

A REVIEW OF THE REPORT ON THE SURVEY
OF THE TENNESSEE RIVER BASIN MADE BY THE CORPS OF
ENGINEERS U.S.A.

by

Donald Roger Swingle

A THESIS SUBMITTED FOR THE DEGREE

of

BACHELOR OF SCIENCE

in

ELECTRICAL ENGINEERING

The University of Tennessee

1929

Preface

A survey of the Tennessee river basin was authorized by acts of Congress in 1922, 1926, and 1927. This survey, which was made by the Corps of Engineers U.S.A., covered three important subjects, namely, (1) water power resources, (2) navigation, and (3) flood control.

This thesis deals only with the water power of the Tennessee River and its tributaries as given in the report made by the Engineers in charge of the survey.

The survey was begun under Major Harold C. Fiske, and has been completed under the direction of Major Lewis H. Watkins. At the present time (May 1929) a final report on the completed survey has not been made. This study was based on the "Report from the Chief of Engineers on Partial survey of the Tennessee River and its Tributaries", House Document No. 185, 70th Congress, 1st session.

The writer wishes to express his gratitude for the valuable help rendered him by Mr. P. H. Timothy, First Lieut., Corps of Engineers, U.S.A., and for the suggestions given by Professor J. A. Switzer, University of Tennessee, Knoxville.

Statement of Purpose

It has been the object of the writer to make a careful study of the methods used in the determination of the potential water power of the Tennessee river basin, and to give a detailed description of the methods used.

The Tennessee River Basin

The Tennessee river is formed by the confluence of the Holston and French Broad Rivers in the east central part of the state of Tennessee. It flows southwesterly across the eastern part of the state into Alabama, and northerly between Alabama and Mississippi and across the western part of Tennessee and Kentucky into the Ohio river at Paducah, Kentucky. Its length is 652 miles. Its drainage area is 40,600 square miles. The elevation of low water at its source is 800 feet above mean sea level. The elevation of the pool of Dam No. 52, Ohio River, is 302 feet above mean sea level.

The major tributaries of the Tennessee River and the drainage areas of each are as follows:

River	Drainage Area Square miles
Holston	3,810
French Broad	5,140
Little Tenn.	2,650
Clinch	4,400
Bear	940
Duck	3,560

These tributaries have their sources in the states of Tennessee, Virginia, North Carolina, Georgia, and Alabama.

All of the above tributaries and the main stream have been surveyed and the seemingly good dam and reservoir sites have been located. Eleven dam sites have been recommended for the main stream and a much larger number for the various

tributaries. All of the major reservoir projects are located on the upper tributaries. This is due to the fact that the main stream flows for most of the way through a low flat country. If large reservoirs were created much valuable property would be covered with water, thus making the reservoir cost prohibitive. The upper tributaries are in the highland and afford excellent locations for reservoir projects.

A faint, circular embossed stamp is visible in the center of the page. It features a circular border with the word "JAPANESE" at the top and "MADE IN U.S.A." at the bottom. In the center of the stamp is a stylized emblem, possibly a crest or a logo, which is difficult to discern clearly due to the fading.

Description of Method Used to Determine the Water-Power Resources of the Tennessee River Basin.

1. Reservoir Operation

From the description of the Basin given above it is seen that there is a large water shed upon which there are a number of reservoirs and power developments. The determination of power possibilities on such a water shed differs a great deal from the considerations given a single isolated power project. In the case of the isolated plant, the effect of its operation on other plants in the same water shed is not taken into consideration. On the other hand if all the plants in a water shed are to be interconnected, then the effect of the operation of any one plant on all the other plants must be considered. In other words all the power plants and reservoirs must be so operated as to give the maximum possible primary power for the entire system, and therefore, not necessarily the maximum primary power for each plant. In an interconnected system, the reservoirs not only furnish stream flow during low flow periods, but contribute the power generated in excess of their prime rating, and thereby furnish additional regulation by interchange of power as well. During high flow periods the reservoir projects carry no load, the total load of the system being carried by the lower run-of-river projects. This power, which otherwise would be secondary at the lower project, is thus converted into prime power through interchange. Thus the reservoirs are allowed to fill at a more rapid rate during high flow, thereby increasing the utilization factor of the reservoirs.

2. Natural Power

The first step in arriving at the power possibilities within the basin is the determination of the natural or unregulated energy in the system. The data from all the gaging stations in the system are brought together and the average monthly natural flows at these stations are tabulated for the period of study. It is understood that at least one gaging station must be used for each tributary. The use of more than one is preferable, especially on the larger streams.

In this thesis curves and charts will be referred to in order to explain the methods used. These curves and charts are a part of the report made on the survey. * Table IX Appendix B part I shows the natural and regulated power for the Little Tennessee River (taken for illustration), and Table I, sheet II, shows the basic data from which Table IX was prepared. The period 1903 to 1909 is typical, containing a very dry year and also a very wet year. On Sheet II, Table I it is seen that two gages are used for the Little Tennessee, namely, Judson and McGhee. Under the column marked "head feet", is tabulated the normal head at each project. In column marked "C" the ratio of the drainage area of each project to that of its respective gaging station is entered. Thus at the Judson gaging station the drainage area is 668 square miles at the

* These charts are on file with the department of Hydraulic and Sanitary Engineering, University of Tennessee, Knoxville. They may also be secured from the U.S.A. Engineering office at Chattanooga, Tenn.

Santeetlah project the drainage area is 175 square miles. The value of "C" then is $175 \div 668 = 0.262$. The column "Ch" is the product of the normal head at the project times "C" for that project. Now if Q is the discharge in second feet at a power plant and h is the head in feet on the turbine, then the power in kilowatts is

$$KW = \frac{0.746 Qh}{8.8} \times \text{turbine efficiency} \times \text{generator eff.} \times \text{conduit eff.} \times \text{evaporation factor}$$

$$\text{Turbine eff.} = 92\%$$

$$\text{Generator eff.} = 96\%$$

$$\text{Conduit eff.} = 95\%$$

$$\text{Evaporation factor} = 0.95$$

$$KW = 0.0848 Qh \times 0.92 \times 0.96 \times 0.95 \times 0.95 = 0.0677 Qh$$

Then "Ch" for each project multiplied by 0.0677 multiplied by the actual flow at the gaging station gives the unregulated power for that project. The value of this unregulated power in thousands of kilowatt months is entered in the first column under each project on Table IX. For the projects on the main Tennessee River the natural and regulated power is determined from the natural and modified flows at the projects by means of the power duration curves shown in Appendix E. These curves which were corrected for head and tail water effects, were used for the Tennessee river projects because the drainage areas of these projects are only partially controlled by reservoirs and their power output is influenced a great deal by head and tail-water effects, especially in time of high flows.

From the natural energy, obtained as above, a mass curve is next plotted. This curve, which covers the 6 year

period of study is shown on Chart II Appendix B Part I. The ordinate of this curve is the total available energy produced by natural stream flow at all plants from the initial month to any given month thereafter. The value of this ordinate is a function of the amount of water that has passed through each power house and the head through which the water acts at each power house.

3. Regulated Power.

Before establishing the rate lines of the regulated mass curve, the amount of energy stored in the various reservoirs, which may be called upon to produce a uniform power from the irregular flow of the stream, must be known. The energy available from the useful storage at each project is shown in Table I Sheet II. This energy is equal to the product of the accumulated heads from the mouth of the Tennessee River by the useful storage in month second feet times the constant 0.0677. The total of this potential energy, called Q.K.W.M. (meaning potential kilowatt months) is the available stored energy for the system. The amount of useful storage made available at each reservoir was gotten by the determination of its most economical draw down. When an increase in draw down is made, power output is decreased at that plant due to loss of head. However, the water let out of the reservoir passes thru other power plants and thus furnishes more power for regulation. The value of the increased potential energy is balanced against the value of the power lost by the loss of head and the economical limit of draw down is obtained.

The regulated mass curve, as shown on Chart II, may now be drawn. The vertical intercept between the natural and regulated mass curves cannot at any time be greater than the total available stored energy. The rate lines are drawn so that the greatest possible uniform rate is obtained over as long a period of time as possible. The vertical intercept between the natural and regulated mass curves shows the potential energy that is drawn out of the system at any period. When the curves coincide the reservoirs are full. When they are at a distance apart equal to the total stored energy all of the reservoirs are completely drawn down. Thus it is seen that the algebraic difference between the vertical intercept at the beginning and end of a month gives the amount of energy that has been stored or discharged in the system during that month.

4. Method of Operation of Reservoirs.

For best results a system of reservoirs should be operated so as to waste as little water as possible. Hence the reservoirs are drawn upon in proportion to their capacity to fill. By this method, if a heavy rain occurs on any drainage area, all reservoirs on that drainage area would fill proportionately and no one would spill while the others were filling.

5. Stored Water and Energy Charts.

The reservoirs in the Clinch Powell system will serve to explain the stored water and energy charts used in reservoir operation. Figure 1 shows the diagrammatical layout of the reservoirs in this system.

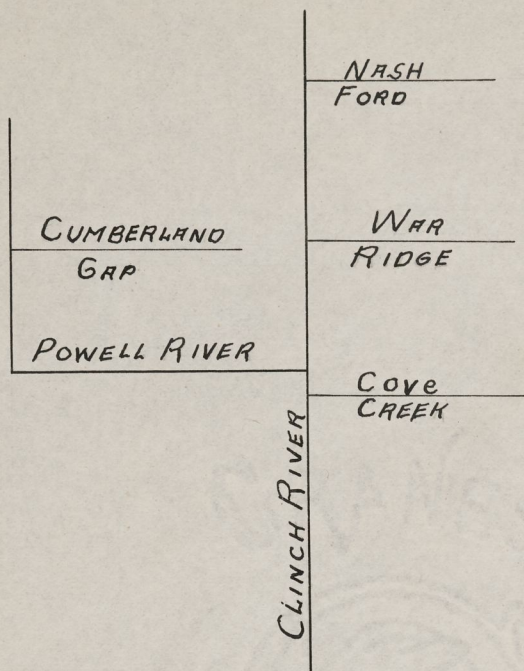


Fig. 1.

The useful storage at each project is shown in Table I Sheet II. Now one foot runoff on a square mile is equal 27,878,400 cubic feet and this is equivalent to

$$\frac{27,878,400}{2,620,000} = 10.614 \text{ month second feet}$$

The drainage area above Cumberland Gap Reservoir is 685 square miles and its useful storage is 7072.4 month second feet (MSF). Therefore, the runoff (R.O.) in feet required to fill Cumberland gap reservoir is $\frac{7072.4}{685 \times 10.614} = 0.975$ feet. Likewise, the drainage area above Nash Ford Reservoir is 490 square miles, and its useful storage is 1529.6 MSF. The runoff required to fill the reservoir then is 0.295. Now while Nash Ford is filling, War Ridge, which is below Nash Ford, fills only on the drainage area between War Ridge and Nash Ford. Nash Ford is full at 0.295. Then War Ridge, during the same time fills

$0.295 \times 10.614 \times (1500 - 490) = 3160$ MSF. The total useful storage at War Ridge is 9638.2 MSF, so that there are $9638.2 - 3160 = 6478.2$ MSF yet to be supplied. The runoff on the total drainage area of War Ridge is now available to fill the reservoir. The additional runoff to fill War Ridge then is $\frac{6478.2}{1500 \times 10.614} = 0.407$ feet. In a similar manner Cove Creek fills on the drainage area between Cumberland Gap and War Ridge until War Ridge is filled, when it continues to fill on the additional drainage^{area} of War Ridge. When Cumberland Gap is filled Cove Creek then continues to fill on its entire drainage area which is 2,949 square miles. On the stored water curves for the Clinch River system, which are shown on Chart XV, it is noticed that there are two breaks in the curve for Cove Creek. The first break is the point where War Ridge is filled and Cove Creek continues to fill on the War Ridge drainage area. The next break is the point where Cumberland Gap is filled and Cove Creek begins to fill on its entire drainage area.

It may be noted here that an adjustment was made for the fact that the intensities of runoff on the various drainage areas are not the same. The average runoff per square mile was determined for each gaging station. The average of these runoffs was used as the basis of adjustment. The runoff points for each system were then adjusted by multiplying by the ratio of the averaged runoffs to the average runoff at the gaging station.

To convert the stored water into potential energy the stored water in MSF for each runoff value is multiplied

by the accumulated head at the project times the constant 0.067. Chart 14 shows the stored energy of the Clinch system and Chart 23 shows the total stored energy on all tributaries.

6. Methods of Using Stored Water and Energy Charts.

In the discussion on mass curves it was shown that the difference between the vertical intercepts of the natural and regulated mass curves at the beginning and end of a month gives the amount of potential energy of draw or fill during that month. If the intercept is greater at the end of a month there was a draw during that month. If the intercept is less there was a fill during the month. The draws and fills in energy for each month are tabulated in chronological order and by use of the Total Stored Energy for the System Chart (Chart 23), the corresponding runoff points for the system are determined. Thus from the mass curve, Chart 2, it is seen that we begin to draw July, 1, 1903 and draw until the end of February 1904. The amount of energy required is 200 millions of K.W.D. (kilowatt days) From the stored energy Chart 23, 200 millions of K.W.D. corresponds to a runoff of 0.66 feet. During March and April 1904 we fill to the amount of 82 millions of K.W.D. which corresponds to a runoff of 0.2 feet. Since all reservoirs fill together the draw and fills start at the origin each time. Thus we fill from 0 to 0.2. May 1, 1904 we commence to draw again. This draw runs from 0 to 0.2, which we just filled and then picks up at 0.66 where we left off the preceding year, and runs to depletion at 2.2.

After the runoff points are determined as above, the draws and fills of water in MSF for each reservoir in the system

are found by the use of the stored water curves shown on Charts 4 to 23. Knowing the amount of water and the head, the power available from the use of stored water can be calculated. This power added to the natural monthly power of the project gives the total regulated monthly power output of that project.

Determination of Primary Power.

In order that economic investigation may be made it becomes necessary to determine what portion of the monthly power output at each plant, becomes primary power in the system output. If steam auxiliary capacity is introduced into the system then the prime output of the plants in the system is increased. When there is no steam capacity, then the prime power output (that available 97% of the time) is called the hydro prime base of the system. If steam capacity is introduced into the system, then the prime output is called the hydro-steam base of the system. The most economical hydro-steam base of each project, when there is an appreciable amount of storage available, was taken approximately as that secured by the normal head of the project, and its average annual flow. The hydro-steam base for the system then is the sum of the hydro-steam bases of several projects.

Two tables were prepared for each system, one table showing the prime output for each project under the hydro-prime base, the other table showing the prime power output under the hydro-steam base.

(1) Prime Power Under Hydro-Prime Base.

The prime output of each plant under the hydro-prime base was determined as follows: The sum of the average annual output of all plants in a system gives the average annual output of that system. With no steam the minimum output of the system, during the period of study, is the prime rating of the system, or in other words it is the hydro-prime base of the

system. Now to determine the prime ratings of each plant in the system, under the hydro-prime base, the average annual output of each plant is reduced in proportion to the hydro-prime base of the system divided by the average annual output of the system. Having the prime rating of each plant we can now determine the amount by which the monthly production of a plant is less than or greater than its prime rating. If the plant output is less than its prime rating the amount of power needed to bring the output up to prime is termed deficit. The amount is tabulated and a minus sign placed before it. The amount of output over the prime rating is termed excess. This excess is tabulated and a plus sign placed before it. Now the total deficits and the total excess occurring in the system for each month are determined. Since the hydro-prime base of the system by definition, is the minimum output which occurred during the period of study, then it is evident that total excesses must always be equal to or greater than the total deficits and it follows, therefore, that all deficiencies occurring in the system during each month can be supplied from the excesses at other plants. The amount of excess supplied by the plants having excess, to fill deficiencies at other plants is called prime excess. The prime excess for such plants is found by the formula;

$$\text{Prime excess} = \text{Plant excess} \times \text{Total deficiency} / \text{Total excess}.$$

The values of these prime excesses for the various plants are entered in a column in the tables.

The prime output of a plant is now its actual output

when that value is below its prime rating, or its prime rating plus its prime excess when the plant is producing excess. These values are entered in a column for each plant. The sum of this column for the period studied is shown and its average value in KW is determined. The maximum value is also given for an installation limit. From the tables thus made out the income from each plant in the system can be found and, therefore, the size of installation required.

(2) Prime Power Under the Hydro-Steam Base.

When steam capacity is introduced in a system then the method of determining the prime output of each plant is not so simple. The following discussion, taken from the report, pages 38, 39, and 40, shows clearly the method used to determine the prime power under the hydro-steam base.

Table XA has been chosen for the description.

Table XA

"This table is based on the operation of the following plants to form a system: Cove Creek, Clinton, Milton Hill, Kingston, Hales Bar, and Dam 2 (Wilson Dam). The system so formed becomes a unit producing hydroelectric power and may be treated as such in which we introduce steam capacity to raise the rate of firm power production in exactly the same manner as in case of an individual plant. From a preliminary study of the power duration curve for this system it was found approximately true that a steam capacity which will bring the prime output up to the average annual regulated output of the system may be economically installed. The average annual regulated power produced in this system during the period June 1, 1903, to May 31, 1909, inclusive, when regulated as shown by Table VIII is 475,000 KW. The minimum power production of this system and regulation is 260,200 KW. Hence to permit a continuous output to the value of 475,000 KW, a steam capacity of $(475,000 - 260,200) = 214,800$ KW must be introduced in the system.

Preparation of Table XA.

The monthly power production of the system is the sum of the production of the individual plants, hence the average annual production of the system for the period under discussion and with the method of regulation as shown by Table VIII is the sum of the average annuals of the individual plants for the same period and regulation. As the prime output of the system is raised to the average annual with the assistance of steam so will the individual primes of each plant in the system be raised to its average annual with the assistance of steam. So we can now prepare the first columns of Table XA.

Referring to Table VIII, we note the average annual output of Cove Creek Plant is 50,400 KW. The actual production in hydropower at Cove Creek for the month of September, 1903, is 92,000 KW, which is in excess of its prime rating (50,400 KW) by 41,800 KW. This amount is entered in the first column, headed "Excess or deficit", and is preceded by a plus sign which indicates the amount to be an excess. The actual production at Cove Creek for the month of July 1903, is 35,400 KW, which is less than its prime rating (50,400 KW) by 15,000 KW. This amount is entered in the first column and preceded by a minus sign which denotes it to be a deficiency. The column is completed for the period in the same manner entering the values as excess or deficit as they occur. In like manner the first column is prepared for Clinton, using its prime rating of 5,600 KW as a base for determining excess or deficiencies.

When the aforementioned columns are prepared for all projects, the total excesses and deficiencies are determined for each month by adding across all the excesses occurring at plants in the system for that month and adding the deficiencies which occur at the remaining plants in the system for that month.

Now if the total excesses for a given month are greater than the total deficiencies, we can supply the full deficiencies at the plants where they occur from the excesses at other plants where such occur by virtue of interconnection; e.g., during the month of June 1903, as shown by Table XA, there is an excess produced at Hales Bar and Dam 2 which totals 58,500 KW. There are deficiencies existing at Cove Creek, Clinton, Milton Hill, and Kingston, which totals 36,200 KW. The problem now confronting us is to determine the portion of the excesses produced, at Hales Bar and Dam 2, respectively, that is converted to prime power by virtue of supplying the deficiencies in firm power existent at the other plants in the system. The solution is to interchange sufficient power from these plants to fill the existing deficiencies in proportion to the excess existing at each plant, respectively. Thus: Dam 2 has an excess of 47,400 KW. Its proportion converted to firm power by interchange is

$$\frac{(\text{Total deficiency}) 36,200 \text{ KW}}{(\text{Total excess}) 58,500 \text{ KW}} \times (\text{Excess at plant}) 47,400 \text{ KW} = 29,300 \text{ KW}.$$

Hales Bar has an excess of 11,100 KW. Its proportion converted to firm power by interchange is

$$\frac{36,200}{58,500} \times 11,100 = 29,300 \text{ KW.}$$

Much can be said to support the fairness of thus apportioning the conversion of excess power to firm. Briefly, it throws the burden of providing the power for interchange on those plants where the most power is available and whose installations are more naturally sufficient to meet the demand.

The preceding paragraph treated of the case in which the total power in the system is in excess of the system prime. We have two other conditions which will exist, namely, when the total excesses just balance the total deficiencies and where the total deficiencies are greater than the total excesses. When the total excesses and deficiencies balance it is evident that all deficiencies will be filled and all excesses converted to prime power. In case the total deficiencies are greater than the total excesses it is evident that all excesses will be converted to prime power, but the deficiencies can be supplied only to an amount equal to the total excess. We have now to determine by what amounts the deficient plants may draw on the total excess to improve their power output. This is accomplished by granting the excess to the deficient plants in the ratio of their deficiency to the total deficiency; e.g., in the month of September 1903, the total deficiencies is 243,000 KW. The total of the excesses is 57,000 KW. The deficiency existing at Hales Bar is 48,400 KW.

$$\frac{(\text{Total excess}) 57,000 \text{ KW}}{(\text{Total deficiency}) 243,000 \text{ KW}} \times (\text{Deficiency at plant}) 48,400 \text{ KW} = 11,300 \text{ KW}$$

which is the amount Hales Bar may draw for the improvement of its output. The deficiency existing at Dam 2 is

194,600 KW.

$\frac{57,000}{243,000} \times 194,600 = 45,700 \text{ KW.}$ which is the amount of the excess Dam 2 may draw for the improvement of its output.

In accordance with the two preceding paragraphs, the column labeled "Interchange" was prepared for each plant in the system, showing the values of power supplied the plant as positive quantities and the values of power supplied by the plant to fill deficiencies at other plants in the system as negative quantities. In other words, power coming to a plant is shown positive as an augmentation and power sent from the plant is shown negative as a negation.

Next in order is the preparation of a column for each plant headed "Regulated hydro output". The values to be entered in this column is the actual hydroelectric power which is available at the plant for commercial consumption and contains power produced at the plant when it is operating below its prime output plus power sent to it in interchange when such is available or the prime output of the plant when it is producing an amount equal to or in excess of its prime. The purpose of this column is for determination of the steam requirements at the plant as the difference between the value given in this column for any given month and the prime output of the plant is the steam required for that month; e.g., for the month of April 1907. At the Kingston plant the actual production was 10,000 KW as shown by Table VIII, which is less than its prime. There is an interchange of plus 800 KW available, which brings the regulated hydro output to the value of

10,000 plus 800 equals 10,800 KW. The prime rating for this plant is 11,200 KW. Hence for the month in question the steam requirements is $11,200 - 10,800 = 400$ KW.

The steam requirements for each month have been calculated and entered in the column headed "Steam required" for each plant.

The preparation of a final column for each plant is quite necessary. This is the column headed "Prime output" and shows the exact amount of prime hydro power produced at the plant each month. The values are obtained directly from the KW output column of Table VIII when the output is less than the prime rating of the plant; or in case the production is over the prime rating the prime output is the sum of the prime rating and the interchange sent from the plant; e.g., during the month of May 1907, the Milton Hill plant produced below its firm rating, so its actual production was entered (11,500 KW). June 1907 the same plant produced more than its prime rating, but as there was no power sent from the plant in interchange the value entered was its firm rating (22,000 KW). July 1907 the same plant produced more than its prime rating and sent out power in interchange, so its prime was (Table XA) 22,000 plus 15,200 equals 37,200 KW."

The total installation at each plant is the installation required to maintain the hydro-steam base, which has been previously explained, under an assumed annual load factor of 50 percent. It is assumed that the steam capacity, while in use, is operating under a 100 percent load factor and that the hydro installation is carrying the peak load. Then the total hydro installation required is the total installation, at 50 percent load factor, minus the steam installation.

Conclusions

Something like five years were spent in making the survey and over one million dollars were expended. The work has been so voluminous that the necessary time to check over all the results obtained, has not been available to the writer. In fact no attempt has been made to check results. However, it is the writer's opinion that the methods employed by the Engineers in charge of the survey are good sound methods. While some of the operations seem long and roundabout, yet it must be remembered that it is quite a difficult matter to determine the available water power on a large water shed.

On first thought it seems that the amount of power available as given by Major Watkins in his report is very high, in fact beyond reason. On closer study, however, the amount as given in the report does not seem to be so unreasonable. It must be remembered that the results obtained by Major Watkins hold true only when all the projects belong to one interconnected system and when they are under a single management. Furthermore it is assumed that a ready market for all power produced is available. While at present it seems impossible to meet all the above requirements, yet from the modern trend to consolidation and the rapid industrial development in the south, these requirements may be met in the near future. We may conclude, therefore, that while the results obtained through the survey are theoretical yet they may be by no means impractical.

APPROVAL

The foregoing thesis is hereby approved as a creditable study of an engineering subject, carried out and presented in a manner sufficiently satisfactory to warrant its acceptance as a prerequisite to the degree for which it has been submitted. It is to be understood that by this approval the undersigned does not necessarily endorse or approve any statement made, opinions expressed, or conclusions drawn therein, but approves the thesis only for the purpose for which it is submitted.

Name

J. A. Switzer

Title

Prof. of H. & S. Eng.