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Scene between interchanges 20 and 19, Connecticut and Wisconsin Avenues, on the Maryland portion of the Capital Beltway, Interstate Highway 495

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Timesharing Between Two Driving Tasks

Simulated Steering and Recognition of Road Signs

BY THE TRAFFIC SYSTEMS RESEARCH DIVISION BUREAU OF PUBLIC ROADS

Reported by [1] Burton W. STEPHENS, Research psychologist, and Richard M. MICHAELS, Chief, Human Factors Research Branch [2]

The reported study was designed to determine general driver ability to steer a vehicle while simultaneously searching for a specific sign and to measure the timesharing basis used in performing the two tasks. Four types of analyses were conducted to determine: (1) the influence of constituents of the tracking task upon performance of the search-and-recognition task, and (2) the influence of components of the search-and-recognition task upon tracking performance. These included testing of the significance of the differences between means of each of the treatments used. Integrated tracking error variances were analyzed, as were the recognition time variances for each of the conditions associated with the dynamic recognition task. In the second kind of analysis, basic to the inquiry was a test of the generalized timesharing hypothesis, which states that there is a trade-off between the two tasks; that very erroneous performance on one of the tasks is highly correlated with relatively accurate performance on the other. The erroneous recognition of signs presented was examined in the third kind of analysis. The fourth kind of analysis was made of control tests that were conducted to: (1) ascertain the possible effects of learning occurring throughout the experiments, and (2) make a comparison of experimental and baseline test conditions in which the tracking tasks and search-and-recognition tasks were presented singly. The tracking data and recognition-time data are separately presented, and the interactions of the two performances are considered together in an examination of the trade-off hypothesis.

Analysis of individual timeshared trials indicated that performance on each of the two tasks is essentially independent. Tests of the specific hypotheses indicate that operator pacing increases as the complexity of the two tasks increases. However, in all comparisons of the independent tasks and their timeshared counterparts, the performance of test operators deteriorated when the tasks were shared. The tests were conducted under highly controlled conditions in the laboratory.

Introduction

MAINTAINING alinement of an automobile on public highways and roads is an essential part of the task of driving and requires the driver to operate the vehicle within somewhat narrow bounds. In addition, he must search for, select, and relate a variety of road signs to his progress and handling of the vehicle. These two tasks require two very different visual tasks that compete for the driver's time and must in some way be evaluated so that minimal variation in steering is achieved. Interactions between the two tasks have not been reported previously by researchers. How these two types of operator performance interact and their effects on highway traffic is not well understood. Yet the efficiency and safety of the highway system depends upon the proficiency of drivers in processing the two tasks. The experiments discussed here provide some basis for the baseline conditions predicted in the research described in this article.

Definitions

The following list contains definitions for some terms used in this article:

Amplitude.—Amplitude is the extreme range of movement obtained by a periodic oscillation translated onto the abscissa of the display (in centimeters when expressed in terms of the display face, or in degrees when expressed in terms of angular extent in relation to location of the eye and the display face).

Coincidence circuit.—A coincidence circuit is an electronic circuit in which an output signal is produced only when each of two or more input pulses occur simultaneously.

Exteroceptive cues.—Exteroceptive cues are information presented to sense organs—visual cues.

Frequency.—Frequency is the number of cycles per second in a periodic vibration.

Kinesthetic cues.—Kinesthetic cues are information (not visible) presented to sensory nerves in the muscles, tendons, and joints.

Line of regard.—The line of regard is an imaginary horizontal straight line through the center of the forehead of the test operator and perpendicular to the plane of a display.

Proprioceptive feedback.—Proprioceptive feedback is an indication of the degree of performance of the muscles, tendons, and joints of the human operator.

Psychomotor response.—Movements of or pertaining to muscular action ensuing directly from a mental process is a psychomotor response.

Objective velocity.—Objective velocity is the first derivative of position with respect to time.

Rho-correlations.—Rho-correlations are rank ordered or ordinal scaled relationships, the degree of which covers a range of plus and minus unity.

Sensory modality.—Sensory modality is a receptor system, such as sight or hearing.

Signing practices.—Signing practices are presently adapted means of presenting road sign information, such as speed limit, route destination, intersection, and curvature.

Sinusoidal waveform or input.—A periodic vibration that rises to its maximum and minimum in equal time by smooth gradation is a sinusoidal waveform or input.

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[1] Presented at the 43d annual meeting of the Highway Research Board, Washington, D.C., Jan. 1964.

[2] Members of the Bureau of Public Roads acted as test operators during this study, and members of the Electro-Mechanical Research Branch of the Office of Research and Development aided in developing a facility for Human Factors laboratory research.

Stimuli separation and speed.—The angular displacement between targets or pertinent aspects of displays and the rate of angular change of such a separation is referred to as stimuli separation and speed.

T-test.—The *t*-test is a statistical method used for testing hypotheses comparing the average errors under different conditions.

Time pacing.—Time pacing is the manner in which time is devoted to one task and then another; a pattern that may reveal a regular recurrence.

Visual feedback.—An indication of the degree of performance of visually presented tasks is termed "visual feedback."

Findings

The main findings of the study reported here were:

(1) When a test operator was required to share his time between two tasks, each type of performance was poorer than when he performed only one task.

(2) An increase in the number of message units that appeared in the recognition task did not affect the operator's performance of simulated steering.

(3) The increase in the number of message units that appeared in the recognition task increased the time required to recognize the key word.

(4) As speed of the simulated steering task increased, recognition time decreased.

(5) If a specific message had equal liklihood of appearing or not appearing, recognition time was greater when the key word did not appear.

Background

One-dimensional tracking

Tracking has been assumed to be an analog of the steering task and is so defined in this article. Adams has described it as a paced task where an ". . . externally driven input signal defines an index of desired performance and the operator activates the control system to maintain alignment of the output signal of the control system with the input signal. The discrepancy between the two signals is the error and the operator responds to null the error" (*1*).[3]

Compensatory tracking—simulated steering—provides a signal of any error and requires only a reference and control mechanism. Such a situation is analogous to minimizing deviations from a prescribed path or roadway. Configurations may be displayed on the face of an oscilloscope. Use of a low-frequency sinusoidal wave form provides a geometrically smooth input similar to roadway curvature. The amount of error correction that must be achieved within a relatively stable response period increases in proportion to the frequency of the tracking signal. This requirement may be considered to be an information load. As the frequency input increases, the information load also increases. Consequently, any time that is consumed in the evaluation of other portions of the environment would be expected to lead to less proficient guidance.

Test operators match input frequencies up to 3 or 4 cycles per second (c.p.s.), according to Ellson and Gray (*2*). McRuer and Krendel (*3*) put this figure around 1 c.p.s. Specific controls or display configurations may affect the psychomotor response sufficiently to account for these differences.

In a field situation, amplitude has been shown to affect the operator's error-free performance of guidance. Results of a study were discussed at the National Conference on Driving Simulation in Santa Monica, Calif., late in February 1961, under the title *Simulation Techniques in Automotive Human Factors Research.* It was reported that on a test track having sine wave patterns, drivers reduced their speed in order to effectively track higher amplitude curves. The field study under discussion suggested that increments of angular change remain constant over a time span that probably is associated with the test driver's response time, or an increment of angular displacement of the course target.

Brown (*4*) has shown that many examples involving objects in motion may be seen as a constant proportion of the velocity of angular change, which suggests that a single measure may predict tracking error for a particular control configuration.

Recognition time

Recognition has been defined by Munn (*5*) as the ability ". . . to differentiate beween the familiar and the unfamiliar or what has been experienced and what is new." Recognition time may be defined as the time delay between the presentation of some information display and recognition of it by an observer. In the research reported in this article, search-and-recognition activities were measured. The distinction between simple recognition and the in-motion task discussed here is that the in-motion task was not localized; it had to be pursued, at least briefly. The message had to be searched for, followed, recognized, and finally reported by some action.

In the static state, discriminations have been evaluated from measures of time consumed in making a decision. Considerable evidence supports the assumption that recognition time increases as the task becomes more complex. Classical experiments indicate that reaction time increases as the number of alternate responses increase (*6*, *7*). In 1960, R. D. Desrosiers of the Bureau of Public Roads, in a study of simulated driving, showed that the mean recognition distance of a test operator approaching a sign at a constant speed varied inversely with the number of alternate messages on the sign. On the basis of Desrosiers' laboratory results, an increase in recognition time would be predicted. Although Desrosiers found no significant differences in recognition time in field test data, this lack of significant differences was attributed to the great variance of performance in field situations.

Task sharing

Many studies have been conducted from which information on separate and discrete tasks was organized in the most desirable way and translated to control devices by human operators (*8*). Most of these studies have involved the sharing of tasks between more than one sensory modality.

Briggs and Howell (*9*) have provided data on the interaction of two continuous tracking activities in which the authors considered the effects of speed for each stimulus. These researchers have considered both peripheral and central aspects of the timesharing process. Although more than one source of information was to have been observed during their study, three major differences existed between their study conditions and those reported in this article. First, both tasks required tracking performance that demanded forced pacing in a pattern of alternation between inputs by the operator, unless he neglected one of the two components of the timesharing situation. Second, the spatial separation of targets was fixed for any one experimental condition, reducing search time and also the applicability of such a configuration to the situation in question; that is, information sources used in the Briggs and Howell study were themselves in motion, although the observer was not. Third, neither task required the separate decoding of visual information implicit in the recognition task. Results of all of the studies reviewed indicated a general degradation of performance as task complexity was increased.

In an earlier study conducted at the Institute of Transportation and Traffic Engineering at UCLA (*10*), as many as 15 percent of the drivers were reported to have ". . . made poor selection of routes due to confusion of messages on the signs . . ." or because they ". . . had not seen the signs in time to make proper maneuvers." The driver is faced with a dilemma in negotiating high-speed roadways. A wrong decision in selecting a ramp may cause the driver to go frustrating miles away from his desired destination.

Procedure

On the basis of information developed by other researchers, six hypotheses were formulated for the research reported in this article.

Hypotheses tested

- Tracking error will increase proportionally with the tracking frequency and amplitude.
- Tracking error will increase proportionally with the number of words on the sign (complexity of the search-and-recognition task).
- Recognition time (measured as time from the sequence beginning) will be proportional to the frequency and amplitude of the tracking signal (a sine wave).
- The number of false alarms in recognition will increase proportionally as the frequency and amplitude of the tracking signal is increased.
- Tracking error will not be dependent upon the presence or absence of a specific message on the sign.

[3] References cited by italic numbers in parentheses are listed on p. 88.

• A systematic inverse relationship will exist between tracking error and recognition time if timesharing is determined on an individual trial basis.

The six hypotheses suggested uniform trends but did not predict quantitative values. They were intended to ascertain the relative effects of the concurrent operations that test operators were requested to perform.

Experimental design

A balanced, five-factorial design, in which randomized presentations were made of the different search-and-recognition levels for each tracking condition, was employed. Six test operators were given tracking tests under two amplitude and three frequency conditions. A film that had signs containing two, four, or six messages was used in the tests. The key message, which was PIDFOH, was in half of the presentations. Each of the test conditions was presented to each test operator five times.

Control tests of tracking performance were paired with each of the timeshared (experimental) runs. In the first half of the trials a control test requiring tracking without the filmed presentation was followed by an experimental trial where both tracking and search-and-recognition activities were to be performed. The latter half of the trials for each operator was a reversal; each experimental trial was followed by a control test. Data were collected from 30 trials for each of the tracking control conditions.

Two control trials providing only recognition information were conducted during the first and second halves of the experimental session. No tracking was required.

The tracking task

The test operator was seated, as shown in figure 1, at a console that contained a circular cathode-ray tube (c.r.t.) display, the diameter of which was 12.5 centimeters. The c.r.t. display was situated slightly below the line of vision at a 12-degree tilt to the vertical axis of the room. A low intensity, encompassing brightness of 10^{-3} *m*L surrounded the scope face. The brightness of the tracking signal was approximately 1 *m*L.

The signal was a point of light normally driven horizontally across the face of the c.r.t. and was to be corrected by manipulation of a handcrank. The control mechanism had a 7.5-centimeter diameter, and a 2.25-kilogram flywheel was attached to smooth the jerking movement of the control system. Two of these cranks were located so that one could be operated easily by the test operator with whichever hand was preferred. The two cranks were mounted on the face of the console at a 45-degree angle to the floor. The crank was adjustable to such a height that the elbow required support by a rubber pad. Hence, rotary control was achieved almost entirely by wrist motion.

The search-and-recognition task

On a rear projection, ground-glass screen a series of motion pictures was presented that contained scenes of a new section of the Interstate Highway near Washington, D.C. The screen was located 8 feet from the seated

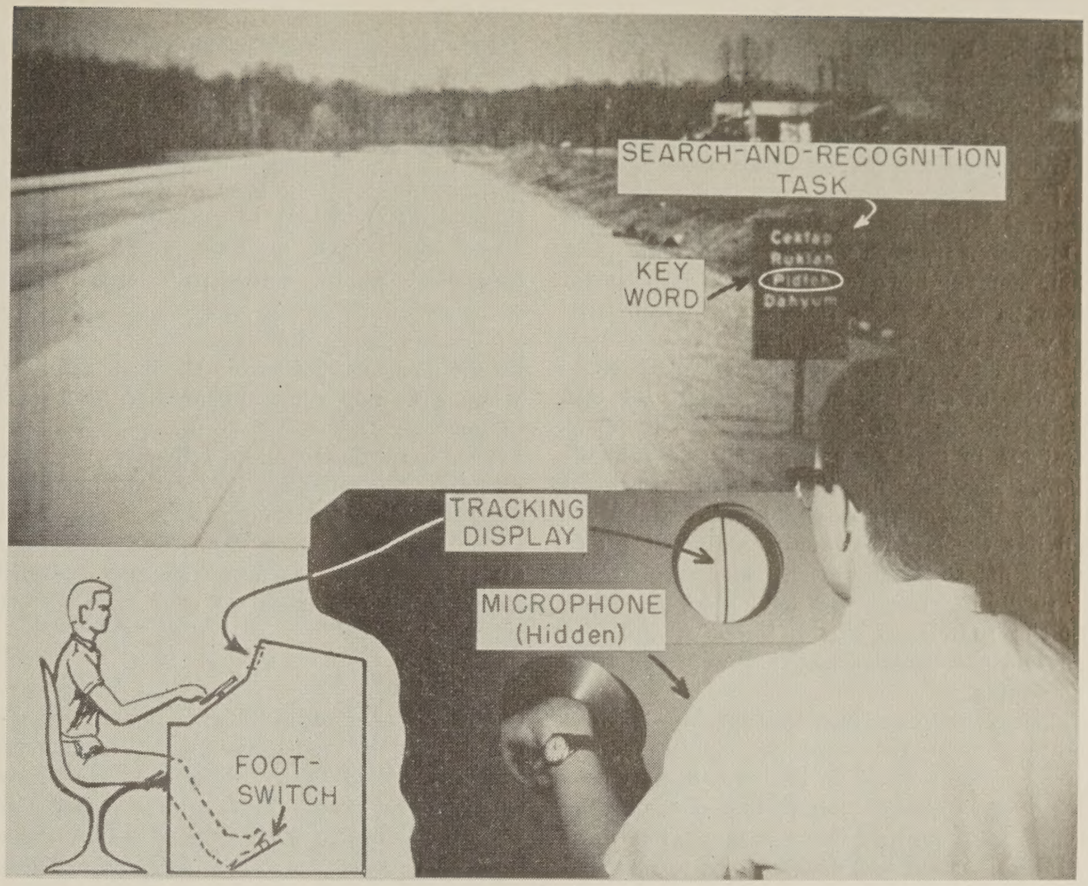

Figure 1.—Test operator seated at driving console, performing tracking tasks and search-and-recognition tasks.

test operator, and it was vertically alined to the c.r.t. No apparent texture masked the projected images, and the angle of inclination required for a visual shift from one display to another was slight.

A sign-reading task was shown on the face of the screen. It contained messages composed of nonsense syllables having association values in the range of 27 to 47 percent. Each message unit had six letters, and the lengths of the messages were matched, as were the contours of the letters in the message units. The apparent size of the signs was the same as those on an actual highway. That is, the visual angle opposite the sign at the operator's eye level was matched for the time from the sign that corresponded to the distance of an actual vehicle traveling at constant speed. Each approach scene was projected at a rate of 24 frames per second, and lasted 16 seconds, including 1 second of film that simulated passing and receding of the sign.

Test Method Operators

To conduct the tests developed to evaluate the hypotheses previously listed in this article, equipment was set up in the Bureau of Public Roads laboratory and operators were selected. The general relationship of the task configuration to the response devices is shown in figure 2. Each of these blocks in its inter-

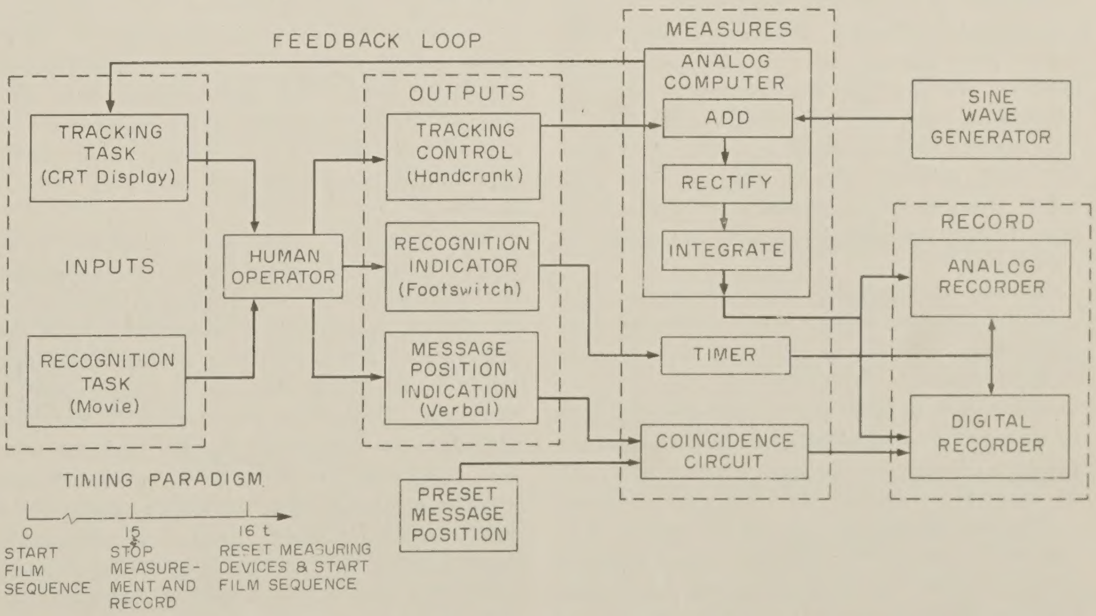

Figure 2.—Timesharing simulation system block diagram.

acting role is discussed in the following paragraphs. In addition to the presentation and response systems, timing, measurement, and recording systems for the experiment are also discussed. The relative positions of the displays and control devices are shown in figure 1.

Six test operators from the staff of the Bureau of Public Roads, Office of Research and Development, were selected at random. The four males and two females, whose ages ranged from 21 to 45 years, reported no irregularity of vision or psychomotor impairment, and all had had several years of driving experience.

Prior to the experimental session, the test operators received approximately 4 hours of training in tracking and search and recognition. The film for the recognition control tests was also used for training. Training for all but the last operator was given the day preceding the experiment. The experiments were divided into two 3-hour sessions. Each of the 14 trials lasted 8 minutes, and rest periods between trials lasted for approximately 8 minutes.

During the experimental runs, the test operators were requested to simultaneously track—keep the dot on the c.r.t. display centered on a vertical black line dividing the scope face—and to indicate when the word PIDFOH could be recognized on the motion picture display. Operators pressed the foot switch as soon as they recognized PIDFOH or as soon as they recognized that the key word was not shown. Then, immediately, they verbally gave the position of the key word by reporting the numerical position—1 through 6—or zero when PIDFOH did not appear on the sign. Operators were not instructed to pace the task in any particular manner, but merely to perform as well as possible throughout each trial. They were told to indicate recognition of the key word as soon as possible, without guessing. Otherwise, the experimental situation was relatively unstructured.

Prior to the photographing of the highway section, portable sign standards were erected. Their green backgrounds nearly reproduced the color of the present standards used for destination signs on The National System of Interstate and Defense Highways. During photographic sessions, interchangeable messages were placed on the standard backgrounds, and the signs were erected so that the brightness was approximately equal for all. The camera was mounted near the head position of the driver. Then motion pictures were taken that, from the operator's view, would give the test operator the feeling of driving on a roadway.

During photography, four standards were placed 1,000 feet apart. One of 30 sign configurations, selected at random, was assigned to each location. Each sign contained a combination of two, four, or six message units, with or without the key message PIDFOH, and the position of the key message was also assigned at random to one of the available positions.

The developed pictures were duplicated so that seven completely different edited versions were available for the experiment. Each film had the 30 scenes of the standardized signs in a different order.

Timing

The timing system provided sampling of performance on the two timeshared tasks. The timing pattern is shown in figure 2. Timing of the two tasks was synchronized by employing the film as a common time base. A small hole was cut in the corner of frames that would be shown 15 seconds and then 1 second part. Light from the projector source energized a photoresistor in the upper corner of the screen. The test operator seated on the other side of the ground glass screen could not see the flashes of light from the projector and, hence, saw only what appeared to be a continuous roadway.

The photoresistor pulsed a flip-flop mechanization that alternately: (1) reset the measurement devices to a deenergized state, followed by an activated state of measurement, and (2) stopped the measurements and digitally recorded performances on each of the test operator's tasks.

Measurement

Measurements of rectified integrated tracking error, time from the sequence start, when test operators indicated recognition associated with the sign-reading task, and correctness of verbal response to the key word on the highway sign were recorded digitally. These measures were used as the dependent variables for determining the tenability of the timesharing hypotheses. Analog records of tracking performance and a separate indication of recognition time were also collected.

The system of measurement of cumulative tracking error is shown in figure 3. This error measurement system is essentially the one developed by Gain and Fitts (*11*) for a series of tracking studies. In this system, one of the cranks was attached to a potentiometer for measuring and controlling a d.c. voltage. This voltage in turn, was added to a low-frequency sine wave, and the algebraic sum (shown on the cathode-ray display) was multiplied by a constant value empirically derived for minimal error of computation, rectified, and integrated. An output pulse from the flip-flop actuated a double-pole, double-throw relay between the rectifier output and the integrator at the termination of each 15-second sampled sequence. This relay in turn energized a delay sample circuit associated with a d.c. digital voltmeter. The voltmeter in turn issued a print command to a digital recorder. Total system error measured during any one day was less than 1 percent.

The sampled sequence initiation pulse from the flip-flop actuated another double-pole, double-throw relay that issued a short pulse to the clamping circuit associated with the integrator, thereby zeroing the unit and permitting an accurate cumulative error score to develop. Time from the end of the sampled sequence to recognition by the test operator was measured by the second set of contacts on this pulsed relay. A positive pulse of 80 volts started the count of an electronic timer. A stop pulse was initiated by either the test operator's pressure on a foot switch or by the one set of relay contacts associated with the stop phase of the flip-flop.

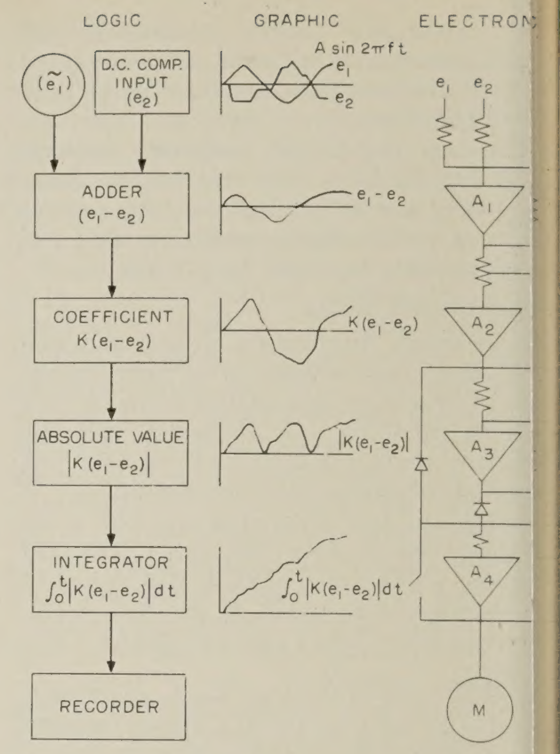

Figure 3. Method for recording tracki[ng] error—logically, graphically, and ele[c]tronically.

Verbal indication of the position of the k[ey] word on the search-and-recognition displ[ay] was measured for correctness of respon[se]. At the beginning of each trial, for each [se]quence, the experimenter set into a ser[ies] circuit the position associated with the k[ey] word. The test operator's verbal respo[nse] was recorded when he pressed the seco[nd] switch in the pair of cascaded switches. [If] the position reported was the same as th[e] preset by the experimenter, the digi[tal] recorder printed an indication of positi[on] correctness.

Discussion

Interactions between the independent a[s]pects of tracking and search-and-recogniti[on] activities have not been reported on by pre[vi]ous researchers. Although results of stud[ies] on timesharing between different senso[ry] modalities and two-dimensional tracking ha[ve] indicated general degradation of performan[ce] beyond certain input loads, consideration [of] tasks having different, basic functional r[e]quirements has been lacking. Information [on] an investigation into the interaction process[es] between these two tasks is reported in th[is] article. Changes in responses, when tracki[ng] and search-and-recognition performances we[re] measured in a nontimesharing role, have al[so] been compared.

Tracking Performance

The five factors of tracking performance a[nd] their interactions, as used in the experimen[t,] are summarized in table 1. These data refle[ct] analysis of presentations when test operat[ors] were required to perform tracking and searc[h-]and-recognition tasks concurrently. Infe[r]ences drawn from these data, therefore, [do] not reflect the effects of only the tracki[ng]

Table 1.—Cumulative tracking errors: Summary of analysis of variance

Factor	Sum of squares	df	Mean sum of squares	F, ratio
Frequency	5, 582. 52	2	2, 791. 26	[1] 493. 15
Amplitude	4, 593. 27	1	4, 593. 27	[1] 811. 53
Messages, number	22. 58	2	11. 29	1. 99
Presence	59. 52	1	59. 52	[1] 10. 52
Test operator	2, 481. 67	5	496. 33	[1] 87. 69
FxA	2, 244. 01	2	1, 122. 00	[1] 198. 23
FxM	33. 85	4	8. 46	1. 49
FxP	14. 01	2	7. 00	1. 24
FxT	490. 69	10	49. 07	[1] 8. 67
AxM	1. 06	2	0. 53	0. 09
AxP	12. 97	1	12. 97	2. 29
AxT	635. 52	5	127. 10	[1] 22. 46
MxP	26. 58	2	13. 29	2. 35
MxT	35. 39	10	3. 54	0. 62
PxT	19. 82	5	3. 96	0. 70
FxAxM	22. 10	4	5. 52	0. 98
FxAxP	13. 69	2	6. 84	1. 21
FxAxT	509. 41	10	50. 94	[1] 9. 00
FxMxP	60. 59	4	15. 15	2. 68
FxMxT	124. 93	20	6. 25	1. 10
FxPxT	50. 21	10	5. 02	0. 87
AxMxP	12. 76	2	6. 38	1. 13
AxMxT	49. 89	10	4. 99	0. 88
AxPxT	25. 47	5	5. 09	0. 89
MxPxT	87. 22	10	8. 72	1. 54
FxAxMxP	54. 24	4	13. 56	2. 40
FxAxMxT	108. 15	20	5. 41	0. 96
FxAxPxT	60. 65	10	6. 06	1. 07
FxMxPxT	146. 28	20	7. 33	1. 30
AxMxPxT	17. 23	10	1. 72	0. 30
FxAxMxPxT	157. 80	20	7. 89	1. 39
Residual	4, 894. 44	864	5. 66	------
TOTAL	22, 676. 20	1, 079	--------	------

[1] Significant with probability less than 0.01.

ttribute but also the influence of attributes of the search-and-recognition task. Data n table 1 show that on the basis of frequency, mplitude, and presence of the key word perators have demonstrated differential effects greater than can be expected by chance percent of the time. Further, only the combined interactions involving frequency, amplitude, and operators are significant.

Tracking error as a function of the significant variables of frequency, amplitude, and resence of the key word is shown in figure 4. The data for all test operators have been combined. The differential effects of tracking rror compared to the control condition (tracking without the timeshared task) are clearly hown by the information in figure 5. These lata showed the relative magnitude of differnces and illustrated the degredation caused y combining the two tasks. In both the ow- and high-amplitude tests, a clear decrement in proficiency occurred when the operators were confronted with the two tasks. The error score in the dual task increased verall about 80 percent; but the differences etween the presence and absence of a key word were separated by only a small but eliable amount—about 15 percent.

Using a method of matched test conditions or all test operators, both presence and absence of the key word and all sign complexities, comparison by means of student's t-test f the lowest frequency-amplitude condition, ith and without the interpolated task, ields $t=3.92$, which is significant at the 0.01 evel. Therefore, tracking performance for he lowest average velocity condition was onsidered to be superior to the comparable meshared condition.

Search-and-recognition time

Test operators' differences in recognition time are also significant, as were measures of tracking performance. A summary is shown in table 2 for recognition-time conditions when the key message was on the sign. Of the two components of the tracking task, only frequency appears to have differentially affected performance on the dynamic recognition task. In figure 6, recognition time data is shown for each of the tracking frequencies. The effects of task sharing may be seen. The curve in this figure is only for illustration because operator differences influenced such a plot. The time required to recognize the key message on the sign was greatly increased when tracking was used as a secondary task.

The lack of interactions involving the number of message units on a sign indicated that test operators responded in essentially the same manner to different numbers of message units on the signs. The differences between two, four, and six words reflected a steady increase in recognition time as the number of message units increased. The time increase between the two- and six-message signs rose only about 4.4 percent, or slightly less than one-half second. The range of increase on the timesharing tests was from approximately one-half second to 2 seconds beyond the recognition time for the control tests when the film was shown without the displayed tracking task.

The means of both the control and experimental conditions are shown in figure 7. For the control conditions, a dip is shown at four message units per sign. This effect does not parallel the general trend of the data from experimental tests. The time differences were significant between two and four message units at the 0.05 level but failed to reach significance between four and six units.

Search-and-recognition performance was tested to learn whether there were any changes between the first and second halves of the experiments. Using a t-test for matched test conditions, the mean recognition times for each operator were compared for the 5th and 10th trials. No statistical difference at the 0.05 level was obtained.

The errors in judgment were determined from the responses of the test operators to the position of the key word on the signs. The error scores are listed in table 3 by percentage of misses and by false alarms—the error rates incurred by each of the operators when they reported the key word in wrong positions or in a position when it was not present (false alarms). These rates were sufficiently low so that no test was required to discriminate between guessing and nonguessing. The total number of errors was well below the 5 percent criterion imposed; therefore, the erroneous responses were not analyzed further.

Timesharing

If operators gave their best performance on one of the two imposed tasks, they should have given performances that were very negatively correlated with each other. Samples of performance were taken at random for

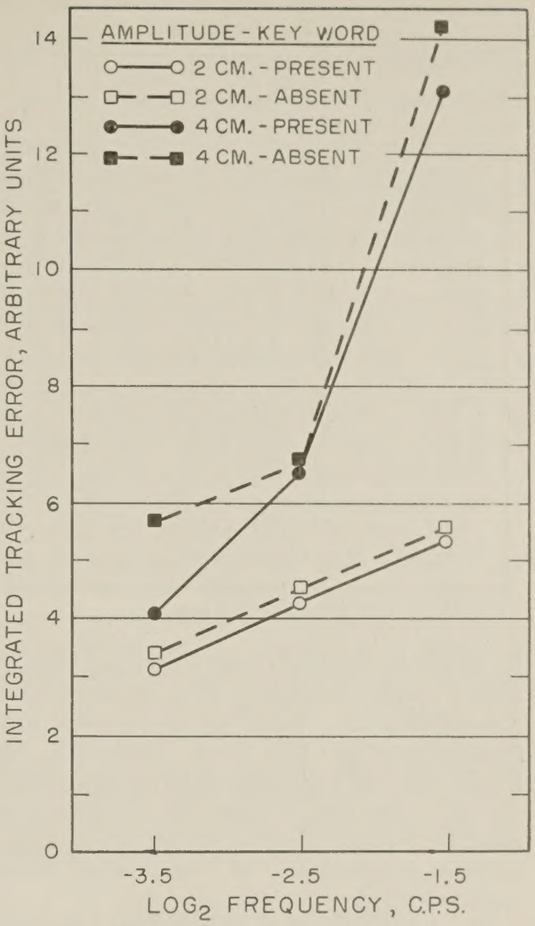

Figure 4.—Tracking error data showing relative effects of frequency, amplitude, and presence of the key word.

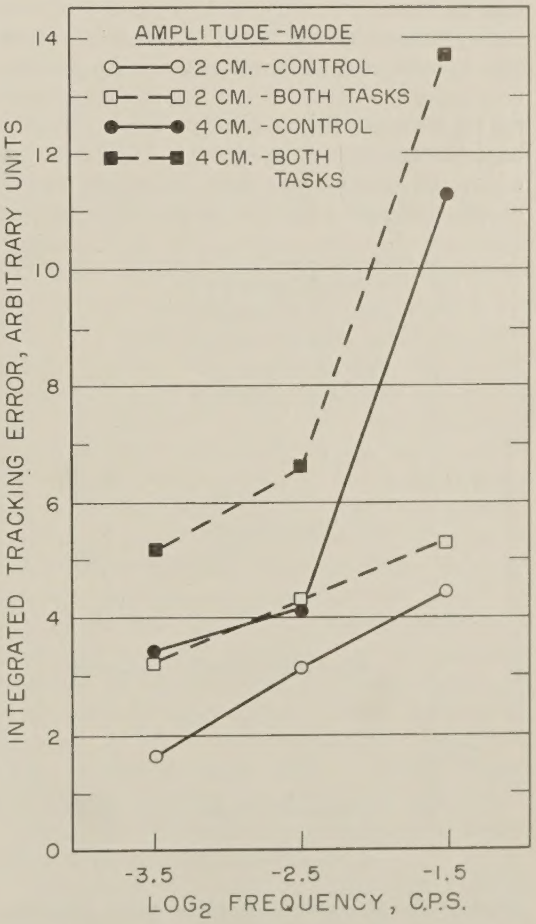

Figure 5.—Tracking error data showing relative effects of the sign reading task.

Table 2.—Recognition time: Summary of analysis of variance

Factor	Sum of squares	*df*	Mean sum of squares	F, ratio
Frequency	9.53	2	4.76	[1] 4.81
Amplitude	3.82	1	3.82	3.86
Messages, number	20.61	2	10.30	[1] 10.40
Test operator	1,062.65	5	212.53	[1] 214,68
FxA	5.84	2	2.92	2.95
FxM	2.29	4	0.57	0.58
FxT	28.22	10	2.82	[1] 2.85
AxM	0.11	2	0.06	0.06
AxT	5.45	5	1.09	1.10
MxT	17.14	10	1.71	1.73
FxAxM	4.80	4	1.20	1.21
FxAxT	28.12	10	2.81	[1] 2.84
FxMxT	27.48	20	1.37	1.38
AxMxT	11.13	10	1.11	1.12
FxAxMxT	28.89	20	1.44	1.45
Residual	1,256.08	107	------	-------
Error	428.47	432	0.99	-------
TOTAL	1,684.55	539	------	-------

[1] Significant with probability less than 0.01

timesharing conditions of individual operators. Twenty samples were subjected to rho-correlations. Only one correlation was significant at the 0.05 level. Therefore, the hypothesis that a significant correlation existed between the two timeshared performances must be rejected because the number of significant correlations did not exceed those expected by chance alone.

The conclusion that no significant correlation existed between the timeshared performance was derived from an analysis of the pattern of response, the number and dispersion of errors of tracking and search-and-recognition performance. The fact that the number of messages on the signs had no effect on tracking performance suggested that the overall time required by the dynamic recognition task was not affected differentially by the number of messages. Yet the number did contribute to an increase in recognition time. Such a paradox suggests that either: (1) The differences in recognition time, although significantly different, were so small that they did not affect tracking performance; that is, the variance associated with other factors was relatively large; or (2) the test operator quickened his alteration response to or from the tracking task and decreased time spent in the search-and-recognition task.

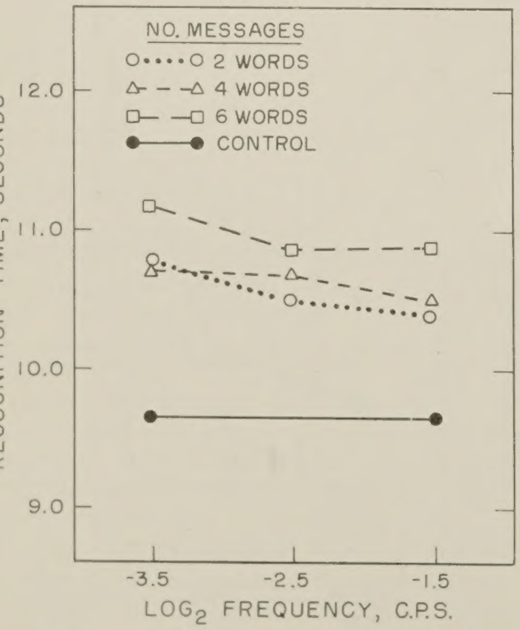

Figure 6.—Recognition time data showing effects of timesharing with tracking task.

Differences in the differential error between timeshared tests and control tests involving tracking alone are not great for each of the frequency-amplitude combinations. The trend, however, is toward smaller differentials, rather than greater ones, as the tracking frequency is raised. If a constant differential between each control and experimental comparison is assumed, then the same increment of error can be attributed to each of the frequencies.

Although no difference exists between the integration of sine waves of differing frequencies (unless the integration time is very short), the lack of visual feedback for 1 or 2 seconds becomes increasingly important as the frequency is increased. Gottsdanker (*12*) has indicated that essentially the same processes operate in anticipating a course under visual and visually deprived conditions. Test operators, however, showed more variable and less accurate performance when they were visually deprived. The operator maintained some proprioceptive feedback and was able to anticipate the course, but this ability decreased as frequency was increased.

Briggs and Howell imply that when tasks to be performed are spatially separated the operator must discretely sample these tasks. When more than one task competes for the operator's efforts, then the sampling rate is paced according to the objective velocity of the stimuli of the tasks, but often this rate is modified by some subjective criterion. A decrement in performance shows a lack of visual error feedback or, expressed differently, a reduction of the sampling rate of the error signal by the test operator. If the rate of increase is less than would be expected by reduced feedback information, then the operator must increase his sampling rate; this has an associated effect on some other aspect of behavior. This may be presumed to be true only if the operator is responding well within the limits of his capacity to assimilate information.

Recognition or Tracking Error

If equal time is spent on the search-and-recognition task and is independent of the tracking task, then the analysis of variance of recognition times should show no significant differences for tracking frequency, amplitude, or their interactions; that is, recognition times would not be increased or decreased because of the addition of the secondary task (but, as stated earlier, the average recognition times did decrease as the frequency of the tracking task was increased). Furthermore, if an increment in tracking error exists in the timesharing condition, then the size of such an increment should increase as a function of increased frequency. If the reverse were obtained, then it might be presumed that a time reduction in recognition time had been

Table 3.—Erroneous response percentage by test operators

Test operator	Error	False alarm	Total erroneous response
	Percent	*Percent*	*Percent*
1	0.8	1.7	1.2
2	5.8	2.5	4.2
3	2.5	0.8	1.7
4	1.7	0.8	1.2
5	0.8	0.0	0.4
6	0.8	0.8	0.8
Average	2.1	1.1	1.6

used in minimizing tracking error. The te data clearly substantiated these presumption Although the number of messages display to operators had no effect upon their trackir performance, frequency and the compl interactions of frequency, amplitude, ar test operator substantially affected recogn tion time. A reasonable inference is that, frequency (a component of angular change the target) was increased, the rate of samplir of the course increased and search-an recognition behavior of the operator w consequently altered. Comparable to tl field situation, in which the steering task ma be considered in the same context as trackin the operator's search-and-recognition behavi will decline as sign reading becomes mo complex but will actually improve as travelir speed is increased.

The effects on tracking performance whe the key word did not appear on the sign su gest that expectancy played some part i diverting the attention of test operators fro the simulated steering. The significant i crease in tracking error leads to the conclusio that more time was spent in attempting t find the missing key word.

Cues in Nontimeshared Recognitio Trials

In the comparison of control and exper mental data, a decrease was noted in reco nition time associated with increased numbe

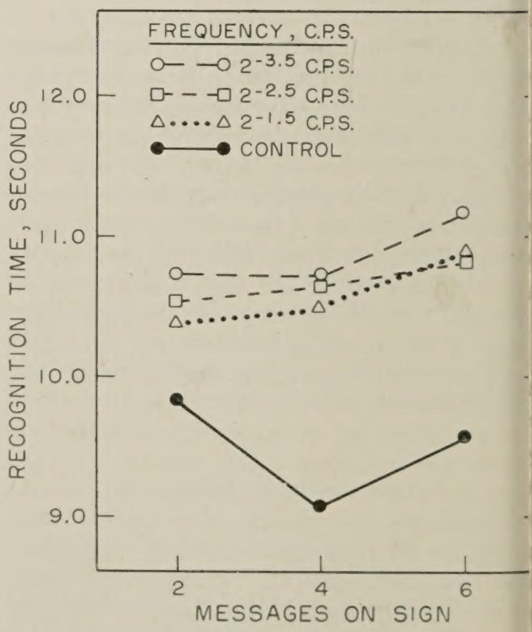

Figure 7.—Recognition time data showin effects of number of words on sign and tracking frequency.

of messages in the search-and-recognition activity when no timesharing was required. It is most likely that, because of using the control film for training, disproportionate learning was associated with the four message signs. There was no way of directly testing this hypothesis. Close observation of these films, however, revealed considerable activity in the periphery of the scenes during photography of the four message signs. When test operators were required to view only the film (which had been repeatedly shown during training), it is likely that such peripheral cues were noticed and used. This most likely explains the U-shaped curve associated with the control tests, shown in figure 7.

Spatial Separation of Information

Although care was taken to present a reasonable projection of the roadway (rates of change of objects in the simulated view of the road being kept comparable to those in the field), accuracy of detail in the films used required much larger messages for recognition. This, in effect, also meant that the lateral movement of objects across the viewed field was much further from the line of regard in the laboratory situation than on an actual highway. Concurrently, the angular velocity of the signs was much higher at the time of recognition. This constraint meant that the message, when detected, was displayed about 10 degrees from the line of regard. In the field, however, previous tests under comparable speed conditions showed recognition of signs of the type used in this study to be at about 400 feet. At the time of recognition, the displacement of the sign was about 2 degrees from the line of regard, which is within the foveal region of the eye. The shift of the point of fixation for the field situation was very small, thereby reducing the transition time between the two information sources: visual steering feedback and the messages on the signs.

Shifting cues

Control devices used to respond to repetitive inputs permitted development of some reliable cues for the test operator in the simulated steering task. Because the compensatory tracking signal produced high redundancy in the experiment described, the error, incurred during periods when the operator directed his attention toward the signs, was probably minimized. In tasks dependent upon both visual and proprioceptive cues, Bahrick and Shelly (*13*) determined that during prolonged trials a gradual change occurred from visible cues to proprioceptive control. So, indeed, there may have been a reduction in the errors scored under these high redundancy conditions. However, the use of a balanced design in analysis of errors scored reduced the influence of this factor in the findings reported here.

Frequency-Amplitude

Frequency and amplitude are recognized in this article as aspects of the same phenomena—rate of angular change of the source of the tracking target stimulus. A report by Bowen and Chernikoff (*14*) contains a hypothesis concerning the cumulative tracking error of test operators; they suggest that an error estimate may be determined by the frequency-amplitude product,

$$E=k(fa).$$

Their tests of this relationship yielded good fits of the data. Although this relationship did not take into account the gain of the specific control used by operators, significant trade-off between these two aspects of the tracking task provides the reason as to why each should have had pronounced differential effects and as to why an interaction should have existed between them.

Bowen and Chernikoff showed that equal frequency-amplitude combinations should yield equal tracking error. This point is not germane to the central topic of this article, but making comparisons of conditions having equal average velocities is essential to determining the applicability of the principle in the body of the research reported. So as to not confound the argument by possible interactions not shown by previous analysis, matched groups of all test conditions: operator, presence or absence of the key word, and complexity of tasks were compared for the equal frequency-amplitude combinations. Where,

$f_1=2^{-3.5}$ c.p.s.,
$f_2=2^{-2.5}$ c.p.s.,
$f_3=2^{-1.5}$ c.p.s.,
$a_1=2$ cm.,
$a_2=4$ cm.,

and E is the error associated with conditions dictated by the subscripts, the following listed hypotheses were tested by use of the t-test. The corresponding probabilities of the differences exceeding t are given:

	Hypotheses	*Statements*
	H1,	$E_{f_1}a_2=E_{f_2}a_1$, $0.3<p<0.4$;
but,	H3,	$E_{f_1}a_1=E_{f_1}a_2$, $p<0.01$;
and,	H2,	$E_{f_2}a_2=E_{f_3}a_1$, $0.5<p<0.6$;
but,	H4,	$E_{f_2}a_2=E_{f_2}a_2$, $0.05<p<0.10$.

On the basis of the preceding analyses, the frequency-amplitude equality concept can be considered to be valid. The differences between the equal fa products were not significant. However, when the cumulative error was compared for matched groups for like frequencies but different amplitudes, differences were significant or were near the critical level of accepted difference.

Angular Velocity Stimulus

In addition to Bowen and Cherikoff's treatment of the frequency-amplitude combination as a predictor of tracking error, Brown has classified these components as those that may be translated into angular velocity, a primary stimulus to the human operator. Such a concept permits the translation of vehicular speed and road curvature into these terms. The stimuli used ranged in maximum angular velocities from 0.74 to 5.37 degrees per second For a curve having a radius of 1,330 feet with a superelevation of 5 percent, AASHO design standards indicate an angular velocity range of 2.59 degrees per second for a vehicle entering the curve at 60 m.p.h., down to 1.50 degrees per second for a vehicle entering at 30 m.p.h. On such curves the driver does not in theory need to make more than an initial correction, whereas test operators in this study were negotiating a very crooked road.

Although the differences between tracking error for equal frequency-amplitude combinations were not greater than could be expected by chance, the two amplitude conditions exhibited relative differences that are worthy of note. Inspection of the configurations confronting the test operators showed at least two types of differences between the conditions. The first pertained to the angular velocity of the control conditions: The average velocities for test differed almost 30 percent, but the maximum velocities did not differ; in the other test, the maximum velocities differed by almost 10 percent, but the average differed only a few percent.

The Right Decision

It is especially critical to the driver who is unfamiliar with a specific course to make the right decision. He may attempt to make the best of the situation so that he has more time in which to reach a decision—he may reduce speed. He may direct his attention primarily to the roadway from external visual sources, such as signs. It is conceivable that his control, particularly lateral control, will decrease appreciably.

The suggestion that substantial research is needed about locations where the driver must make decisions concerning alternate courses is supported by the evidence from the study discussed in this article of the interaction effects of steering and search-and-recognition activities, together with the report of the ITTE. Congestion along the highway, such as at ramps, does not explain the many accidents in these areas. Mullins and Keese (*15*) report that more than 20 percent of accidents in freeway sections studied occurred at ramps where signs or oncoming traffic must be searched out, located, recognized, and acted upon. If recognition is to occur in time for a decision, then scanning time on driver's position on the roadway must be decreased (but this was not indicated by data collected in this research) or the angular velocity of the roadway must be decreased. This may be accomplished by a decrease in driving speed, a factor probably associated with accident rates (*16*). Where speed variability is high on high-speed roadways, there is also considerable evidence of a reduction in road capacity (*17*).

The issues to consider are alternate methods of presenting information to the operator so that he is not overburdened, and determination of ways that will permit the driver to maintain speed for such decision points along the highway. Finally, where a message is definitely expected, an indication of the proper direction should be on the sign, otherwise more time will be given to the sign reading task than to maintaining steering control.

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Evaluation of Laboratory Vane Shear Test

Y THE MATERIALS DIVISION
UREAU OF PUBLIC ROADS

Reported by [1,2] ROGER D. GOUGHNOUR and
JOHN R. SALLBERG, Highway Research Engineers

The laboratory vane shear device produces shear strength measurements that are reliable, according to the research results reported in this article. The accurate determination of the shear strength of soft foundation soils is an important factor in the design of modern highways. Consequently, the Bureau of Public Roads is conducting a study of laboratory shear strength tests and devices to determine the strength parameters measured by the different laboratory tests and to evaluate the usefulness of such tests in relation to highway design. The test discussed in this article covers only one facet of the study. The results obtained on the evaluation of the laboratory vane shear test show that this device provides reliable values of shear strength. This, coupled with the ease of testing and the relatively small degree of disturbance of the specimen, makes the vane shear test a desirable tool, especially for use on soft, sensitive soils.

Introduction

WITH THE present expansion of the highway construction program, the highway gineer is frequently required to locate and ild highways and particularly interchanges er poor, submarginal lands, sometimes even amplands. One problem in designing interange embankments over soft soils is the ermination of the initial shear strength of foundation soil. This shear strength may estimated from the results of the standard netration test, obtained during subsurface estigations, or measured directly by the d vane test. In general, however, the tial shear strength of the foundation soil is sed upon laboratory unconfined compresn tests of undisturbed samples. When the disturbed samples are very sensitive, or so ak they fail under their own weight, aner type of test is needed.

The Materials Research Division of the reau of Public Roads has purchased a labtory vane shear device (figure 1) for testing y soft soils directly in the sampling tubes. e test consists of inserting the vane into sample and measuring the resistance to ation. The shear strength can then be culated from this resistance to rotation. is device was evaluated by comparing the ar strength result obtained thereby with shear strength result obtained from the confined compression test.

n initial tests, the laboratory vane shear t and the unconfined compression shear t did not yield the same shear strengths for identical remolded specimens of soil. In an attempt to explain this difference, additional tests were run on both undisturbed and remolded soils. The remolded soils were studied for the effects of aging of the specimens before their being tested, the rate of shear, and the vane size.

A few researchers have compared the shear strength obtained from tests made with the field vane, the laboratory vane (undisturbed sample left in the tube when tested), and the undisturbed, unconfined compression tests (*1*, *2*).[3] Generally the field vane test results showed the greatest shear strength, the unconfined compression test results showed the least strength, and the results of the laboratory vane test showed a strength between the other results. Gray (*1*) believed that for the sensitive clays he tested, the difference was caused by the disturbance of the soils when the samples were obtained and when the unconfined compression test specimens were prepared. Results of the consolidated undrained triaxial shear tests made by Fenski (*2*) were close to results of the field vane test. Therefore, he concluded that the difference between the results of the field vane test and the unconfined compression test was caused by the different stress conditions created when the soil was removed from the ground.

Summary

The results of the study reported in this article are as follows:

Laboratory vane shear and unconfined compression tests on a variety of fine grained soils, molded into test specimens at moisture contents between the plastic and liquid limits, showed that the ratio of the vane shear strength to one-half the unconfined compressive strength was constant for a given soil. This vane-*uc* ratio varied from soil to soil, ranging from 0.6:1 to 1.4:1. Soils having plasticity indexes of less than 14 had vane shear strengths less than the unconfined compressive shear strengths, and soils having plasticity indexes greater than 14 had vane shear strengths greater than the unconfined compressive shear strengths. Possible reasons for this difference in shear strengths are:

- A remolded soil having a high plasticity index probably has nonuniform structure. As the test specimen in the vane test failed along a fixed surface and the test specimen in the unconfined compression test failed in the weakest area, nonuniformity of structure caused the vane strength to be greater. The vane-*uc* ratios of the undisturbed soil increased from 0.9:1 before being remolded to 1.20:1 after being remolded. Also, the vane-*uc* ratio decreased as the age of the specimen increased. It is probable that the structure of undisturbed samples and specimens aged after their being remolded was more uniform than the structure of specimens immediately after they had been remolded, thus causing the lower vane-*uc* ratio.

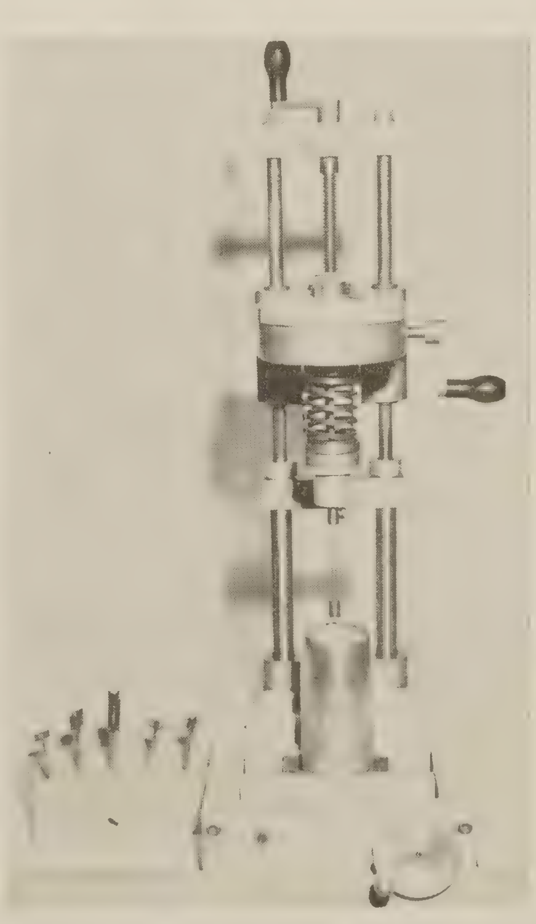

Figure 1.—Laboratory vane shear apparatus.

[1] Presented at the 43d annual meeting of the Highway earch Board, Washington, D.C., Jan. 1964.
[2] Comments on the tests reported were made by Professor il E. Wilson, Department of Civil Engineering and Engiring Mechanics of McMaster University, Hamilton, ario, Canada, and are reproduced at the end of this cle. Comments of the authors on Professor Wilson's arks are also included.

[3] Numbers in parentheses indicate references listed on p. 93.

Table 1.—Summary of soil tests and soil properties

Group and type of test	Test	Ratio of vane shear to one-half *uc* strength	Ratio of penetrometer shear to one-half *uc* strength	Samples tested	Moisture content, *w*	Dry density	Basic soil properties: Liquid limit	Plastic limit	Plasticity index	Clay, <0.005 mm.	Silt 0.074–0.005 mm.	Sand 2.0–0.074 mm.	Classification: AASHO	USDA texture
A:	*No.*			*No.*	*Percent*	*P.c.f.*								
Determination of vane-*uc* ratio (remolded soils).	1a	1.0:1	1.5:1	54	37.0 to 44.0	73.0 to 80.6	51	30	21	44	49	7	A-7-5(15)	Silty clay loam.
	2a	1.4:1	1.5:1	22	20.3 to 35.5	83.2 to 97.9	48	20	28	37	23	40	A-7-6(13)	Clay loam.
	3a	0.8:1	2.0:1	6	33.6 to 35.1	80.7 to 82.9	41	35	6	4	33	63	A-4(4)	Sandy loam.
	3b	1.3:1	1.6:1	3	35.9 to 36.0	89.1 to 89.8	36	28	8	22	34	44	A-7-6(12)	Loam.
	5	1.4:1	2.1:1	3	47.8 to 47.9	71.7 to 71.8	49	33	16	83	10	7	A-7-5(20)	Clay.
	6	1.25:1	1.5:1	3	64.0 to 65.0	59.6 to 61.1	88	41	47	92	7	1	A-7-5(20)	Clay.
	7	0.6:1	2.1:1	3	24.7 to 24.8	98.0 to 100.7	89	34	55	77	12	11	A-2-4(0)	Clay.
	8a			8			30	24	6	15	18	67		Sandy loam.
		1.3:1	1.7:1		33.9 to 34.0	85.9 to 87.0							A-7-6(19)	
	9a			3			55	25	30	83	13	4		Clay.
B:		0.9:1	1.1:1		46.2 to 47.9	109.7 to 112.0							A-7-6(14)	
Determination of vane-*uc* ratio (undisturbed soil).	10a			5			46	24	22	46	52	2		Silty clay loam.
		1.2:1	2.0:1		44.8 to 46.3	110.4 to 118.5							A-7-6(14)	
	10b			7			46	24	22	46	52	2		Silty clay loam.
C:		1.4:1	------------		25.0 to 31.6	89.7 to 98.7							A-7-6(10)	
Rate of shear.	2f	0.5:1 to 1.0:1	2.3:1	10	22.1 to 22.6	101.9 to 102.7	41	19	22	37	23	40	A-2-4(0)	Clay loam.
	8b			8			30	24	6	15	18	67		Sandy loam.
D:		0.3:1 to 1.4:1	------------		26.2 to 26.7	95.5 to 96.3							A-7-6(10)	
Effect of age.	2d	1.4:1 to 1.5:1	------------	6	24.9 to 25.8	96.9 to 97.5	41	19	22	37	23	40	A-7-6(10)	Clay loam.
	2e	1.2:1 to 1.4:1	------------	9	32.0 to 33.0	87.7 to 87.9	41	19	22	37	23	40	A-7-6(19)	Clay loam.
	9b			11			55	25	30	83	13	4		Clay.
E:		1.1:1	1.7:1		38.1 to 38.9	78.2 to 82.9							A-7-5(8)	
Effect of vane size.	1c	1.3:1	1.3:1	18	24.9 to 34.8	84.3 to 98.9	51	30	21	44	49	7	A-7-6(10)	Silty clay.
	2b			54			41	19	22	37	23	40		Clay loam.
F:		1.3:1 to 2.7:1	1.3:1 to 2.2:1		19.0 to 21.4	102.3 to 107.3							A-7-6(10)	
Effect of testing procedure.	2c			8			41	19	22	37	23	40		Clay loam.

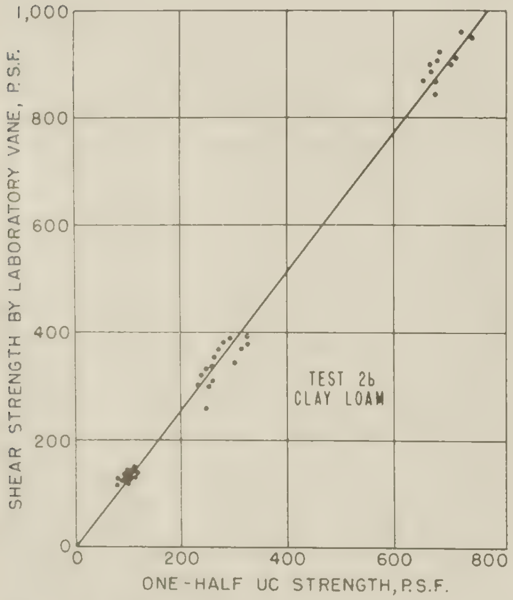

Figure 2.—Vane shear versus one-half unconfined compressive strength.

- A soil having a low plasticity index probably has an intergranular friction force that is mobilized in the unconfined compression test, but not in the vane shear test. This causes low vane-*uc* ratios for such soils.

The buildup of pore-water pressure in the test was studied indirectly by the effect of rate of shearing on the vane-*uc* ratio, but the results were inconclusive. However, increasing the rate of rotation of the vane for a soil having a low plasticity index did cause an increase in the shear strength. As the soil tested was dilatant, negative pore-water stresses were probably induced during the shear deformation. This negative pore-water pressure contributed to the increase in shear strength. No such effect was noted for clays. The length and the number of blades made little difference on the results of the vane test for the soils tested.

The difference noted by other researchers between the unconfined compressive shear and the vane shear strengths may have been caused by differences in the modes of failure rather than in the actual shear strength of the soil.

The shear strength values obtained with the laboratory vane shear device appear to be reliable. The ease of testing and the relatively small degree of disturbance to the specimens make this a desirable test, especially for soft, sensitive soils.

Vane Shear Apparatus

The vane shear apparatus used for the study reported here (fig. 1) is equipped to measure both torque and rotation of the vane in degrees. Torque is applied to the vane through a calibrated spring by rotating the crank handle. The base of the apparatus was replaced by a clamp to hold the sampling tubes. The vane normally used has four blades, each one-half inch in height and one-fourth inch in width.

Calculation of Shear Stress

The surface of rupture and the possibility of progressive failure for the vane test has been studied for sand and clay by Swedish researchers (*3*). Their study was conducted by placing wetted tissue paper, which had a pattern marked on it, on the surface of the samples. The distortion of the pattern w[as] observed as the vane test progressed. It w[as] concluded that, for the sand and clay teste[d], the surface of rupture was a circular cylind[er] of which the diameter (D) equaled that of t[he] vane, and any progressive character of failu[re] was slight and did not appreciably affect t[he] test results.

When the vane shear strength, S, was c[al]culated in the study reported here, it w[as] assumed that the failure surface was t[he] circular cylinder of revolution created [by] rotating the vane. The shear stress w[as] assumed to be constant along the vertic[al] surface and to have a linear distribution [at] the ends ranging from zero at the center [to] maximum at the edge. The resultant formu[la] for the shearing strength is:

$$S_{vane}=\frac{2\ TM}{D^2\left(H+\frac{D}{4}\right)}$$

Where,

TM = Maximum torque
D = Diameter or overall width of the va[ne]
H = Height of the vane.

The unconfined compressive shear streng[th] was computed using the conventional e[x]pression:

$$S_{uc}=\frac{q_u}{2}$$

where q_u is the unconfined compressi[ve] strength, which is defined as the maximu[m] applied load divided by the average cro[ss] section of the specimen.

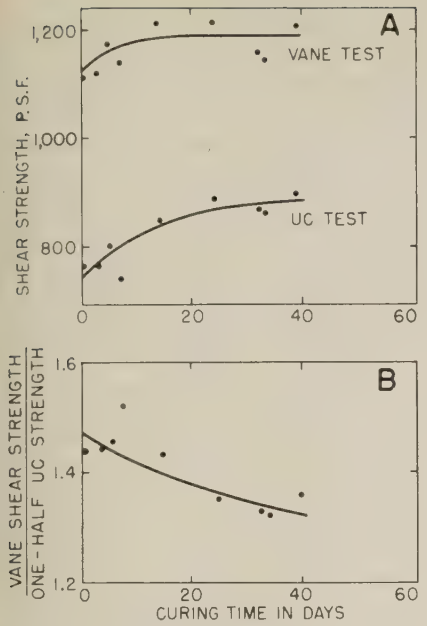

Figure 3.—Effect of curing time on shear strength of remolded clay loam specimens, test 2e.

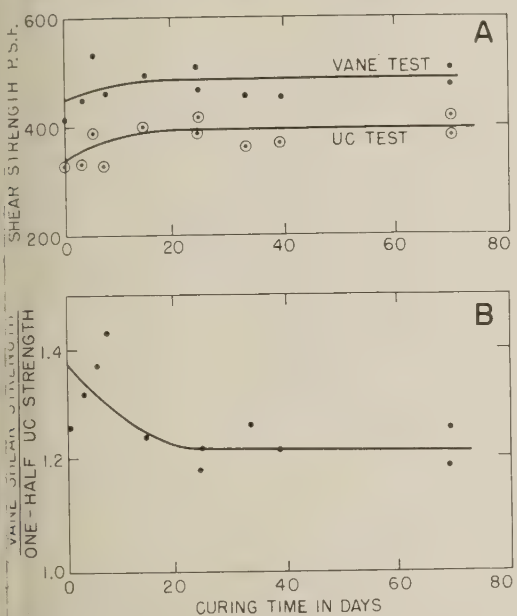

*Figure 4.—Effect of curing time on shear strength of remolded clay specimens, test 9b.***

oil Preparation and Initial Testing

The 10 soils tested were four clays, two lty clay loams, a clay loam, a loam, and two ındy loams. The types of tests performed, ıe test results, and the mechanical properties : the soils are summarized in table 1. The ɔil to be used for the remolded tests was air ried, pulverized to break up clay lumps, and enerally sieved through the No. 10 sieve to move coarse particles—one exception, a lty clay loam, was sieved through the No. 4 eve. Water was then added and thoroughly ıixed with the soil to bring it to the selected ıoisture content. The mixture was then ored in a moist cabinet for at least 24 hours efore it was molded and tested.

The remolded specimens were prepared in mold that was 2 inches in diameter and 5 ches long. The soil was put in the mold in nall increments and manually tamped with wood rod three-fourths of an inch in diameter. The density of duplicate specimens could be reproduced within a range of 1.0 p.c.f. with this method. The vane shear tests generally were performed on these specimens while each was still in the mold. The vane was inserted into the soil until the top of the vane was approximately one-half inch below the top of the specimen. After the vane test, the specimens were pushed from the mold and trimmed to a length of 4 inches for the unconfined compression test. The tests listed under Group A in table 1 were made by using this procedure. For each soil molded into test specimens at moisture contents approximately between the plastic and liquid limits, the ratio of the vane shear strength to one-half the unconfined compressive strength (represented by vane-*uc* ratio) was constant; this ratio, however, varied from soil to soil and ranged from 0.6:1 to 1.4:1. These vane-*uc* ratios also are given in table 1. Typical test results for one soil, which show this constant ratio, are plotted in figure 2. Duplicate tests were made on this soil to evaluate different vane designs and the result was a seemingly excessive replication at each of the three moisture contents at which specimens were molded.

Four possible causes for the different shear strengths measured by the vane and unconfined compression tests are as follows: (1) Nonuniformity of soil structure; that is, particle arrangement and moisture distribution within the specimen; (2) variations in pore-pressure developments during shear; (3) progressive failure in the vane test; and (4) effects of testing procedures. Additional tests were made to investigate these factors.

Structure

Any nonuniformity of structure or strength within the test specimen would be reflected in the ratio of the vane strength to the unconfined compressive strength. This vane-*uc* ratio would be greater than 1:1 because the vane shears the soil specimen along a fixed surface, whereas the unconfined compression test allows the soil specimen to shear along the weakest surface. Shearing along a fixed surface tends to produce an average shear strength; however, shearing through the weakest part of a specimen produces the minimum strength.

It was hypothesized that a remolded test specimen has a less uniform structure than an undisturbed test specimen. If this were so, the vane-*uc* ratio for the specimens of remolded soil would be greater than the vane-*uc* ratio for the specimens of undisturbed soil. This hypothesis was investigated. Samples of an undisturbed silty clay (test 10a of Group B, table 1) were used; they were obtained from a 12-foot excavation with 3-inch and 6-inch sampling tubes. Unconfined compression test specimens 2 inches in diameter by 4 inches long were trimmed from the samples and tested. The vane-*uc* ratio for this undisturbed soil was about 0.90:1. This material was then thoroughly remolded and tested (test 10b). The resultant vane-*uc* ratio was about 1.2:1. This larger vane-*uc* ratio for the remolded soil appears to support the hypothesis that these ratios for remolded soil samples are less uniform than for undisturbed samples.

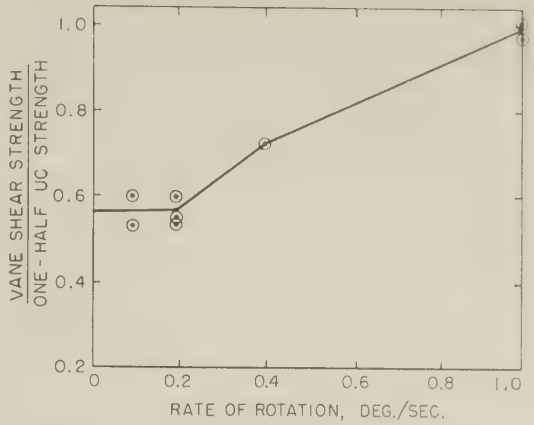

Figure 5.—Effect of rate of rotation on vane-uc ratio for sandy loam, test 8b.

As a further check of the effect of structure uniformity on the vane-*uc* ratio, the effect of age of the molded specimens was studied. It was hypothesized that soil of remolded samples will become more uniform as they are aged and, therefore, the unconfined compressive strength will increase and consequently the vane-*uc* ratio will decrease. This hypothesis was investigated for specimens of clay loam and clay, which were all molded at one time, immediately pushed out of the mold, wrapped in aluminum foil, and stored in a moist cabinet until they were tested.

Data shown in parts A of figures 3 and 4 show strength as a function of curing time and parts B of the same figures show the corresponding changes in the vane-*uc* ratio. A tendency can be seen for both the vane and the unconfined compressive strengths to increase as curing time is increased. However, the unconfined compressive strength increases at a more rapid rate, which causes a decreasing vane-*uc* ratio. This tendency was more pronounced for the clay loam than for the clay. The vane-*uc* ratio decreased from about 1.47:1 at zero time to about 1.33:1 at 39 days for the clay loam (test 2e) and from about 1.37:1 at zero time to about 1.22:1 at 39 days for the clay (test 9b). Based on these results, it appears that a remolded soil becomes more uniform with age; therefore, the difference between shear strengths measured by the two tests was reduced.

Pore Pressure

The second factor investigated was the possibility of pore-pressure buildup during shearing. This was investigated indirectly by studying the effect of rate of shear. A nearly constant rate of shear for the vane test was maintained by rotating the crank handle approximately one revolution per minute, thus obtaining an almost constant rate of stress increase and very little strain as the load was increased. As the load approached the shear strength of the soil, the result was a constant rate of strain of approximately 0.2 degree per second.

The effect of shear rate was investigated by varying the rate of shear at failure between 0.1 and 1.0 degree per second. These effects are recorded in Group C of table 1. A clay loam (test 2f) showed no measurable differences in strength for this range of shear rates.

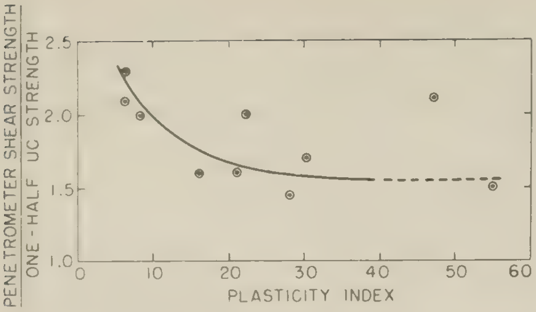

Figure 6.—Penetrometer-uc ratio versus plasticity index.

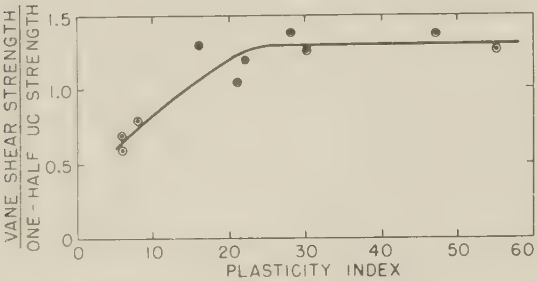

Figure 7.—Vane-uc ratio versus plasticity index.

However, data from test 8b recorded in figure 5 shows that a loam had a vane-*uc* ratio of 0.6:1 at 0.2 degree per second and of 1.0:1 at 1 degree per second. At rates slower than 0.2 degree per second, the vane-*uc* ratio was constant at a value of slightly less than 0.6:1. This apparent constant ratio could have been the result of the difficulty in manually rotating the crank at a constant rate at these slow speeds and the resultant variability in readings. Because 0.2-degree-per-second rotation gave the minimum strength, this rate was considered satisfactory for all tests.

As the loam is a dilatant soil, it is possible that negative pore stresses were induced during shear deformation. The negative pore-water stresses would create or increase normal pressure on the ruptured surface. This would, in turn, possibly increase an intergranular friction force causing an increased shear strength with increased rate of shear.

Progressive Failure

The third factor, the possibility of progressive failure in the vane test, was also studied indirectly. If a progressive failure were taking place in the vane test, a six-bladed vane would create a larger shear surface and cause a higher shear strength than a two- or four-bladed vane. The vane that was supplied with the vane equipment had four blades, each one-half inch high and one-fourth inch wide. Vanes having two and six blades were constructed for use in the tests reported here.

Tests made with the three different vanes produced a very small percentage difference in the measured strength of the soils—not enough to warrant any change from the standard four-bladed vane. The average strengths measured with the two-bladed vane were least; the measurements obtained wi the standard four-bladed vane were 2 perce greater and those obtained with the six-blad vane were 9 percent greater. But, in so silty soils, the six-bladed vane caused signi-cant compression of the soil during its ins-tion. The effect of this disturbance on t measured strength is unknown.

The effect of length of blades was al studied. Vanes having blades 1 and 2 inch long were built and the strengths obtain with them were compared with those obtain with the original vane having the ½-in blades. The calculated shear strengths we essentially equal. As the tests made with t six-bladed vane produced shear strengt slightly greater than the four- and tw-bladed vanes, some progressive failure a-peared to be taking place.

Effect of Testing Procedure

The fourth factor that possibly affects t shear strength, as measured by the vane a the unconfined compression test, is the testi procedure used. As both the vane and t unconfined compression tests were often r on the same test specimen, there was a p-sibility that disturbance by the insertion and testing with the vane would reduce t unconfined compressive strength. To -vestigate this, duplicate samples were p-odically tested by only the unconfined co-pression test. Strengths obtained by the t methods checked very closely and, based

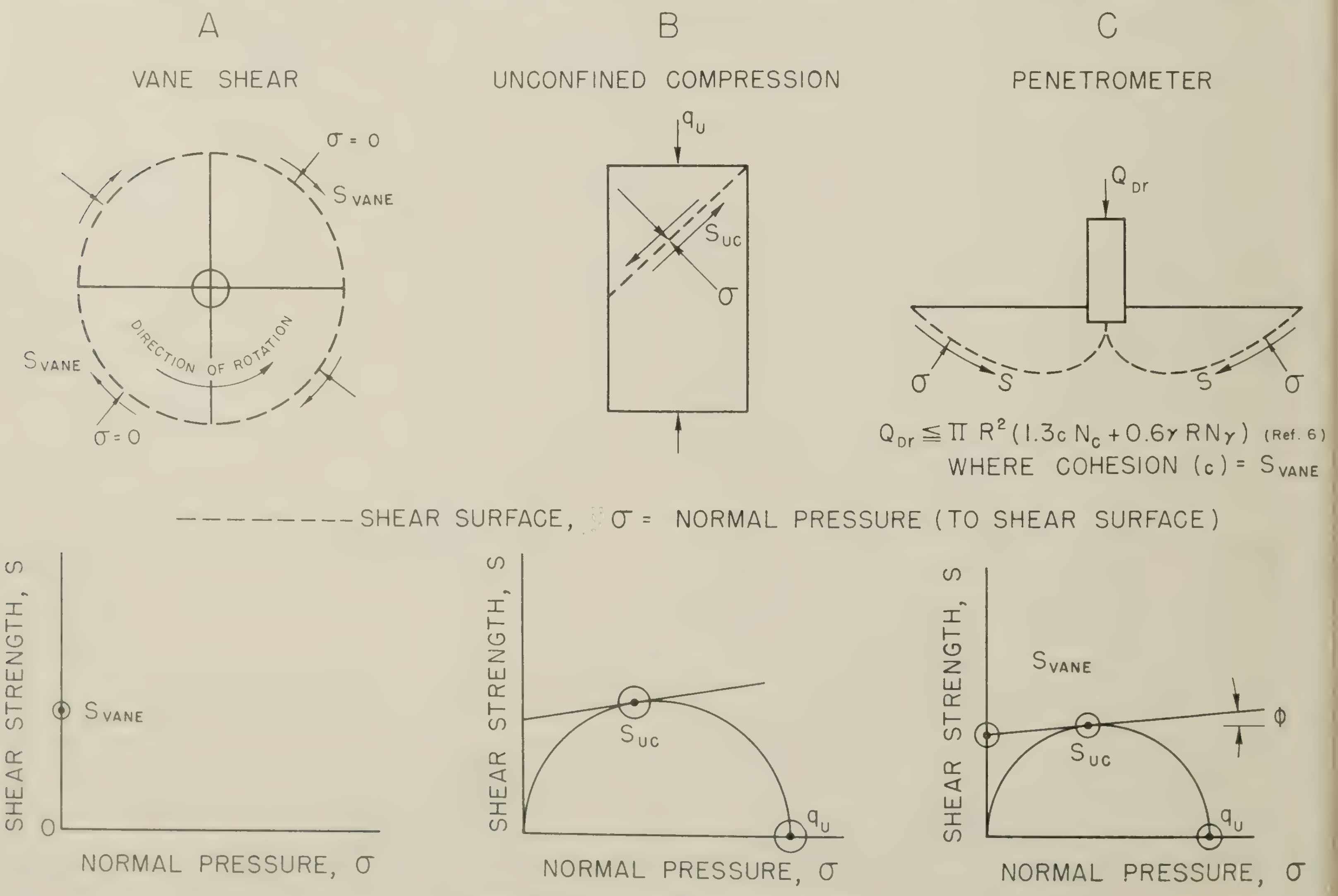

Figure 8.—Theoretical modes of failure.

Table 2.—Measured and computed force to insert penetrometer

Soil test	Cohesion, c	Angle of inter-granular friction, ϕ	Measured force required to insert penetrometer	Computed force from Terzaghi's formula
No.	*P.s.f.*	*Degrees*	*Pounds*	*Pounds*
3a	300	23.0	3.50	3.00
3b	77	13.5	.62	.43
8a	192	26.5	2.27	2.24

hese results, it was concluded that the insertion of the vane made an insignificant lifference.

To determine whether any changes in trength were the result of removing the soil rom the mold, tests were made with the vane on duplicate samples in the mold and after their removal from the mold. The duplicate amples were removed from the molds, wrapped in aluminum foil, and held by hand, while the vane test was being made in accordance with normal procedures. No measurable lifference in shear strengths was observed for the soils, whether tested in or out of the mold, at moisture contents between the plastic and liquid limits.

Although the vane-*uc* ratio was constant for each soil within its plastic range, it increased as the moisture content decreased below the plastic limit. This may have been caused by crumbling of the soil and subsequent reduction of the unconfined compressive strength. When the vane test was conducted on these drier specimens after their removal from the mold, the specimens tended to crack during the test and the result was a reduced vane shear strength. The vane-*uc* ratio then approached the constant ratio obtained in tests for the soils having higher moisture contents.

Penetrometer Tests

In conjunction with the laboratory vane est evaluation, shear strengths were also btained by using a commercially manufactured penetrometer. This device is used to measure the resistance of a soil mass to he penetration of a rod 0.245 of an inch in iameter, at ¼-inch penetration. Penetrometer tests usually were made with each vane hear test. The ratios of the average shear trengths obtained from the penetrometer to the strengths obtained from the unconfined ompression tests are given in table 1. This atio ranged from 1.3:1 to 2.3:1. The elationship between this ratio and plasticity ndex is shown in figure 6.

Mode of Failure

The wide variation in the vane-*uc* ratio, rom 0.6:1 to 1.4:1, indicates that there is a asic difference in the mode of failure between he two tests. As shown in figure 7, the ane-*uc* ratio is related to the plasticity ndex. As the plasticity index increased, he vane-*uc* ratio increased to about 1.4:1. For a plasticity index of 14, the ratio was .0:1.

As noted previously, test specimens having nonuniform structure, water content, and density would tend to have vane-*uc* ratios greater than 1.0:1. It is likely that as the plasticity index of the soil increased, the molded test specimen became less uniform. For the highly plastic soils, the average strength measured by the vane test exceeded the strength measured by the unconfined compression test by 40 percent.

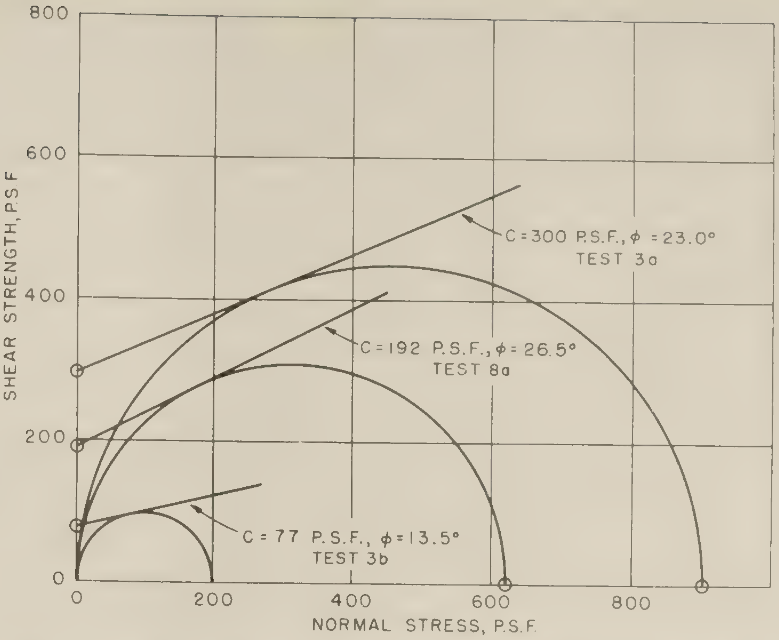

Figure 9.—Interpretation of shear strength measured in vane shear and unconfined compression tests.

The vane-*uc* ratios of less than 1.0:1, indicating greater shear strengths obtained by the unconfined compression test, may have been caused by the inclusion of an intergranular friction component mobilized in the unconfined compression test but not mobilized in the vane test. Parts A and B of figure 8 represent the theoretical mode of failure for the vane and the unconfined compression tests, respectively. In the vane test, if the normal pressure (σ) induced during shear were zero, the shear strength would be a function of cohesion only and would not be affected by intergranular friction. In the unconfined compression test, the shear strength was a function of both cohesion and friction. It was reasonable therefore to expect that as the plasticity index of the soil became smaller, the frictional component would increase in significance and the result would be smaller vane-*uc* strength ratios.

If the assumption were true that the vane measures cohesion only, a useful Mohr diagram could be plotted using results of the vane and the unconfined compression tests. By using the vane measured strength at a zero normal stress and the Mohr circle determined by the unconfined compression test, the Mohr Envelope was established, as shown in figure 9. To check the validity of these Envelopes a comparison was made of the resistance to penetration obtained by use of the penetrometer with the resistance computed by using the Envelopes. The penetrometer resistance was calculated by Terzaghi's formula (*6*),

$$Q_{Dr} \overline{\overline{<}} \pi R^2 \,(1.3cN_c + 0.6\gamma R N\gamma)$$

where,

Q_{Dr}, critical load on a circular footing, lb.;
R, radius of footing, ft.;
c, cohesion, p.s.f. taken from vane shear strength;
N_c, $N\gamma$, bearing capacity factors dependent upon angle of internal friction, ϕ from unconfined compression test;
γ, unit weight of soil, p.c.f.

The theoretical mode of failure for the penetrometer is shown in part C of figure 8. A comparison of the computed penetration resistance with the measured forces is given in table 2. The reasonably good agreement indicated that results obtained by use of the Mohr Envelopes might be correct.

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(*2*) *Deep Vane Tests in Gulf of Mexico*, Symposium on Vane Shear Testing of Soils, ASTM Special Technical Publication 193, November 1957, pp. 16–25.

(*3*) *The Vane Borer: An Apparatus for Determining the Shear Strength of Clay Soils Directly in the Ground*, by Lyman Cadling and Sten Odenstad, Royal Swedish Geotechnical Institute Proceedings No. 2, Stockholm, 1950.

(*4*) *Consistency Limits of Clay by the Vane Method*, by M. Darienzo and E. Vey, Proceedings Highway Research Board, vol. 34, 1955, pp. 559–566.

(*5*) *Vane Tests in the Alluvial Plain of the River Forth Near Grangemouth*, by A. W. Skempton, Geotechnique, vol. 1, No. 2, December 1948, pp. 111–124.

(*6*) *Theoretical Soil Mechanics*, by Karl Terzaghi, John Wiley & Sons, New York, N.Y., 1943, p. 125.

Evaluation of Results of Laboratory Vane Shear Tests With Pore-Pressure Measurements

by [1] Professor NYAL E. WILSON, McMaster University, Hamilton, Ontario, Canada

The following comments on the preceding article, *Evaluation of Laboratory Vane Shear Test*, are those made by Professor Wilson.

"Goughnour and Sallberg proposed two hypotheses regarding the research work on the laboratory vane-shear test; these hypotheses are concerned with (1) the influence of pore-water pressures and (2) the effects of progressive failure. Some interesting research work has been conducted on the laboratory vane shear test and the results of this work substantiate the findings of Goughnour and Sallberg.

"This research involved using the laboratory vane shear apparatus in dilatant soil; the soil used was a medium-fine silt. The rate of testing was accurately controlled by a variable-speed motor and the vane blade was instrumented so that pore-water pressures could be measured on the shear surface (fig. 1). The pore-pressure measurements were taken by welding hypodermic tubing to the edge of one of the vane blades; the end of the tubing was slotted and covered by a No. 200 mesh screen.

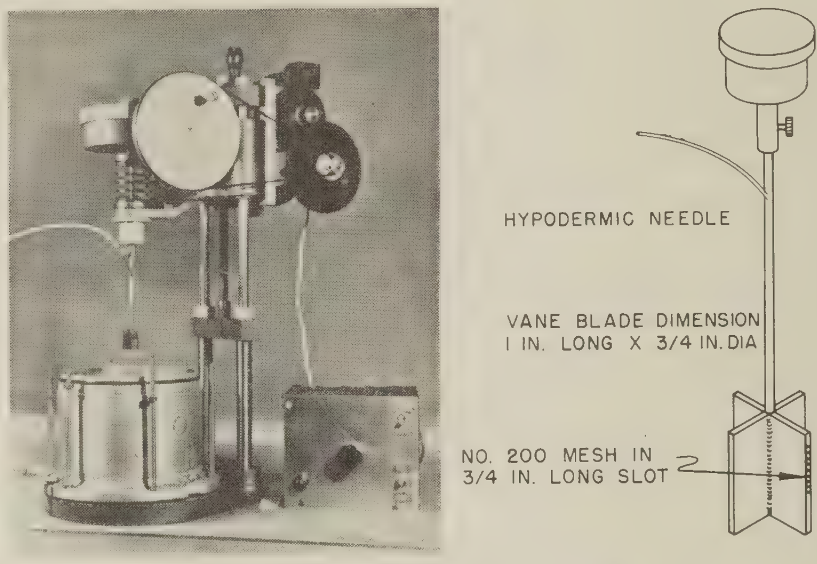

Figure 1.—Laboratory vane apparatus and variable speed motor.

Influence of Pore-Water Pressures

"As in the research by Goughnour and Sallberg, it was found that the torque applied to the vane shaft was dependent upon the speed of testing. Figure 2, showing torque versus testing speed for vane tests in silt, indicated that a higher torque was associated with higher testing speeds.

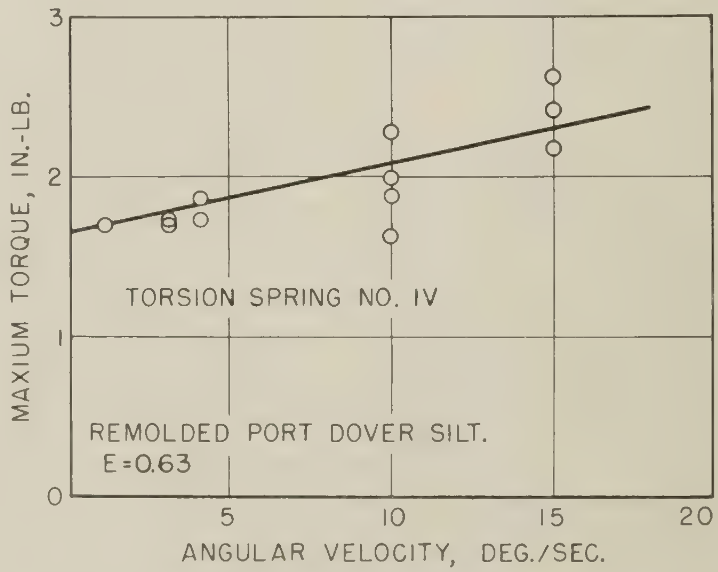

Figure 2.—Dependence of maximum torque on angular velocity of torque dial in vane tests on silt.

"The value of the torque was overestimated by about 25 percent when tested at the usual speed in the laboratory; this overestimation was related to the particular torsion spring used in the test. The deformation of the soil was dependent upon the speed of testing; that is, the angular velocity of the torque dial, and it was related to the rigidity of the torsion spring and varied with each apparatus; this is one of the disadvantages with the laboratory vane test, which is neither rigorously stress-controlled nor strain-controlled.

"To investigate the influence of pore-water pressure on the torque applied to the vane shaft, a series of tests was conducted in silt (fig. 3): these tests, which were conducted at constant speed, also indicated that a change in testing depth from 2 inches to 3 inches had no significance. The results showed that induced pore-water pressures can be in either the negative or positive range depending on the formation of the meniscus at the start of the test. Negative pore-water pressures were applied to the soil to determine the influence over a greater range. The sloped line (fig. 3) indicated that the laboratory vane test, commonly considered as an "undrained" test, acquired the characteristics of a "drained" test in dilatant soils; this anomaly has also been found for tri-axial tests on dilatant soils.

Progressive Failure

"Observations were taken during the tes to investigate progressive failure. The va was inserted to the depth of the vane blad and photographed as the torque was applie and as the angular deformation took pla (fig. 4). At a strain of 10° and when th maximum torque occurred, shear surfac were generated at the tips of the blades an at right angles to them. At this stage in th

[1] Presented at 43d annual meeting, Highway Research Board, Washington, D.C., Jan. 1964

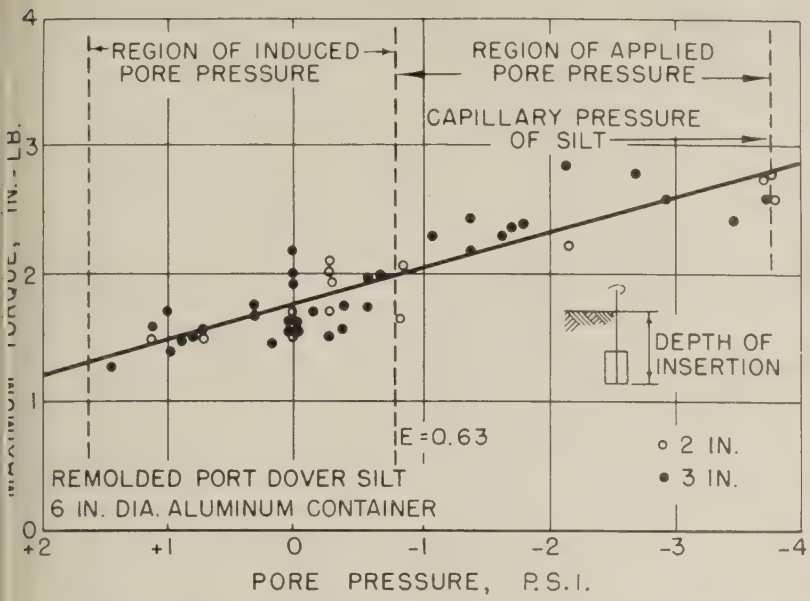

Figure 3.—Maximum torque versus pore pressure from vane tests on silt.

Figure 4.—Vane test in silt.

st, the shear surface was not cylindrical it almost rectilinear. As the angular rain increased and the torque decreased, e shear surfaces extended until, ultimately, cylindrical failure surface was formed. uring these stages of the test, voids were rmed behind the vane blades and the earing resistance was zero at these voids. ven though the ultimate shearing surface as cylindrical, it was not necessary for the ear surface at maximum torque to be cylin- ical or the stress distribution on the walls the cylinder to be uniform. As the stress stribution at the shearing surface and along the vane blades was unknown, it was not possible to use the vane with any accuracy in this type of soil."

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(1) *Techniques of Field Measurement and Sampling,* by M. Q. Golder, Fifth International Conference on Soil Mechanics and Foundation Engineering, Paris, 1961.

(2) *Techniques of Field Measurement and Sampling,* by N. E. Wilson, Fifth International Conference on Soil Mechanics and Foundation Engineering, Paris, 1961.

(3) *The Vane Borer: An Apparatus for Determining the Shear Strength of Clay Soils Directly in the Ground,* by Lyman Cadling and Sten Odenstad, Royal Swedish Geotechnical Institute Proceedings No. 2, Stockholm, 1950.

(4) *Laboratory Vane Shear Tests and the Influence of Pore-Water Stresses,* by N. E. Wilson, ASTM Shear Testing Symposium, 1963.

Comments by Goughnour and Sallberg

Comments of Goughnour and Sallberg re- rding Professor Wilson's evaluation were, as llows:

"The authors are grateful to Professor ilson for his interesting and informative dis- ssion. His development of the pore-pres- re device is a welcome contribution. It uld be of interest to continue the study of pore-pressure on a variety of soils having a wide range of plasticity indexes.

"Professor Wilson refers to the 'usual speed' of vane testing, but in figure 2 shows values up to 15 degrees per second angular velocity of torque dial. These values appear to be much higher than values of normal testing.

"In his last sentence, Professor Wilson states, 'As the stress distribution . . . was unknown, it was not possible to use the vane with any accuracy in this type of soil.' It should be pointed out that the stress distribution is not known for any type of test. It would seem that the vane test could be considered as accurate as any other of the commonly used tests."

NEW PUBLICATIONS

Opportunities for Young Engineers

A revised and updated version of *Opportunities for Young Engineers in the Bureau of Public Roads (1964)* has recently been issued by the Bureau of Public Roads, U.S. Department of Commerce. This 16-page, illustrated pamphlet may be purchased from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C., 20402, for 15 cents a copy. The introduction to this pamphlet tells of the Bureau's responsibilities and its cooperation with other Government agencies and foreign countries.

This publication is intended to provide information for college students interested in careers in highway or highway-bridge engineering. Information is presented on the 3-year training program for young engineers and on the organization, operations, and history of the Bureau.

Additional information regarding opportunities in the Bureau of Public Roads is contained in three folders that may be obtained free of charge by writing to the Personnel and Training Division, Bureau of Public Roads, Washington, D.C., 20235. These publications are: (1) *Opportunities as a Professional Highway Engineer,* (2) *Professional Challenge and Growth for Accounting Majors,* and (3) *Challenging Opportunities in the Bureau of Public Roads Right-of-Way Training Program.*

Typical Pedestrian Bridges

The fifth volume in the Bureau of Public Roads series on *Standard Plans for Highway Bridges (1962)*, Vol. V—*Typical Pedestrian Bridges,* is expected to be issued late in December or early in January 1965 and will be for sale by the Superintendent of Documents, Government Printing Office, Washington, D.C., 20402.

The plans for pedestrian bridges are intended for the guidance of State, county, and local highway departments in the development of suitable and economical highway bridges across the Interstate or dual-highway systems. The plans presented in this publication and the first four volumes should be particularly useful to the smaller highway departments having limited engineering staffs. An effort has been made to provide sufficiently complete information on all bridge plans so that they will approach contract drawings as nearly as practicable. For any given location, however, the requirements imposed by the site conditions probably will necessitate modification of the bridge plans because they have been developed generally only for right-angle crossings, level roadway grades, and typical walkway vertical curves. However, to improve the educational value of volume V, calculations for several of the more difficult to design pedestrian bridges have been included in this publicaion. The inclusion of these calculations will serve as examples and encourage the use of the most suitable bridge for the location for which it is intended. Typical examples of pedestrian bridges are presented. A highway having two, 3-lane roadways separated by a 40-foot median was considered to be the average roadway requiring a pedestrian crossing, and these bridge plans have been presented so that they can be adapted for many situations. All examples shown have been selected on the basis of esthetics and economic suitability.

The inclusion of two-span continuo[us] bridges has been the direct result of a rece[nt] study that showed a favorable economic comparison between two-span and four-spa[n] continuous bridges. Removing the should[er] pier creates an impression of openness, whi[ch] greatly enhances the esthetic qualities of th[e] bridge. In addition, it increases sight distanc[e,] increases safety, and improves conditions f[or] maintenance. It is assumed that normal[ly] the pedestrian bridge can be placed in a c[ut] section or ramp on earth embankment. F[or] those bridges that require stairs or ramps [in] extremely limited space, stairway and ram[p] alternates have been detailed and can [be] adopted for most all bridges.

Appendix A presents a rather comple[te] design criteria for use in the design of pede[s]trian bridges. It is believed that the desi[gn] requirements for these bridges should be mo[re] liberal than for highway bridges. Therefo[re,] the design criteria reflects a considerab[le] number of exceptions to the AASHO spe[ci]fications.

Dimensions and Weights of Vehicl[es]

A report prepared by the Bureau of Pub[lic] Roads, *Maximum Desirable Dimensions a[nd] Weights of Vehicles Operated on the Feder[al-]Aid Systems,* has been transmitted to t[he] Congress by the Secretary of Commerce a[nd] has been published as House Document N[o.] 354 (1964). Copies of H. Doc. No. 354 a[re] sold by the Superintendent of Document[s,] Government Printing Office, Washingto[n,] D.C., 20402, for 45 cents each.

U.S. GOVERNMENT PRINTING OFFICE: 1964

PUBLICATIONS
of the Bureau of Public Roads

A list of the more important articles in Public Roads *and title sheets for volumes 24–32 are available upon request addressed to Bureau of Public Roads, Washington, D.C., 20235.*

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Annual Reports of the Bureau of Public Roads:

1951, 35 cents. 1955, 25 cents. 1958, 30 cents. 1959, 40 cents. 1960, 35 cents. 1962, 35 cents. 1963, 35 cents. (Other years are now out of print.)

REPORTS TO CONGRESS

Factual Discussion of Motortruck Operation, Regulation and Taxation (1951). 30 cents.

Federal Role in Highway Safety, House Document No. 93 (1959). 60 cents.

Highway Cost Allocation Study:

First Progress Report, House Document No. 106 (1957). 35 cents.

Final Report, Parts I–V, House Document No. 54 (1961). 70 cents.

Maximum Desirable Dimensions and Weights of Vehicles Operated on the Federal-Aid Systems, House Document No. 354 (1964). 45 cents.

The 1961 Interstate System Cost Estimate, House Document No. 49 (1961). 20 cents.

PUBLICATIONS

A Quarter Century of Financing Municipal Highways, 1937–61. $1.00.

Accidents on Main Rural Highways—Related to Speed, Driver, and Vehicle (1964). 35 cents.

Aggregate Gradation for Highways: Simplification, Standardization, and Uniform Application, and A New Graphical Evaluation Chart (1962). 25 cents.

America's Lifelines—Federal Aid for Highways (1962). 15 cents.

Calibrating and Testing a Gravity Model With a Small Computer (1964). $2.50.

Catalog of Bridge Plans. $1.00.

Classification of Motor Vehicles, 1956–57 (1960). 75 cents.

Design Charts for Open-Channel Flow (1961). 70 cents.

Federal Laws, Regulations, and Other Material Relating to Highways (1960). $1.00.

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