MISSOURI S&T

Missouri University of Science and Technology

Scholars' Mine

International Conferences on Recent Advances in Geotechnical Earthquake Engineering and Soil Dynamics

1991 - Second International Conference on Recent Advances in Geotechnical Earthquake Engineering & Soil Dynamics

14 Mar 1991, 10:30 am - 12:30 pm

Dynamic Properties of Fine-Grained Coal Refuse

C. Robert Ullrich
University of Louisville, Louisville, Kentucky

Barry K. Thacker
ERCE, Knoxville, Tennessee

Nancy R. Roberts
ERCE, Knoxville, Tennessee

Follow this and additional works at: https://scholarsmine.mst.edu/icrageesd

Part of the Geotechnical Engineering Commons

Recommended Citation

Dynamic Properties of Fine-Grained Coal Refuse

C. Robert Ullrich
Professor, University of Louisville, Louisville, Kentucky

Barry K. Thacker
Principal Geotechnical Engineer, ERCE, Knoxville, Tennessee

Nancy R. Roberts
Geotechnical Engineer, ERCE, Knoxville, Tennessee

SYNOPSIS: A simplified method of slope stability analysis is presented for upstream-constructed coal tailings dams subjected to earthquake shaking. The method employs a conventional method of slices approach, in which dynamic loads are represented as psuedostatic forces applied to each slice. Excess pore water pressures are estimated from cyclic triaxial tests performed on specimens of fine coal refuse.

Cyclic triaxial test results are presented for fine coal refuse materials from six sites in the western Appalachian region. Measured excess pore water pressure values appear to be influenced by fine coal processing procedures, although material plasticity and grain characteristics are also important. Additional studies are ongoing.

INTRODUCTION

A significant expense associated with coal min-
ing is the safe disposal of waste products.
Coarse. coal refuse is generated during the coal
excavation process and contains a sizable shale
fraction. Fine coal refuse is generated during
the coal scrubbing operation and, at the time
of disposal, exists in slurry form.

A relatively inexpensive method to dispose of
waste products is to construct a tailings im-
poundment. In mining operations where re-
latively small quantities of coarse refuse are
produced, the upstream method of construction
is preferred. As shown in Figure 1, a starter
dam is constructed of coarse refuse and the fine
refuse is pumped behind the starter dam. When
fine refuse materials have consolidated under
self weight, the dam can be raised in a second
stage. After multiple raisings by the upstream
method, a significant portion of the tailings
dam consists of fine refuse.

The stability of an upstream-constructed tail-
ings dam depends largely on shearing resistance
generated within the fine refuse. Because fine
refuse materials are fine sand- to silt-size
and are deposited in a loose saturated
condition, seismically induced pore water
pressures must be considered in a stability
analysis.

Since 1986, ERCE, Knoxville, Tennessee, and the
University of Louisville have investigated the
seismic stability of six upstream-constructed
coal tailings dams in the western Appalachian
region between eastern Tennessee and eastern
Ohio. A simplified method of analyzing the
stability of these dams was developed, which
incorporates cyclic triaxial testing of fine
coal refuse materials. In this paper, the
method of stability analysis is described and
results of laboratory tests performed on fine
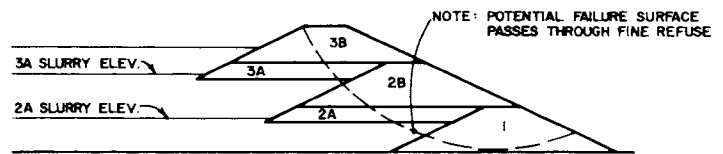coal refuse materials are presented.

Fig. 1   Upstream Construction Method

STABILITY ANALYSIS

The method of analysis used to investigate the
stability of the six tailings dams described in
this paper has been presented by Thacker et al.
(1988). The method is a variation of that
developed by Klohn et al. (1978). The
stability analysis is an effective stress
analysis using a conventional method of slices
slope stability technique, incorporating
estimates of excess pore water pressure
generated by earthquake shaking. The computer
program STABR (Duncan and Wong, 1985), which
employs the Bishop Modified Method of Slices,
was used to analyze stresses along a slip
surface passing mainly through fine coal refuse.
An example cross-section is shown in Figure 2.

The computer program STABR calculated and out-
put values of normal stress σ_n and shear
stress τ on the base of each slice, as shown in
the inset in Figure 2. The effective stress on
the base of each slice was calculated as

$$\tilde{\sigma}_n = \sigma_n - u_s \qquad (1)$$

where u_s is the static pore water pressure.
Major and minor principal stresses, $\tilde{\sigma}_{1s}$ and
$\tilde{\sigma}_{3s}$, were calculated for static conditions for
each slice using the geometry of the Mohr
circle shown in Figure 2. The consolidation
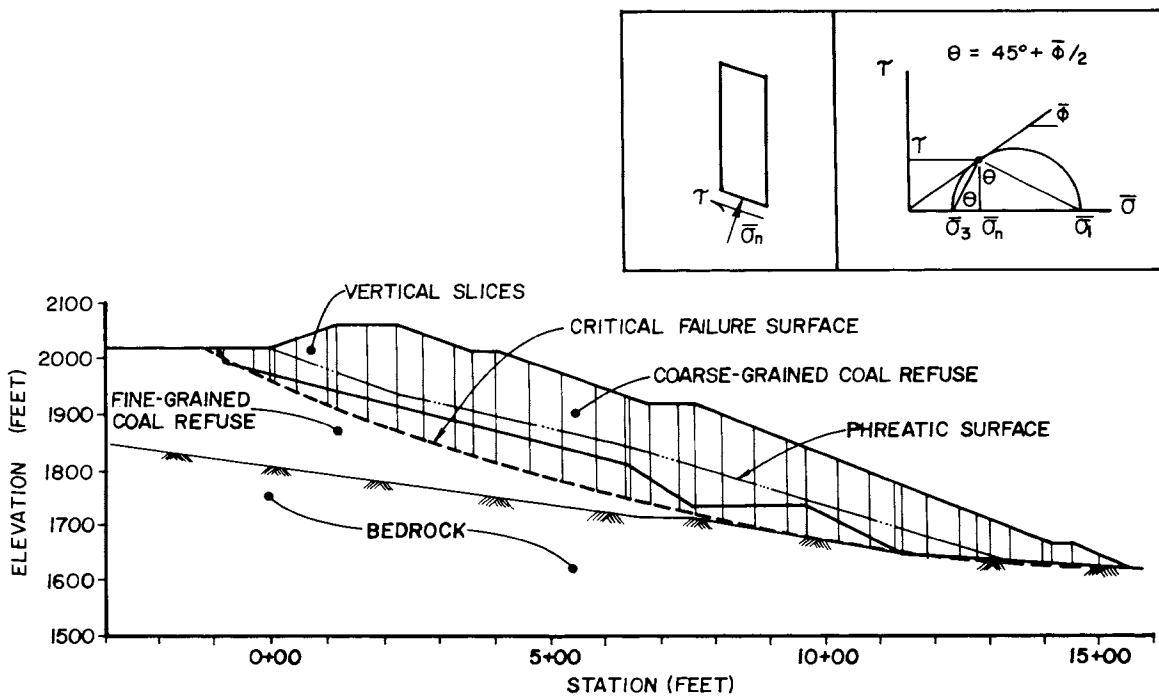ratio K_c was calculated for each slice using

Fig. 2   Cross-Section of Abner Fork Impoundment

the equation

$$K_C = \bar\sigma_{1s}/\bar\sigma_{3s} \qquad (2)$$

The range of values of $\bar\sigma_{3s}$ for all slices analyzed was used to select consolidation pressures for cyclic triaxial testing. All tri-axial test specimens were consolidated aniso-tropically using an average value of K_C for each analysis.

The psuedostatic approach was used to estimate dynamic stresses along the slip surface. A psuedostatic force kW was applied at mid-height of each slice having weight W. The seismic co-efficient k was chosen using regional charts of k, such as that presented by Donovan et al. (1978). The computer program STABR was used to perform a psuedostatic slope stability analysis using the appropriate value of k and to cal-culate σ_n and τ on the base of each slice. Values of dynamic principal stresses $\bar\sigma_{1d}$ and $\bar\sigma_{3d}$ were calculated for each slice using values of σ_n and τ. The cyclic stress ratio SR was calculated for each slice using the equation

$$SR = \frac{(\bar\sigma_{1d}-\bar\sigma_{3d})-(\bar\sigma_{1s}-\bar\sigma_{3s})}{2\,\bar\sigma_{3s}} \qquad (3)$$

The average value of SR for all slices was used to dynamically load cyclic triaxial test specimens.

Cyclic triaxial tests were performed on each of the six fine refuse types to estimate excess pore water pressures generated during earth-quake shaking. All tests were performed on saturated specimens consolidated from thick

slurries. Four tests were performed on each refuse type using a CKC e/p Cyclic Loader (Chan, 1981). Values of effective confining pressure, consolidation ratio, and cyclic stress ratio were chosen as described above. Specimens were dynamically loaded by uniform cycles of stress using a frequency of one cycle per second. The number of cycles of loading was chosen as follows: The 50-year, 95% prob-able earthquake magnitude was estimated using data presented by Algermissen et al. (1982). The number of equivalent uniform cycles corresponding to an earthquake of this magni-tude was estimated using data presented by Seed et al. (1975). Parameters used in cyclic tri-axial testing of each refuse type are listed in Table I.

Each cyclic triaxial test produced a record of pore water pressure build up versus time, from which the maximum excess pore water pressure was normalized by dividing $\bar u_{max}$ by the con-solidation pressure $\bar\sigma_{3c}$. Values of pore pressure ratio ($\bar u_{max}/\bar\sigma_{3c}$) were plotted versus $\bar\sigma_{3c}$, which permitted estimation of excess pore water pressure on the base of each slice.

A final slope stability analysis was performed, in which a psuedostatic force kW was applied to each slice and pore water pressures were esti-mated by adding excess pore water pressures from cyclic triaxial testing to static pore water pressures. In each of the six cases analyzed, the dynamic factor of safety was at least 1.2.

TABLE I. Parameters for Cyclic Triaxial Testing

Site	Location	$\bar{\phi}$ for Fine Refuse,deg.	Range of $\bar{\sigma}_{3s}$ for Tests,KPa	Consolidation Ratio,Kc	Cyclic Stress Ratio,SR	Number of Cycles	Frequency, cps
Abner Fork	Eastern Kentucky	30	100-500	2	0.2	8	1
Bennetts Branch	Eastern Kentucky	30	100-400	2	0.2	8	1
Gum Branch	Eastern Tennessee	31	60-660	2	0.2	8	1
TCC No.1	Eastern Tennessee	30	60-600	2	0.2	8	1
Meigs	Eastern Ohio	29	60-600	2	0.2	8	1
Muskingum	Eastern Ohio	32	60-600	2	0.2	8	1

PHYSICAL PROPERTIES

Index tests, including specific gravity tests, grain size analyses, and Atterberg Limits tests, were performed on fine coal refuse specimens from each site. Results of these tests are summarized in Table II (right). Grain size distributions are shown in Figure 3.

Dynamic slope stability analyses performed for each site resulted in the following parameters being used for all tests: consolidation ratio = 2, cyclic stress ratio = 0.2, number of uniform stress cycles = 8, and frequency of stress cycles = 1 cps. Since sites were grouped closely in the western Appalachian region, a seismic coefficient of 0.1 was used in each slope stability analysis. Also, the 50-year, 95% probable earthquake magnitude was 6.1 for each site. Finally, values of angle of internal friction (Table I) were similar for all six materials (Table I). Therefore, it is not surprising

TABLE II. Index Properties of Fine Coal Refuse

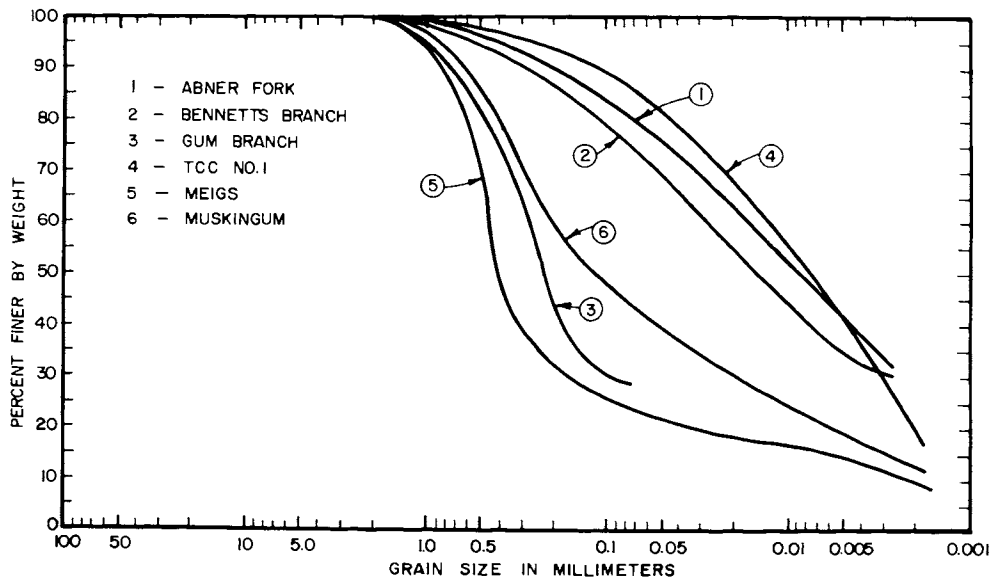| Site	Specific Gravity	Percent Fines	Liquid Limit	Plastic Limit
Abner Fork	1.85	82%	35.9%	26.6%
Bennetts Branch	-	76	43.6	30.9
Gum Branch	1.87	31	nonplastic	
TCC No.1	1.97	86	nonplastic	
Meigs	2.49	24	nonplastic	
Muskingum	1.79	44	31.1	23.5

Fig. 3 Grain Size Distributions for Fine Coal Refuse

that specifications for cyclic triaxial tests would be the same for all six materials. This circumstance permitted direct comparison of cyclic triaxial test results to investigate similarities and differences in behavior.

Although values of excess pore pressure after eight cycles of deviator stress were required for dynamic slope stability analyses, many cyclic triaxial tests were continued through as many as 50 cycles of loading. Further, although test results in which a cyclic stress ratio of 0.2 was used were required for dynamic slope stability analyses, additional cyclic triaxial tests were performed in which other cyclic stress ratio values were used. An example of a test series in which cyclic stress ratio was varied is shown in Figure 4 for the Muskingum material. In this figure, pore pressure ratio at the end of each cycle ($\bar{u}/\bar{\sigma}_{3c}$) is plotted versus number of cycles for four cyclic triaxial tests in which cyclic stress ratio was varied. Each test specimen was consolidated under stresses 400 kPa (vertical) and 200 kPa (lateral). Each specimen was subjected to 50 cycles of deviator stress at a frequency of 1 cps. Two features shown in Figure 4 are significant: First, pore pressure ratio increases gradually with number of cycles for cyclic stress ratio values of 0.1, 0.15, and 0.2, indicating a progressive breakdown in specimen fabric when subjected to cycles of deviator stress small in comparison to consolidation pressure. Pore pressure ratio increases rapidly with number of cycles for SR = 0.3, indicating a rapid fabric breakdown under cycles of deviator stress large in comparison to consolidation pressure. Secondly, pore pressure ratio reaches a constant value of about 0.72 after about 20 cycles of stress for a cyclic stress ratio of 0.3; i.e., liquefaction did not occur.

As mentioned above, values of pore pressure ratio of interest in dynamic stability analyses corresponded to eight cycles of loading using a cyclic stress ratio of 0.2. None of the materials tested liquefied under these test conditions. Values of pore pressure ratio are plotted versus confining pressure in Figure 5 for all materials tested. Test conditions were those outlined in Table I. Test results shown in Figure 5 may be divided into two groups by site: One group of sites consists of sites in eastern Kentucky and Ohio. Pore pressure ratios measured for materials from these sites fall between 0.01 and 0.20. At these sites, a fine coal cleaning process is employed, which removes sand-size coal particles from the fine coal refuse. Also, three of the four materials from eastern Kentucky/Ohio sites possess measurable plasticity, which serves to limit pore water pressure build up under cyclic loading.

The second group of sites consists of two sites in eastern Tennessee where fine coal cleaning is not employed. Pore pressure ratios for these materials range from 0.40 to 0.60. Neither of these materials possesses measurable plasticity, although the TCC No. 1 material contained 86% fines.

Although the groups of sites described above and shown in Figure 5 imply that pore pressure ratio is controlled by the use or nonuse of fine coal cleaning, it is obvious that other factors influence pore pressure ratio, notably material plasticity. As shown by the specific gravity values listed in Table II, all materials contain an appreciable amount of coal. Also, all materials contain a significant percentage of fines, although this parameter bears no apparent relation to pore pressure ratio. It is hoped that as additional cyclic triaxial tests are done on materials from other sites and more data points are added to Figure 5, a clear pattern of behavior will emerge which will allow
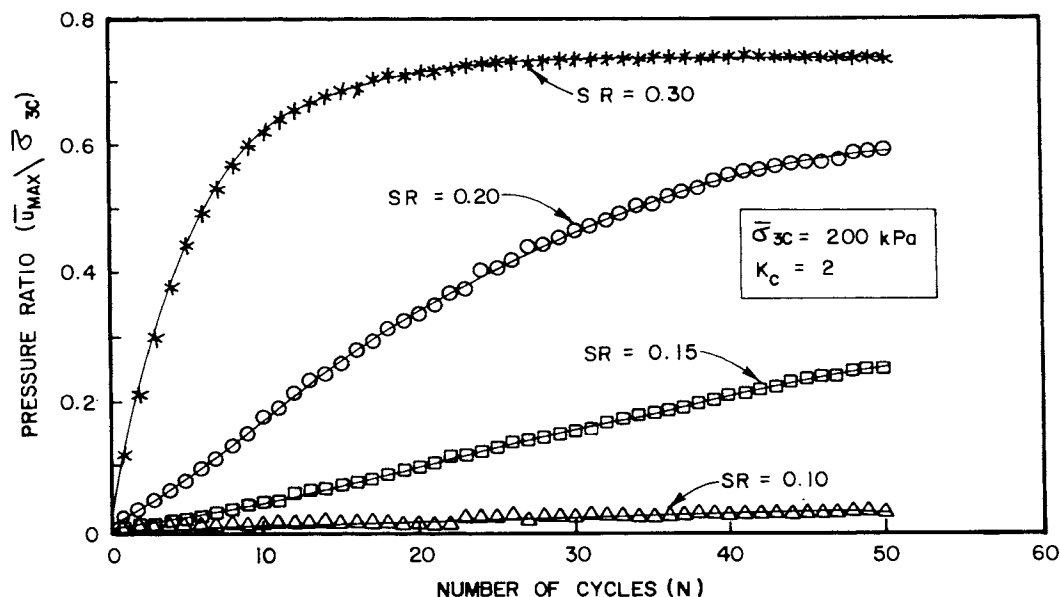

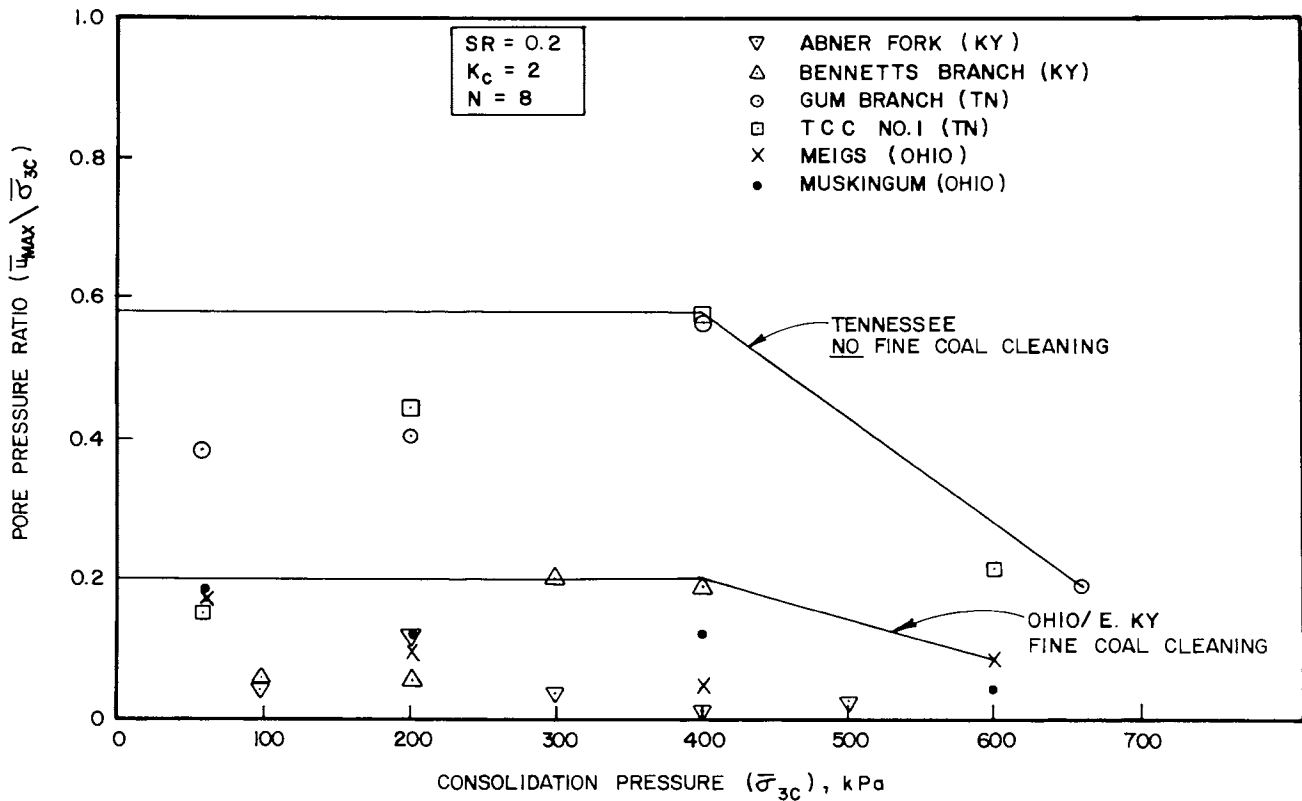Fig. 4 Cyclic Triaxial Test Results for Muskingum Material

Fig. 5   Pore Pressure Ratio Values for All Sites

designers of coal tailings dams to estimate ex-
cess pore water pressures generated by seismic
shaking.

CONCLUSIONS

A simplified method of slope stability analysis
for coal tailings dams has been presented which
accounts for earthquake loading and accompany-
ing build up of excess pore water pressure
within the embankment.   The slope stability
analysis uses a conventional method of slices
approach in which the effect of the dynamic
loading is represented as a psuedostatic force
applied to each slice.   Excess pore water
pressure values are estimated on the basis of
cyclic triaxial tests done on fine coal refuse
materials.   The procedure for specifying cyclic
triaxial test parameters is explained in this
paper.

Cyclic triaxial test results were presented for
fine coal refuse materials from six sites.   Al-
though none of these materials may be expected
to liquefy under conditions of dynamic loading
at each site, two types of behavior were noted:
for sites at which fine coal cleaning was used,
measured pore pressure ratios varied from 1% to
20%.   For sites without fine coal cleaning,
pore pressure ratios varied from 40% to 60%.
Other factors, such as plasticity, character of
fines, and percentage of fines, are thought to
influence pore pressure ratio; however, more
data is needed and further studies are in pro-
gress.

REFERENCES

Algermissen, S. T., et al. (1982), Probabilistic
    Estimates of Maximum Ground Acceleration and
    Velocity in Rock in the Contiguous United
    States, U.S. Geological Survey Open-File Re-
    port 82-1033.

Chan, C. K. (1981), "An Electropnuematic Cyclic
    Loading System," Geotechnical Testing Journal,
    ASTM, Vol. 4, No. 4, pp. 183-187.

Duncan, J. M. and K. S. Wong (1985), STABR: A
    Computer Program for Slope Stability Analysis
    with Circular Slip Surfaces, Microcomputer
    Version, 2nd ed., User's Manual, Virginia
    Polytechnic Institute and State University,
    Department of Civil Engineering, 19, pp.

Klohn, E. J., et al. (1978), "Simplified Seismic
    Analysis for Tailings Dams," in Earthquake
    Engineering and Soil Dynamics, ASCE, Vol. 1,
    pp. 540-556.

Seed, H. B., et al. (1975), Representation of
    Irregular Stress Time Histories by Equivalent
    Uniform Stress Series in Liquefaction Analyses,
    Report No. EERC 75-29, University of
    California, Earthquake Engineering Research
    Center, Berkeley.

Thacker, B. K., et al. (1988), "Evaluation of a
    Coal Refuse Impoundment Built by the Upstream
    Method," in Hydraulic Fill Structures, ASCE,
    Geotechnical Special Publication No. 21, pp.
    730-749.