineers a symposium in May 1972 on Fibrous Concrete. At this conference numerous research papers emphasized fibrous concrete as the construction material of the 1970's. The conference dealt with many types of fibers such as steel, glass, asbestos, etc.

B. The U.S. Army Construction Engineering Research Laboratory has achieved unprecedented results with steel fibrous concrete used in airfield paving. This organization found that the fibrous concrete withstood greater loads (using C5A Transport Aircraft) and a greater number of load applications, and exhibited far less damage than regular concrete twice the thickness.

C. The Federal Aviation Agency, the U.S. Corps of Engineers, and others sponsored an overlay on a taxiway at the Tampa International Airport. It appears to be very satisfactory.

D. The Ohio Department of Highways in 1971 placed a 500 by 16-foot by 4-inch steel fibrous concrete pavement section at the entrance to a truck weighing station near Ashland, Ohio. It appears to be holding up well.

E. Spalled areas on the main runway at O'Hare International Airport in Chicago have been repaired with steel fibrous concrete. After two years the patches appear to be in good shape.

F. Two-inch precast slabs were made of steel fibrous concrete for use in quick replacement of spalled areas in the Queens Midtown Tunnel in New York City. Spalled concrete areas were sawed out and prepared for the precast slab insertions. Traffic was permitted to use the roadway almost immediately. This repair has given satisfactory service.

G. In 1973 a large-scale test was made on an urban expressway in Detroit using a 3-inch thick steel fiber reinforced concrete on eastbound lanes carrying 100,000 vehicles per day. Traffic was put back on it in three days where there was flexural strength greater than 1000 psi.

H. In 1973 the Beaumont District of the Texas Highway Department made an overlay of approximately 100 feet on continuously reinforced concrete pavement on I-10 southwest of Beaumont. The CRCP had cracked badly under industrial and oil field traffic. Fibrous concrete was tried as a repair method. Reflective cracking came through the overlay after a period of time under traffic. Final analysis indicated that these cracks had faulted under loads caused by other factors. The fibrous concrete performed better than expected for this particular problem.(4)

## II. PURPOSE

The deterioration of bridge decks and failure of concrete pavements in high volume traffic areas have made speed of repair critical. Steel fiber reinforced concrete has shown in pilot tests that fast, efficient patching on overlays with this material will give durable concrete with high early flexural strengths and that normal traffic may be handled many days sooner than with regular concrete. Since use and acceptance of this material is increasing it may be specified in certain applications for Departmental work. The objective of this study was to explore the unique mixing, testing, and handling techniques that may be necessary and to offer technical assistance to field personnel in their pilot projects. Special conditions were tested to determine the effects of temperature variation on mixing, the use of lightweight aggregate versus hard rock, and the rusting of steel fibers on the job site.

## III. CONCLUSIONS AND RECOMMENDATIONS

The results of this study demonstrate that quality fibrous concrete can be produced and tested for controlled use on highway construction or maintenance projects. To utilize steel fibers in quality concrete it is necessary to determine the best type of fiber for the job and the optimum amount of each selected material. It is also necessary to control the material by standard procedures for quality assurance.

Following are specific conclusions drawn from experience with the particular concrete mix used in this study:

A. Trial batches of concrete indicated that the optimum amount of one-inch long steel fibers to use per cubic yard of concrete was 160 pounds.

B. Three sacks of fly ash could be used economically to replace three sacks of cement in the original design of eight sacks of cement per cubic yard of concrete. The fly ash gave increased workability to the mix.

C. Increased air entraining agent was needed to counteract the de-air entraining tendency of the carbon which is higher in fly ash than it is in cement.

D. Extra equipment was needed for safety purposes and to weigh and introduce the steel fibers into the dry aggregate feed.

E. Fibers dispersed well when mixed with dry aggregate, but tended to ball up when added to moist aggregate or when introduced to the wet mix.

F. High early strength was contributed by the steel fibers and not by the extra sacks of cementitious material.

G. Concrete mixes made at 85 F and mixes made with lightweight aggregate and mixes made with rusty steel fibers produced quality concrete.

It is recommended that the current standard design procedures be extended to include the use of fibrous concrete and allow use of fly ash as cementitious fines in structural concrete. Current procedures do not make provisions for the addition of steel fibers in concrete, and standard specifications preclude the use of significant quantities of fly ash in concrete. At the present time fly ash can be used only as a mineral filler to correct deficiencies in fine aggregate gradation.

The development of extra high strength concrete was not part of this study. With the innovations in refined fly ash and super water reducers that are now commercially available, basic research into these two new materials indicates that extra high strength concrete can be developed incorporating fly ash and steel fibers.

## IV. MATERIALS

The fibrous concrete used in this study was made of material that is available to concrete producers. Several steel manufacturers produce and market fibers for use in concrete. This study used one-inch long, rectangular shaped fibers packaged in forty-pound boxes. Other fiber shapes and lengths are commercially available in packaged or bulk lots.

Fly ash is available in bags or bulk form and is marketed in a manner similar to portland cement. Raw fly ash such as used in this study is purchased from companies using lignite coal in their power generating plants. There are approximately twenty-five such plants in Texas and the surrounding states.

The Type III high early strength cement, the concrete admixtures, the locally produced clean, well graded limestone-siliceous sand and pea gravel aggregate, and the expanded burnt shale lightweight aggregate are materials which are currently used on highway projects. These materials were stockpiled in large enough quantities to complete all the testing. The physical characteristics of these materials are shown in the Appendix "Materials Used in This Study," pages 29 - 31.

The steel fibers can be tested for tensile strength in a low-range testing machine. Yield strength and elongation measurements for high strength steel are dependent on measuring strain in the specimen during loading. The small size of the fiber makes these measurements very subjective and difficult.

There is a standard test method, ASTM C 618-73 "Fly Ash and Raw or Calcined Natural Pozzolans for Use in Portland Cement Concrete" for determining the desired quality of fly ash. The more significant chemical analyses are: the total silica, alumina and iron oxide content, the pozzolanic activity index with cement, the available alkalies and the carbon content (Loss on Ignition). Other tests such as fineness, soundness (autoclave) and drying shrinkage of mortar are also prescribed by this test method.

A combination of several of the above may effectively control the uniformity of fly ash. Care should be taken, though, as the quality of the product will vary at a particular plant to a notable degree. Further, the quality of fly ash from one plant to the next will differ greatly. In particular, the Fineness and Carbon Content will vary with the efficiency of the plant. The effect that variations in these characteristics have on the performance of concrete is not well known and should be the subject of further research. Fly ash with high carbon content acts as an air de-entraining agent. Normal dosages will have to be increased to get the desired entrained air in the hardened concrete.

## V. EQUIPMENT

Concrete Mixer: Gilson Model 3-1/2 - SH(non tilt type), 2 HP Electric Motor, Drum Speed - 16 RPM.

Molds: Compression Test: All Steel 6" x 12" diameter

Flexural Beam Test: All Steel 6" x 6" x 20"

Freeze-Thaw Test: All Steel 3" x 4" x 16"

Length Change Test: All Steel 3" x 3" x 11-1/4"

Compression Testing Machine: Baldwin Universal, Capacity 400,000 pounds

Beam Breaker Machine: Rainhart Series 416, Load Range 0 - 1000 psi. Tinius Olsen UEH 400,000-pound Testing Machine with third-point loading apparatus. Load range 1000 psi plus.

Freeze-Thaw Cabinet: Conrad/Missimer Model CB 70-705 with 7-1/2 ton cooling capacity at 3 hours per cycle.

Linear Traverse Apparatus: As described in Linear Traverse Method, ASTM C 457 "Microscopical Determination of Air-Void Content and Parameters of the Air-Void System in Hardened Concrete."

## VI. PROCEDURE FOR ACQUIRING DATA

The design and proportioning of the mixes were by the absolute volume method as outlined in the Departmental manual, Construction Bulletin C-11 (Rev. Nov. 1974). This was done to incorporate the steel fiber and fly ash into both the normal and lightweight concrete in a manner consistent with standard field practice. Since accuracy of this method depends on the accurate determination of physical properties of all of the materials used, each material was tested by a standard test method.

The absolute volume method of proportioning fibrous concrete with fly ash required two additional steps. The steel fiber volume (160 pounds or 0.327 cubic feet) was added to the coarse aggregate volume to find the volume of mortar. The volume of fly ash was based on an absolute volume of 0.507 cubic feet per one dry loose cubic foot (portland cement = 0.485). This volume was added to the volume of portland cement and used as the volume of cementitious material.

All the mixes used in this study contained eight sacks of cementitious material - five sacks of portland cement and three sacks of fly ash. Other constants were: six percent entrained air, coarse aggregate factor approximately 0.47, steel content 1.21 percent and water content approximately 5.4 gallons per sack of cementitious material. The "Standard Design Work Sheet" (page 31 in Appendix) was modified to accommodate the steel volume and the inclusion of fly ash as cementitious material. All minor batch corrections and changes were made on "Batching Work Sheet" (page 32 in Appendix).

The batches were mixed in a 3.5 cubic foot capacity drum mixer. Each batch was full size and was charged systematically to assure comparable results. The batch material was charged into the mixer by the following steps:

1. Introduce all weighed coarse and fine aggregate into the mixer.
2. With mixer going add all the fibers by hand (Fig. 6).
3. Add 70% of the mix water followed by the air-entraining agent diluted in 15% of the mix water - mix for two minutes.
4. Add cement and fly ash to mixer followed immediately by the chemical admixture (Type A or Type D) diluted in the final 15% of the mix water.
5. Mix for three minutes.
6. Stop mixer for three minutes (temperature of mix recorded).
7. Mix for two minutes.

The fresh concrete was then dumped into a large pan and the standard slump, air content (Pressure Method) and unit weight tests were performed (Figs. 7 and 8).

Test specimens for strength tests were then made using standard test methods. With the exception of tests using rusty fibers, three identical batches were mixed for each condition tested. This gave an average of three specimens for each test age. Only one specimen was made per test age for rusty fiber tests.

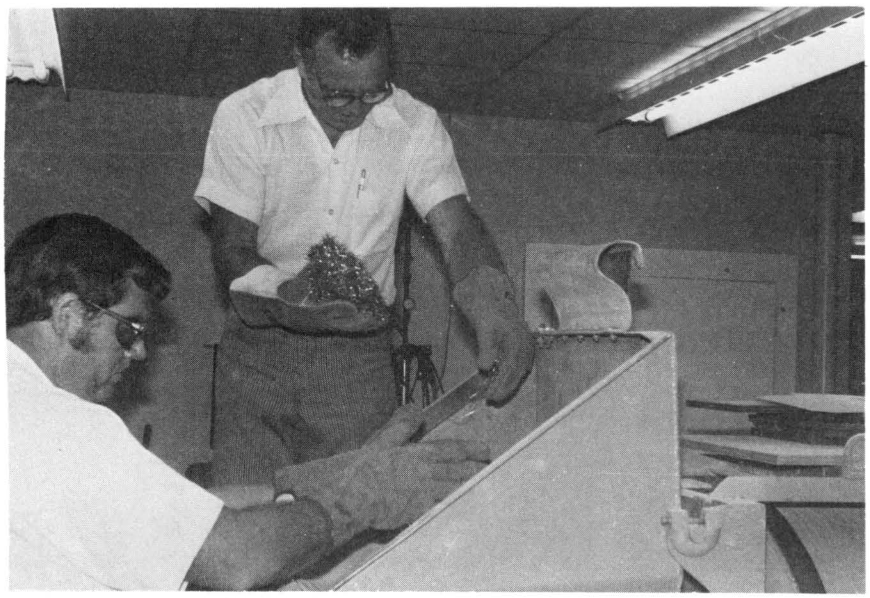

Figure 6 In the laboratory as well as on small patching jobs, fibers can be hand-sprinkled into the mix to prevent the balling effect. Protective leather gloves and goggles are worn to prevent injury during this operation.

Figure 7 The slump must be increased to provide workability so that the fibrous concrete can be removed from the mixer and placed and finished properly. No change in standard test procedure is needed for fibrous concrete.

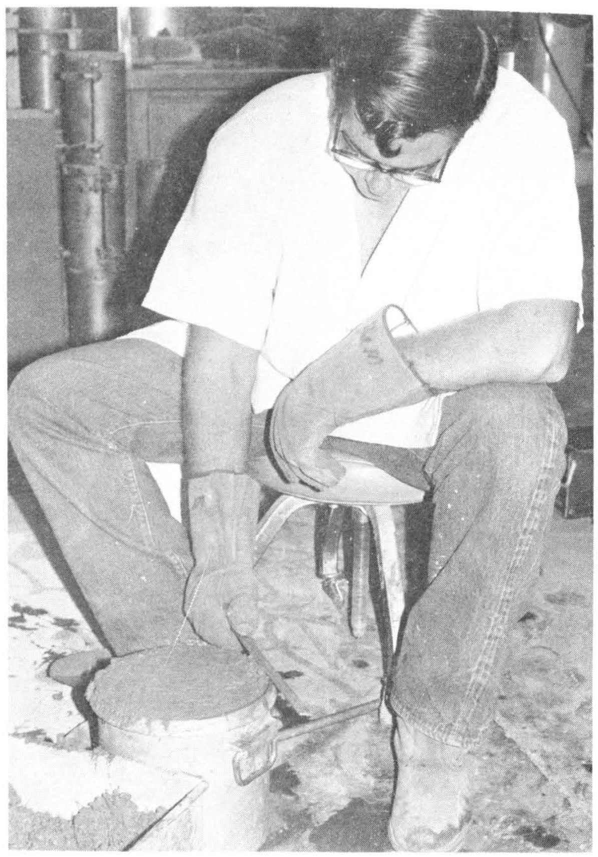

Figure 8 The unit weight and air content are tested by standard procedures. It was noted that wire fibers do flip off the edges during screeding, so safety precautions are necessary.

## VII. DISCUSSION

### A. Design

In order to develop a basic design for concrete tested in this study, reference was first made to work reported by researchers using steel fibers and fly ash in concrete.

Initial research[4] investigating fibrous concrete used a rich mortar to provide workability to mixes containing 350 pounds (approximately 2.5% by volume) of steel fibers per yard. Later research showed that greater strengths could be achieved with mixes containing 200 pounds (approximately 1.5% by volume) of steel fibers and limiting the portland cement to eight sacks per yard. Small size coarse aggregate was used to reduce the amount of sand in the mortar and it was found to add strength without loss of workability.

From that research an optimum amount of fly ash (three sacks of fly ash to five sacks of portland cement) was utilized satisfactorily and economically to replace a portion of the portland cement and yet achieve the strength required for quality concrete. The basic mix design of 200 pounds of steel fibers was tried in concrete made with sand and pea gravel. This design of 200 pounds of fibers per yard resulted in a spongy unworkable mix saturated with fibers.

Trial batches indicated that 160 pounds of one-inch long steel fibers was the optimum amount that could be used per cubic yard. This was the upper limit before the mix, using the particular material selected for this study, became too difficult to control.

The amount and quality of fly ash will cause mix water adjustments. However, once the amount of fly ash replacement is established and mix design is pilot tested, mix water adjustments should be no more of a problem than plain concrete control. The carbon content is currently limited to 12 percent by ASTM Specifications. This amount has a decided de-air entraining effect with the result that more air entraining admixture must be used. But again, once the dosage is established by trial mixes no more than normal variation should occur.

Type III portland cement was used because the generally envisioned application for fibrous concrete is a fast-setting repair operation. But this does not imply that Type I or Type II portland cement could not be used with steel fibers where high-early strength is not important.

B. Batching

One of the important findings of this study was that successful batching of fibrous concrete can be accomplished in a manner consistent with current field practice. Too many steel fibers or uneven distribution will cause the mix to have an interlocking effect and will give too much cohesiveness to the fresh concrete which interferes with its placement and finishing.

The introduction of steel fibers into the mixer does require extra equipment for weighing (if not in pre-weighed containers) and separating the fibers and delivering them to the mixer. The length of the fiber and the available batching equipment will determine the best type of fiber handling equipment to use for each job. Steel fibers batched with or onto dry aggregate in laboratory mixes dispersed uniformly and quickly even though some bulking of fibers occurred going into the drum mixer. It appears that wet aggregate, especially sand, having a free moisture content of more than one percent will inhibit dispersion of the fibers after they are in the mixer.

The extreme fineness of fly ash gives it a fluid-like consistency when it is dry. In order to contain fly ash in standard weighing hoppers, it is weighed on top of the cement in the cement hopper. This prevents leakage and utilizes existing equipment.

C. Testing

The testing procedures used in this study were the same as those used to proportion and test preliminary trial and pilot tests as outlined for field construction. Standard test methods for slump, air content, unit weight, and yield of fresh concrete were used to control the quality of concrete.

Trial batches made with too many fibers could not be tested properly because the concrete specimens could not be consolidated or finished in the molds. Although some of the strength test specimens developed good strength, companion specimens showed erratic results. Tests on the hardened concrete may present problems when the strengths of the fibrous concrete exceed the capacity of the testing machine. Standard beam breakers can only handle strengths up to 1000 psi. Certain design mixes of fibrous concrete may exceed this at 28 days.

The air content of the fresh fibrous concrete (Pressure Method) was compared to the air-void content of the same concrete after it had hardened (Linear Traverse Method). The air content values determined by the two methods were very close to being the same in each specimen. The spacing factors of the air-void system in each case, 0.008 for natural aggregate fibrous concrete, are considered adequate for concrete resistant to freeze-thaw damage. Results of these tests are shown in "The Concrete Test Data" in the Appendix.

The high early strengths indicated by beam tests are the result of the reinforcing action of the fibers and not the extra cement. See Figs. 9 and 10. The extra three sacks of cement are put in for better workability, so it is more economical to replace these three sacks with fly ash. Fly ash will give the initial workability needed for mixing and will contribute some strength through normal pozzolanic action.

D. Experience

In mixing, placing, finishing, curing, and testing fibrous concrete, there is a significant difference in procedures, observations, and patterns of test results from those of regular concrete. Personnel who are working with fibrous concrete for the first time should take note of the following differences:

1. There is a need for greater slump with fibrous concrete in order to get workability and satisfactory placement. A four-inch slump is the generally accepted value.

2. Fibrous concrete has a spongy consistency when being mixed, handled, and placed and will resist shearing and movement. It is difficult to push a shovel into the plastic mix. Yet it can be raked into place more easily than regular concrete. Mechanical

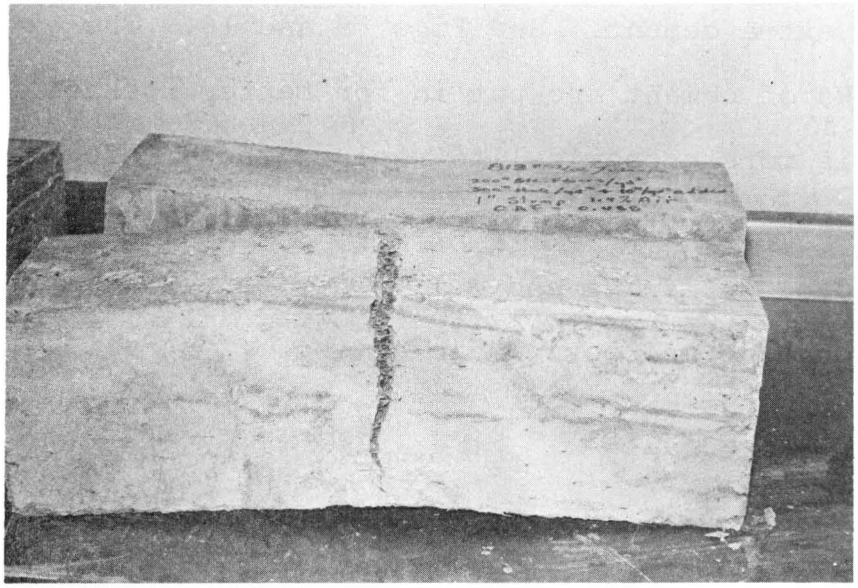

Figure 9 A fibrous concrete beam after being tested to failure. Sudden failure does not occur in fibrous concrete due to the bond between the fibers and concrete.

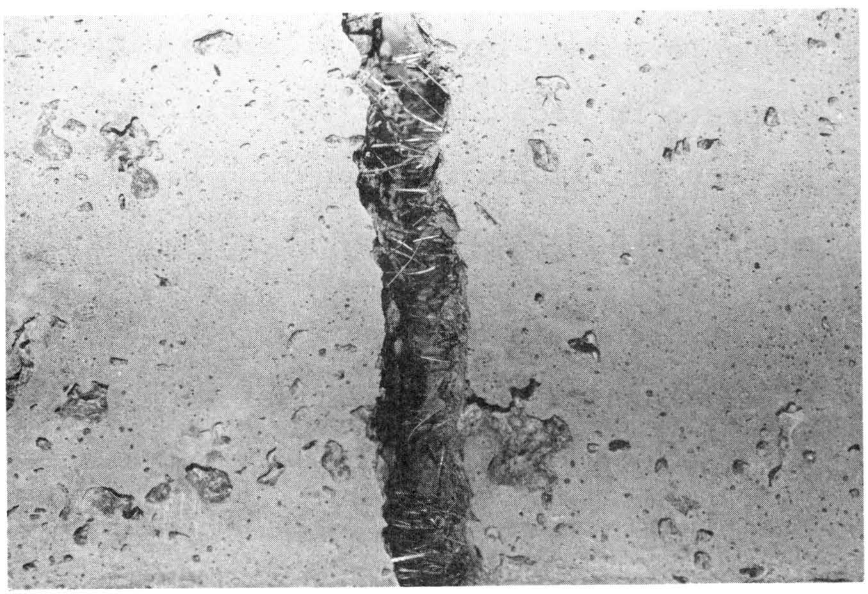

Figure 10 A close-up of the fracture in the fibrous concrete beam. These fibers held the crack closed until additional load was applied to break the bond.

vibration aids in movement of this concrete and makes it workable. Workmen in rubber boots can walk on the concrete to help consolidate it.

3. The balling of the steel fibers is the major problem in mixing operations (Figs. 11 and 12). Dumping the fibers directly into the mixer from either boxes or drums will result in these undesirable balls. The fibers ball up and are impossible to separate by mechanical mixing. The fibers must be separated (fluffed up) prior to entering the mixer. This has been done by hand-shaking the fibers onto a board that slides them into the mix at a steady rate. Fibers may be shaken into a grizzly (Fig. 13), picked up on a conveyer belt and fed onto the regular materials conveyer belt prior to entering the central mixer. This proved very successful on an M-60 Tank parking lot at Ft. Hood, Texas.[5]

   Some success was obtained in laboratory mixing using a Gilson Drum Mixer in which loosely packed fibers were dumped into the skip of the mixer. There was a breaking action in the mixer that achieved a good distribution of fibers. After extended mixing a fairly uniform concrete was obtained. This is not recommended for field construction.

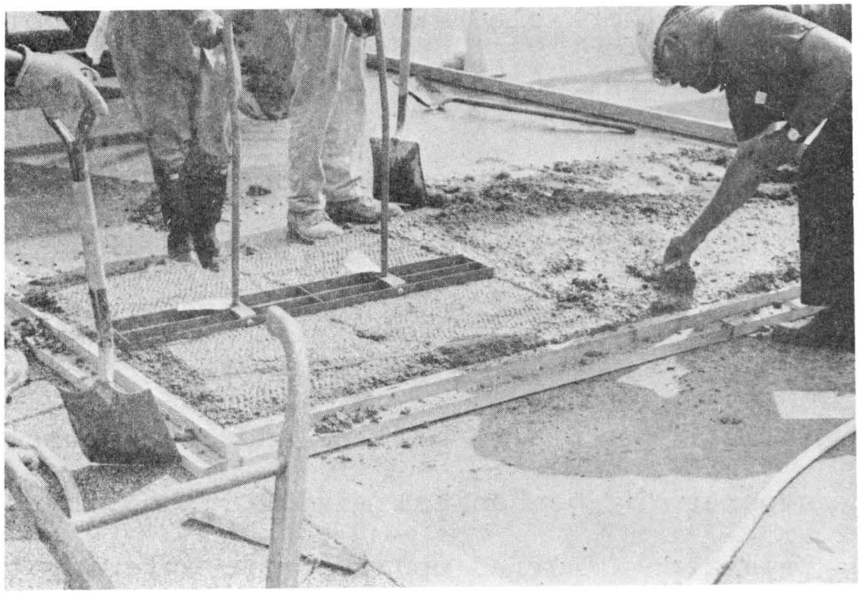

Figure 11 At the initial start up of the overlay on I-10 near Beaumont, fiber balls could not be broken up with shovel or mechanical vibrators, so the workmen had to hand remove the individual balls.

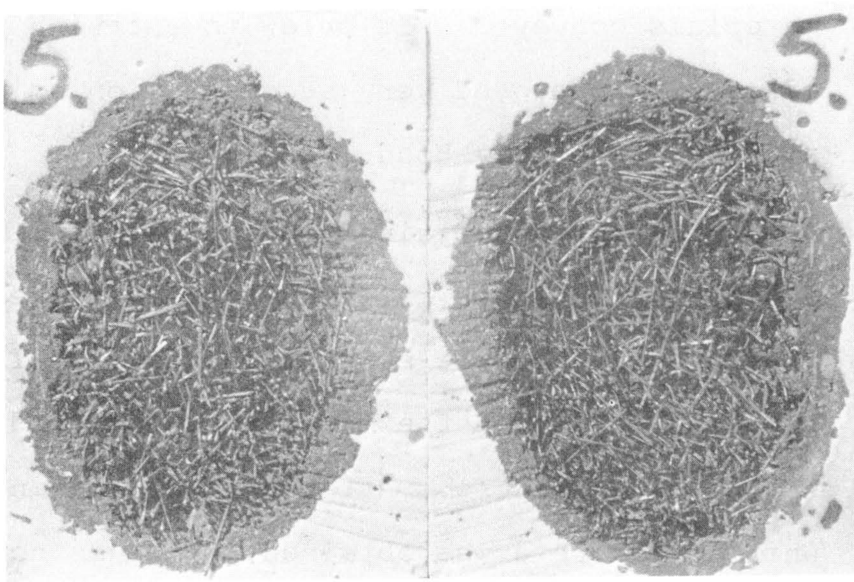


Figure 12 A fibrous ball, removed from the Beaumont job, was cast in plaster and then sawed in half. This shows the balling effect where some of the mortar and aggregate have penetrated the outer fringes of the ball. The interior is void of any mortar.

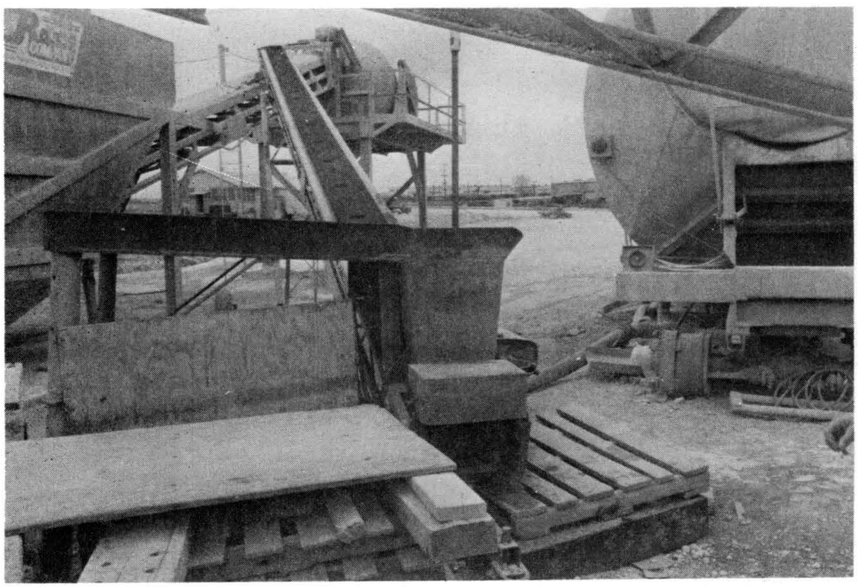

Figure 13 This is the Grizzly used for induction of fibers at the Ft. Hood Project. Boxes were broken on the platform and then fed into the vibrating Grizzly separating the fibers. Fibers fell onto a belt feed that deposited the fibers on top of the fly ash, cement, and aggregates on the regular material belt feed to the mixer.

4. Extra caution is needed in mixing, placing and finishing fibrous concrete. The steel fibers are needle-like and will stick through anything other than heavy duty (leather) gloves and hard rubber boots. In handling and finishing concrete, the steel fibers can flip or spring out of the plastic concrete. Safety goggles should be required for all personnel working around fibrous concrete.

5. The purpose of the trial use of slightly rusty fiber was to simulate field storage. It was desired to know if light rust would be a cause for rejection. From this work it was determined that the rusty fibers were harder to shake apart, but no harmful effects were noted in the hardened concrete.

6. Mixes containing lightweight aggregates for improved skid resistance concrete were produced with no loss in quality.

7. Quality fibrous concrete was produced at an elevated temperature (85 F) with satisfactory workability, strength and durability as compared with concrete made at 73 F.

## REFERENCES

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2. Highway Focus, U. S. Department of Transportation, Federal Highway Administration, Washington, D. C., Vol 4, No. 5, October 1972.

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4. Highway Focus, U. S. Department of Transportation, Federal Highway Administration, Washington, D. C., Vol 4, No. 5, October 1972, pp 22-35.

5. American Concrete Paving Association, "Fibrous Concrete Overlay on Army Tank Pad," ACPA Newsletter, Vol 10, No. 6, June 1974.

APPENDIX

MATERIALS USED IN THIS STUDY

A. Cement: Type III ASTM C 150

Material Characteristics: Specific Gravity = 3.10

Specific Surface Area = 2520 $cm^2$/gr

Normal Consistency = 26.0%

Producer: San Antonio Portland Cement Company

B. Fly Ash Class F ASTM C 618-73

Material Characteristics: Specific Gravity = 2.42

Amount Retained on #325 Sieve = 49.2%

Loss on Ignition = 7.11%

Moisture Content = 0.8%

Dry Loose Unit Weight = 76.67 #/cu ft

Producer: Aluminum Company of America, Rockdale, Texas

C. Steel Fibers: USS Fibercon Steel

Material Characteristics: Size 0.010" x 0.022" x 1.0"

Specific Gravity = 7.85

Tensile Strength = 93,600 psi

Producer: United States Steel Corporation, Pittsburgh, Pa.

D. Aggregate: ASTM C 33

Fine Aggregate (Limestone and Siliceous Sand)

Material Characteristics: Specific Gravity = 2.60

Unit Weight SSD = 102.13#/cu ft

Solids = 62.8%

Absorption = 1.0%

Sand Equivalent Value = 93

Gradation =
Sieve Size #4 Retained 0%

Size #8 Retained 5.9%

Size #16 Retained 26.7%

Size #30 Retained 53.8%

Size #50 Retained 83.1%

Size #100 Retained 93.9%

Fineness Modulus = 2.63

Mortar Tensile Strength = 107% of Standard

Producer: Capitol Aggregates, Inc., Austin, Texas

Normal Weight Coarse Aggregate (Limestone and Siliceous Gravel)

Material Characteristics: Specific Gravity = 2.58

Unit Weight SSO = 99.83#/cu ft

Solids = 61.9%

Absorption = 1.6%

Gradation =
Size 1/2" Retained 0%

Size 3/8" Retained 15.3%

Size #4 Retained 98.5%

Soundness $MgSO_4$ = 10.2%

$Na_2SO_4$ = 3.9%

L.A. Abrasion = 24 (Type C)

Producer: Capitol Aggregates, Inc., Austin, Texas

Lightweight Coarse Aggregate (Expanded Burnt Clay)

Material Characteristics: Specific Gravity = 1.57

Unit Weight = 52.77 #/cu ft

Solids = 58.52%

Absorption = 7.3%

Gradation =
Size 1/2" Retained 2.1%

Size 3/8" Retained 47.8%

Size #4 Retained 97.1%

Producer: Featherlite Corp., Ranger, Texas

E. Admixtures (ASTM C 260 and C 494)

Air Entraining Agent: Darex AEA (Old Formulation)

Type A Water Reducer: WRDA with HYCOL

Type D Water Reducer-Set Retarder: Daratard 40

Producer: W. R. Grace & Co., Cambridge, Mass.

Example
FIBROUS CONCRETE DESIGN WORK SHEET

| Design Constants: | Batch I.D.: NA-1, 2 & 3 |
|---|---|
| Cement Volume (C.V.) = 5 sks/yd | Date: 9-16-74 |
| Fly Ash Volume (F.A.V.) = 3 loose $ft^3$/yd | C.A.F.: 0.46 |
| Slump = 3" ± 1" | Water Factor (W.F.): 37.21 Gal/Cu. Yd. |
| Air Content = 6.0 ± 1.5% | AEA Dosage: 9.3 oz/100# Cmt. Mat. |
| Concrete Temp. = 73 ± 3 F | Type A Dosage: 5.0 oz/100# Cmt. Mat. |
| Ambient Temp. = 73 ± 3 F | Type D Dosage: - oz/100# Cmt. Mat |

| Material Characteristics: | Sp. Gr. | S.S.D. Unit Wt. | Solids | Abs. |
|---|---|---|---|---|
| Coarse Aggregate | 2.58 | 99.83 | 61.9% | 1.6% |
| Fine Aggregate | 2.60 | 102.13 | 62.8% | 1.0% |
| Fly Ash | 2.42 | 76.67 | | |
| Steel Fiber | 7.85 | 490.0 | | |

| Design Volumes | ($27\ ft^3$) | | 62.5xSP.GR. | Design Wts. ($27 ft^3$) |
|---|---|---|---|---|
| 1. Volume of Coarse Aggregate 27xC.A.FxSolids | 27x 0.46x0.619 | 7.688 | x62.5x2.58 | 1240 |
| 2. Volume of Steel Fibers $\frac{\text{Steel Wt.}}{\text{Unit Wt. Steel}}$ | $\frac{160}{490}$ | 0.327 | x62.5x7.85 | 160 |
| 3. Volume of Mortar 27-C.A.-Steel | 27-7.688-0.327 = 18.985 | | | |
| 4. Volume of Water $\frac{\text{W.F.}}{\text{Gal./Cu.Ft.}}$ | $\frac{37.21}{7.5}$ | 4.961 | x62.5 | 310 |
| 5. Volume Cementitious Material C.V.xAbsolute Vol./Sk.Cmt. | 5x0.485 | 2.425 | x62.5x3.10 | 470 |
| Loose Cu.Ft. Fly Ash x Absolute Vol/Loose Cu.Ft. | 3x0.507 | 1.521 | x62.5x2.42 | 230 |
| 6. Volume of Air Air Factorx27 | 0.06x27 | 1.620 | | |
| 7. Volume of Fine Aggregate Mortar Volume - (Vol. C.M. + Vol. Air + Vol. Water) | 2.425 +1.521 +1.620 = 5.566 +4.961 = 10.527; 18.985- 10.527 | 8.458 | x62.5x2.60 | 1374 |
| | Total Volume | 27.00 | | |

Example
BATCHING WORK SHEET

BATCH I.D. NA-1, 2 & 3 DATE 9-16-74

| ADMIXTURES | DOSAGE RATES | | BATCH DOSAGES |
|---|---|---|---|
| Darex AEA | 9.3 | oz/100 lbs Cmt Mat x 7 x .13 lbs x 29.57 cc/oz = | 250.3 cc |
| WRDA/HYCOL | 5.0 | oz/100 lbs Cmt Mat x 7 x .13 lbs x 29.57 cc/oz = | 134.5 cc |

| AGGREGATE CORRECTION FACTORS: | Fine Aggregate | 3/8 | #4 |
|---|---|---|---|
| Moisture Content (M) | 0.014 | 0.000 | 0.000 |
| Absorption Factor (A) | 0.010 | 0.016 | 0.016 |
| Correction Factor 1 + M - A | 1.004 | 0.984 | 0.984 |

| BATCH WEIGHTS: | 27 ft$^3$ Wts SSD | Batch Factor | Batch Wts SSD |
|---|---|---|---|
| Coarse Aggr. | 1240 | 0.13 | 161.20 |
| Fine Aggr. | 1374 | 0.13 | 178.62 |
| Cement | 470 | 0.13 | 61.10 |
| Fly Ash | 230 | 0.13 | 29.90 |
| Steel Fiber | 160 | 0.13 | 20.80 |
| Water | 310 | 0.13 | 40.30 |

BATCH FACTOR

$$= \frac{3.51\ ft^3}{27\ ft^3}$$

$= 0.13$

| | Batch Wt SSD | Correction Factor | | Gradation Factor | Batch Wt | Pan Wt | Gross Wt |
|---|---|---|---|---|---|---|---|
| Coarse Aggr. | 161.20 | 3/8 | 0.984 | 0.25 | 39.66 | 8.00 | 47.66 |
| | | #4 | 0.984 | 0.25 x 3 | 39.66 x 3 | 8.00 | 47.66 x 3 |
| Fine Aggr. | 178.62 | 1.004 | | 0.25 x 4 | 44.83 x 4 | 8.00 | 52.82 x 4 |

Aggr. Total SSD Wt - Total Batch Wt Water Correction + Design Water = Total Water
339.82 - 337.95 + 1.87 + 40.30 = 42.17

| | Batch Wt SSD | | | Batch Wt | Pan Wt | Gross Wt |
|---|---|---|---|---|---|---|
| Cement | 61.10 | 0.50 x 2 | | 30.55 x 2 | 8.00 | 38.55 x 2 |
| Fly Ash | 29.90 | | | 29.90 | 8.00 | 37.90 |
| Steel Fiber | 20.80 | | | 20.80 | 8.00 | 28.80 |
| Total Water | 42.17 | 0.70 | Initial | 29.52 | 5.15 | 34.67 |
| | | 0.15 | Dil. AEA | 6.33 | 0.21 | 6.54 |
| | | 0.15 | Dil. Admix. | 6.32 | 0.21 | 6.53 |

| Batch No. | Room Temp. | Concrete Temp. | Slump | Air Content | Wet Wt | Tare Wt | Vol. | Unit Wt |
|---|---|---|---|---|---|---|---|---|
| NA-1 | 75 F | 74 F | 2-1/4 | 4.1 | 98.88 | 27.61 | 0.500 | 142.54 |
| NA-2 | 74 F | 73 F | 2-1/4 | 5.6 | 97.80 | 27.61 | 0.500 | 140.38 |
| NA-3 | 75 F | 72 F | 2-3/4 | 5.4 ) | 98.02 | 27.61 | 0.500 | 140.82 |
| | | | | | | | | |

CONCRETE DESIGN VOLUMES PER CUBIC YARD

CEMENT = 2.425 $Ft^3$: FLY ASH = 1.521 $Ft^3$: STEEL FIBER = 0.327 $Ft^3$

ENTRAINED AIR = 1.620 $Ft^3$

| | WATER $Ft^3$ | PASTE $Ft^3$ | SAND $Ft^3$ | MORTAR $Ft^3$ | COARSE AGGREGATE $Ft^3$ |
|---|---|---|---|---|---|
| NORMAL WEIGHT CONCRETE | | | | | |
| MIX #1 | 4.961 | 10.527 | 8.458 | 18.985 | 7.688 |
| MIX #2 | 4.880 | 10.445 | 8.539 | 18.985 | 7.688 |
| NORMAL WEIGHT CONCRETE (Mixed at 85 F) | | | | | |
| MIX #3 | 5.165 | 10.731 | 8.240 | 18.971 | 7.702 |
| MIX #4 | 5.013 | 10.579 | 8.406 | 18.985 | 7.688 |
| NORMAL WEIGHT CONCRETE (Rusty Steel Fibers) | | | | | |
| MIX #5 | 4.961 | 10.527 | 8.458 | 18.985 | 7.688 |
| MIX #6 | 4.880 | 10.446 | 8.539 | 18.985 | 7.688 |
| LIGHTWEIGHT CONCRETE | | | | | |
| MIX #7 | 5.842 | 11.408 | 7.840 | 19.332 | 7.425 |
| MIX #8 | 5.491 | 11.057 | 7.964 | 19.021 | 7.652 |
| LIGHTWEIGHT CONCRETE (Mixed at 85 F) | | | | | |
| MIX #9 | 5.842 | 11.407 | 7.840 | 19.248 | 7.425 |
| MIX #10 | 5.520 | 11.134 | 7.887 | 19.021 | 7.652 |

## CONCRETE DESIGN WEIGHTS PER CUBIC YARD

CEMENT = 470 lbs.: FLYASH = 230 lbs.: STEEL FIBER = 160 lbs.

| | WATER lbs. | AGGREGATES lbs. FINE | COARSE | ADMIXTURES OZ./SK. TYPE-A | TYPE-D | AEA |
|---|---|---|---|---|---|---|
| NORMAL WEIGHT CONCRETE | | | | | | |
| MIX #1 | 310 | 1374 | 1240 | 5.0 | | 9.3 |
| MIX #2 | 305 | 1388 | 1240 | | 7.0 | 9.3 |
| NORMAL WEIGHT CONCRETE (Mixed at 85°F) | | | | | | |
| MIX #3 | 323 | 1336 | 1240 | 5.0 | | 11.5 |
| MIX #4 | 313 | 1366 | 1240 | | 7.0 | 10.5 |
| NORMAL WEIGHT CONCRETE (Rusty Steel Fibers) | | | | | | |
| MIX #5 | 310 | 1375 | 1240 | 5.0 | | 9.3 |
| MIX #6 | 305 | 1388 | 1240 | | 7.0 | 9.3 |
| LIGHTWEIGHT CONCRETE | | | | | | |
| MIX #7 | 365 | 1288 | 719 | 5.0 | | 10.5 |
| MIX #8 | 343 | 1288 | 741 | | 7.0 | 12.3 |
| LIGHTWEIGHT CONCRETE (Mixed at 85°F) | | | | | | |
| MIX #9 | 365 | 1288 | 719 | 5.0 | | 12.7 |
| MIX #10 | 366 | 1282 | 741 | | 7.0 | 14.2 |

## CONCRETE TEST DATA

### FRESH CONCRETE TEST

| | SLUMP in. | % AIR | UNIT WEIGHT lbs./cu.ft. |
|---|---|---|---|
| NORMAL WEIGHT CONCRETE | | | |
| MIX #1 | 2.50 | 5.0 | 141.3 |
| MIX #2 | 3.00 | 5.4 | 140.9 |
| NORMAL WEIGHT CONCRETE (Mixed at 85°F) | | | |
| MIX #3 | 3.75 | 5.4 | 140.6 |
| MIX #4 | 2.75 | 5.8 | 140.0 |
| NORMAL WEIGHT CONCRETE (Rusty Steel Fibers) | | | |
| MIX #5 | 2.25 | 7.1 | 138.3 |
| MIX #6 | 2.50 | 5.8 | 141.1 |
| LIGHTWEIGHT CONCRETE | | | |
| MIX #7 | 3.50 | 4.7 | 122.5 |
| MIX #8 | 3.25 | 5.0 | 122.9 |
| LIGHTWEIGHT CONCRETE (Mixed at 85°F) | | | |
| MIX #9 | 3.75 | 5.3 | 119.7 |
| MIX #10 | 3.00 | 5.0 | 122.8 |

CONCRETE TEST DATA

COMPRESSIVE STRENGTH TESTS

| | | STRENGTH in PSI | | | | |
|---|---|---|---|---|---|---|
| NORMAL WEIGHT CONCRETE | AGE: | 3 DAYS | 7 DAYS | 28 DAYS | 6 MONTHS | 1 YEAR |
| MIX #1 | | 4060 | 4460 | 5210 | 7160 | 7620 |
| MIX #2 | | 3980 | 4740 | 5750 | 7440 | 7860 |
| NORMAL WEIGHT CONCRETE (Mixed at 85°F) | | | | | | |
| MIX #3 | | 3840 | - - | 5040 | 6630 | 7150 |
| MIX #4 | | 3870 | - - | 5510 | 6920 | 7200 |
| NORMAL WEIGHT CONCRETE (Rusty Steel Fibers) | | | | | | |
| MIX #5 | | 3650 | 4020 | 4950 | 6360 | 6900 |
| MIX #6 | | 4070 | 4750 | 5720 | 7610 | 7850 |
| LIGHTWEIGHT CONCRETE | | | | | | |
| MIX #7 | | 3700 | 4190 | 5130 | 7180 | 7800 |
| MIX #8 | | 3980 | 4740 | 5830 | 7930 | 8460 |
| LIGHTWEIGHT CONCRETE (Mixed at 85°F) | | | | | | |
| MIX #9 | | 3480 | - - | 5070 | 6760 | 7360 |
| MIX #10 | | 3850 | - - | 5880 | 7750 | 8390 |

CONCRETE TEST DATA

FLEXURAL STRENGTH TESTS

| | AGE: | STRENGTH in PSI<br>7 DAYS | 28 DAYS | 6 MONTHS | 1 YEAR |
|---|---|---|---|---|---|
| NORMAL WEIGHT CONCRETE | | | | | |
| MIX #1 | | 690 | 710 | 810 | -- |
| MIX #2 | | 660 | 750 | 850 | 920 |
| NORMAL WEIGHT CONCRETE (Mixed at 85°F) | | | | | |
| MIX #3 | | 680 | 770 | 960 | 909 |
| MIX #4 | | 660 | 750 | 840 | 940 |
| NORMAL WEIGHT CONCRETE (Rusty Steel Fibers) | | | | | |
| MIX #5 | | 520 | 650 | 840 | 840 |
| MIX #6 | | 650 | 740 | 890 | 910 |
| LIGHTWEIGHT CONCRETE | | | | | |
| MIX #7 | | 580 | 650 | 760 | 777 |
| MIX #8 | | 660 | 750 | 810 | 814 |
| LIGHTWEIGHT CONCRETE (Mixed at 85°F) | | | | | |
| MIX #9 | | 540 | 680 | 805 | 800 |
| MIX #10 | | 620 | 730 | 860 | 870 |

## CONCRETE TEST DATA

### LENGTH CHANGE AND FREEZE-THAW DURABILITY

| | LENGTH CHANGE % | DURABILITY FACTOR |
|---|---|---|
| NORMAL WEIGHT CONCRETE | | |
| MIX #1 | 0.039 | 56.8 |
| MIX #2 | 0.029 | 60.9 |
| NORMAL WEIGHT CONCRETE (Rusty Steel Fibers) | | |
| MIX #5 | 0.027 | 62.9 |
| MIX #6 | 0.022 | 57.8 |
| LIGHTWEIGHT CONCRETE | | |
| MIX #7 | 0.017 | 55.0 |
| MIX #8 | 0.021 | 59.3 |

CONCRETE TEST DATA

HARDENED CONCRETE (LINEAR TRAVERSE)

| SAMPLE # | AIR CONTENT(%) | PASTE CONTENT(%) | AGGREGATE CONTENT(%) | SURFACE AREA $IN^2/IN^3$ | SPACING FACTOR(IN) |
|---|---|---|---|---|---|
| Mix #1 | 5.5 | 37.1 | 57.4 | 805 | .007 |
| Mix #2 | 5.3 | 35.8 | 58.9 | 669 | .008 |
| Mix #7 | 4.8 | 40.1 | 55.1 | 1161 | .005 |
| Mix #8 | 4.8 | 33.5 | 61.7 | 1140 | .005 |

Steel Fibers were included as Aggregate. Fly Ash particles (glassy spheres) were included with Paste.