Paper Engineering Senior Theses

Chemical and Paper Engineering

2-1962

# The Rate of Weakening of Paper Due to an Applied Stress

Emmett F. Finley
*Western Michigan University*

THE RATE OF WEAKENING OF PAPER DUE TO AN
APPLIED STRESS


A Thesis submitted by

Emmett F. Finley


in partial fulfillment of the requirements
of Course No. 570, Research Problems in
Pulp and Paper


February, 1962

186395

## TABLE OF CONTENTS

# INTRODUCTION

When a load is applied to a sheet of paper, the paper may break immediately or it may support the load for some period of time. It is recognized that the paper, while under a stress less than that required to cause immediate break, is weakened until it is finally unable to support the stress. Since in the normal use of paper the stress to which paper is subjected is less than that needed to cause immediate break this weakening is an important factor in many cases.

A few examples of such cases are the winding of the paper onto the reel of the paper machine during manufacture, the use of paper in bags, and possibly most important of all the running of paper through a printing press.

Since approximately 90 per cent of all paper is printed by some means or another, and during the printing process the paper is subjected to stresses, the subject of weakening while under stress is very important. Should the paper be weakened to the breaking point in the printing operation, many costly shutdowns and wastes of materials could result.

### FACTORS CONTRIBUTING TO PAPER STRENGTH

Paper strength is a vague term and is meaningless if not accompanied by an understanding of the particular strength property desired and a means of determining this property.

Paper strength is dependent upon many factors, some of which are better understood than others, and are believed to contribute more than others. The factors considered to be the most important to paper strength are: (1) the strength of the fibers of which the sheet is made, (2) the strength of the fiber-to-fiber bonds, (3) the number of bonds, and (4) the formation of the sheet.

Casey(1) claims that fiber-to-fiber bonding is the most important single factor affecting the strength of paper and that deficiencies in the strength of paper must be attributed to deficiencies in bonding, and not to a lack of intrinsic fiber strength. Forman (2) says that the total bonded area and the strength of the fiber-to-fiber bonds are major contributors to the strength of a sheet of paper.

Van den Akker, Lathrop, Voelker, and Dearth (3) have shown that fiber strength is not unimportant in sheet strength. It was found by them that fiber strength has a very significant influence in sheet strength. In their investigation of the relative importance of fiber failure and bond breaking in sheet failure, they found that by using a technique of tagging

(dying) a small fraction of the fibers making up the paper it could be shown that a substantial percentage of the tagged fibers were broken or pulled apart during tensile failure of the paper even when the degree of beating was moderate.

Ratliff (4) postulates that, at least during the early stages of beating, the amount of fiber bonding fairly well determines the sheet strength. As the total strength of the fiber bonding approaches the strength of the fibers themselves, fiber strength may increasingly become the limiting factor. He believes that other limiting factors may be the specific strength of the fiber bonds and increased concentration of stresses at weaker spots as fiber bonding is increased.

The degree of bonding which is present between fibers in a sheet of paper is dependent upon a great number of factors. Among these are the nature of the fiber surface and the way in which the fibers have been formed into the sheet. The area of the fibers in contact and the number of bonds formed is a result of the formation of the sheet. The treatment which the fibers receive in beating shows an effect upon the degree of bonding because of the effect of fiber surface and the flex-ibility of the fiber.

Emerton (5) believes that the flexing of the fibers which takes place during beating breaks bonds within the fiber and makes it more flexible. This flexibility is termed conformab-ility and allows a fiber to bond with other fibers. Thode

and Ingmanson (6) believe that this flexibility gives less fiber damage and therefore results in a more efficient beating operation.

Casey (1) says that in the beating operation one of the first things which may be accomplished is the rupture and partial removal of the primary wall, thereby exposing the secondary wall of the fiber. Once this is accomplished, the bruising and rubbing action of the beater causes the fibers to fray out into fine fibrils which increases the amount of exposed surface area of the fibers, and at the same time makes the fibers increasingly flexible. The increased specific surface obtained increases the magnitude of the surface tension forces drawing the fibers together and also makes it possible for an increased area of fiber surface to come into contact during sheet formation, thereby increasing the adhesion between fibers.

Nissan (7) claims that the ultimate effect of the beating operation on fiber bonding is to (1) rearrange the bonds from within the fibers to bonds between them, and (2) to increase the number of bonds per unit volume, or compact the paper, while the total number of bonds per unit mass is not materially affected.

Forman (2) points out that on beating a pulp, the fiber area may be increased by fibrillation, hydration, and cutting, and the bonded area in a sheet therefore tends to increase as

the surface area of the pulp increases.

Ingmanson and Thode (8) believe that the "total" area available for bonding is not determined by the specific surface developed, but is a constant which is determined only by the surface area of the original unbeaten fibers. They believe that the fibrils on the surface of the fibers and the fines generated by beating are bonded back to the surface of the fibers, and therefore their area is not available for bonding.

Casey (1) suggests that fiber flexibility is increased by reduced lignin content, increased fiber length, as well as by increased beating. Ratliff (4) found that kraft pulps which were delignified with chlorite exhibited greater strength at a range of 40-50 per cent yield and that an increase in strength was came about as the yield lessened from 50 to 42 per cent. Keeney (9) found that the specific bonding strength (bonding strength divided by the percentage bonded area) increased as the lignin was removed in a semichemical kraft pulp.

Casey (1) believes that fiber length does not have a great effect upon fiber bonding, but fiber length is a property to be considered, because after a maximum of fiber bonding has taken place, the strength of paper depends principally upon the length of its component fibers.

McDonnell (10) states that inter-fiber bonding strength of paper is improved by bleaching because of the increased

surface area, possible better fiber flexibility, and increased
efficiency of utilization of the available surface area which
resulted from exposing better bonding surfaces. It was shown
in this study that in a particular system, the level of strength
is defined by the balance between bonding and fiber strength,
but the maximum achievable strength is limited by whichever of
the two factors is the weaker, relative to the other.

When dealing with the total bonding strength it must be
realized that this strength is dependent upon the bonded area,
the strength of the bonds, and the way in which these factors
are distributed (11). In measuring bonded areas difficulty
arises and the most recent discussions of this measurement have
been done by Ingmanson and Thode (8) and by Swanson and
Steber (12).

Parsons (13) made use of the specific surface measurement
and the Kubelka and Munk equation in the determination of the
area of optical contact. Ratliff (4) showed that the area of
optical contact is a function, not a direct measure, of the
area of fiber-to-fiber bonding.

One of the first methods suggested for the measurement of
bonding strength in a sheet of paper was that of Hoffman-
Jacobsen (14). This suggested method was concerned with the
ratio of ordinary tensile strength to zero-span tensile
strength.

Van den Akker (15) suggests that bonded area contributes to sheet strength but may depend upon the internal structure of the bond. In this investigation, the stress applied to a sheet in a direction parallel to the plane of the sheet is mentioned and it is hypothesized that in a typical well-bonded sheet the individual fiber-to-fiber bonds are subjected to simple shear forces when this is carried out.

Ratliff (4) suggests that the hemicelluloses in pulp manifest their effects upon pulp properties by enabling a high specific surface and bonded area to be developed during beating without much decrease in fiber strength. This indicates that hemicelluloses do have an increasing effect on fiber bonding as their percentage increases.

Campbell (16) points out that when fibers themselves are broken the result is a rupture of shear between bonded fibrils inside the fibers and that fibers are broken is evidence that the bonding of these fibers to neighboring fibers is stronger than whenever bonding takes place in the fiber itself and which may be due to primary chemical bonds or to hydrogen bonding or both. He also says that possibly a great deal of the bonded surface is broken in the earlier stages of loading while distortions take place in the course of setting up the continuous chains of bonded units which carry the final load.

## HISTORICAL SURVEY OF THE EFFECT OF A TENSILE STRESS ON PAPER STRENGTH

If paper is subjected to a tensile stress it may break immediately or it may support the stress for a period of time. Rance (17) showed that a relationship exists between the load and the logarithm of the time period that the paper supports the load before the break occurs. The relationship he obtained is shown in Fig. 1.

Jacobsen (18) also found this relationship. This seems to show that within the sheet there is a stress-dependent mechanism which affects the sheet strength.

Griffin and McKinley (19) show that paper will break under a reduced load if the time of application of this load is increased and, conversely, state that the load required will be higher if the paper is broken rapidly. They attribute this to the flow in paper and to the time element involved in the separation of fibers just prior to rupture.

Doughty (20) says that ultimate tensile strength of paper is decreased with increasing basis weight. He attributes this principally to variation in fiber orientation, therefore showing that fiber orientation or alignment has an effect upon the response of paper to a tensile stress.

Schulz (11) points out that the manner in which stress is distributed within the sheet while supporting a load is a factor which must be considered. If stress is distributed uniformly the least strain will be realized. Because of the variety in the size and shape of the elements which compose the sheet it is not likely that this uniform distribution is ever present in paper.

Schulz (11) states that publications by Nordman, Gustafsson, and Olafsson and Sandborn show an increase in the light scattering coefficient of paper after it was subjected to

stress. A relationship between the change in scattering coefficient and the work done by the load on the paper was found. It is generally believed that the light-scattering coefficient varies directly with the unbonded area in the sheet, so a change in the internal sheet structure is indicated.

Schulz (11) also says that Maynard and McKee showed changes in the thickness of paper while supporting a load. It is believed that the breaking of fiber-to-fiber bonds is responsible for this change in thickness.

## PRESENTATION OF THE PROBLEM

It has been shown by Rance (17) and Jacobsen (18) that
when paper is subjected to a load there is a relationship
between the load and the logarithm of the time period that the
paper supports the load.

This implies a stress-dependent mechanism within the sheet
which affects the strength of the sheet. The weakening of paper
until it is finally broken has been attributed to the breaking
of fiber-to-fiber bonds in the sheet.

This work involved a study of the relationship between the
weakening of paper to the time under load at periods of time
less than that required for sheet rupture. Two objectives were
to be served. First, it was proposed to obtain results which
would enable an accurate prediction of the tensile strength of
paper after it had been subjected to a load for a period of time.
The second objective was an attempt to show that this weakening
is due to the breaking of fiber-to-fiber bonds in the sheet.

EXPERIMENTAL PROCEDURES

## PREPARATION OF HANDSHEETS

DESCRIPTION OF PULP

The pulp used in this work was a Weyerhauser softwood alpha pulp obtained from the Hawthorne Paper Company in Kalamazoo, Michigan and used by them in their daily operations. The pulp was obtained in bale form and was stored at room conditions. The pulp was refined in a Valley laboratory beater according to TAPPI Standard T 200 m-45. Before beating, the pulp was soaked in water for four hours and was defibered in a Williams Standard pulp disintegrator. The pulp was beaten with a load of 5500 g. on the bedplate. The results of the beater evaluation are shown in Table I.

TABLE I

BEATER EVALUATION OF PULP

| Beating Time Minutes | Freeness ml. CSF | Basis Weight g./sq m | Average Thickness 1/1000 in. | Average Tensile lbs. | Average Burst psi | Fold MIT |
|---|---|---|---|---|---|---|
| 0 | 729 | 62.6 | 5.8 | 1.55 | 1.9 | 0 |
| 15 | 550 | 61.2 | 3.9 | 7.92 | 18.3 | 19 |
| 30 | 260 | 59.5 | 3.4 | 10.93 | 24.1 | 37 |
| 45 | 101 | 60.0 | 3.1 | 11.12 | 24.9 | 91 |

STUDY OF THE REPRODUCIBILITY OF HANDSHEETS

This study was made to enable the preparation of handsheets

without great variations in physical properties, in order that
further work would be free from error because of deviations in
handsheet properties. It was evident that to obtain reproducible
handsheets from this pulp, a study of this kind must be carried
out because of variations in handsheets observed during the beater
evaluation.

In studying the reproducibility of handsheets made from this
pulp two areas were considered as major variables. First, a study
of the reproducibility of sheet properties at different degrees of
beating was made.

The second area of study was that of the reproducibility in
properties of handsheets of different basis weights.

In preparing handsheets for the study of various degrees of
beating and its effect on handsheet properties, TAPPI Standard T
205 m-53 was followed, using a British sheet mold and a hydraulic
press. Drying was carried out in a conditioned room using standard
drying rings. After conditioning of the sheets, they were cut into
strips as shown in Figure 2. The cutting of these strips was done
with a razor blade to permit a very accurate size to be obtained.

Strips A, E, F and Z (see Figure 2) were used to determine
zero-span tensile strength, while strips B, C, and D were cut to a
length of 150 mm, weighed and the tensile strength determined.
Strips A, E, F and Z were cut to a length of 100 mm, weighed, and
then reduced to 40 mm to enable easier handling. All strips were
cut 15 mm wide.

Figure 2

Handsheet Division
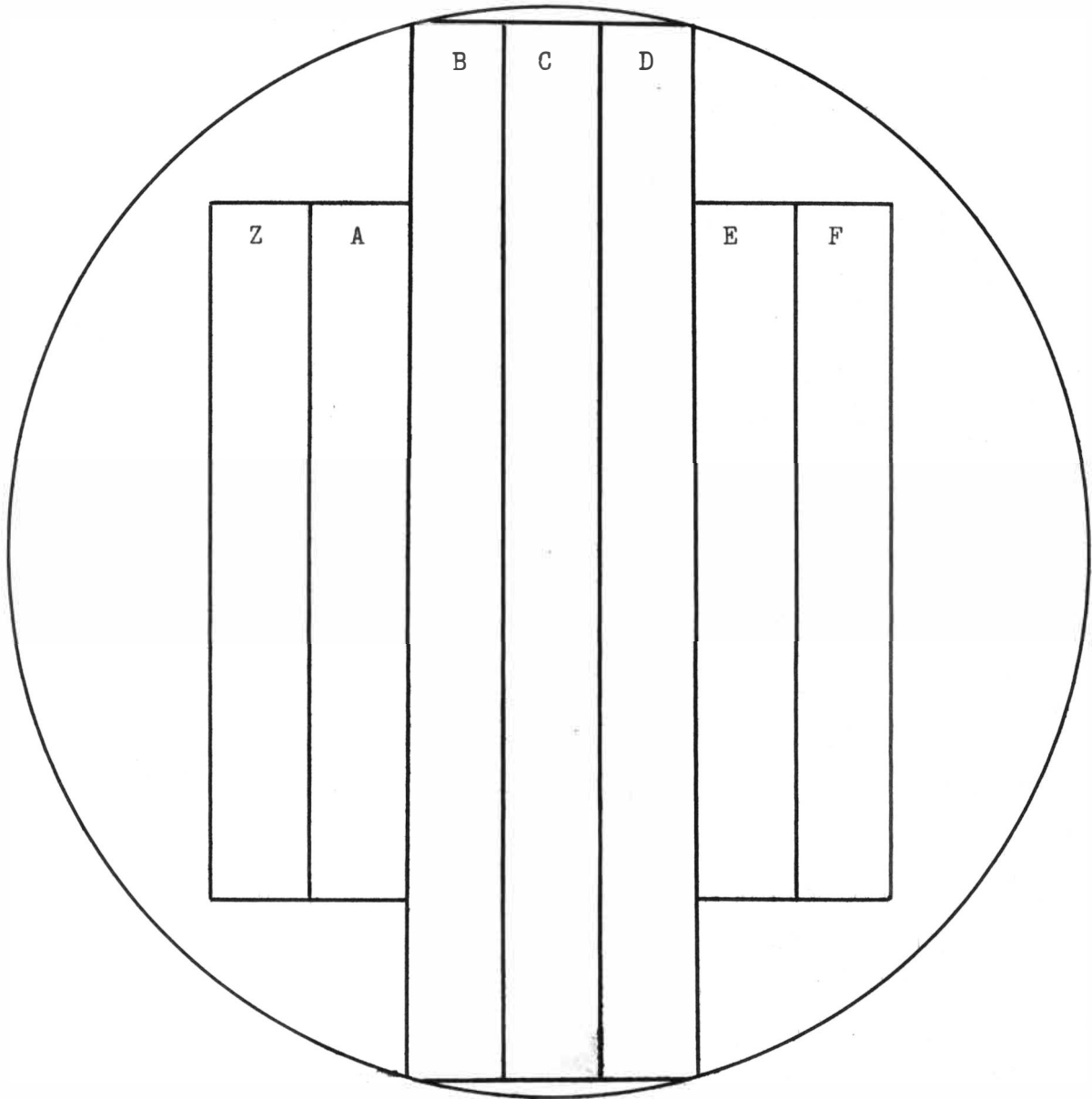
The basis weight, tensile strength, and zero-span tensile strength of each strip was determined and calculations made to give breaking length and zero-span breaking length by use of the following formulas:

Breaking length $= \dfrac{30,240\ p}{r}$

where $\underline{p}$ is the tensile break load in pounds on a 15 mm strip and $\underline{r}$ is the moisture-free basis weight in grams/square meter

Zero-span breaking length $= \dfrac{30,240\ p}{r}$

where $\underline{p}$ is the zero-span tensile in pounds on a 15 mm strip after correction for the weight of the zero-span upper jaws and knurled screw and $\underline{r}$ is the moisture-free basis weight in grams/square meter

After the zero-span tensile strength was determined, the line of rupture was examined under a microscope to observe the type of break which had occurred and it was found that as the beating time increased up to 45 minutes, the line of rupture became increasingly sharper.

The data obtained in this study are shown in Tables II and III.

From the data in Tables II and III, a measure of the variations in sheet properties was calculated by dividing the "range" of values of breaking length and zero-span breaking length obtained at each degree of beating by the average value of breaking length and zero-span breaking length at each degree of beating, and multiplying by 100. The value of the "range" was obtained by subtracting the lowest reading obtained from the highest reading.

TABLE II
EFFECT OF DEGREES OF BEATING ON REPRODUCIBILITY OF HANDSHEETS

| Beating Time Minutes | Breaking Length Meters | Zero-span Breaking Length Meters | Beating Time Minutes | Breaking Length Meters | Zero-span Breaking Length Meters |
|---|---|---|---|---|---|
| 0 | 593 | 8201 | 30 | 5222 | 10634 |
|   | 578 | 7087 |    | 5155 | 10343 |
|   | 575 | 7081 |    | 5188 | 10132 |
|   | 572 | 7079 |    | 4990 | 9820 |
|   | 547 | 7093 |    | 4950 | 9712 |
|   | 524 | 7025 |    | 4924 | 9689 |
|   | 520 | 6970 |    | 4900 | 9573 |
|   | 496 | 6845 |    | 4900 | 9539 |
|   | 481 | 6703 |    | 4832 | 9378 |
|   | 494 | 6769 |    | 4701 | 9375 |
|   | 466 | 6551 |    | 4558 | 9271 |
|   | 441 | 6351 |    | 4534 | 9214 |
| 15 | 3712 | 11449 | 45 | 5832 | 10476 |
|   | 3707 | 11209 |    | 5707 | 9950 |
|   | 3648 | 10193 |    | 5640 | 9693 |
|   | 3598 | 10135 |    | 5607 | 9673 |
|   | 3548 | 10118 |    | 5542 | 9518 |
|   | 3543 | 10086 |    | 5444 | 9440 |
|   | 3541 | 9916 |    | 5427 | 9223 |
|   | 3528 | 9906 |    | 5364 | 9223 |
|   | 3476 | 9848 |    | 5355 | 9122 |
|   | 3471 | 9838 |    | 5138 | 9072 |
|   | 3461 | 9793 |    | 5135 | 8756 |
|   | 3402 | 9356 |    | 4744 | 8302 |

TABLE III
AVERAGE AND RANGE VALUES FROM DEGREE OF BEATING
STUDY ON REPRODUCIBILITY

| | AVERAGES | | | RANGES | |
|---|---|---|---|---|---|
| Beating Time Minutes | Breaking Length Meters | Zero-span Breaking Length Meters | Beating Time Minutes | Breaking Length Meters | Zero-span Breaking Length Meters |
| 0 | 524 | 6807 | 0 | 152 | 1850 |
| 15 | 3553 | 9983 | 15 | 310 | 2093 |
| 30 | 4898 | 9585 | 30 | 688 | 1420 |
| 45 | 5413 | 9159 | 45 | 1088 | 2174 |

This measure of variation is termed variation percentage, and the values for it obtained at the degrees of beating studied are shown in Table IV.

TABLE IV
VARIATION PERCENTAGE AT VARIOUS DEGREES OF BEATING

| Beating Time Minutes | Variation Percentage Breaking Length | Variation Percentage Zero-span Breaking Length |
|---|---|---|
| 0 | 29.0 | 27.2 |
| 15 | 8.7 | 20.9 |
| 30 | 14.1 | 14.8 |
| 45 | 20.3 | 23.7 |

Upon examination of Tables II, III and IV, it can be seen that a great deal of error was present at each degree of beating. At a beating time of 30 minutes there seemed to be the greatest reproducibility and this degree also seemed to give the best handsheet formation upon visual examination.

In studying the reproducibility of handsheets of different basis weights, pulp beaten for 30 minutes was used. Handsheets were formed on a British sheet mold and pressing done on a hydraulic press. Drying was carried out in standard drying rings and in a conditioned room. Handsheets were formed in the above manner weighing approximately 2.0 and 3.3 grams per sheet. These handsheets were divided into strips according to Figure 2, cut in the same manner as those used in the study of the effect of degrees of beating on handsheet reproducibility, weighed, and tested for tensile strength and zero-span tensile strength. Calculations of breaking length and zero-span breaking length were made and are presented in Tables V and VI.

## TABLE V
### EFFECT OF BASIS WEIGHT ON REPRODUCIBILITY

| Sheet Weight g./sq. m | Breaking Length Meters | Zero-span Breaking Length Meters | Sheet Weight g./sq. m | Breaking Length Meters | Zero-span Breaking Length Meters |
|---|---|---|---|---|---|
| 106.7 | 5060 | 11480 | 164.8 | 5190 | 10080 |
| 108.4 | 5275 | 11120 | 165.1 | 5130 | 9850 |
| 108.4 | 5025 | 11500 | 164.6 | 5100 | 9730 |
| 105.3 | 5490 | 11180 | 164.3 | 5250 | 9640 |
| 105.8 | 4875 | 10950 | 163.0 | 5175 | 10370 |
| 105.5 | 5100 | 10950 | 166.1 | *4900 | 10410 |
| 108.2 | 5600 | 10660 | 162.6 | 5290 | 10250 |
| 108.0 | 5660 | 11000 | 161.4 | 5340 | 10070 |
| 108.9 | 5559 | 10300 | 162.5 | 5270 | 10650 |
| 107.9 | 5112 | 10800 | 164.8 | 5321 | **9700 |
| 108.5 | 4958 | 11620 | 161.8 | 5364 | 10110 |
| 108.4 | 5040 | 11080 | 164.9 | 5226 | 9720 |
| 106.7 | 5481 | 11420 | 163.6 | 5120 | **9490 |
| 107.3 | 5478 | 11100 | 164.4 | 5316 | 10890 |
| 108.4 | 5423 | 10300 | 164.1 | 5270 | 11130 |
| 106.9 | 5408 | 10800 | 164.9 | 5300 | 10290 |
| 106.0 | 5327 | 11010 | 164.3 | 5374 | 9890 |
| 106.2 | 5316 | 10350 | 163.6 | 5342 | 10890 |

* wood sliver found at point of failure

** jaws of zero-span tensile strength tester not at zero-span

### TABLE VI
### AVERAGE AND RANGE VALUES FROM EFFECT
### OF WEIGHT STUDY ON REPRODUCIBILITY

| AVERAGES | | | RANGES | | |
|---|---|---|---|---|---|
| Sheet Weight g./sq. m | Breaking Length Meters | Zero-span Breaking Length Meters | Sheet Weight g./sq. m | Breaking Length Meters | Zero-span Breaking Length Meters |
| 107.4 | 5288 | 10980 | 107.4 | 795 | 1320 |
| 164.0 | 5240 | 10180 | 164.0 | 274 | 1490 |

From the data in Tables V and VI, a measure of the variations
in sheet properties was calculated by dividing the "range of values
of breaking length and zero-span breaking length obtained at each
sheet weight by the average value of breaking length and zero-span
breaking length at each sheet weight, and multiplying by 100. The
value of "range" was obtained by subtracting the lowest reading
obtained from the highest reading. This measure of variation is
termed variation percentage, and the values for it obtained at the
sheet weights studied are shown in Table VII.

TABLE VII
VARIATION PERCENTAGE AT DIFFERENT SHEET WEIGHTS

| Sheet Weight g./sq. m | Variation Percentage Breaking Length | Variation Percentage Zero-span Breaking Length |
|---|---|---|
| 107.4 | 15.1 | 12.2 |
| 164.0 | 5.3 | 14.7 |

Upon examination of Tables V, VI, and VII, it can be seen that,
in comparison with the deviation found in the study of the effect
of the degrees of beating on handsheet reproducibility, the deviation
has been reduced considerably. As the zero-span tensile strength test
results are usually expected to vary considerably it can be said that
a variation percentage of 5.3 for breaking length, as is the case with
the handsheets of an average basis weight of 164.0 g./sq. m is very
satisfactory for this type of work. Therefore, sheets of this weight
were selected for use in further studies. The forming of heavier
handsheets did not see to be justified once this variation percentage
had been reached.

The tensile strength testing machine was periodically checked for accuracy by hanging different weights on the top jaw of the tester and reading the scale after allowing the tester to come to equilibrium. A check was also made to note the effect of using a 2-inch span while making the tensile strength test, but no significant variations were discovered by using this method.

## EXPERIMENTAL RESULTS

STUDY OF THE RELATIONSHIP OF TIME TO BREAK VERSUS LOAD APPLIED

To meet the objectives set up for this work, it was necessary to make a determination of the relationship of the time to break versus the load applied to a sheet. To determine this relationship it was necessary to apply loads of different magnitudes to strips of paper and find the time required for the strips to break.

A timing apparatus and clamps in which to hold the strip while applying load were needed and these were designed and made by the author.

The timing apparatus, used to measure the length time the samples supported the load, consisted of an electric clock, a wooden base, an on-off push-type electric switch, a metal coil spring, and a wooden pedal with hinge attachment.

The procedure used to make this timing device was to drill into the base deep and large enough to allow the electric switch to be pushed off by a weight falling on the pedal without damage to the switch. The pedal was attached and the spring inserted between the base and the pedal to return the pedal to its original position after shutting the switch off. The clock was wired in connection with the switch so as to allow the switch to shut the clock off.

The clamps were made of a copper-brass alloy. Rubber used in the clamps was from an automobile tire inner tube and bolts were of stainless steel. These are shown in Figure 3.

The study of the relationship of time to break versus load applied was carried out in a conditioned room of controlled temperature and
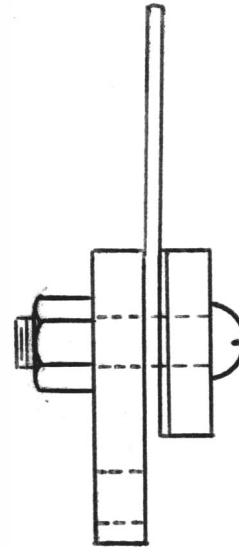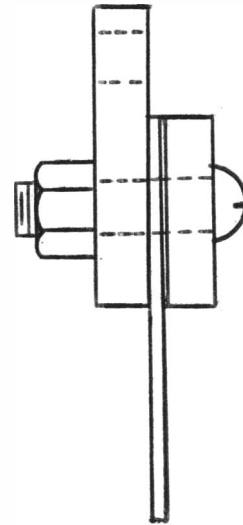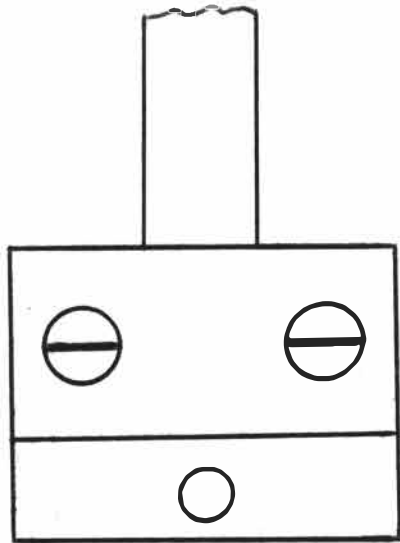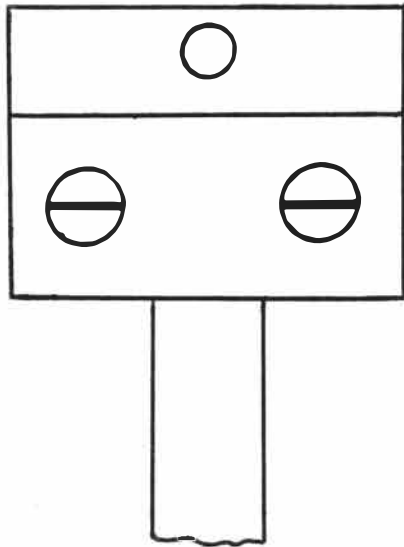
Figure 3. Clamps

humidity. The upper clamp was suspended and the lower clamp held the load. Loads used were 14.76, 13.73, 12.72, 10.89 and 9.90 pounds. Strips were cut 15 mm wide from selected handsheets and placed with a 4-inch span between the clamp jaws. The timing apparatus was located directly beneath the load in such a position that upon breaking the sheet, the weight would fall and shut the electric clock off. This arrangement is shown in Figure 4. The time of placing the strip under load was noted and with the clock being stopped upon sheet rupture, the time under load could be determined very easily.

The results of the study of the relationship between time to break and load applied is shown in Figure 5.

It is evident from this study that sheets will break at loads less than the maximum tensile load required for immediate rupture. From Figure 5, it can be seen that, for a period up to one week, the time to break increased with decreasing load applied. This relationship is linear between the logarithm of the time required for sheet rupture and the load applied, over this time period.

These data are useful because they verify the work of Rance (17), shown in Figure 1.

After sheet rupture occurred in the study of the relationship of time to break versus load applied, the zero-span tensile strength was determined. The results of these zero-span tensile strength tests are shown in Table VIII.
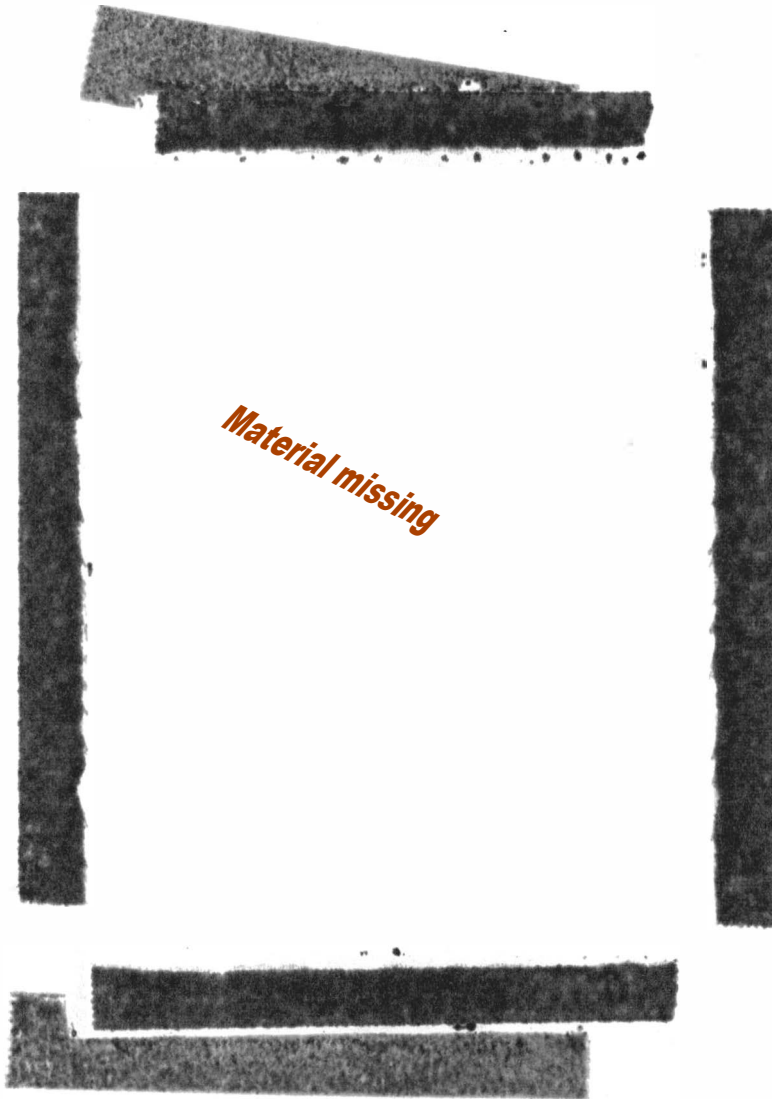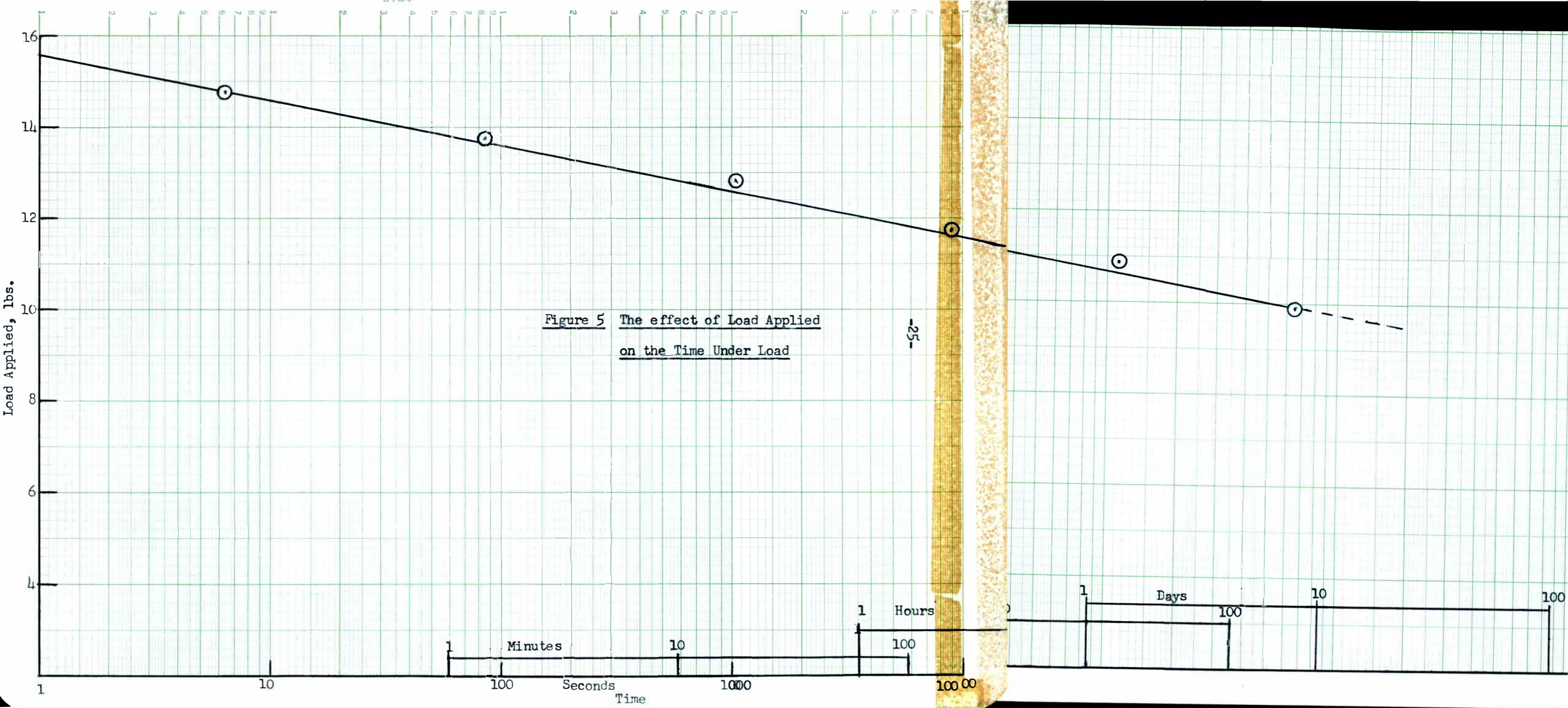
Figure 4.  Assembled Apparatus

Figure 5   The effect of Load Applied on the Time Under Load

-25-

## TABLE VIII

### EFFECT ON ZERO-SPAN TENSILE STRENGTH OF APPLIED LOAD

| Load Applied lbs. | Average Time to Rupture | | Average Zero-span Tensile Strength lbs. |
|---|---|---|---|
| 14.76 | 6.5 | seconds | 45.3 |
| 13.73 | 85 | seconds | 46.6 |
| 12.72 | 20 | minutes | 45.4 |
| 10.89 | 30 | hours | 46.0 |
| 9.90 | 1 | week | 45.2 |

From Table VIII, it can be seen that there is no change in the zero-span tensile strength that can be attributed to the weakening of the fibers of the sheet. The small differences are assumed to be due to experimental error, indicating that in the weakening of a sheet until it ruptures, by means of applying a tensile load, the breaking of fiber-to-fiber bonds within the sheet takes place. Also shown is that the intrinsic strength of the fibers is not affected during this weakening.

DETERMINATION OF THE RATE OF WEAKENING DUE TO AN APPLIED LOAD

It was found in the study of the relationship of time to break versus load applied, that in the time period studied, a sheet, when subjected to a tensile load less than that required for immediate rupture, is weakened continually until it finally fails. It was also indicated by this study, that this weakening is due to the breaking of fiber-to-fiber bonds within the sheet.

The determination of the rate of weakening due to an applied load was carried out to examine this weakening effect and determine the effect of different tensile loads and the time of application of these loads on the rate of weakening of a sheet.

In determining the rate of weakening due to an applied load, loads of 13.73, 12.72, 11.89 and 10.89 pounds were used. The time to break at each of these loads had been determined in the study of the relationship of time to break versus load applied.

These loads were applied at periods less than that required for immediate rupture and the tensile strength determined after removal of the load. The results of applying loads for less than the time required for immediate rupture is shown in Table IX and Figures 6, 7, 8, and 9.

## TABLE IX

EFFECT OF LOAD APPLIED FOR VARIOUS TIME PERIODS ON TENSILE STRENGTH

| Load Applied Previous To Tensile Strength Test-Lbs. | Time Under Load | Tensile Strength Lbs. |
|---|---|---|
| 0 | 0 | 15.8 |
| 13.73 | 30 sec. | 15.4 |
| 13.73 | 60 sec. | 15.1 |
| 12.72 | 10 min. | 14.3 |
| 12.72 | 15.min. | 14.5 |
| 11.89 | 30 min. | 14.6 |
| 11.89 | 60 min. | 15.1 |
| 11.89 | 90 min. | 14.4 |
| 10.89 | 8 hours | 15.3 |
| 10.89 | 16 hours | 15.1 |
| 10.89 | 24 hours | 14.5 |

From examination of Table IX and Figures 6, 7, 8 and 9, it can be seen that the tensile strength will decrease because of an applied load continuously until rupture and that the tensile strength decreased as the time under load increased. There is also some evidence that the rate of weakening of a sheet increases as the time under load increases until rupture occurs.

Figure 6    The Effect of Time on the Tensile Strength at a Load of 13.73 Pounds
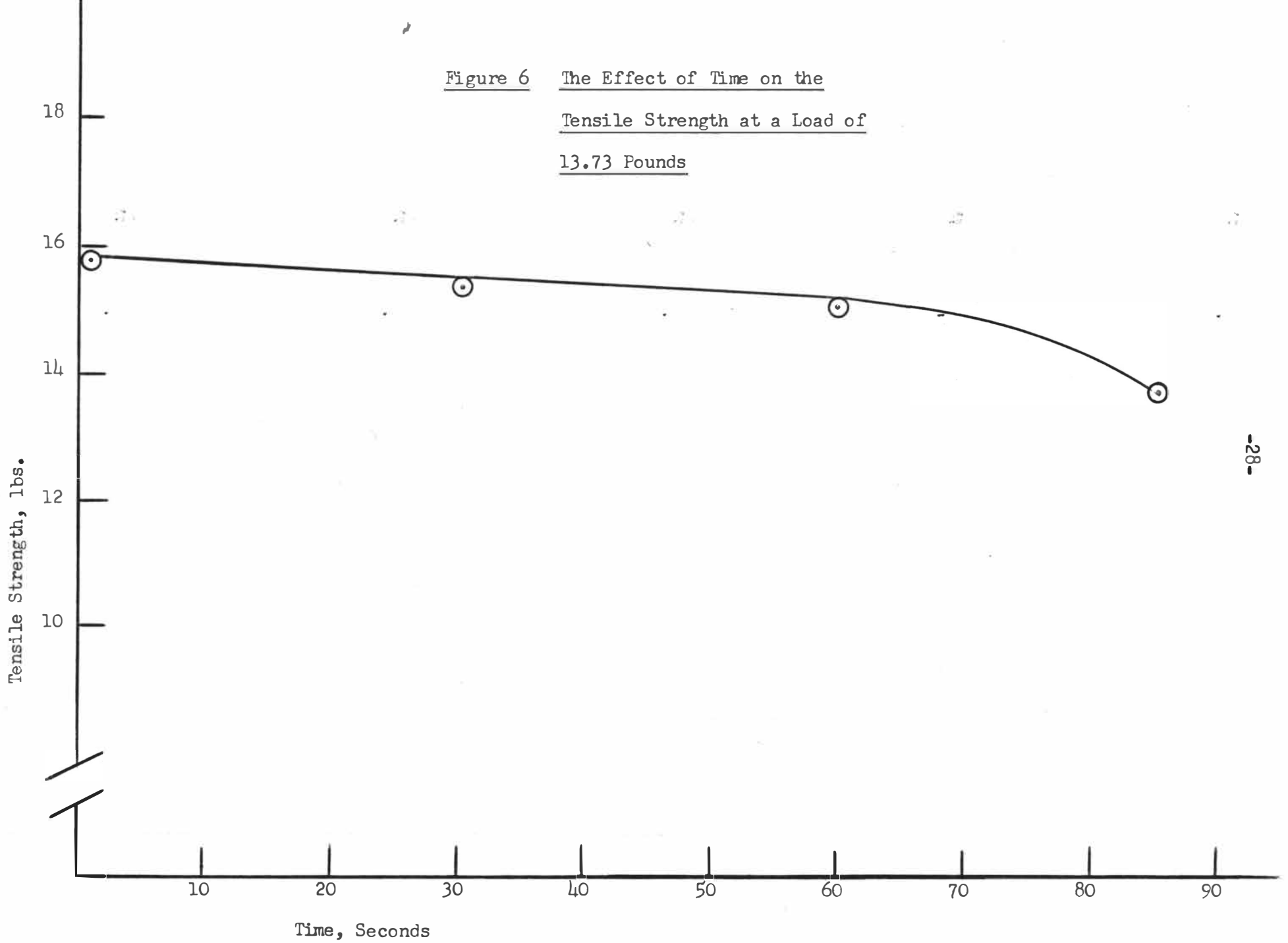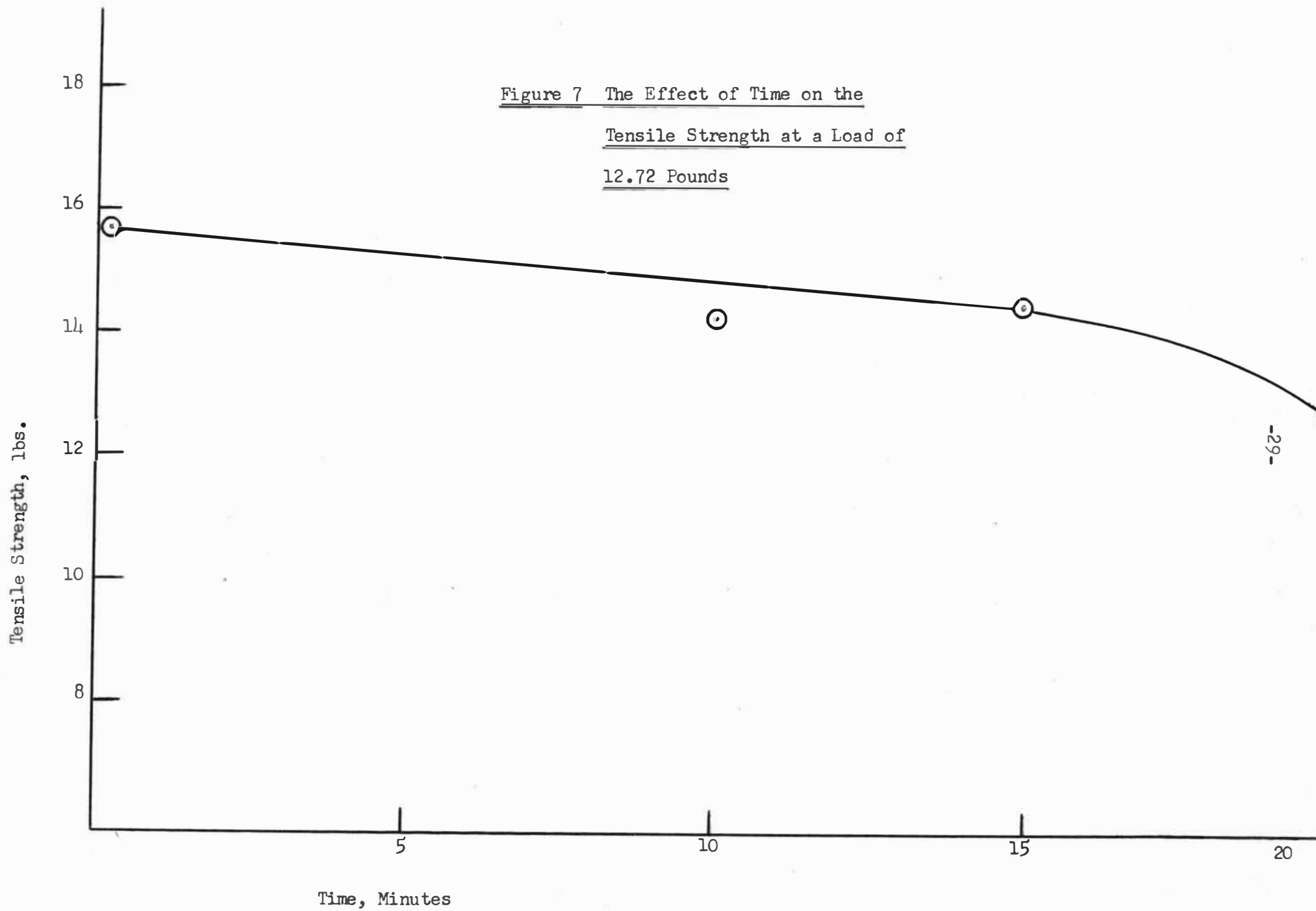
Figure 7    The Effect of Time on the
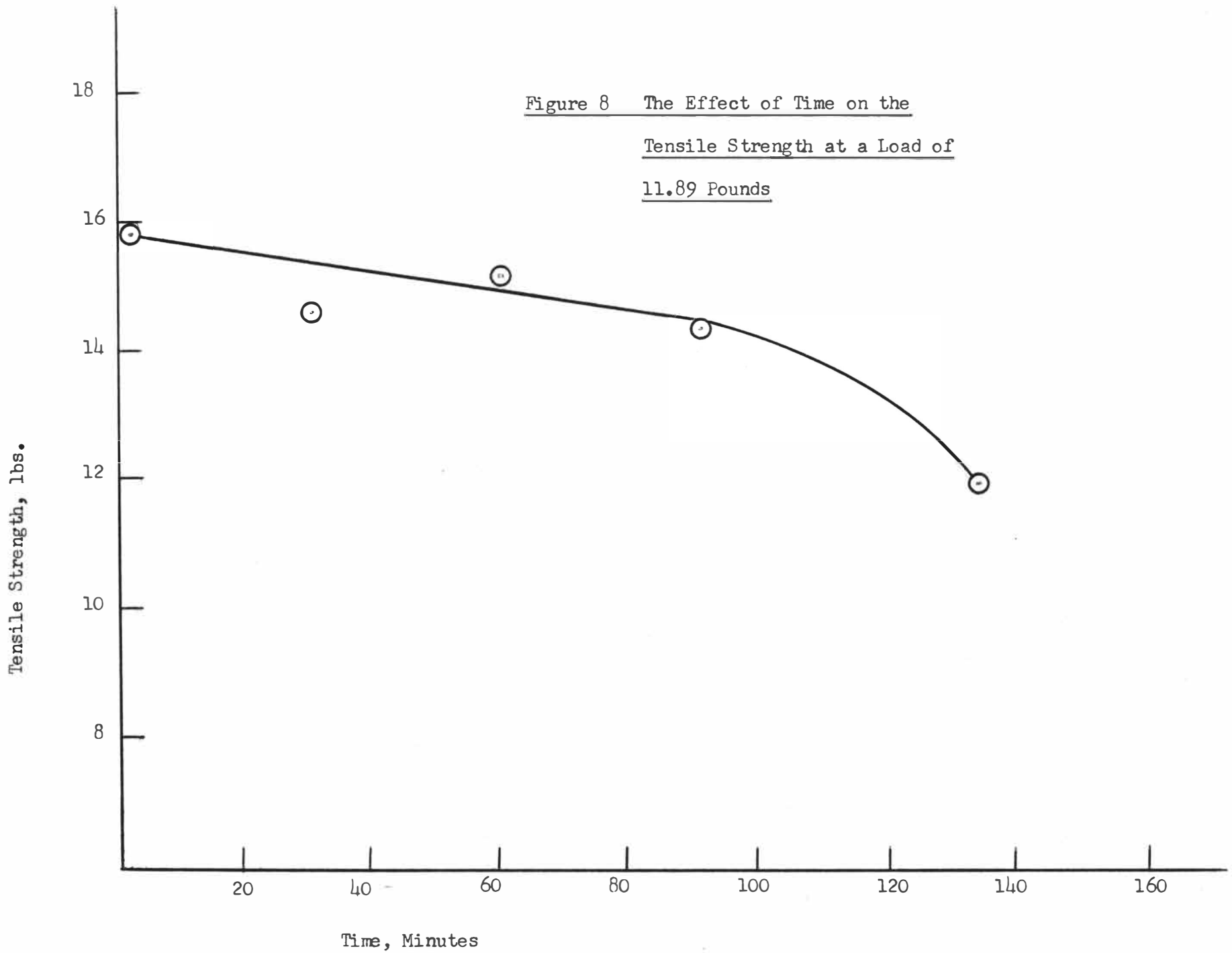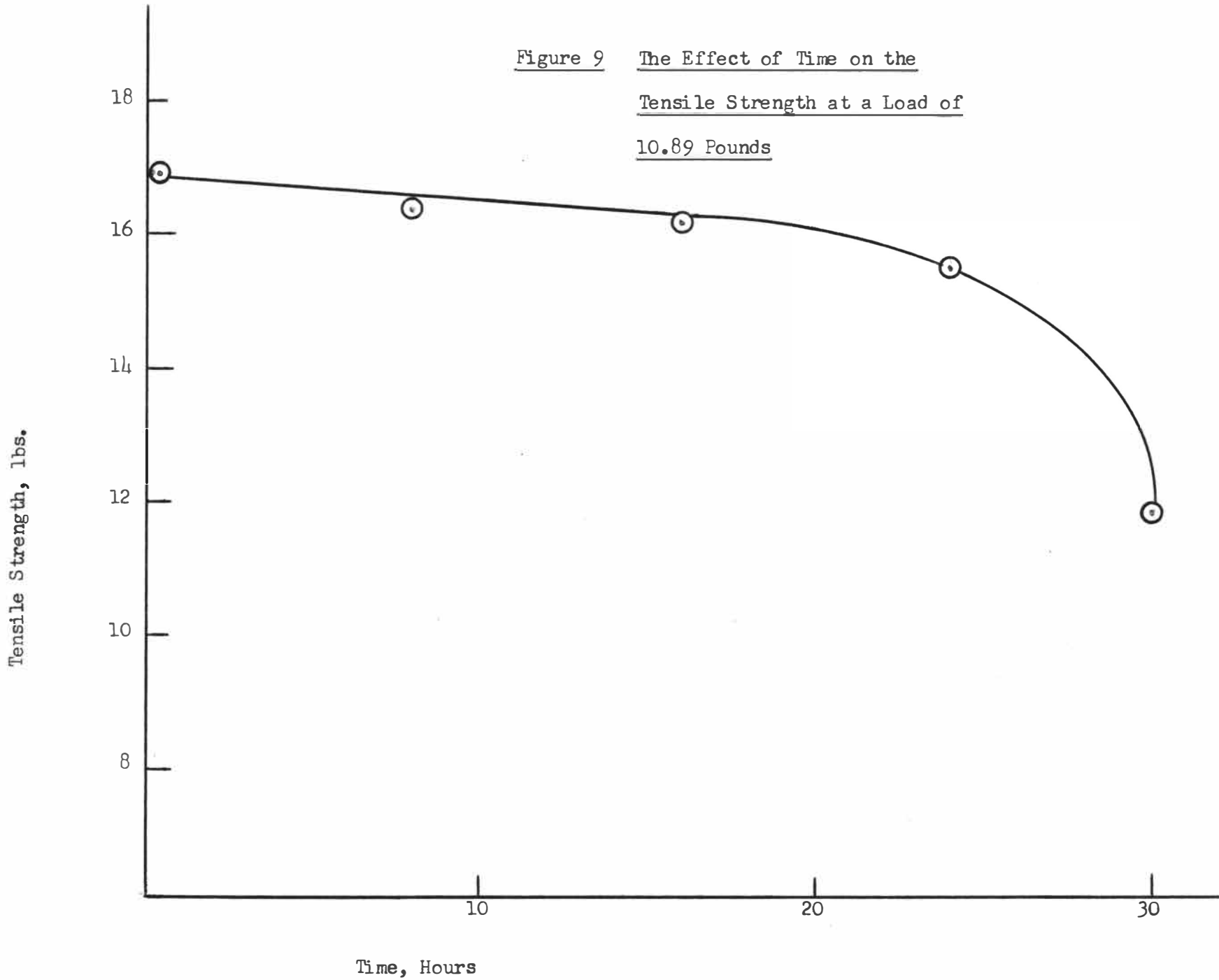Tensile Strength at a Load of
12.72 Pounds

-29-

Figure 8    The Effect of Time on the Tensile Strength at a Load of 11.89 Pounds

Figure 9    The Effect of Time on the
Tensile Strength at a Load of
10.89 Pounds

## SUMMARY AND CONCLUSIONS

Procedures and equipment were designed and constructed to determine the rate of weakening of paper and the factors which were effected by this weakening.

A softwood alpha pulp was used in all work. A study of handsheet reproducibility was carried out, followed by a study of the relationship of time to break versus load applied, previous to the determination of the rate of weakening.

From the work carried out it is evident, that a sheet will be weakened continually until rupture, because of an applied load. As the intrinsic fiber strength is not effected by the applied load, the weakening can be attributed to the breaking of fiber-to-fiber bonds within the sheet. As the load applied is increased, but less than the maximum tensile strength of the sheet, the time required for rupture decreased at periods up to one week. The rate at which a sheet is weakened will increase as the time under load is increased until rupture.

LITERATURE CITED

1. Casey, J. P. Pulp and paper. New York, Interscience, (1960).

2. Forman, L. V., Tappi 33, no. 9:444-50 (Sept., 1950).

3. Van den Akker, J. A., Lathrop, A. L., Voelker, M. H., and Dearth, L. R., Tappi 41, no. 8:416-25 (Aug., 1958).

4. Ratliff, F. T., Tappi 32, no. 8:357-67 (Aug., 1949).

5. Emerton, H. W. Fundamentals of the beating process. Kenley, England, The British Paper and Board Industry Research Assoc., 1957, 198 p.

6. Thode, E. F., and Ingmanson, W. L., Tappi 42, no. 1:74-83 (Jan., 1959).

7. Nissan, A. H., Tappi 41, no. 3:131-134 (March, 1958).

8. Ingmanson, W. L., and Thode, E. F., Tappi 42, no. 1:83-93 (Jan., 1959).

9. Keeney, F. C., Tappi 35, no. 12:555-563 (Dec., 1952).

10. McDonnell, L. F., A study of the chemical and physical changes affecting strength during the hypochlorite bleaching of neutral sulphite semichemical aspen pulp. Doctor's Dissertation. Appleton, Wis., The Institute of Paper Chemistry. June, 1959, 113 p.

11. Schulz, J. H., The effect of strain applied during drying on the mechanical behavior of paper. Doctor's Dissertation. Appleton, Wis., The Institute of Paper Chemistry. June, 1961, 161 p.

12. Swanson, J. W., and Steber, A., Tappi 42 no. 12:986-94 (Dec., 1959).

13. Parsons, S. R. Paper trade j. 115 no. 25:360-368 (Dec.,17, 1942).

14. Hoffman-Jacobsen, P. M., Paper trade j. 81 no. 22:52-53 (Nov.26, 1925).

15. Van den Akker, J. A. Tappi 42 no. 12:940-7 (Dec. 1959).

16. Campbell, W. B., Tappi 42 no. 12:999-1001 (Dec., 1959).

17. Rance, H. F., The mechanical properties of paper. In Meredith's mechanical properties of wood and paper. New York, Interscience Publishers, Inc., 1953, 298 p.

18. Jacobsen, P. M. Hoffman World's paper. tr. rev. 134:150 (July 20,1950)

19. Griffin, R. C. and McKinley, R. W. Paper trade j. 102 no. 2:20-21 (Jan. 9, 1936).

20. Doughty, R. H. Paper trade j. 93 no. 15:162-167, 172 (Oct. 8, 1931).