The interrelation of soil mechanics and the design and operation of vehicles

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NATIONAL RESEARCH COUNCIL OF CANADA

ASSOCIATE COMMITTEE ON SOIL AND SNOW MECHANICS

TECHNICAL MEMORANDUM NO. 3

THE INTERRELATION OF SOIL MECHANICS AND THE DESIGN AND OPERATION OF VEHICLES

A contribution from the Directorate of Operational Research, NDHQ, Ottawa, which is also distributed as

CAORG REPORT NO. 43

Summary

A digest of all the information obtainable on this subject from the private reports and general engineering publications available to the Committee. It has been prepared as a background for projected experiments and for general information.

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1945

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NATIONAL RESEARCH COUNCIL OF CANADA

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The Interrelation of Soil Mechanics and the Design and Operation of Vehicles

A: INTRODUCTION

The trafficability of any vehicle is related to the ground over which it operates. For successful operation the ground must provide (a) support for the vehicle and (b) the necessary reaction to the tractive forces of the vehicle. In peacetime, vehicle designers were concerned in general, only with good, hard surfaced roads. Thus the question of soil mechanics did not present itself as a very important factor in vehicle design until the wartime problem of the design and operation of cross-country combat vehicles developed.

E. G. McKibben (1) has stated that: "Cross-country combat vehicles are immobilized by (i) an increase in the resistance to their motion, and (ii) a decrease in the traction for producing motion. Increased resistance to motion is caused by (a) decreased soil support under transport mechanisms and (b) increased adhesion of soil to the moving parts of these mechanisms. The former results in excessive sinkage with no belly clearance, and the latter causes clogging of moving parts. Reduced traction results from (a) decreased friction between traction surfaces and the soil; (b) decreased friction between soil surfaces; (c) decreased shearing strength of the soil; (d) increased adhesion of mud between grousers. The study of possible solutions of these basic questions i.e. increased resistance to motion and reduced traction, and their related specific problems, indicates that until both qualitative and quantitative data are available on all these problems there can be no sound design procedure. There can also be no logical defence of recommended designs or even intelligent debate of the relative merits of competing or controversial designs".

The aim of this memorandum is to outline the nature of these basic problems associated with the interrelation of soil mechanics and the design and operation of vehicles, and to present a digest of the approaches to the solutions of these problems which have been followed by various organizations.

B: RECENT MILITARY INTEREST

(-a) Great Britain:

As a result of the increased use of cross-country combat vehicles in the World War of 1939-1945, it became apparent to the military authorities of such countries as the United Kingdom and the United States of America that their respective Ordnance Departments had been designing cross-country vehicles without the aid of factual data on the effects of the various elements that influence cross-country operation. Many trial runs of vehicles in mud had been conducted, but there were few quantitative measurements of the actual drawbar pulls developed by various vehicles in different soils under varied conditions.

In Great Britain, as a preliminary to the invasion of Northwest Europe, the problem arose in February, 1944, of enabling vehicle performance to be forecast by the provision of soil maps and meteorological data. This problem was investigated by collaboration between the School of Tank Technology, Ministry of Supply, Army Operational Research Group, Inter-Service Topographical Department, and the Meteorological Office (Air Ministry). This investigation brought forth the realization that much qualitative and quantitative information was required on the various factors which influence cross-country operation. To facilitate research into these matters the British Mud-Crossing Committee was formed in July, 1944.

The members of the Committee represent the following organizations:

Directorate of Tank Design, Ministry of Supply
Directorate of Mechanization, Ministry of Supply
Inter-Services Topographical Department
Directorate of Mechanical Engineering, War Office
Directorate of Royal Armoured Corps (T), War Office
Assault Training and Development Centre
Meteorological Office, Air Ministry
Road Research Laboratory, Department of Scientific and Industrial Research
School of Tank Technology, Military College of Science
Army Operational Research Group
Rothampstead Experimental Station
Fighting Vehicle Proving Establishment, Ministry of Supply
National Institute of Agricultural Engineering

The aim of the committee was, in brief, to investigate and advise on the effect of soil characteristics on the performance of track-laying A.F.V's in general, and the performance of such vehicles over soft mud or boggy ground in particular.

(B-b) United States of America:

In the United States of America, the first approach to a quantitative determination of the performance of various vehicles in mud appears to have begun early in 1943, at the Ordnance Desert Proving Ground, Camp Seeley, California. By flooding sections of the desert, mud courses were prepared and by the use of a field dynamometer truck with a hydraulic brake cylinder and pressure gauge as a measuring element, maximum drawbar pulls were determined. This work was the first step, but control of the condition of the courses was very erratic and difficult to obtain, and the accuracy of the results was open to considerable question.

In February, 1944, the Aberdeen Proving Ground leased the use of the facilities of the Department of Agriculture's Farm Tillage Machinery Laboratory at Auburn, Alabama, for conducting controlled mud tests. These facilities were developed by the Department of Agriculture to test tillage machinery in various types of soils and were capable of measuring the drawbar pull and resistance to traction of light vehicles in selected soils. In order, however, to determine the characteristics of the tracks and tires used on all the Ordnance vehicles, it was thought necessary to have a controlled testing facility established by the Ordnance Department. This facility was to be similar to the one at Auburn but on a much larger scale. Due to the limited amount of information available for designing facilities of this kind and upon the conducting of mud tests, steps were taken to secure this information.

The Society of Automotive Engineers Tractor War Emergency Committee was requested by the Ordnance Corps to set up an Advisory Mud Testing Committee composed of representatives from both the automotive and tractor industries to study the entire problem and furnish information on the procedure and equipment for controlling soil conditions, and the instruments and operating procedure in conducting tests. This committee was established at Auburn, Alabama, in September, 1944, the members representing the following organizations:

Allis Chalmers Manufacturing Company
Utica Proving Grounds of the Chrysler Corporation
Caterpillar Tractor Company
Milford Proving Grounds of General Motors Corporation
Cleveland Tractor Company
Firestone Tire and Rubber Company
International Harvester Company
Massey-Harris Company (of the United States of America)

The Ordnance Research and Development Centre, Maryland, was to provide the facilities and Personnel for carrying out the work, and the United States Department of Agriculture to provide facilities and Personnel for consultation at the Tillage Machinery Laboratory at Auburn, Alabama.

<u>(B-c) Canada:</u>

In Canada an Associate Committee on Soil and Snow Mechanics of the National Research Council of Canada was instituted in April, 1945, following discussions between representatives of the Council, Army Engineering Design

Branch of the Department of Munitions and Supply, the Canadian Army (Directorate of Operational Research and Directorate of Vehicles and Small Arms) and other interested groups. The initial purpose of this committee was to consider the military problems under review by the corresponding groups in the United States and Great Britain, from the Canadian point of view, and to make such contributions to their solution as appear possible. Participation of the National Research Council in this work is closely linked with the possibility of eventually extending the initial work in relation to the special problems of civilian land transportation in Canada, with special reference to travel over snow and muskeg and to the design of agricultural machinery.

C: BASIC PROBLEMS

The question of trafficability in relation to the character of the terrain has become important in time of war, because military strategy has demanded that military vehicles be capable of travelling almost anywhere, avoiding roads and highways whenever possible. Since military vehicles must usually be armoured and therefore heavy, the problem of increasing flotation and so of lowering unit bearing pressure has led to the development of the track-laying vehicle.

There thus developed the transition from the wheeled military vehicle -- for use on roads and highways and only exceptionally for cross-country movement, to the track-layer -- for use in cross-country performance with the added requirement of being able to travel on roads within the rear lines of communication without causing excessive damage. This transition was empirical in its initial stages, with the half-track as evidence of the attempt to unite mobility with trafficability, thus retaining ease of steering whil at the same time gaining flotation.

The basic problems for both wheeled and tracked vehicles are similar. Unit pressure is, of course, greater for wheels than for tracks, but in both cases the problem of tractive soil stresses arises, albeit in different degree. The problem of the design of tread modifications for tires is analogous to the question of dimensions of grousers for track shoes. Since, however, cross-country performance is of major immediate importance, the question of track-layers will alone be dealt with in this report.

It has been suggested by E. W. Micklethwait (2) that: "a modern tank track should have adequate support and traction under the widest possible range of conditions and should have low rolling resistance on soft ground. These questions are intimately bound up with the properties of the soil upon which the tank is operating. It is, therefore, of the greatest importance to study the properties of typical classes of soil in order to have some idea how one track will compare with another on average soils of various types and under different weather conditions. The question of support is, of course, bound up with an examination of actual ground pressure and the question of traction also clearly involves a knowledge of soil properties and in particular their resistance to failure in shear. This includes the study of factors governing the choice of depth, width, and distribution of grousers. With regard to rolling resistance, it must be clear that on soft ground a large part of the power developed by the engine is devoted simply to squashing down the ground which may absorb hundreds of horsepower. If the power wasted in this way could be reduced, the speed and range of the tank would immediately be increased without any alteration to the engine or transmission."

A further problem is presented in Canada as cross-country performance is considered, and that is the question of over-snow as compared with over-soil trafficability. Over-snow travel, of course, involves much lower unit pressure than average soil-going, and snow has many characteristics which are different from those of both cohesive and cohesionless soils. The Canadian committee is also very much concerned with the problem of trafficability over muskeg, the characteristics of which probably bear little resemblance to those of either snow or the common inorganic soils.

D: SPECIFIC PROBLEMS

The basic problem of improving the trafficability of tracks involves many separate and specific problems. An analysis of the factors affecting the interrelation of soil mechanics and tracked vehicles results in a breakdown as shown in Appendix A. Many of the questions, although specific, bear a definite relation to one another. For example, the sinkage of a vehicle in operation is related to the question as to whether it has been designed with open or closed tracks. The numbered factors in the Appendix (including their breakdown) will be treated as separate items because, in general, they have each been investigated as separate problems.

The design of a vehicle involves certain factors which affect its trafficability. These can be listed as follows:

1. Belly clearance:
2. Drive sprocket arrangement:
3. Material (adhesion):
4. Bearing surface or area (pressure distribution):
5. Grousers (grouser ground pressure):
6. Open or closed tracks

The last four can be grouped as defining the type of track.

operation of a vehicle involves other factors affecting its trafficability. These are:

7. Soil conditions:
8. Rolling resistance:
9. Effect of the disturbance of the soil:

Much work and research has been carried out in the past twenty years on the above specific problems. A digest of the information gathered during the past six months concerning what has been done on each problem is now presented.

(D-1) Belly Clearance

As was stated in the introduction, decreased soil support under the transport mechanism will result in excessive penetration even to the point where there is no longer clearance between the body or frame of the vehicle and the soil. Corresponding resistance to motion may be decreased by increasing the frame and body clearance, that is, the distance between the bottom of the track and the bottom of the hull. In this way, no power would be wasted in bulldozing the vehicle forward in the case of soft ground where the penetration was excessive. This solution is limited, however, by the fact that increased clearances mean the exposing of a larger target to enemy fire and a higher centre of gravity with decreased stability and thus impaired uniformity of pressure distribution.

It was determined in studies of flotation at Camp Seeley, California, in August, 1944 (1.1) that in mud and snow, traction and ground clearance were more important than flotation for the trafficability of tracked vehicles.

A report (1.2) was issued on the tractive resistance tests of the 105 mm. airborne Howitzer tractor, with and without skid pans at Auburn, Alabama in October, 1944. It was found that extremely high pulls were required to move towed loads through soft, deep mud because of the tendency of the load to sink into the mud. As a result skid pans were designed to cover the irregular surfaces of the gun carriages and present a smooth streamlined surface which would increase the flotation and decrease the tractive resistance and the tendency of the carriages to dig in and push mud ahead of them. It was concluded that incorporation of the skid pans greatly reduced the tractive resistance when towed in terrain where the penetration of the wheels exceeds the ground or belly clearance of the undercarriage.

From trials at Chaklala, India, April, 1944 (1.3) it was concluded that the Locust was inferior in a bog to the Stuart M3A3 and Carrier T15 due primarily to the lack of adequate belly clearance.

In a report (1.4) on a visit to Australia and New Guinea, it was noted that the strong point of the Australian tracked truck, 1 ton, was its very high clearance compared with the British armoured carrier. This enabled it to act as a load carrier over terrain too swampy to take any other known vehicle.

In reports M.C. 61 and 82 (1.5, 1.6) on comparative trials held on Somerset coastal sites in England with various A.F.V. tracks in May and June, 1945, results were tabled after three to five runs under the heading "Residual Belly Clearance". The effect was observed of a number of vehicles following the same route, on a single track with an underlayer of firm clay, and it was concluded that this test emphasized the value not only of belly clearance but the necessity for bulldozing ability.

The U.S. Mud Testing Committee concluded in February, 1945 (1.7) that vehicles are liable to fail by reason of external or internal conditions, for example, by bellying and subsequent lack of sufficient traction. Failure will always be liable to occur through the vehicle encountering external conditions surpassing its limits of mud-crossing capacity.

(D-2) Drive Sprocket Arrangement

This factor can very properly be related to the question of the effect of disturbances on the soil. The velocity imparted to the track by a sprocket, which necessarily has polygonal pitch lines, is not uniform. This causes the characteristic clattering of the track, which involves certain losses of a dynamical character. The theoretical evaluation of these losses is not easy. Some investigations were carried out in this regard in connection with chain transporters designed for materials in bulk. There are, however, very few investigations in regard to tracks. A theoretical evaluation was made in July, 1944 (2.1) which showed that a short pitch was better from the standpoint of reducing the shocks and clattering which result from the lack of propulsion uniformity.

Another factor to be considered when discussing sprocket drive arrangement is the question of front versus rear drive. The Germans in 1936 (2.2) measured the movement resistance for various driving track mechanisms in relation to speed and the results showed that a rear drive increases the movement resistance because the rear drive sprocket also carries the vehicle's weight.

(D-3) Material (Adhesion)

This factor has been repeated in the breakdown because it is of importance in regard to both the body and the track. For example, if the body is made of a material which does not shed the soil easily, then obviously more and more load is added to the vehicle in travelling over say, bog, and this results in an increase in unit pressure which in turn causes excessive penetration until finally the vehicle will be bogged down. In the case of a track made of a material to which soil sticks, the result may be that the effective grouser height is reduced in travelling over bog and this in turn will reduce the traction which will lower the trafficability of the vehicle.

It was stated by Major W. C. Christopher (3.1), Automotive Chief, Aberdeen Proving Ground, in December, 1944 that "the tracks currently in production and under development can be divided basically into two types, the rubber track and the steel track. Assuming that a track has all good properties, such as adequate flotation, durability, does not throw easily, etc., the criterion of a rubber track is traction. The coefficient of traction of a rubber track is very good on hard dry surfaces. This coefficient rapidly falls off as the surface becomes wet, frozen or muddy. The rubber grouser cannot be as aggressive as is required to operate over slick, muddy or frozen ground, so a steel grouser can be attached to the rubber track to give the vehicle a sufficient coefficient of traction to meet most off-the-road requirements. This was proven without a question of doubt in the mud dynamometer testing conducted by the Ordnance Research and Development Centre in 1944. Inherently, with a rubber track also, better bogie life is experienced and this is extremely important now that we have to make bogies out of synthetic rubber. One of the biggest objections to steel tracks is the so-called tendency to skate when a vehicle is so equipped. Also, it goes without saying that in off-the-road service under muddy conditions the cleaning properties of a track also seriously affect traction and the rubber track cleans better under all conditions."

In a study of "soil dynamics" by M. L. Nichols 1925 (3.2), research was made into the mechanical properties of soil as they affect implement design with a view to handling the extremely sticky and tenacious soils of Alabama. From the studies made it seemed possible to lay down tentatively certain fundamental laws in sliding friction between metal surface and the soil, remembering that these hold only between certain limits.

(a) "Friction Phase:" In a dry soil if the soil does not wet the slider, and the bearing power of a soil is less than the applied pressure, the coefficient of sliding friction, U', varies with the speed, the pressure per unit area, the smoothness of the surface and the materials of which the surfaces consist.

(b) "Friction Phase": If the bearing power of a soil is greater than the pressure per unit area and the slider does not get wet, the magnitude of the friction is proportional to the total pressure between the two surfaces. The value of U' depends upon the smoothness of the surfaces and the materials of the surfaces but is independent of the area of contact and of the speed of sliding.

(c) "Stiction Phase:" If there is enough moisture present to cause the soil to adhere to the sliding surface, but not enough to leave moisture brought to the surface, then U' varies with the speed, the area of contact, the pressure per unit area, the surface tension of the film moisture, and the surface and kind of metal.

(d) "Sliction Phase:" If there is enough moisture present to give a lubricating effect, U' varies with the pressure per unit area, the speed, the moisture content, the viscosity and the smoothness of the surface and amount of material of which the surface is composed.

It will be seen that the coefficient of sliding friction is a dynamic and constantly varying factor rather than a fixed quantity and that in any soil it is affected by moisture content and particle size. The importance of these factors in practical plow design is obvious. In the (a) phase, a shape that would give the least surface speed of soil over the metal surface and the least pressure per unit area of contact would give the least frictional resistance.

The study of physical properties of the soil as they affect implement design was continued by Nichols in 1927 (3.3). Particular attention was given to adhesion and it was found that the adhesive properties of the metal can be varied by various heat treatments, rapid cooling in mercury giving the least adhesion.

Nichols continued his study of "soil dynamics" in 1939 (3.4). The studies of the friction of soil and metal showed that the increased pull caused by the adhesion of the soil to metal was due largely to the colloid content of the soil. The place in the moisture range of soil at which adhesion took place was affected by both the metal and soil. The maximum cohesive power of the soil state was also found to be in direct proportion to colloid content. A new method of measuring adhesion of soil to metal was evolved. This consisted of measuring capillary pull exerted by metal on water and comparing this to the capillary pull of a metal whose adhesion to soil had been measured by the slider method.

Studies of adhesion between soil and metal surfaces were made by M. L. Nichols and F. A. Kummer in 1935 (3.5). A group of metals extending over a wide range of chemical composition was selected. The structure of the metals was determined by metallographic methods and varied by standard heat treatments. Soil solutions of a group of soils varying in chemical properties were displaced from field soils and used in the special testing apparatus to measure the spreading angle of the solution on the metal. This angle was used as a measure of the traction between a metal and a soil solution. Metals in which the various ingredients are held in solid solution have a low spreading angle which is apparently due to the lack of separation between the ingredients. Metals with free graphitic carbon, such as cast iron, have a great attraction for the soil solution. It was found that impurities, when segregated, materially increased the variations in surface potential and it is believed that the difference in potential between the different grains of the metal materially affects the spreading angle and consequently the adhesion of the soil to the metal.

In further studies on the development of reduced friction surfaces and materials for experimental plows by F. A. Kummer, 1938 (3.6) comparative field tests were conducted at the Black Belt stations of Alabama and Mississippi with bottom plows, impregnated wooden surfaces or standard steel mold boards. In order to determine the extent to which various factors contribute to scouring, the materials were subjected to sliding friction and adhesion tests in the laboratory. The results of tests from sliding friction on metal showed that under the same conditions considersbly less force was required to pull the steel sliders over the soil. It has been generally conceded that adhesion between soil and metal is caused by the competition of the soil and plow surface for film moisture. Since greased or waxed surfaces do not compete strongly for such moisture, it is believed that the improved scouring of impregnated surfaces is caused by the decreased competitive action betwen the two solids.

In a consideration by the British Mud-Crossing Committee, February, 1945 (3.7) of the mud crossing properties of tracked vehicles, in the light of the plastic behaviour of clay, it was stated that the degree of adherence of clays to metal depends upon the metal.

In a study of the results of comparative trials on Somerset coastal sites with various A.F.V. tracks in soft ground conditions (MC 82, March, 1945) (3.8) it was determined that the steel track had greater tractive power than rubber. It was thought that this pointed to a probability that actual surface adhesion of the track material to the soil was a greater factor than appeared to be generally realized.

In a report by the 21st Army Group, April, 1945 (3.9) it was indicated that during a drive to the south by the 1st Canadian Army from the neighborhood of Nijmegen to Gech, uncontrollable skids were experienced by the Shermans on the frozen roads and these were more frequent with the steel than with the rubber chevron tracks. The Valentine track had greater adhesion on ice-covered roads than other types. Units of the 1st Canadian Army were unanimous in stating that on ice-covered roads rubber chevron tracks gave better adhesion than the steel.

Various trials have been carried out by the Australian Operational Research Section in Australian New Guinea with the object of determining the best type of tank track for use over muddy ground (3.10). One of the conclusions was that the metal tracks of the Matilda tank are more effective than the rubber tracks of the Grant and Sherman, and that further, the Sherman fitted with metal tracks was more efficient in crossing mud than when fitted with rubber tracks.

(D-4) Bearing Surface (Pressure Distribution)

The support that the ground must provide is influenced by a number of factors of vehicle design. These include (a) the vehicle ground pressure which depends on the length, width of track, and weight of vehicle; and (b) the load distribution on the track as influenced by the number and location of the bogie wheels, the location and shift of the centre of gravity, and the pitch and tension of the track.

In a study by J. W. Randolph and M. L. Nichols in 1924 (4.1) of the fundamental factors influencing the traction of wheeled tractors it was found that the factor of greatest importance was the weight upon the wheels. An extensive study had been made by the Alabama Polytechnic Institute at Auburn on the effect of weight on traction.

In a German publication of September 1933 (4.2) there is a graph showing the influence of load on wheel size and rolling resistance. Another German publication of 1937 (4.3) gives a graph representing the same vehicle with its centre of gravity in three positions:

(a) nose
(b) centre
(c) tail.

The graph showed that (a) is the best type of agricultural tractor because its traction was best. The same result was also given by a Russian publication called the "Theory of the Auto" by Chudakov.

In a discussion by Merrit (4.4) of the design of high-speed tracked vehicles (1939) it was indicated that, in general, an increase of length tends to improve the possibility of good riding properties over irregular ground, but in all other respects increases of dimension or of weight add to difficulties of design. The problems of suspension were outlined in regard to track profile, that is the number and disposition of the bogie wheels and the way in which they are inter-connected and constrained with reference to obstacle crossing capacity. The discussion included the question of load distribution curves and damping rates for the various wheels. It stated that a multi-wheel is better than a four-wheel arrangement due to the smaller effect of the surface waves of short pitch in relation to the track base of the vehicle.

E. G. McKibben (4.5) carried out a large amount of research on the question of transport wheels for agricultural machines. In March, 1940, he and J. Brownley Davidson, both at Iowa Agricultural Experimental Station, in cooperation with the S.A.E., determined the effect of wheel arrangment on rolling resistance. They gave data for the rolling resistance of single, dual and tandem arrangements of 6.00-16 implement tires when operated at loads of 500-1000 pounds per tire on blue grass, tilled loam and blue sand. The rolling resistance for the dual arrangement did not differ greatly from that with a single tire. Of the three dual spacings studied, 8, 12 and 16 inches apart, only the intermediate 12 inch spacing appeared to have a slight advantage. The tandem arrangement materially reduced the rolling resistance, particularly on the heavier load on loose sand, where the reduction was 34%. Repeated trials of single wheels run in the same track confirmed results obtained with the tandem arrangement and emphasized the gain in power quantity to be obtained by arranging for the wheels on field equipment to track whenever practicable.

In July, 1940, E. G. McKibben and J. B. Davidson published an article (4.6) on the "Effect of Radius and Slippage of Wheels". The loaded radii and distances of forward travel per revolution were measured for all the steel wheels and pneumatic tires used in the rolling resistance studies reported in earlier articles. The effect of radii and slippages were concluded from these data. Slippage occurred in all tests on agricultural soils. This slippage was approximately proportional to the square of the coefficient of rolling resistance.

Vehicle pressure tests were also carried out at Ottawa by the National Research Council of Canada in January, 1944 (4.7). The gauge used was of the pressure plate type, 6" in diameter, built to assimilate the action of the Tellermine 42. The gauge acted by mutual inductance and phase cancellation. Measurements by electric gauges of the load under the tracks of a snowmobile, also by the National Research Council at Ottawa in February, 1944 (4.8) indicated that the load exerted by the track is extremely variable, also that a track without projections beneath the bogies might give a more uniform distribution of the load and much smaller peak loads.

The U.S. Mud Testing Committee, under the supervision of the S.A.E. carried out flotation and traction studies at Aberdeen Maryland, in February, 1944 (4.9) and arrived at the following specific conclusions:

(a) An increase in width of a closed track with short straight grousers has little effect on the tractive coefficient of clay, in dry condition, but it does increase the tractive coefficient in loam, and extends the operating range in the moist-loose conditions of both courses;

(b) the wide track was the most satisfactory of all tracks tested in all conditions of both clay and loam courses;

(c) an increase in track width of a closed track with short straight grousers caused an increase of tractive resistance in dry-firm conditions of both loam and clay courses.

It was also determined that the five track types tested had the same tractive resistance relationship in dry-firm conditions of both clay and loam courses.

In a British report of March, 1944 (4.10) the effect of track tension on sinkage was considered mathematically as was the effect of size and number of wheels, of long-pitched tracks and of closely-spaced wheels. Mean ground pressure was defined as $p = \frac{T}{2LW}$ where 'T' is the weight of tank, 'L' is the length of track, 'W' is the width, and 'p' is in lbs. per sq. in.

E. W. Micklethwait discussed in July, 1944 (4.11) the question of pressure distribution and track tension in detail in his publication "Tracks for Fighting Vehicles". The study is primarily a theoretical one and involves some mathematics. It is noteworthy that he discussed the question of mud-packing beneath the track and rear sprocket and its effect on track tension. The effect of wheels and track length on distribution is also treated theoretically.

It was determined in studies of flotation in California in August, 1944 (4.12) that a track will either sink down until it reaches a solid base in mud, or if the mud is quite thick, sink until it has gained sufficient additional contact area to support it. It was also determined that in soft sand the tread design is important only as it affects flexibility. However, with tracks in sand performance is mainly governed by the degree of loading. It was also reported that for the traffic of track vehicles over sand the centre of gravity should be low.

In a British Mud-Crossing Committee report of August, 1944 (4.13) a theoretical treatment is given of the design of tracks, considering the track variables such as pitch, width, etc. The question of the supporting power of soils as related to pressure distribution is also treated theoretically.

In November, 1944 (4.14) the U.S. Mud Testing Committee carried out traction tests on 23 tracks and track combinations and listed their comparative tractive abilities both in mud and on hard dirt. The variables were track width, pitch, tread, and pressure distribution. It was indicated that the size of wheel should be a maximum for best performance.

A report was issued by the British Mud-Crossing Committee in November, 1944 (4.15) in which the opinion was expressed that with a flexible track, long pitch favours soft ground in performance. It was also indicated in this report that the soil profile determines whether the long narrow track is better than the short wide track. The opinion was given that in general the latter is better.

In a consideration by the British Mud-Crossing Committee in November, 1944 (4.16) of the mud-crossing performance of track vehicles in the light of the plastic behaviour of clay, it was suggested that the maximum useful reaction both vertically and horizontally of the soil would be obtained with a rigid or closely-spaced suspension with a minimum of link oscillation.

The effect of the projected area of the grouser pressure face and the track ground surface area were compared with the tractive coefficient determined in the Palmer Test Area mud test in December, 1944 (4.17). The relative order of the mud test readings agreed perfectly with that of the grouser pressure face areas. The main advantage of increased track contact area was to enable the vehicle to maintain road clearance in adverse muddy conditions. It was also brought out in the first report on the flotation and traction studies at Auburn, Alahama, that a track type superior in one soil is not necessarily superior in all soils. Tests to that date had indicated that track width will increase the operating range of the vehicle concerned into the more severe course conditions without increasing the drawbar pull performance in more favourable drier conditions, while increasing the grouser pressure face area will show an increase in drawbar pull.

Some work on the trafficability of different types of vehicles with and without loads had been done by the M.G.O., in India and reported upon in December, 1944 (4.18). Trials were held over paddy fields in various moisture conditions. It was illustrated by the comparison of the Locusts T9E1, Stuart M3A3 and a Carrier T15 that power-to-weight ratios are not the only factors on which performance in mud can be assessed.

In a report of December, 1944 (4.19) on the work of the British A.O.R.G., it was concluded by trial and analyses that for the reduction of sinkage it was necessary that

(a) tracks be wide;
(b) the number of bogie wheels be large;
(c) the track pitch be large;
(d) the radius of the bogie wheels be large.

The maximum sinkage had been calculated taking into account the number of bogie wheels and track pitch, assuming the centre of gravity to be symmetrically placed. The resulting conclusions involved track tension of which very little was known. Nevertheless, whatever values were selected, the sinkage of the tanks worked out in the order given, in trials held at Ayrshire. The relative importance of each factor was found to vary under different circumstances. These results compared favourably with theory.

In a report on "B" Vehicles from C.M.H.Q. of December, 1944 (4.20) information was given to the effect that trials were held to compare the performance of the Snowmobile with that of the M29 Weasel and a Canadian tracked jeep in traversing mud. Although the theoretical ground loading of the Snowmobile was less than the Weasel ($1\frac{1}{2}$ p.s.i., as compared to 2.1 p.s.i.), the weight of the Snowmobile was not as well distributed as that of the Weasel, so that the actual specific ground loading was believed to be greater than that of the Weasel.

The T36 Snow Cruiser developed by the U.S. Forest Service in January, 1945 (4.21) gave indications of being a good experimental vehicle by virtue of the large number of suspension wheels on the track ensuring even distribution of the weight on the track. One of its best features is its low and longitudinally symmetrical centre of gravity which is capable of easy variation.

The U.S. Committee has had carried out considerable research on the question of weights, e.g. the Royal Armoured

Corps Technical Situation Report No. 31 (4.22) issued by the British Army Staff in Washington to the War Office lists the relationship of weights to pressures for medium and light tanks.

Various types of tracks were tested in comparative trials held by the British Mud-Crossing Committee in March, 1945 (4.23). The results were tabulated under the headings of the different track variables such as width and pitch. The various types of tracks were tried on the Sherman and Cromwell tanks. It was felt that grouser depths and extenders were the dominant factors and that the long-pitch tracks had been made because they facilitated the addition of a large extender.

In March, 1945 (4.24) the British Committee undertook to do some ground pressure distribution tests with the A41 tank using soft soil. This was as a result of their comparative trials on Somerset coastal sites with the Sherman and Cromwell tanks. It gave a fair indication of the A41's probable mud crossing performance in relation to other tanks whose pressure distribution had been similarly examined. However, the March, 1945, experiments were carried out to determine what happens to soil with the various tracks and suspensions during motion. This was accomplished by ground pressure distribution tests with piezo-electric cells and cathode ray oscillographs. The Churchill tank was found to give a more even pressure distribution than any other tank tested.

In a report on the work of the U.S. Committee issued in March, 1945 (4.25) flotation on soft ground and the effect of track and wheel design was discussed by mentioning the different means of load distribution to the track and then to the ground. Various factors affecting flotation, for instance, increase of wheel base and long track pitch, were described.

In a report on German A.F.V's in winter by G.S.I, 21st Army Group, May, 1945 (4.26) it was stated that to obtain improved traction for their A.F.V's in adverse conditions, the Germans resorted to widened tracks.

Tests were conducted with a light cargo carrier M29C (Weasel) over a Norfolk sand test plot at Auburn, Alabama, in June, 1945 (4.27). The purpose of these tests was to determine the effect of various load distributions and the consequent shifting of the centre of gravity position on vehicle performance. It was revealed that the maximum pull occurs at and above approximately 40% track slippage and that additional dynamometer brake load results only in more track slippage and does not increase the drawbar pull value. The composite curves of drawbar pull versus track slippage, at different centres of gravity and with varying load distributions, illustrated the advantage of having a portion of the pay load ahead of the centre of the vehicle. Tractive resistance tests of each of a number of varied test conditions were conducted in conjunction with the drawbar pull tests, that is, the centre of gravity was varied by placing the pay load at different spots in the vehicle. Very little difference in pull was recorded. During these tests the moisture content of the sand was varied from 5 to 12%. Course compaction or density was determined prior to each test by the air pressure pycnometer as to "total pore space volume", that is the lower the percentage of pore space volume, the more compact the test soil. Graphs were presented of tractive resistance versus road speed, and drawbar pull versus track slip.

(D-5) Grousers

With a smooth track, traction is provided only by friction between the track and the ground. With a track having grousers the friction between the track and the ground is one factor, but in addition the shear value of the ground trapped between the grousers is added. In order that this last factor be fully utilised, the questions of spacing, height, length and shape of the grousers must be investigated to determine the requirements for optimum traction, that is, so that the ground can give the best reaction to the propelling forces of the track.

At the request of the Gulf Coast Horticultural Society, in 1924, work was started to find the best grouser equipment for tractors in sandy soils of the southern part of Alabama. This is described in a study of the fundamental factors influencing the traction of wheeled tractors by J. W. Randolph and M. L. Nichols in 1924 (5.1). A study of tractors in the field and factors entering into traction of wheeled tractors indicated that the problem of traction can be studied best one factor at a time. Testing equipment and methods were devised having a direct relation to the tractor driving wheels and grousers. The grouser and wheel-testing equipment consisted essentially of a wheel mounted so that the input, weight, output, and various other factors could be measured accurately by means of calibrated scales. Factors of the tractor which could be varied at will were width of rim, and size and shape of the grouser. It was found that the factors influencing traction had the following order of importance in Norfolk sand: the weight upon the wheel, the depth of grouser, the width of grouser, and the angle of grouser across the rim.

In 1925, the study of fundamental factors influencing traction and wheeled tractors was continued (5.2). It was determined that with a given width of rim, output increased up to a maximum as the weight carried by the wheel was increased up to a certain point. With further increase in weight the output decreased. The highest force ratio (efficiency) is produced with a weight carried by the wheel just sufficient to force the grouser into the soil. Output increases with the width of the rim when the weight is sufficient to force the grousers into the soil. It was concluded that the resistance to shear determines the tractive value of the soil. If the soil is confined by a rim (or arch action) the shear area is increased by bringing the line of shear nearer parallel to the surface of the ground, the shear angle of unconfined soil being 45 degrees. The compressing action of the rim increases not only the arch action but the shear value per square inch.

J. W. Randolph published a report in 1929 (5.3) on the variation of the grouser design factors affecting traction. The tractive resistances for different soils obtained by varying the factors affecting tractor design were plotted as curves. In all cases the formulae for these curves were similar, varying only in the constants of the equations. The variation of these constants appeared to depend largely on the colloid content of the soil. Grouser depth, weight disturbance and grouser volume rank in the same order of importance for the soil tested.

In a publication of 1939 (5.4) by C. Culpin it was indicated that studies on tractor wheels had been carried out at many state colleges and universities in North America. Davidson and McKibben made a detailed study of tractive efficiency of the farm tractor (5.5). One of their conclusions was that the principal causes of a low efficiency is a high rolling resistance. Grousers of an excessive length were usually found to cause a loss of efficiency due to their high rolling resistance but on a loose surface with a firm sub-soil, 9 inch grousers were better than 6 inch or 7 inch though not as good as 4 inch. On sticky soils angle iron grousers extending over the edge of the rim have been found advantageous for increasing traction. The fitting of extensions, rims and grousers was found more satisfactory than increasing their weight. Increasing the diameter of wheels progressively from 38 to 52 inches resulted in progressive increases in tractive efficiency.

In November, 1944 the U.S. Mud Testing Committee carried out traction tests on 23 tracks and track combinations and listed their comparative tractive abilities both in mud and on hard dirt. The variables were grouser length, height, grouser ground pressure, grouser ground pressure-face projected area and angle.

In a report by the British Mud-Crossing Committee of November, 1944 (5.6) the opinion was expressed that the thinner the grouser the better from an adhesion standpoint.

The effect of grouser pressure face and track ground surface area were compared with the tractive coefficient in December, 1944 (5.7) by the U.S. Ordnance Research and Development Centre. The relative order of the Mud Test ratings agreed perfectly with that of the grouser pressure face areas. The main advantage of increased track contact area was to enable the vehicle to maintain road clearance in adverse muddy conditions. It was also brought out in the first report on flotation and traction studies at Auburn, Alabama, that a track type superior in one soil is not necessarily superior in all soils.

Tests to that date indicated that track width will increase the operating range of the vehicle concerned into more severe course conditions without increasing the drawbar pull performance in the more favourable drier conditions, while increased grouser pressure face area will show an increase in drawbar pull.

In comparative trials with various A.F.V. tracks reported in January, 1945 (5.8), the cross-country performance of the Sherman tanks in conditions of extremely soft going were compared with tracks as follows:

(a) standard steel chevrons with extended end connectors,

(b) standard steel chevrons with universal grousers.

It was concluded that the additional traction given by the grousers was outstanding.

Some specific conclusions were arrived at in flotation and traction studies carried out by the U.S. Mud Committee at the Aberdeen Proving Ground in February, 1945 (5.9):

(a) A closed track with chevron grousers is more effective than one with straight grousers of the same height in extending the operating range in moist-loose conditions of the clay course, while these two tracks develop approximately the same tractive coefficient in dry-firm conditions of this same course;

(b) a closed track with straight grousers develops a greater tractive coefficient than one with chevron grousers of the same height in all conditions of the loam course;

(c) an increase in grouser height of a wide, open track with straight grousers causes a large increase of tractive resistance in all conditions of both loam and clay.

It was concluded that for maximum performance in mud, grousers should be of sufficient size to transmit the maximum tractive effort of the vehicle in low gear at full throttle. Five types of tracks were tested with different grousers and dimensions on two courses, clay and loam, and many specific conclusions were arrived at regarding tractive resistance and grouser ground pressure.

Another report of March, 1945 (5.10) gives a description of the platypus grouser and of trials held near Cleve, Italy over water-logged ground, each tank taking a virgin path. The trial was a comparative one between platypus and standard tracks on concrete and bituminous highway in order to determine damage done to the road by each type. The conclusions were that (a) the Sherman tank track fitted with platypus grousers gives superior performance in mud to other standard or extended end connectors; and (b) the platypus will do more damage than the standard track on road when steering in short radius or when running along the road edges.

As a result of comparative trails held on Somerset coastal sites with various A.F.V. tracks in soft ground conditions in March, 1945 (5.11) various grousers were discussed generally and it was felt that grouser depth was one of the dominant factors in improving trafficability of tanks and A.F.V's. Lists were given of the relative merits of various tracks with variable grouser dimensions. Results were tabled for various tracks under the heading "Traction" for the Sherman, Cromwell, Panther, and Churchill tanks. The results were fully described in regard to (1) method of analysis (2) details of tests (3) investigations of statistical significance.

Pressure cone versus applied load studies on model grousers were carried out at Auburn, Ala. in April, 1945 (5.12). These are described in detail in the section on "Soil Conditions".

In the Pienza area, Italy, over which the 8th British Army had been fighting, a "rat grouser" was developed which was 9" longer than the width of the track and fitted to alternate track plates. It was found to perform very well in the sodden soil of that area.

The U.S. Mud Testing Committee reported in May, 1945 (5.13) than an M5A1 high-speed tractor track had been designed to give a three-point contact since the apex of one grouser and the sides of two grousers occur on each link.

The T36 Snow Cruiser developed by the U.S. Forest Service indicated the value of a low departure angle, ensuring track tension in the line of the track in contact with the ground and hence the absence of distortion of the track on the ground.

In his "Tracks for Fighting Vehicles" July, 1944 (5.14) E. W. Micklethwait studies the question of rolling resistance on hard ground in detail. The study is a theoretical one in the main, but many test results are included. These results were obtained from reports of the Mechanization Experimental Establishment.

(D-6) Open or Closed Tracks

This question involves both the problems of self-cleaning and of bearing pressure. Some authorities have felt very strongly that the open track is desirable because of better cleaning but the question is still open as to whether it can give bearing pressures better than or even equal to that of the closed track.

Some specific conclusions were arrived at in studies carried out by U.S. Mud Testing Committee at the Aberdeen Proving Ground in February, 1945 (6.1): (a) On dry-firm conditions of the clay course, an open track with short straight grousers developed a greater tractive coefficient than did a closed track having the same grouser height, while on dry-firm conditions of the loam course, the two tracks developed approximately the same tractive coefficient; (b) on moist-loose conditions of the clay course, a closed track with short straight grousers and an open one with the same grouser height had approximately the same value, while for the moist-loose conditions of the loam course, the closed track was more effective in extending the operating range.

(D-7) Soil Conditions

In consideration of the basic problems, E. W. Micklethwait was quoted as suggesting that it is of the greatest importance to study the properties of typical classes of soil in order to have some idea how one track will compare with another on average soils of various types and under different weather conditions. This involves (a) a knowledge of the physical properties of soils; (b) the preparation of soil maps of the world; (c) the development of methods of measuring soil conditions; and (d) the correlation of tests in soil bins with performance in the field. A thorough knowledge of soils and their conditions is therefore essential for the proper operation of the vehicles which must use these soils as their supporting medium.

M. L. Nichols carried out studies of "soil dynamics" in 1923 at Auburn, Alabama (7.1). A study of the resistance of soil to compressive force showed that the relationship of the thickness (T) of a given layer of soil to a compressive force (P) could be concluded by the empirical formula $TP^k = a$, where k and a are specific soil constants depending upon the moisture content and plasticity constants. While this formula was found to be sufficiently accurate for practical conclusions its obvious implications for extreme values for either T or P indicated the need for further investigations which were carried on.

It was found that the rate of penetration of a plunger, where the reaction was free to arch over a considerable area was proportional to pressure, and that the ratio was a function of the apparent specific gravity. Compression and arch reaction studies were continued to determine the relationship of these factors to the rolling resistance of a wheel. The exact nature of the soil reactions and of wheel slippage was determined by special laboratory apparatus. It was found that the generally accepted theory did not explain the true nature of slippage on soils since slippage consisted of a compressive action in front of the wheel resulting in actual forward movement with no rotation of the wheel on its axle.

In a study of the fundamental factors influencing the traction of wheeled tractors by J. W. Randolph and M. L. Nichols in 1924, (7.2) all known methods of measuring force distribution in the soil were tried but none found satisfactory. A new method of measuring soil stresses was devised which was called the "Plaster Cast Method". This method consisted of arranging the soil to be tested in a box of layers separated by thin sheets of fragile paper. A wheel and grouser were tested over this soil through any desired distance. With the wheel removed the distortions of the sheets of paper were studied and cast in plaster of paris for future study. A report of this method is given in the Journal of the American Society of Agricultural Engineers.

In further study of "soil dynamics" by M. L. Nichols at Auburn, Alabama, in 1925 (7.3) studies were made of the mechanical properties of soil as they affect implement design with a view to handling the extremely sticky and tenacious soils of that state. From the studies made it seemed possible to lay down tentatively certain fundamental laws for sliding friction between a metal surface and the soil. These were detailed in the section on "Materials (adhesion)".

Further studies were made by Nichols on "soil dynamics" in 1930 at Auburn (7.4). Various soil constants or properties were studied to determine which could best be used as an index of the physical factors affecting tillage. The properties considered were: percentage of colloid, heat of wetting, moisture equivalent, capillary pull, freezing point depression, and the Atterberg consistency constants. It was concluded that the

Atterberg consistency constants were the most satisfactory indices to the physical properties of the soil. Experiments were conducted with a series of soils varying in chemical and physical composition to determine the relationships of these constants to specific soil properties. It was found that a definite relationship existed between friction values, shear, resistance to compression, and these constants. The general reaction of a soil to an implement was also studied by means of pulling "chisels" through it; it was found that this reaction was a function of the physical properties as indicated by the Atterberg constants. The work showed that the reation due to these properties could be accurately predicted at any moisture content from these constants.

A method of measuring and studying compression and the arch action was developed by F. A. Kummer in 1940 (7.5) in his studies of physical reactions of tillage tools causing compression and arch formation also at Auburn. By this method the soil was placed in a glass-faced metal box and an external force in the form of a plunger, for instance a track shoe, was applied to the surface of the soil. The penetration of the plunger caused particle movements within the soil mass which were observed through the glass plate. Each moving soil particle traced its own path across the coated glass surface, thus making it possible to detect the relative magnitude and direction of even the smallest movement. Graphical analyses of records thus obtained made it possible to obtain the force distribution and the area of greatest compression produced in the soil of different-shaped plungers. A method of geometrical vector analysis was used to include variations resulting from different soil conditions.

In a British report of March, 1944 (School of Tank Technology) (7.6) a discussion is given as to the effect of consolidation and bearing capacity on trafficability. Two cases are discussed theoretically:

(1) assuming that all the sinkage is due to consolidation, with pressure varying directly as sinkage; and
(2) assuming that it is all due to shear, the pressure being a constant equal to the bearing capacity of the soil.

In July, 1944, E. W. Micklethwait (7.7) discussed soil mechanics with regard to tracks in great detail. He discussed:

(a) its importance;
(b) soil as an engineering material;

(c) types of surfaces normally considered throughout the world, e.g. shingle sand, clay, etc.;
(d) the adhesion and shearing strength of soils;
(e) the bearing capacity of soils.

In a British report of August, 1944, by the School of Tank Technology (7.8) there was a complete summary of the development of tank-going maps. It was suggested that:

(1) Soil maps be prepared with a legend showing:

(a) the deterioration in the resistance of the soil due to moisture; and

(b) the comparative performances of the various tracked and wheeled vehicles with respect to the soil on which they would be operating.

(2) That soils should be classified as follows:

(a) good going;
(b) fair going;
(c) fair going but locally bad after heavy rain;
(d) poor going but locally possible.

The following subjects affecting the problem were discussed:

(1) Topography and Geology;
(2) Meteorology;
(3) Field capacity; connecting the effect of rainfall and evaporation of soils;
(4) Weather forecasts;
(5) Physical properties of soils;
(6) Vegetation;
(7) Vehicle characteristics.

A theoretical treatment was given of the relationship between the physical properties of soils and the question of the design of track for example, supporting power. The question of tank-going was also discussed in relation to soil conditions -- "a slightly damp soil of any type will, if anything, improve the grip of track vehicles whereas with wheeled vehicles with rubber tires, a short heavy shower of rain, whether in a wet or dry time of year, may render quite gentle slopes temporarily impassable. The effect of traffic on soils below field capacity is to decrease their permeability so that when heavy rain is experienced, drainage is slower and surface mud may be expected".

A study was undertaken in November, 1944 (7.9) by the British Mud-Crossing Committee to determine the physical properties of soil influencing vehicle performance. The factors studied were:

(a) methods of measuring these properties; and
(b) methods of working soils to achieve the desired physical characteristics.

The M.G.O., India, reported in December, 1944 (7.10) that in general, flooded fields are easier to traverse than saturated paddy fields. Trials were carried out in fields of very soft, heavily saturated clay of extremely glutinous consistency offering severe resistance to traction. Tests were also conducted in these fields in a flooded condition.

In a report by the British Committee in December, 1944 (7.11) the theory and design of tank suspension are outlined. Starting from work of Terzaghi on the supporting power of the soil, it is assumed that this can be applied in the case of tanks, allowance being made for sinkage. It is shown that the bearing capacity of the soil, p can be expressed by a simple equation $p = \alpha + \beta(x)$ where x = sinkage and α and β are constants depending upon the type of soil.

In view of this simple equation the soils need not be classified by their internal angles of friction and cohesive strengths. Trials were held at Ayrshire where an attempt was made to correlate the data for comparing the mobility of German and British tanks with the information given by a number of different penetrometers, for example, the Campbell Stick; tests were also made on a rolling wheel apparatus for reconnoitring terrain.

Laboratory tests were carried out in January, 1945 (7.12) by the U.S. Committee at Auburn, in glass boxes coated with lavigated alumina mixed in alcohol. A measured pressure was then applied to the track shoe and the movement of the soil scratched the alumina on the glass thus giving a pressure pattern.

In January, 1945, pressure cone studies of model grousers (7.13) were made at Auburn to determine the relative shear areas set up in the soil that is, the soil which would shear if a vehicle were to slip in its tracks. The size and shape of this cone of sheared soil is indicative of the effectiveness of a grouser. In order to obtain comparable results each grouser was implanted in the soil in such a manner that the soil began compressing along the full surface of the grouser immediately the grouser was moved. Each grouser was forced into the soil the same distance, thus allowing the pressure cones to attain the same development due to penetration. The distances travelled and the pressures required to move the grousers were recorded simultaneously and motion pictures were taken to show the pressure cones in their various stages. When the pre-selected penetration was reached, a still photograph was made of the evolved pressure cone. By superimposing these final cones on each other, the relative areas were determined.

Comparative trials were held on Somerset coastal sites with various A.F.V. tracks in January, 1945 by the British Mud-Crossing Committee (7.14). Bearing in mind the limitation imposed by the use of a single test site, having soil conditions generally of the same type (a very churned up, saturated mixture of fibrous loam, sand and clay with a semi-hard clay underclay) and the absence of real bog, the vehicles were as follows:

(1) Churchill - the only vehicle which did not fail;
(2) Panther - almost but not quite as good as the Churchill;
(3) Cromwell - ($15\frac{1}{2}$ inch tracks) good performance;
(4) Sherman - (with platypus, EEC & steel chevrons) all these types can be very easily bogged in comparison with Churchill and Panther;
(5) Tiger - very poor.

The British A.O.R.G. in January, 1945 considered the line of attack necessary to produce reliable going maps (7.15) that is,

(1) soil maps of a required area;
(2) the possibility of predicting moisture content;
(3) finding relation between moisture content and "going" for a given soil.

In a mobile laboratory set up in January, 1945 by the British A.O.R.G. (7.16) for recording tank going data, the bulk of equipment was for measuring soil characteristics, for example, classification of soil type, determination of soil profile, shear strength, moisture content, compaction. Sufficient data could be collected in one day so that analysis may produce indicative results unaffected by a change in weather conditions. This is important in the preparation of soil maps.

In a report by the British A.O.R.G. in January, 1945 (7.17) on the relation between soil moisture content and tank-going, the following measurements are discussed:

(a) Atterberg tests;
(b) unconfined compression tests;
(c) Proctor needle tests.

The relationship between moisture content and sinkage is also [illegible]ussed.

It was concluded generally by the U.S. Committee February, 1945 (7.18) that the relative importance of traction and flotation depended on the soil type and soil condition of the terrain encountered. They also concluded that work on clay soils at or near saturation point was the most likely to produce results useful to the war effort. In their consideration of controlled soil bins for research and quantitative study they recommended various methods of controlling soil conditions for reproducability of tests.

In a consideration by the British Mud-Crossing Committee in February, 1945 (7.19) of the mud-crossing performance of tracked vehicles in the light of the plastic behaviour of clay, small scale experiments were considered of definite value. Methods were suggested, for instance an angular ring capable of being loaded both with a known load and in torque. Various types of tracks for testing were also suggested, for instance, concave and flat.

The British Mud-Crossing Committee in their comparative trials with various A.F.V. tracks in March, 1945 (7.20) took careful note of the soil conditions and considered the question of physical properties of the soil by making a number of soil measurements:

(a) moisture content profile from 0 to 24 inch depth daily;
(b) unconfined compression profile;
(c) plastic and liquid limits;
(d) mechanical analysis of the topsoil and subsoil;
(e) A.O.R.G. vane testing shear strength;
(f) Campbell stick measurements.

Tests were on virgin ground with primarily soft ground conditions.

In a [illegible] U.S. [illegible] Committee, in March, [illegible] (7.[illegible]) a means was suggested of preparing tank-going maps including a method of classification with regard to passability and soil moisture content.

In April, 1945 (7.22) the Scientific Advisor to the Army Council in Britain described a suggested questionnaire to be given by A.O.R.G. to personnel in Western Europe to aid in a study of soil conditions and tank mobility.

Pressure cone versus applied load studies on model grousers were carried out at Auburn, in April, 1945 (7.23). The first phase of this program was the measurement of the pressure cone formed when an object such as a grouser was forced through the soil. Sand was chosen as the test medium for the study. The original test equipment consisted of a hand-cranked feed which forced the test probe into a box filled with soil. The soil box was located on platform scales and the amount of force exerted was indicated by the balance of these scales. The penetrometer was adapted to this test and then penetration versus force required was recorded during a test run. Later, a larger box was constructed with a glass viewing-window and with scales along the vertical and horizontal axes. Model grousers were constructed, each one-quarter normal size. The sides of the grousers were relieved and thus eliminated contact with the soil of any part of the grousers except the leading edge (the grouser face). After further testing it was decided that at least three basic shapes should be tested of the same sectional area. Three models of one square inch projected area were constructed with three bearing face angles 0°, a 45° chevron and a 60° chevron. Tests on all standard grousers were made with the grousers embedded when the soil was compacted. The glass window was sprayed with lavigated alumina and alcohol which upon drying formed a white coating on the glass. The grousers were driven through the soil in contact with the coated window and the resultant forces in the soil were translated into scratches or tracks in the coating. Motion pictures were made of the entire cone evolution from 0 to 2 inch penetration. After a series of tests had been run the data were plotted in graph form and analyzed. Most of the grousers gave approximately the same pressure-penetration characteristics. Areas of less than one square inch gave variations in results that could not be explained. Results indicated that regardless of shape, if the grousers have the same projected areas, pressure required to force them through the sand will be the same. From the motion picture, grouser action in soil can be studied at small increments of the pressure cone evolution up to the formation of the full pressure cone. The result indicates that in sand, if track cleaving and penetration are comparable for two vehicles, the track having the greatest grouser shearing area (length x height) will have the greatest traction and cross-country mobility regardless of grouser contour. Graphs were evolved in the model grouser studies of applied pressure versus penetration of grouser for both metal and wooden grouser. Open grousers were compared with closed. Schematic diagrams of the apparatus for vertical cone studies were also included in the report.

In a report by the British Mud-Crossing Committee of May, 1945 (7.24) soil investigations in Italy by the A.F.V.(T) H.Q. 8th Army were summarized:

(1) One of the best methods of conveying conditions to people who are not able to see for themselves is to carry out comparative trials with vehicles of known performance over the same conditions; many such trials have taken place in the 8th Army;

(2) taking tests of liquid and plastic limits seems to give a good indication of the physical properties of the soil;

(3) use of a California Testing Machine, a hydraulic jack to measure pressure versus sinkage of a tank that is, measuring the supporting power of a soil;

(4) use of the Campbell Stick - criticisms were given of this instrument and suggestions were made for making it more efficient as an instrument for reconnaissance on foot before an operation involving vehicles.

In July, 1945, at Auburn, Alabama (7.25) tests were carried out on soil preparation and control. This phase of the test was to study mechanical methods of soil preparation and re-conditioning for test condition duplication. Observations of the operation of a rotary type tiller indicated the possibility of adapting the principles of this type of machine to soil preparation and reconditioning. The Fowler-Storey Gyrollete is a tractor attachment featuring two slow-speed vertical axis (egg-beater type) rotors. In an effort to determine the feasibility of the Gyrollete as a soil conditioner the unit was operated in test courses consisting of the following soils:

(a) Norfolk sand;
(b) Davidson loam;
(c) Cecil clay;
(d) Eutaw clay.

The 11th. Army Group, S.E.A.C., A.F.V. Technical Staff, submitted a description (7.26) of tank action in various regions of Burma outlining the types of terrain encountered and the performance of Lee and Valentine tanks in negotiating these types of ground. Experienced tank men agreed that soft swampy country was the most serious obstacle. Flooded paddy fields were deceptive; if plowed they were not negotiable but if they were unplowed they could generally be crossed safely. The paddy roots, although giving some cohesive action, are insufficient to bind the soil to withstand the pressure of tanks. Bamboo causeways were tried and proven to be inefficient.

The country in the Fienza area in Italy over which the 8th Army (7.27) fought presented serious problems in the operation of tracked vehicles. The soil consisted of apparently bottomless agricultural clay which had become sodden from the abnormally heavy rains and had further deteriorated due to the destruction of the drainage system by the enemy as a deliberate measure to delay the allied advance. In many of these areas the main tanks became bogged and even the Churchill was unable to manoeuvre with freedom. The requirement for methods of improving the performance of our tanks lead to the design and use of "platypus grousers" and "rat grousers".

(D-7a) Soil Testing Devices

Various testing instruments have been developed for the purpose of aiding in the improvement of vehicle trafficability. Some of these are now detailed.

The test equipment at Auburn, Alabama, in 1935 (7.28) consisted of two major units, the power car with special dynamometer and the test unit car. The power car unit furnishes the motive power and measures and records the forces necessary to hold the article being tested in its working position. The car, with a 135 H.P. gas engine, is mounted on 8 tires 7.00-34, and weighs approximately nine tons. It has a speed variation from 0.2 to 10 m.p.h. The dynamometer (hydraulic) is of 5000 pounds capacity, measures the three directional components of draft, and is mounted on a superframe of the power car in such a manner that it can be moved crosswise on the car. The three components of draft are recorded on a chart with distance and time, thus making it possible to check the components of draft and speed for any part of any test.

The test units are mounted in a car which is hitched rigidly to the power car and consist of a beam with the front end carried on the dynamometer and the rear end mounted on two hydraulic units supported on a frame which may be moved crosswise of the plot in the framework of the car. A third hydraulic unit is located to take up the horizontal force exerted on the track bottom by the resistance of the soil to turning. The net horizontal reaction is the algebraic sum of this force and the horizontal force on the dynamometer. The algebraic sum of the loads on the two hydraulic units supporting the beam and the vertical component on the dynamometer, minus the weight of the track on these units, gives the upward or downward force exerted by the track bottom. This unit with the power car dynamometer enables the reactions on the track being tested to be measured as the track is held in its working position entirely by hydraulic units. The load on each unit is recorded continuously for a test.

The Germans developed in 1936 (7.29) a testing device for track vehicles to be used at a German proving ground. This makes it possible to measure vehicles up to 20 tons in weight and is adapted to speeds up to 50 m.p.h. Single tracks can be attached for testing purposes.

The Russian Scientific Technical Institute in 1938 (7.30) also designed a testing device for track and suspension design.

Research on tillage implements was carried out by the Department of Agricultural Engineering of the

University of Munich, Germany, where fairly elaborate equipment was available for the work (7.31). Part of the equipment consisted of a pit about 40 by 10 by 2 feet with rails running along both sides and a 4-wheel track which spanned the pit which could be followed along the rails by means of an electric motor and a winch. The equipment to be tested was mounted on a truck so that the forces acting on it in three planes at right angles could be recorded simultaneously. This apparatus permitted detailed study of the gears of some tillage tools.

E. G. McKibben and D. O. Hull published a paper in 1940 (7.32) on soil penetration tests as a means of predicting rolling resistance. The relation between the penetrations obtained with two penetrometers (Iowa and Rototiller) and the rolling resistance for two steel wheels and two pneumatic implement tires were investigated for a variety of load and field conditions. The correlation coefficients obtained for the eight comparions ranged from 0.92 to 0.98 and in all cases were very significant statistically.

There is an article by I. F. Reed published in 1940 (7.33) on a method of studying soil packing by tractors. It is stated that Culpin in 1936 developed an apparatus for forcing a "probe" into soil at a constant rate to any desired depth. The probe was forced down by calibrated springs whose deflections were recorded on a strip chart, thus giving an indicator type chart for each test. This unit was light in weight, easily operated and produced very satisfactory measurements, but it had a disadvantage in that the movement of the probe was retarded by the amount the springs were extended. This might cause considerable variation in the speed of penetration when hard or soft layers were encountered. The U.S. Tillage Machinery Laboratory at Auburn developed a soil resistance recorder which operated on the same principle as the device developed by Culpin but it was driven by an electric motor instead of by hand and used an hydraulic unit for recording the pressures; the length of the chart was the same as the depth of test. It was heavier in weight but, as used at Auburn, it was mounted on the special test car. The probe was forced into the ground at approximately 8 inches per second by an electric motor-driven worm gear. The pressure was created and recorded on a chart by means of a helical spring pen mounting. Cupped, conical, rounded and flat heads were tried. Since there was no significant difference in the resistance to the different types, the flat head was used for all tests. Culpin showed that the speed at which the probe was forced into the soil affects the resistance in a complicated relationship that may be similar to that for plows. This variable was eliminated for this study by using one speed for all the tests. Preliminary data obtained with the recorder indicated that all types of traction units compact the soil to a considerable depth and that this packing effect extends for appreciable distances beyond the edge of the tread to which pressure is applied.

A device employing the principle of a varying di-electric constant to give varying capacity and thus serve as an indicator of the moisture content of the medium surrounding the electrodes has been developed by the California Experimental Station, 1942 (7.34). Laboratory studies were made of reproducability in behaviour of the block capacity.

A device was developed by the U.S. Department of Agriculture in 1942 (7.35) which was called a stabilimeter, for use for quick field determinations of soil moisture conditions. It is a diamond-shaped blade on a shaft. The measurement of the resistance of the soil to rotation of this point is termed "the soil stability" and is evaluated in terms of torque. A generalized relationship is developed to facilitate the preparation of a soil moisture stability calibration for an area without the necessity of detailed laboratory work.

The A.F.V. Technical Staff of the British Army developed in April, 1944 (7.36) an electronic device (mutual inductance) for measuring ground pressure on the basis of the displacement of a diaphragm by means of an armature on which is wound two coils. Pressure-time graphs can thus be constructed.

In a report by the British A.O.R.G. dated December, 1944 (7.37) there is a detailed discussion about finding an instrument which could be used for the tactical reconnaissance of soil. The instrument discussed is a penetrometer called the Machine, Beach Test MK 3, or Campbell Stick, and it was found to give reasonable estimates of the "going" over the site of the trials. Curves relating the readings given by the Campbell Stick with the sinkage of both the Sherman and Churchill with moisture content have been produced. Recommendations were made for improvement.

In a report by the British Committee dated December, 1944 (7.38) a rolling wheel apparatus for reconnoitring terrain was discussed, as used in trials held at Ayrshire for comparing the mobility of German and British tanks with that of reconnaissance vehicles.

A mobile laboratory was set up in January, 1945 by the British A.O.R.G. (7.39) for recording tank-going data. They used a 4 inch post-hole auger with extensions for penetration in order to determine soil profile. They also had various types of penetrometers to determine the shear strength of soil.

Preliminary tests held in January, 1945 (7.40) by the British Mud Committee with piezo-electric pressure gauges set in the ground in the paths of Crusader and Churchill tanks suggested that the technique employed afforded a useful method of comparing the uniformity of ground loading obtained by different designs of track and suspension. Vehicle speed did not greatly affect the relative magnitude and form of the records obtained.

Dr. F. A. Kummer and A. V. Cooper published a paper in January, 1945 (7.41) in which was described the use of the Air Pressure Pycnometer to determine the porosity of soil. A diagram and a description of the method was given, the latter being dependent on Boyle's Law.

A report from the Milford Proving Ground (7.42) gives the ground rules for a good recording drawbar, that is:

(1) accuracy within 2% of scale of temperature;
(2) durability, greater than towing cable;
(3) dependability;
(4) size easily handled by one man.

Reference is made to an article by R. L. Cox in the Journal of Scientific Instruments describing the bridge circuit used and its advantages in linear response. The report gives details of the development work on the circuit of the inductance type drawbar and its application to measurement.

The U.S. Committee recommended in February, 1945 (7.42) certain major pieces of equipment for the controlled soil bins proposed for Aberdeen Proving Ground, for instance, a special dynamometer chassis for testing full-scale tracks, incorporating input power measurement and variable track loading devices.

In a report (7.43) of the work of the U.S. Committee, dated March, 1945, an instrument called a "bog-stick", for measuring the load-carrying capacity of a soil, is described. To give a satisfactory measurement of bearing capacity, it is suggested that an instrument must cover a reasonably large area and also be able to test the maximum depth to which a tank may be permitted to sink. A dimensionsed drawing of the proposed instrument is included. An apparatus known as a "Power-driven Resistance Recorder" has been developed to study the compacting of soils by a track and a description of this equipment is given in this report with an illustration of it.

The Proctor Needle Penetrometer was tested by the Dept. of Mechanization, Australia, in March, 1945 (7.44). Conclusions were:

(1) Ground bearing capacities of areas can be accurately determined with the penetrometer; the correlation of these capacities and the ground pressures of vehicles when in motion is not considered practicable;

(2) soil reconnaissance, however, would be of great value prior to the large-scale movement of automotive vehicles (such as an operation over doubtful terrain) and the needle offers a simple and accurate method of reconnaissance. The interpretation of readings obtained in a new area should be based on previous experience in areas of known bearing capacity.

The Instrumentation Panel of the British Committee met at the National Physics Laboratory in May, 1945, and discussed drawbar and sprocket torque dynamometers and resistance wire gauges. A system for measuring deceleration embodies a D.C. generator connected to a condenser and milliameter. Special brakes were considered, the load being applied by a braked, towed vehicle which could act as a mobile laboratory as well.

In a report by the British Mud-Crossing Committee (7.45) a summary was given of soil investigations in Italy by the A.F.V.(T) H.Q.8th Army, using these instruments:

(a) California Testing Machine - a hydraulic jack to measure pressure versus sinkage of a tank that is, measuring the supporting power of a soil;

(b) Campbell Stick - criticisms were given of this instrument and suggestions for making it more efficient. This kind of instrument is for reconnaissance on foot before an operation by vehicles.

A memorandum issued by the British A.O.R.G. in June, 1945 (7.46) describes a method estimating tank going using the towed wheel. The object of the test was to establish the relation between the sinkage of a towed, loaded wheel and that of a tracked vehicle crossing the same ground. A T15 carrier pulled a 2-wheeled trailer on 5-inch steel band wheels over two sites. There was evidence for believing that the sinkage of the 2-wheeled trailer, properly loaded, is simply related to the sinkage of the tracks of a track-laying vehicle.

(D-8) Rolling Resistance

This factor involves the problem of reducing sinkage since a major portion of the rolling resistance of a vehicle in operation is caused by the work it does in squashing the ground. This reduction may be accomplished by the addition of extended end connectors during operations.

Other factors affecting rolling resistance are speed and slippage, the former by its effect on the coefficient of friction between the track and the soil and the latter by its effect on traction, for example, the increased power necessary for movement when slipping occurs. Sliding sidewise while running on a slope not only causes loss of control, but frequently throws off one or both tracks by building up mud under the bogie wheels or by tipping of the blocks.

Laboratory studies of the rolling resistance encountered by tractor wheels on sandy soils were undertaken by Randolph in 1930 at Auburn, Alabama (8.1). The coefficient of rolling friction for a single wheel in Norfolk sand was found to be extremely high. The rolling resistance of a wheel with grousers varies in reference to grouser position. Grousers tended to prevent the wheel from sinking into the soil but they increased the rolling resistance. An empirical formula of Jaudasek (Automotive Industries, June, 1917) gives the rolling resistance of a wheel as equal to the product of three-eighths of the angle of rim and the soil contact in front of an axle centre, and the weight of the wheel. Laboratory results checked closely with results given by this formula.

In his studies of "soil dynamics" in 1933 at Auburn (8.2) M. L. Nichols found that the exact nature of the soil reaction and of wheel slippage consisted of a compressive action in front of the wheel resulting in actual forward movement with no rotation of the wheel on its axle.

In a German publication of September, 1933 (8.3) a graph is given showing the influence of load on the question of wheel size and rolling resistance.

Three agricultural tractors of the same weight were tested in the same conditions by the Germans in 1935 (8.4). One of them was provided with tracks, another with low pressure tires and the third one with spudded steel wheels. The result was that the best drawbar pull versus slippage was given by the tracked tractor.

Movement resistance for various tracks was plotted against speed by the Germans in 1936 (8.5) with the test site being a hard road. The effect of track sizes and vehicle weight on movement resistance was also investigated.

The Russians have carried out (1938) (8.6) experiments on the rolling resistance of driven steel wheels on various types of terrain, for instance, dry sand, deep mud and concrete, and have produced graphs relating rolling resistance to wheel width.

In 1938 the Germans published (8.7) graphs relating rolling resistance to speed.

In a paper published by Merrit in 1939 (8.8), the question of rolling resistance was discussed in detail. It was stated that the net power available to produce acceleration or overcome rising gradients is the difference between the gross engine output and the sum of a large number of losses caused by:

(a) essential services; and
(b) frictional resistance.

The latter is termed rolling resistance and consists of:

(a) transmission losses;
(b) rolling friction of wheels over tracks;
(c) work done in deforming the ground by the varying loading in each track shoe; and
(d) air resistance.

The question of accounting for skidding and slip and the effect of speed on rolling resistance was also discussed.

In July, 1940, E. G. McKibben and J. B. Davidson published an article on the "Effect of Radius and Slippage of Wheels" (8.9). The loaded radii and distances of forward travel per revolution were measured for all the steel wheels and pneumatic tires used in the rolling resistance studies reported in earlier articles. The effect of radii and slippages were studied from these data. Slippage occurred in all tests on agricultural soils. This slippage was approximately proportional to the square of the coefficient of rolling resistance.

In a report by the British Mud-Crossing Committee, of March, 1944 (8.10) ground pressure is defined as follows: It is customarily used in connection with tanks to signify the mean ground pressure on the whole area of track in contact with the ground.

Let p = mean ground pressure;
T = weight of tank;
L = length of track;
W = width of track;

then $p = \frac{T}{2LW}$ lb. per sq. in.

But if the pressure is much greater than 'p' at one point, the ground will be squashed to a corresponding maximum depth and this depth will not be reduced merely because the pressure is less at other points. Thus in considering how far the ground is squashed down, 'p' is of small importance, what is needed being the maximum pressure, which is the subject of the report.

In a report by the British School of Tank Technology, of August, 1944 (8.11) the question of the horizontal resistance to slip of a tracked vehicle is treated theoretically.

In a study of flotation of military vehicles at the Ordnance Desert Proving Ground at Camp Seeley, California in August, 1944 (8.12) three types of terrain were considered: sand, mud and snow. It was determined that for sand one needs flotation, and low centre of gravity, traction being unimportant. For mud and snow, traction and ground clearance are of first importance but flotation is also of some importance. In mud, a track will either sink down until it reaches a solid base or, if the mud is quite thick, it will sink until it has gained sufficient additional contact area to support it. Adequate flotation in mud requires much less ground pressure than for sand. Snow differs fundamentally from both sand and mud since it is easily compressible.

A report by the U.S. Committee (8.13) was issued on the tractive resistance tests of the 105 mm. airborne Howitzer tractor, carried out in October, 1944. It was found that extremely high pulls were required to move towed loads through soft, deep mud because of the tendency of the load to sink into the mud. As a result, skid pans were designed to cover the irregular surfaces of the gun carriages and present a smooth streamlined surface which would increase the flotation and decrease the tractive resistance and the tendency of the carriages to dig in and push mud ahead of them. It was concluded that incorporation of the skid pans greatly reduced the tractive resistance when towed in terrain where the penetration of the wheels exceeds the ground clearance of the undercarriage. This report contains the results of measurements to determine tractive resistance when towing through soils of various moisture contents and densities.

A report by the British Mud-Crossing Committee of December, 1944 (8.14) outlined the theory of the design of tank suspension. They started from Terzaghi's theory for calculating the supporting power of the soil. It was shown that the bearing capacity of the soil can be expressed by the simple equation $p = \alpha + \beta\ (x)$ where (x) is the sinkage and α, β are constants depending upon the type of soil. Assuming the centre of gracity to be symmetrically placed and that spring constants are known, the maximum sinkage was calculated, taking into account the number of bogie wheels and their radius, the track breadth and track pitch, the resultant equation for sinkage including also factors involving track tension, of which very little is known. Nevertheless, whatever values were selected, the sinkage of the tanks worked out in the order given in trials held at Ayrshire. It was determined at these trials that for the reduction of sinkage it was necessary that (a) the tracks be wide; (b) the number of bogie wheels be large; (c) the track pitch be large; and (d) the radius of the bogie wheels be large. The relative importance of each factor was found to vary under different circumstances. It was concluded that the velocity of the tank is unimportant if less than 15 m.p.h.

The British A.O.R.G. published a report in January, 1945 (8.15) with regard to the relation between soil moisture content and tank-going. Tanks were run over soil of varying moisture content at a constant speed and sinkage versus moisture content measured. The curves of moisture content versus sinkage gave an indication of the relative performance of the various tanks. There was a definite relationship between moisture content and sinkage. The same group have taken the sinkage of the tank tracks into the soil, measured after the load passed, as a measure of the ability of the tank to proceed. In their mobile laboratory for recording tank data the only instrument for measuring tank performance is one for measuring sinkage; the method followed is described in detail.

In traction studies carried out at the Aberdeen Proving Ground by the U.S. Committee in February, 1945 (8.16), an increase in speed from 0.6 to 8.0 m.p.h., caused the tractive resistance of all tracks to increase approximately the same amount in the dry-firm conditions of both loam and clay courses. It was also concluded that in general the drawbar pull of a vehicle increases as the track slip increases up to the point of highest measured slip on sustained operation regardless of soil type, soil condition, or track type; and, as the soil conditions change from dry-firm to moist-loose, the maximum pull occurs at lower value of slip, after which the track goes completely out of traction.

At a joint meeting of the British and U.S. Committee in February, 1945 (8.17), it was decided that the Aberdeen Proving Ground should follow the Milford Proving Ground's practice of using the term "rolling resistance" to mean the losses as measured by means of a torquemeter from the sprocket outwards. The British agreed to recognize this nomenclature. Further, for any kind of a towed load when the test vehicle is being towed, the load will be called the "tractive resistance".

Comparative trials were held on Somerset coastal sites with various A.F.V. tracks in soft ground conditions by the British Mud-Crossing Committee in March, 1945 (8.18). Since soil requirements for flotation tests were not considered in the same way as for traction tests, two separate but comparable sites were surveyed and put into use. In a test for sinkage each vehicle made a number of runs at 2 to 3 m.p.h., over the same ground and sinkage was measured until bellying occurred. Tests were on virgin ground parallel to other tests. Controlled tanks with standard tracks were used as daily checks of consistency and independent sets of readings taken for each track variable. Various types of extenders were also tested, and it was felt that these were amongst the dominant factors in improving trafficability.

A memorandum from the Utica Proving Ground dated April, 1945, (8.19) reported on the test of the T80 track with extended end connectors. The report stated that the increased flotation was a definite improvement during operations over muddy and snow-covered terrain.

A recording of sinkage and of angular movements of track links of A.F.V's was reported by the British Committee in April, 1945 (8.20). Measurements were made of the vertical and angular movement of individual track links on a Churchill tank travelling in soft mud overlying a hard sandy soil, and with a Sherman tank on a hard and soft silty clay at speeds of 5 to 8 m.p.h. The main object was to investigate the method of measurement. Satisfactory measurements of the progressive sinkage of the track and its angular movement were obtained. On the Churchill tank, due perhaps to soil conditions, track movement was small; with the Sherman on other soils there was a progressive sinkage after the passage of each wheel, followed by an appreciable elastic recovery. The total angular movement amounted to about plus or minus 5° and occurred in two stages: a rapid tilt occurred while the wheel was over the track link, followed by a slower return movement after each wheel had passed. The effect of increasing the tank speed from 5 to 8 m.p.h. appeared to be confined to accentuating the spasmodic character of the angular movement of links without affecting the amplitude of the movement.

In a report of April, 1945 by the British 21st Army Group (8.21) the British Directorate of Tank Design recorded interest in the grouser and extended end-connector problem from two aspects:

(a) flotation; and
(b) tractive effort.

Trials with grousers and no extended end-connectors showed no gain in tractive effort and very little gain in flotation. Trials with extended end-connectors greatly increased in length showed that there is a limit to the size which can be used. If this is exceeded the track length on the ground cants inwards and the track is rapidly shed.

A test of the M29C Cargo Carrier in the Norfolk sand test plot was conducted by the U.S. Committee at Auburn in April, 1945 (8.22). Since it was desirable to conduct traction tests at predetermined increments of track slippage, a slip meter was designed and constructed by the personnel at Auburn and proved itself capable of indicating track slippages to an accuracy of 3%. The drawbar pull and track slippage data were obtained from the hydraulic recording dynamometer car instruments. The test vehicle towed the car and the simultaneous record of drawbar pull, road-speed, engine speed and track slippage was recorded. The moisture content of the soil was determined before each test. Analysis revealed that regardless of vehicle load, engine speed or course condition the maximum tractive effort occurs at and above 40% track slippage. Increases in the dynamometer load resulted only in increased track slippage and not an increase in tractive effort. This indicated that the maximum tractive effort of the M29C equipped with the standard 20" track in Norfolk sand is limited by the shear resistance of this soil. It was also revealed that the tractive effort increased with gross load. This was to be expected, since research conducted by soil scientists has brought forth the information that shear strength of soil is a function of unit loading. Graphs were evolved of drawbar pull versus track slip for various course conditions and loads.

Vehicles equipped with various types of tracks were tested on a concrete roadway both in wet and dry conditions by the Army Engineering Design Branch of the Dept. of Munitions and Supply, Ottawa, in April, 1945 (8.23) to assess the resistance to skidding of the tracks.

In the report of a test held by the U.S. Army Armored Board in May, 1945, (8.24) it was noted that in all future track design and development, the basic track width should be sufficient to provide flotation and grouser area so that resort to extensions is unnecessary.

A report was issued in May, 1945 by the British Mud-Crossing Committee (8.25) on the comparative trials on Somerset coastal sites with various A.F.V. tracks in soft ground conditions. The method used for sinkage determination was reasonably accurate and had the great merit of simplicity. The method gave also the residual belly clearance which was of direct practical importance. It was agreed that in general a record should be made of belly sinkage at two known points, thus giving the attitude of the vehicle. The effects were explained of taking sinkage readings at: (a) an arbitrary point along the tank; (b) three points; and (c) the optimum point. The Committee agreed that the instrumentation panel should continue to devise and develop methods of sinkage measurement suitable for recording absolute track sinkages irrespective of belly height so as to permit comparisons between similar and dissimilar vehicles. In reports on tests for traction, the instruments and technique were described. The set-up being ready for trial, the engine of the test vehicle was speeded up and the clutch engaged as smoothly as possible in first gear. The anchor tank had its tracks on and gears engaged. Thus the full power of the test vehicle was applied to shear the top layer of soil and when this was done the tracks continued to rotate with the tank stationary. Thus three distinct load magnitudes were consistently observed: (a) a peak immediately prior to track slip; (b) a low reading immediately the track slipped; and (c) a gradual build-up to a suitable reading near to, but usually less than the peak.

In a report by the Scientific Advisor to the British Army Council, of May, 1945 (8.26) on the performance of tanks in mud, comparative trials were held with the Sherman tank and with the following tracks:

(1) standard rubber chevron tracks and platypus grousers;
(2) standard steel chevron tracks and extended end-connectors; and
(3) standard rubber chevron tracks, rat grousers and extended end-connectors.

Rat and platypus grousers were found to perform equally well over the same course. The generally-held opinion in this theatre was that extended end-connectors were worth fitting for ordinary work, but that the improvement to be expected was only slight. Platypus grousers should be available for special operations as they entirely revolutionize the performance of the Sherman in mud and make it rather better than the Churchill. The platypus grouser however, can only be fitted to rubber tracks.

Tests were conducted of a light cargo carrier M29C (Weasel) over a Norfolk sand test plot at Auburn in June 1945 (8.27). The purpose of these tests was to determine the effect of various load distributions and a consequent shifting of the position of the centre of gravity on vehicle performance. The results with regard to track slippage and drawbar pull were given in the section (D-4) on "Bearing Surface".

In comments on the report MC-82 of the British Mud-Crossing Committee at their eleventh meeting in June, 1945, a discussion was held by the members on the method of determination of the "figure of merit", for example, drawbar pulls at no slip, first slip, and continuous slip, with the average taken. It was found that the soil reaction under slipping conditions may not be related to the reaction under mobile conditions.

A memorandum issued by the British A.O.R.G. in June, 1945 (8.28) described a method of estimating tank going using the towed wheel as noted in the preceding section. There was evidence for believing that the sinkage of the two-wheeled trailer properly loaded is simply related to the sinkage of the tracks of a track-laying vehicle.

A memorandum of June, 1945 from the British A.O.R.G. (8.29), predicted from theory the sinkage of three A.F.V.'s (A41,A41A,A43) in terms of the supporting power of the ground, and compared their performance in this respect with that of existing tanks of similar design: the Churchill, Sherman and the Cromwell. Reasonable agreement has been found with the observations so far available and it is felt that some confidence can be placed in the predicted relative performance of various tanks. The theory related sinkage in a homogeneous, cohesive medium with the main characteristics, weight, number of bogies, breadth of track.

A report was issued in June, 1945, by the British Mud-Crossing Committee (8.30) on rolling resistance of track vehicles. The object was to obtain uniformity of nomenclature on the rolling resistance of tracked vehicles. It was pointed out that the resistance as measured by the test vehicle or by allowing it to decelerate differs materially from the rolling resistance of a vehicle when propelling itself on the level at constant speed. It is therefore recommended that the following nomenclature be adopted in all test work on track layers.

Rolling Resistance: the resistance between the sprocket and the ground of a track-layer when propelling itself on the level at constant speed consists of (a) external rolling resistance plus (b) internal rolling resistance. It is expressed as a force, eg. pounds per ton of vehicle weight.
Tractive resistance: the resistance obtained by differentiating the speed-time curve when allowing a track-layer to decelerate in neutral gear.

Various trials were carried out by the Australian Operational Research Section in Australia and New Guinea in 1945, with the object of determining the best type of tank track for use over muddy ground. One of the conclusions reached was that the provision of extensions to the tracks (duck-bills), both on the inside and outside, is of considerable assistance, increasing the bearing surface by 15 to 20%. These, however, had two disadvantages:

(1) They took some time to fit, when on the move: and
(2) if left on when the tank was crossing snow or hard rough ground, they were very soon broken.

Their advantages, therefore, appear to be small except over soft flat ground. The strong point of the tracked one-ton truck, (Australian) was its very low track pressure and high clearance compared with the British armoured carrier. These characteristics enabled it to act as a load carrier over terrain too swampy to take any other known vehicle.

(D-9) Effect of Soil Disturbance:

This question involves the effect on the ground of: (a) repeated runs over the same track; (b) a sudden stop or start; and (c) vibrations. All these disturbances may cause a breakdown in the supporting power of the soil and thus reduce the trafficability of the vehicle. For example, since the coefficient of friction is greater when starting, the excessive initial thrust needed to propel the vehicle forward may easily cause it to dig in where the terrain consists of a thin hard crust on top of soft boggy soil.

It was found by M. L. Nichols in 1931 (9.1) that the injurious puddling effect of pressure varies with the colloid content of the soil and that a sliding motion of the surface applying force resulted in greater puddling injury than when the pressure was applied directly.

In comparative trails on Somerset coastal sites (England) with various A.F.V. tracks in soft ground conditions (January, 1945) (9.2) the effect was observed of a number of vehicles following the same route. A single track with an underlay of firm clay was used and it was concluded that this test emphasizes the value not only of belly clearance but the necessity for bulldozing ability.

Some consideration of the mud-crossing performance of track vehicles was made in the light of the plastic behaviour of clay in a report by the British Committee of February, 1945 (9.3). It was stated that under the very small applied force, plastic clay does not possess an elastic range. Also some clay-water mixtures, normally quite solid, will flow like a viscous liquid if subjected to vibration. This checks with the release of stresses between each wheel centre. The stress should be gradually applied and once applied, steadily maintained for minimum deformation.

In March, 1945 the British Committee (9.4) were studying progressive sinkage rates and shoe oscillation. Track shoe oscillation was found to be less with the Churchill tank than with the Sherman, suggesting the superiority of the single-pin joint over the two-pin joint from a soil displacement point of view.

In a report on a visit to Australia and New Guinea by No. 10 British O.R.S., it was noted that the advantage of the 6 x 6 over the Ford 3J, 4 x 4, appears to be on soft and newly constructed roads. The 4 x 4 vehicle tended to tear up the road and to wear out new roads. The 6 x 6 tended to flatten it down and this improved the surface.

The T36 Snow Cruiser developed by the U.S. Forest Service was evidence of the value of solid suspension as a means of ensuring the absence of waves in the track on the ground.

The Russians (9.5) have discussed the effect on drawbar pull and rolling resistance of multiple driving along the same track; for instance, a trailer driven about 30 yards along the same track caused an increase of required drawbar pull of about 100 pounds.

E: WORK CURRENTLY IN PROGRESS

(a) Great Britain:

Important steps have been taken by the British Mud-Crossing Committee in planning future work and methods. Separate panels of the Committee have made detailed appreciations of Mobile Rig Testing, Static Rig Testing, Full Scale Field Testing and Soil Testing. The object in each case has been to improve technique beyond earlier methods. For example, in mobile rig testing, no fewer than 125 differently proportioned tracks are required in order to arrive at a clear appreciation of the effects of combinations of track width, track pitch and grouser depth. The number of tests involved in the systematic series will be many times 125 as tests combining track, suspension, soil and speed variations are necessary. This is admittedly a vast undertaking but, until it is done, dogmas and prejudices may continue to govern design.

As regards the technique of full scale field testing, development is now planned for applying electronic methods to torque measurement. Preliminary trials of soil bath techniques are proceeding steadily and a great deal has been learned, including something of what can not be done.

Initial steps are now being taken to supplement the work of the British Mud Committee by a small executive department working full-time and co-ordinating the work of the various bodies undertaking parts of the research program. A system of performance and soil reporting overseas is being introduced. A permanent reporting party has already operated with 15th Army Group.

A paper has just been produced by the Committee (MC 93) discussing the background and principles involved in soil classification and suggesting a condensed basic classification suitable for military needs.

A report (A.O.R.G.253) has also been issued recently on the theory of Tank Sinkage based on the earlier theories of Terzaghi for the mode of shear under a long narrow footing. This enables an estimation to be made of the performance of tanks in terms of suspension and track characteristics.

It has been planned to bomb areas of differing terrain and to photograph the craters so formed from the air. A variety of amphibian and land vehicles would then be driven over the sites. Correlation will be attempted between the aerial photos and vehicle trafficability.

(b) United States of America:

Tests have been planned and are being carried out at the Aberdeen Proving Ground, Maryland, by the Special Projects Branch of the Automotive Division, U.S. Ordnance. Tanks with various types of tracks will be run over the courses so that the mud encountered will deepen until forward motion of the vehicle is stopped. Two controls will be used for each group of tracks run at any one time.

A horizontal testing box is now being designed at Auburn, Alabama, which can hold a sample of soil and will move it in the horizontal plane at varying speeds. At the same time a model suspension and track is being constructed so that it can be variously loaded to give a wide range of ground pressures. It will also be possible to drive this track relative to the motion of the soil box so that varying degrees of slip can be simulated.

The U.S. Soil Conservation Service has agreed to make a series of soil maps covering the world. Comparison maps will be made showing water table characteristics for the translation of the soil maps into probable soil conditions and soil reactions.

The U.S. Mud Testing Committee have initiated a track widening program on medium and light tanks, e.g. the medium M-4, M-5A, and the M-24.

Various organizations in the United States have been working on the problem of producing a suitable "bog-stick", that is, a man-portable penetrometer which on a reconnaissance will give an indication of the trafficability of any terrain without involving the actual passage of a vehicle over the ground investigated.

The U.S. Engineering Board have carried out trials at Yuma, Arizona, during 1945, with various vehicles over "paddy fields".

(c) Canada:

One of the major undertakings of the Canadian Committee on Soil and Snow Mechanics has been the accumulation of information and facts concerning the problem of the interrelation of soil mechanics and the design and operation of vehicles. This memorandum is a result of this work.

A soil survey is being made of the No. 1 Vehicle Proving Ground at Ottawa, Ontario. This will be a useful addition to the controls presently used in the testing of military vehicles by the Canadian Directorate of Vehicles and Small Arms. This survey was carried out with the aid of a Mobile Laboratory equipped for soil analysis.

A memorandum has been issued recently by the Committee describing a field soil testing device (combining vertical and horizontal shear) which could be used on a reconnaissance and which is man-portable. This device has been developed by D.V.S.A. Another memorandum has been prepared on the question of shearing planes in sand as observed by model tests in sand boxes. The sand was in layers, alternating with thin white layers and thus photographic records could be obtained of the visible planes of shear and the resultant strains established by moving various model tracks and grousers. An extensive experimental program along these lines will be carried out at the University of Toronto during the winter of 1945-46.

Work is being planned for the winter involving the investigation of snow properties in the light of snow mechanics and its relation to the design and operation of vehicles. Canada's geographical position and climate are obviously suitable for research of this kind and it is felt that a useful contribution can be made from Canada to the present knowledge of snow characteristics.

F: CIVILIAN INTEREST

Although recent investigations of the problem under review have been in connection with the military use of tracked vehicles, the problem of the trafficability of such vehicles is of course of much wider interest. Establishments concerned with the design and manufacture of agricultural equipment are naturally concerned with the problem so that it is not surprising to find (as has been indicated) that State Agricultural Colleges have done much investigational work on the interrelation of soil mechanics and implement design and performance, a closely allied field. Correspondingly, the manufacturers of agricultural machinery have a lively interest in the problem; they are represented, for example, on the S.A.E. Advisory Mud Testing Committee in the United States. In a similar way, manufacturers and users of earth-moving equipment are concerned with the effect of soil properties upon their products; they, too, are represented on the S.A.E. Committee.

Preliminary discussions have been held in Canada with such civilian interests, but the Canadian Committee has, up to the present, confined itself to the military problem. This memorandum would not be complete, however, without a brief reference to the special civilian applications of such researches as are herein described, which are possible in Canada. Not only is there a wide range of applications in the agricultural and earth-moving fields, but there is the even wider application to transportation over open country, so necessary in all the northern parts of Canada.

At present, most of this transport is done in the winter, when the material traversed is snow, but for mining development in particular, corresponding "roadless" travel in summer is also important, when materials to be traversed will include not only soil, but solid rock and "muskeg". Interested in the general question of transport over open country are such organizations and Canadian Government Departments as the Royal Canadian Mounted Police, the Hudson's Bay Company, and the entire Pulp and Paper and Mining industries of Canada.

It can readily be seen that the economic possibilities of improving transport over open country have very special significance for Canada. Correspondingly, Canada provides unusually good facilities for study of over-snow travel. It is therefore to be hoped that, in due course, the current military studies can be applied and extended to the civilian field, more especially in the directions already indicated. Some civilian interests have already done a great deal of work on the problem, notably the manufacturers of earth-moving equipment in connection with track details, and the Canadian Pulp and Paper industry (together with the Forest Products Laboratory of the Dominion Government) in regard to over-snow travel. There is still, however, much to be done, as this memorandum makes clear.

G: CONCLUSION

This memorandum presents a review of the written records of studies of the interrelation of soil mechanics and the design and operation of tracked vehicles, consulted by the Committee. The record cannot be complete, despite the care with which it has been prepared. It brings together however, in one publication, a significant collection of data and it is hoped that as such it will be as useful to other investigators in the field as it has been to the Canadian Committee. The gaps in present knowledge are clearly indicated, as are also the avenues along which immediate investigation seems to be desirable. Although the inter-connection of soil mechanics and the mechanical design of automotive vehicles appears, at first sight, to be a very tenuous one, this memorandum makes clear that the connection is, or should be, a very close one.

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Approved: Col. J. T. Wilson, D.N.D.
Issued: 21.1.46
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REFERENCES CITED IN THE TEXT

Special Note:

Since so many of the publications to be mentioned are of a military character, military abbreviations have been retained in the following lists.

INTRODUCTION AND BASIC PROBLEMS

1. "Mud and Cross-Country Combat Vehicles" Automotive Division, Ordnance Research and Development Centre (U.S.) A.P.G., Maryland. By E. G. McKibben, Michigan State College. 13 Nov. 44

2. "Tracks for Fighting Vehicles" - Pt. II Chapter II. By E. W. Micklethwait, School of Tank Technology, M.C. of S. (UK). Jul. 44

SPECIFIC PROBLEMS

1. Belly Clearance

1.1 "Tire and Track Flotation of Military Vehicles" S.A.E. Journal, Vol. 52, No. 8. By Lt.-Col. J. E. Engler, Ordnance Desert Proving Ground, Camp Seeley, California. Aug. 44

1.2 "First Report on Tractive Resistance Tests of 105 mm. Howitzer, M3A1, (Airborne) with and without Skid Pans in Controlled Soil Bins at Tillage Machinery Laboratory, Auburn, Alabama," Automotive Division, Ordnance Research and Development Centre (U.S.), APG, Maryland. 18 Sept. 44

1.3 AFV Technical Staff, Fd Forces, 11 Army Gp, SEA Report No. 1 By DDAFV(T) 25 Sept. 44

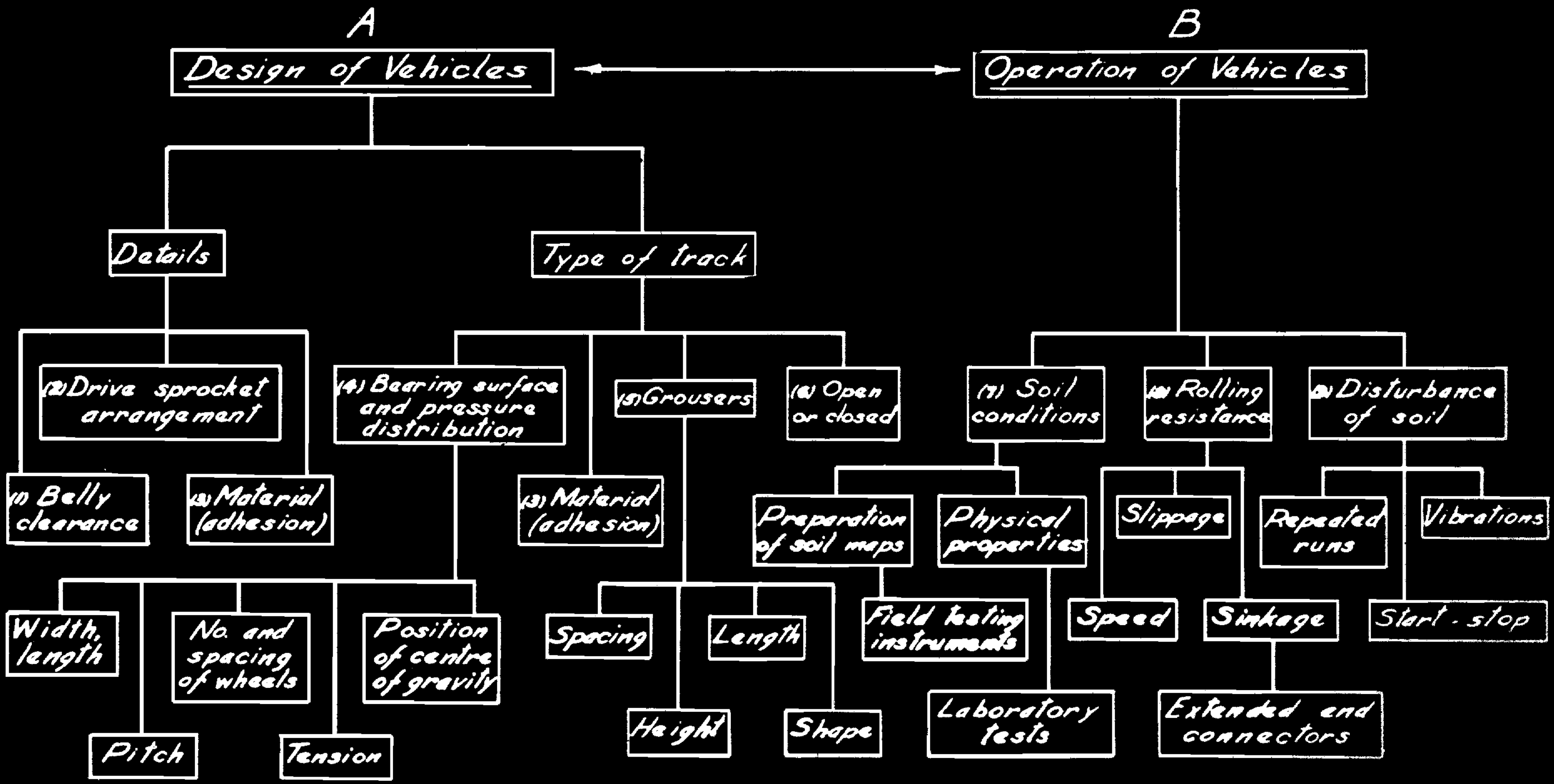
1.4 "Report on a Visit to Australia and New Guinea by #10 A.O.R.S.(Brit)." By By Australian Operational Research Section Nov. 44

1.5 "Comparative Trials on Somerset Coastal Sites with Various AFV Tracks in Soft Ground Conditions" Report #FT 1553 and #FT 1553/1 UK Mud-Crossing Ctee - MC-61 By Lt.-Col. E. Ward 15 Jan. 45

1.6 "Comparative Trials on Somerset Coastal Sites, Etc." Report #FT 1553/3 UK Mud-Crossing Ctee - MC-82 By Capt P. E. Martin 14 May 45

APPENDIX - A

Analysis of the Factors Affecting the Inter-relation of Soil Mechanics and Tracked Vehicles



1.7 Royal Armoured Corps Technical Situation Report #32. By British Army Staff at Detroit to War Office(UK) — Feb. 45

2. Drive Sprocket Arrangement

2.1 Engineering (London), pp. 12 and 14. — July 44

2.2 Verein Deutscher Ingenieur, #7 — 1936

3. Material (Adhesion)

3.1 "Traction and Flotation and Track Development" Ordnance Research and Development Centre (U.S.) APG, Maryland. By Maj. W. C. Christopher — 22 Dec. 44

3.2 "Soil Dynamics" 37th Annual Report of the Agric. Expt. Sta., Alabama Polytechnic Institute, Auburn, Alabama. By M. L. Nichols — 1926

3.3 "Soil Dynamics" 38th Annual Report of the Agric. Expt. Sta., Alabama Polytechnic Institute, Auburn, Alabama. By M. L. Nichols — 1927

3.4 "Soil Dynamics" 40th Annual Report of the Agric. Expt. Sta., Alabama Polytechnic Institute, Auburn, Alabama. By M. L. Nichols — 1929

3.5 "Studies of Adhesion Between Soil and Metal Surfaces" 46th Annual Report of the Agric. Expt. Sta., Alabama Polytechnic Institute, Auburn, Alabama By M. L. Nichols and F. A. Kummer — 1935

3.6 "The Dynamic Properties of Soils as Applied to the Elements of Implement Design. Development of Reduced-Friction Surfaces and Materials for Experimental Plows" 49th Annual Report of the Agric. Expt. Sta., Alabama Polytechnic Institute, Auburn, Alabama. By F. A. Kummer — 1938

3.7 "Some Considerations of the Mud-Crossing Performance of Tracked Vehicles in the Light of the Plastic Behaviour of Clay" UK Mud-Crossing Ctee - MC-73 British Refractories Research Association By H. H. Macey — [illegible]

3.8 "Comparative Trials on Somerset Coastal Sites, Etc." Report #FT 1553/3 UK Mud-Crossing Ctee - MC-82 By Capt. P. E. Martin — 14 May 45

3.9 21 Army Gp AFV Technical Report and Reply #22 By AFV(T) Rear HQ 21 Army Gp BLA — Apr. 45

3.10 "Report on a Visit to Australia and New Guinea by No. 10 ORS (Brit)" By Australian Operational Research Section — Nov. 44

4. Bearing Surface (Pressure Distribution)

4.1 "A Study of the Fundamental Factors Influencing the Traction of Wheel Tractors" 35th Annual Report of the Agric. Expt. Sta., Alabama Polytechnic Institute, Auburn, Alabama. By J. W. Randolph and M. L. Nichols — 1924

4.2 Technik in der Landwirtshaft — Sept. 33

4.3 Verein Deutscher Ingenieur, #7 — 1936

4.4 "Design of High Speed Tracked Vehicles" Proc. Institute of Automotive Engineers p. 398, 1939. By H. E. Merrit — 1939

4.5 "Effect of Wheel Arrangement on Rolling Resistance" Journal Paper J-726 of the Iowa Agric. Expt. Sta. in co-operation with A.S.A.E. Vol. 21, No. 3, pp. 95-96, By J. Davidson and E. G. McKibben — Mar. 40

4.6 "Effect of Radius and Slippage of Wheels" Journal Paper J-768 of the Iowa Agric. Expt. Sta., in co-operation with ASAE, Vol. 21, No. 7, p. 275, By J. B. Davidson and E. G. McKibben — July 40

4.7 "Vehicle Pressure Tests with Dummy Mine Gauges" National Research Council, Ottawa, Ontario. — Jan. 44

4.8 "Load Under the Track of a Snowmobile" National Research Council, Ottawa, Ontario. By R. W. McKay and R. Bailey — 25 Feb. 44

4.9 Royal Armoured Corps Technical Situation Report #32, British Army Staff in Detroit to War Office (U.K.) — Feb. 45

4.10 "Soil Mechanics in Relation to Fighting Vehicles" School of Tank Technology, M.C. of S. (UK), MC-7, TT-351. By E. W. Micklethwait — Mar. 44

4.11 "Tracks for Fighting Vehicles" - Pt. II, School of Tank Technology, M.C. of S. (UK) By E. W. Micklethwait — Jul. 44

4.12 "Tire and Track Flotation of Military Vehicles" SAE Journal, Vol. 52, No. 8 By Lt.-Col. J. E. Engler, Ordnance Desert Proving Ground, Camp Seeley, California. — Aug. 44

4.13 "The Influence of Soils on Operations Involving Tracked and Wheeled Vehicles" School of Tank Technology, (M.C. of S.) UK Mud Ctee MC-8, By Lt.-Col. Skinner — Aug. 44

4.14 Royal Armoured Corps Technical Situation Report #29 British Army Staff in Detroit to War Office (UK) — Dec. 44

4.15 Committee on the Mud-Crossing Performance of Track-laying AFV's Interim Report, M. of S. (UK) - MC-46 — Nov. 44

4.16 "Some Considerations of the Mud-Crossing Performance of Tracked Vehicles in the Light of the Plastic Behaviour of Clay" UK Mud-Crossing Ctee - MC-73 British Refractories Research Association, By H. H. Macey. — Feb. 45

4.17 "Effect of Grouser Pressure Face and Track Ground Surface Area" Automotive Division Ordnance Development and Research Centre (U.S.) A.P.G., Maryland. — 21 Dec. 44

4.18 "Trails of 'B' Vehicles in Paddy Fields" MGO (India) Quarterly Bulletin #4, p. 220, Director of Mechanization Tech. Report #2 — Dec. 44

4.19 "A Report on the Work of AORS 4(a) (Mud) (Brit)" SD 6, CMHQ By Capt. J. H. Whyte — 16 Dec. 44

4.20 Monthly Reports on "B" Vehicles from CMHQ Tech. Liaison Report #17 — 3 Dec. 44

4.21 and 4.22 Royal Armoured Corps Technical Situation Report #31 T-36 Snow Cruiser developed by U.S. Forest Service and

	Iron Fireman Mfg. Co. By British Army Staff to War Office (UK)	18 Feb. 45
4.23	"Comparative Trials on Somerset Coastal Sites, Etc." Report #FT 1553/2 UK Mud-Crossing Ctee - MC-72 By Lt.-Col. E. Ward	14 May 45
4.24	"Comparative Trials on Somerset Coastal Sites, Etc." Report #FT 1553/2 UK Mud-Crossing Ctee - MC-72 By Lt.-Col. E. Ward	23 Mar. 45
4.25	Royal Armoured Corps Technical Situation Report #30 By British Army Staff (Ministry of Supply)	Mar. 45
4.26	"German AFV's in Winter" Sec. 115, MI 10 W.O. By G.S.I (Tech) 21st Army Group	May 45
4.27	"Test of M29C (Weasel) in the Norfolk Sand Test Plot." Report # AP3B Tillage Machinery Laboratory, Auburn, Ala.	28 June 45

5. Grousers

5.1	"A Study of the Fundamental Factors Influencing the Traction of Wheel Tractors" 35th Annual Report of the Agric. Expt. Sta., Alabama Polytechnic Institute, Auburn, Alabama. By J. W. Randolph and M. L. Nichols	1924
5.2	"The Study of Fundamental Factors Influencing the Traction of Wheel Tractors" 36th Annual Report of the Agric. Expt. Sta., Alabama Polytechnic Institute, Auburn, Alabama. By J. W. Randolph and M. L. Nichols	1925
5.3	"Variation of the Lug Design Factors Affecting Traction" 40th Annual Report of the Agric. Expt. Sta., Alabama Polytechnic Institute, Auburn, Alabama By J. W. Randolph	1929
5.4	"Agricultural Engineering in North America and Germany" (with special reference to the organization of Research in Farm Machinery) College of Estate Management, (London) #6, By C. Culpin	1939

5.5 "Tractive Efficiency of the Farm Tractor" Iowa Research Bulletin #189. By J. B. Davidson, E. G. McKibben and E. V. Collins — 1939

5.6 Committee on the Mud-Crossing Performance of Track-laying AFV's Interim Report, Ministry of Supply (UK), MC-46 — Nov. 44

5.7 "Effect of Grouser Pressure Face and Track Ground Surface Area" By Ordnance Research and Development Centre (U.S.) APG. Maryland — 21 Dec. 44

5.8 "Comparative Trials on Somerset Coastal Sites, Etc." Report #FT 1553 and #FT 1553/1, UK Mud Ctee - MC-61. By Lt.-Col. E. Ward — 15 Jan. 45

5.9 Royal Armoured Corps Technical Situation Report #32 British Army Staff at Detroit to War Office (U.K.) — Feb. 45

5.10 "Report on Platypus Grouser" #1 Cdn Sec. AFV(T) Staff Report #7, App. C. By Maj. Sangster DDAFV(T) — Mar. 45

5.11 "Comparative Trials on Somerset Coastal Sites, Etc." Report # FT 1553/2 UK Mud Ctee, MC-72. By Lt.-Col. E. Ward — Mar. 45

5.12 "Pressure Cone versus Applied Load Studies on Model Grousers". By Ordnance Research and Development Centre, APG., Maryland. — 23 Apr. 45

5.13 Royal Armoured Corps Situation Report #34 By British Army Staff to War Office (UK) — 18 May 45

5.14 "Tracks for Fighting Vehicles" By E. W. Micklethwait, School of Tank Technology, M.C. of S. (UK) — July 44

6. Open or Closed Tracks

6.1 Royal Armoured Corps Technical Situation Report #32 By British Army Staff at Detroit to War Office (UK) — Feb. 45

7. Soil Conditions

7.1 "Soil Dynamics" 44th Annual Report of the Agric. Expt. Sta., Alabama Polytechnic Institute, Auburn, Alabama. By M. L. Nichols — 1933

7.2	"A Study of the Fundamental Factors Influencing the Traction of Wheel Tractors" 35th Annual Report of the Agric. Expt. Sta., Alabama Polytechnic Institute, Auburn, Alabama By J. W. Randolph and M. L. Nichols	1924
7.3	"Soil Dynamics" 37th Annual Report of the Agric. Expt. Sta., Alabama Polytechnic Institute, Auburn, Alabama By M. L. Nichols	1926
7.4	"Soil Dynamics" 41st Annual Report of the Agric. Expt. Sta., Alabama Polytechnic Inst., Auburn, Alabama. By M. L. Nichols	1930
7.5	"Physical Reactions of Tillage Tools Causing Compression and Arch Formation, and Analyses of Plow Mold-board Shapes and Materials" 51st Annual Report of the Agric. Expt. Sta., Alabama Polytechnic Inst., Auburn, Alabama. By F. A. Kummer	1940
7.6	"Soil Mechanics in Relation to Fighting Vehicles" UK Mud-Crossing Ctee, MC-7 School of Tank Technology M.C. of S. (UK) By E. W. Micklethwait	Mar. 44
7.7	"Tracks for Fighting Vehicles" School of Tank Technology M.C. of S. (U.K.) By E. W. Micklethwait	July 44
7.8	"The Influence of Soils on Operations Involving Tracked and Wheeled Vehicles" School of Tank Technology, M.C. of S. UK Mud Ctee MC-8. By Lt.-Col. Skinner	Aug. 44
7.9	Royal Armoured Corps Technical Situation Report #29 British Army Staff in Detroit to War Office (UK)	Nov. 44
7.10	"Trials of 'B' Vehicles in Paddy Fields" Director of Mechanization Technical Report #2, MGO (India) Quarterly Bulletin #4, p. 220.	Dec. 44
7.11	"A Report on the Work of AORS 4(a)(Mud) (Brit.) SD 6, CMHQ. By Capt. J. H. Whyte	16 Dec. 44
7.12	Royal Armoured Corps Technical Situation Report #31. By British Army Staff in Detroit to War Office (UK)	18 Feb. 45

7.13	"Pressure Cone Studies of Model Grousers" Ordnance Research and Development Centre (U.S.) APG, Maryland.	15 Jan. 45
7.14	"Comparative Trials on Somerset Coastal Sites, Etc." Report # FT1553 & #FT1553/1 UK Mud Ctee, MC-61. By Lt.-Col. E. Ward	15 Jan. 45
7.15	"The Relation Between Soil Moisture Content and Tank-Going" AORG (Brit) Report #243 - MC-48. By Maj. Parkinson and Capt. William	1 Jan. 45
7.16	"A Description of a Mobile Laboratory for Recording Tank-Going Data" AORG (Brit) Memo #457 AORS 4(a) UK Mud Ctee - MC-49.	2 Jan. 45
7.17	"The Relation Between Soil Moisture Content and Tank-Going" AORG(Brit) Report #243 - MC-48. By Maj. Parkinson and Capt. William	1 Jan. 45
7.18	Royal Armoured Corps Technical Situation Report #32 British Army Staff to War Office (UK)	Feb. 45
7.19	"Some Considerations of the Mud-Crossing Performance of Tracked Vehicles in the Light of the Plastic Behaviour of Clay" UK Mud-Crossing Ctee - MC-73 British Refractories Research Association, By H. H. Macey	Feb. 45
7.20	"Comparative Trials on Somerset Coastal Sites, Etc." Report #FT 1553/2 UK Mud Ctee - MC-72. By Lt.-Col. E. Ward	23 Mar. 45
7.21	Royal Armoured Corps Technical Situation Report #30. By British Army Staff to War Office (UK)	Mar. 45
7.22	"Problems and Questions for Overseas OR's" Monthly Bulletin #8, By SA/AC to NDHQ	Apr. 45
7.23	"Pressure Cone vs Applied Load Studies on Model Grousers". By Ordnance Research and Development Centre (U.S.) APG, Maryland	23 Apr. 45
7.24	Extract from Mediterranean Area AFV Tech Report #27 UK Mud-Crossing Ctee - MC-86 AFV(T) HQ 8th Army. By Lt.-Col. Skinner	26 May 45

7.25 "Soil Preparation and Control Tests" By Ordnance Research and Development Centre (U.S.) Auburn, Alabama — 14 July 45

7.26 "Terrain and Types of Tank Action" 11 Army Gp, SEAC, AFV Technical Staff Fd Force — Apr. 45

7.27 "Performance of Tanks in Mud" para. 2 of AFV Technical Report #26 from Mediterranean Area. — Nov. 44

7.28 "The Farm Tillage Machinery Laboratory at Auburn, Alabama" Agricultural Engineering, Vol. 16, #6, U.S. Dept. of Agriculture. By J. W. Randolph and I. F. Reed — 1935

7.29 Verein Deutscher Ingenieur, #7 — 1936

7.30 Tractor Handbook, p. 502, Moscow U.S.S.R. — 1938

7.31 Technic in Der Landwirtschaft Vol. 17, #1, By H. Meyer and F. Kliefoth — 1936

7.32 "Soil Penetration Tests as a Means of Predicting Rolling Resistance" A.S.A.E. Journal, Vol. 21, #6. By E. G. McKibben and D. O. Hull — June 40

7.33 "A Method of Studying Soil Packing by Tractors" ASAE Journal, Vol. 21, #7, p.281. By I. F. Reed — July 40

7.34 "The Electrical Capacity of the 2-Electrode Plaster of Paris Block as an Indicator of Soil-Moisture Content" Soil Science, Vol. 54. By California Agric. Expt. Sta. Anderson and Endlessen — Mar. 1942

7.35 "A Calibrated Soil Probe for Measuring Field Soil Moisture" Soil Science Vol. 53. By R. B. Allen U.S. Dept. of Agriculture — 1942

7.36 AFV Technical Staff, Fd Forces Report #1 11 Army Gp, SEAC By DDAFV(T) — 25 Sept. 44

7.37 "A Method of Estimating the Trafficability of Soils for Tanks" Tank Mobility - I, AORG Report #238 UK Mud-Crossing Ctee - MC-47. By Maj. Parkinson and Capt. Miller — Dec. 44

7.38 "A Report on the Work of AORS (4a) (Mud) (Brit)"SD6 CMHQ By Capt. J. H. Whyte — 16 Dec. 44

7.39	"A Description of a Mobile Laboratory for Recording Tank-Going Data" AORG (Brit) Memo #457, AORS 4(a), UK Mud Ctee - MC-49	2 Jan. 45
7.40	"An Exploration of Pressure Distribution with Pieso-electric Gauges" UK Mud Ctee - MC-60 By Dept. of Scientific and Industrial Research - Road Research Laboratory	Jan. 45
7.41	Royal Armoured Corps Technical Situation Report #33. By British Army Staff to War Office (UK)	18 Apr. 45
7.42	Royal Armoured Corps Technical Situation Report #32. By British Army Staff to War Office (UK)	Feb. 45
7.43	Royal Armoured Corps Technical Situation Report #30. By British Army Staff to War Office (UK) in Detroit	Mar. 45
7.44	"Proctor Needle Penetrometer for Soil Testing" #20, Item 15. By D. of Mechanization, Australia	1 Mar. 45
7.45	Extract from Mediterranean Area AFV Tech. Report #27 UK Mud Ctee - MC-86 AFV(T) HQ 8th Army. By Lt.-Col. Skinner	26 May 45
7.46	"A Method of Estimating Tank-Going Using a Towed Wheel" AORG (Brit) Memo #533. By Maj. Parkinson	1 June 45

8. Rolling Resistance

8.1	"Tractor Lug Studies" 41st Annual Report of the Expt. Sta., Alabama Polytechnic Institute, Auburn, Alabama. By J. W. Randolph	1930
8.2	"Soil Dynamics" 44th Annual Report of the Agric. Expt. Sta., Alabama Polytechnic Institute Auburn, Alabama. By M. L. Nichols	1933
8.3	Technic in Der Landwirtschaft	Sept. 33
8.4	Verein Deutscher Ingenieur #21	1935
8.5	Verein Deutscher Ingenieur #7	1936
8.6	Tractor Handbook, p. 148, Moscow, U.S.S.R.	1938
8.7	Automotive Technische Zeitung #18	1938

8.8 "Design of High Speed Tracked Vehicles" Proc. Institute of Automotive Engineers, p. 398, 1939, By. H. E. Merrit 1939

8.9 "Effect of Radius and Slippage of Wheels" Journal Paper J-768 the Iowa Agric. Expt. Sta., A.S.A.E. Journal Vol. 21 #7, p. 275. By J. B. Davidson and E. G. McKibben July 40

8.10 "Soil Mechanics in Relation to Fighting Vehicles" School of Tank Technology M.C. of S.(UK) UK Mud Ctee - MC-7, TT-351. By E. W. Micklethwait Mar. 44

8.11 "The Influence of Soils on Operations Involving Tracked and Wheeled Vehicles" School of Tank Technology M.C. of S. UK Mud Ctee MC-8. By Lt.-Col. Skinner Aug. 44

8.12 "Tire and Track Flotation of Military Vehicles" Camp Seeley, Calif. SAE Journal, Vol. 52 - No. 8. By Lt.-Col. L. E. Engler, Ordnance Desert Proving Ground, Camp Seeley, California. Aug. 44

8.13 "First Report on Tractive Resistance Tests of 105 mm. Howitzer M3A1 (Airborne) with and without Skid Pans in Controlled Soil Bins at Tillage Machinery Laboratory, Auburn, Alabama" Automotive Division, Ordnance Research and Development Centre (US) APG, Maryland Oct. 44

8.14 "A Report on the Work of AORS (4a Mud)" SD 6 CMHQ. By Capt. J. H. Whyte 16 Dec. 44

8.15 "A Description of a Mobile Laboratory for Recording Tank-Going Data" AORG (Brit) Memo #457, AORS4(a) UK Mud Ctee MC-49 2 Jan. 45

8.16 Royal Armoured Corps Technical Situation Report #32. By British Army Staff to War Office (UK) Feb. 45

8.17 Royal Armoured Corps Technical Situation Report #32. By British Army Staff to War Office (UK) Feb. 45

8.18 "Comparative Trials held on Somerset Coastal Sites, Etc." Report #FT 1553/2 UK Mud Ctee MC-72. By Lt-Col. E. Ward 23 Mar. 45

8.19	Utica Proving Ground Report No. PG-61901.89 By U.S. Mud Ctee. Royal Armoured Corps Tech Situation Report #34, British Army Staff to War Office (UK)	Apr. 45
8.20	"The Recording of Sinkage and Angular Movement of Track Links of AFV" UK Mud Ctee - MC-79. By Dept. of Scientific and Industrial Research - Road Research Laboratory	Apr. 45
8.21	21 Army Gp AFV Tech Report and Reply #22 By AFV(T) Rear HQ BLA	Apr. 45
8.22	"Test of the Cargo Carrier, M29C (Weasel) in the Norfolk Sand Test Plot at the Tillage Machinery Laboratory, Auburn, Alabama from 5 Apr. to 27 Apr. 1945" Ordnance Research and Development Centre (U.S.), APG, Maryland	1 May 45
8.23	"Resistance to Skidding Tank Tracks" Report E496, By Army Engineering Design Branch, Dept. of Munitions and Supply, Ottawa, Ont.	Apr. 45
8.24	Royal Armoured Corps Technical Situation Report #34. By British Army Staff to War Office (UK)	18 May 45
8.25	"Comparative Trials on Somerset Coastal Sites, Etc." Report #FT 1553/3 UK Mud Ctee - MC-82. By Capt. P. E. Martin	May 45
8.26	SA/AC Monthly Bulletin #10. By SA/AC to NDHQ	May 45
8.27	"Test of M29C (Weasel) in the Norfolk Test Plot at Auburn, Alabama" Report #AP3B. By Ordnance Research and Development Centre (U.S), APG, Maryland	28 June 45
8.28	"A Method of Estimating Tank-Going Using a Towed Wheel" AORG(Brit) Memo #533. By Maj. Parkinson	1 June 45
8.29	"A Prediction of the Performance of Certain AFVs (A41, A41A and A43)" AORG (Brit.) Memo #521. By Maj. Parkinson and G. G. Sherrat	June 45
8.30	"Notes on Rolling Resistance of Tracked Vehicles" UK Mud Ctee - MC-90 DTD Transmission Branch Report #TN88/1. By McEwen	16 June 45

9. Effect of Soil Disturbance

9.1 "Soil Dynamics" 42nd Annual Report of the Agric. Expt. Sta., Alabama. By M. L. Nichols — 1931

9.2 "Comparative Trials on Somerset Coastal Sites, Etc." Report #FT 1553 and 1553/1 By Lt.-Col. E. Ward UK Mud-Crossing Ctee MC-61 — Jan. 45

9.3 "Some Considerations of the Mud-Crossing Performance of Tracked Vehicles in the Light of the Plastic Behaviour of Clay" UK Mud-Crossing Ctee - MC-73 British Refractories Research Association By H. H. Macey — Feb. 45

9.4 "The Recording of Sinkage and Angular Movement of Track Links of AFV" UK Mud Ctee - MC-79. By Dept. of Scientific and Industrial Research — Apr. 45

9.5 Tractor Handbook, p. 642 Moscow, U.S.S.R. — 1938

BIBLIOGRAPHY

....being a list of the references to the subject matter of this Report encountered during the study summarised by the text of the Report, recorded here in brief form for general information.

Great Britain:

"Amphibians-Handling in Rivers and Over Mud"
CMHQ-Monthly Information Summary, 23 Apr. 45, London, Whitehall-HQS 8809-3 Fd 44

"A Description of a Mobile Laboratory for Recording Tank-Going Data"
British AORG Memorandum #457, AORS 4a 2 Jan 45

"A Method of Estimating Tank-Going Using a Towed Wheel"
British AORG Memo #533 1 Jun 45. Maj. Parkinson.

"A Report on the Work of AORS (4a Mud) (Brit)"
Capt. J.H. Whyte SD 6 CMHQ 16 Dec 44

Monthly Reports on "B" Vehicles from CMHQ
Tech. Liaison Report #7, 3 Dec. 44

"Report on Platypus Grouser"
#1 Cdn Sec. AFV Staff Report #7, App C., Maj. Sangster, DDAFV (T) 28 Mar. 45.

"Performance of Tanks in Mud"
Para 20-21 of SAAC Bulletin No. 10.

"Performance of Tanks in Mud"
Para 2 of AFV Tech. Report #26 from Mediterranean Area.

"The Relation between Soil Moisture Content and Tank-Going"
British AORG Report #243 1 Jan. 45
Maj. Parkinson & Capt. William.

Brief Note on Research by Ctee, May 45 and letter from Mud Ctee to New Zealand and Union of South Africa Mil'y Staff 11 May 45
~~Mud-Crossing~~ Ctee UK
A. R. Code DDGFV (E)

UK Mud-Crossing Ctee AFV Div., Min. of Supply - AFV Div. Letter No. 2.

"Penetrometer"
Prof. E. S. Hills
File 14052 MGO 177/OL/147 from A ID.

"Post-War Vehicle Policy"
Para 1 of SD(W) Vehicles Monthly Review No. 14, Mar 45.

"Soil Condition Investigations"
21 Army Gp AFV Tech. Report and Reply No. 20 Par I-RAC and Tracked Art'y Eq'p't-Gen.

"A Method of Estimating the Trafficability of Soils for Tanks"
Tk Mobility-I AORG Report #238, UK Mud-Crossing Ctee, MC-47.
Maj. Parkinson and Capt. Miller Dec 44.

21 Army Gp AFV Technical Report and Reply #22
AFV(T) Rear HQ 21 Army Gp BLA Apr 45

"Problems and Questions for Overseas ORs"
SA/AC Monthly Bulletin #8,p18, Para. 37.
SA/AC to NDHQ, Apr. 45.

"Design of High-Speed Tracked Vehicles"
Proc. Inst. Automotive Engineers, p. 398, 1939.
H. E. Merrit.

"Features of Modern Tractor Design - Tracks vs Wheels"
Wright
Proc. Inst. Automotive Engineers, p. 202, 1935.

"Weasels"
Para 14 of AFV Tech. Report #26 from Mediterranean Area.

Engineering (London), pp. 12 and 14, July 44.

Fighting Vehicle Proving Establishment Report #FT 1582 2 June 45.

Directorate of Tank Design, Report #TN 86.

Tank Mobility III - "A Theory of Tank Sinkage"
British AORG Report #253
Maj. D. Parkinson and G. G. Sherrat, 29 May 45.

"A Prediction of the Performance of Certain AFV's (A41, A41A, and A43)"
British AORG Memo #521
Maj. D. Parkinson and G.G. Sherrat, May 45.

"Studies of the Relation between Cultivation Implements, Soil Structure and the Crop"
C. Culpin, Jour. Agric. Science, Vol. 24 Pt. I, July 36.

SD(W) Vehicles Monthly Review #13 for Feb 45 as prepared by CMHQ.

Minutes of Meetings of U.K. Mud-Crossing Ctee.

Minutes of the 7th Meeting of Ctee, 6 Mar 45.

Minutes of 2nd "A" (Soils) Sub-Ctee Meeting, 23 Mar 45.

Minutes of 8th Meeting of Ctee, 11 Apr 45.

Minutes of Meeting of Instrumentation Panel, 12 May 45.

Minutes of 9th Meeting of Ctee, 14 May 45.

Minutes of Meeting of Mobile Rig Panel, 15 May 45.

Minutes of 10th Meeting of Ctee, 22 May 45.

Minutes of 11th Meeting of Ctee, 6 June 45.

Minutes of 12th Meeting of Ctee, 21 June 45.

Mud Crossing Ctee Reports

MC-1 Bog Crossing performance of tracked vehicles
Directorate of Tank Design
Report No. Tn. 73.

MC-2 Bog Crossing performance of tracked vehicles
D.T.D. Report No. Tn. 73/1.

MC-3 Abstracts of papers bearing on soft ground performance.
School of Tank Technology.

MC-4 School of Tank Technology - Chart of factors contributing to rolling resistance.

MC-5 Proposed research programme.

MC-6 Some notes on the performance of high-speed tracked vehicles
L. P. Little.

MC-7 Soil mechanics in relation to fighting vehicles.
E. W. Micklethwait,
School of Tank Technology, MC of S. (UK)
TT-351 Mar 1944.

MC-8 The influence of soils on operations involving tracked and wheeled vehicles,
School of Tank Technology, MC of S, (UK)
Aug. 1944.

MC-9/B Notes on field testing of A.P.V's instrumentation,
Maurice Olley.

MC-10/A School of Tank Technology - Interim report on research into resistance to slip using sub-scale model tracks.

MC-11/A The flow of mud and sludge,
Babbitt.

MC-12/A M.E. 6(b) - Report on the work of the Beach Recovery Committee.

MC-13 M.E.6 drawings of shoes and grousers used in recovery work.

MC-14/B Proposal for a full scale rig,
Maj. Hoad.

MC-15 Suspension and track data

MC-16 Mud-crossing - A proposed program,
Maj. Hoad.

MC-17/B Scheme drawing of proposed one-third scale rig based on T-16 Carrier.

MC-18 Scope and equipment for laboratory tests,
Major Hoad.

MC-19 Extract from G.H.Q. India Liaison Letter No. 6.

MC-20 Replaced by MC-43

MC-21 Letter on track and suspension design from
C.M.H.Q. to D.T.D.

MC-22/A Soil analyses from Skarn Beach carried out
by R.R.L.

MC-23 Summary of the work of Sub-Committee B.

MC-24 Interim Report of the Soil Sub-Committee
Recce Party.

MC-25 List of clay and silt areas suggested by
I.S.T.D. for Recce.

MC-26 Notes on D.T.D. reports TN. 73 and TN/1
Maurice Olley.

MC-27 Observations on paper MC-26
Maj. Hoad.

MC-28 Short term program proposed by Lt. Col.
E. Ward.

MC-29 Short term program proposed by Lt. Col.
D. R. Skinner.

MC-30 Practical considerations on the bearing
capacity of ground,
Civil Engineering (London), Jan 1944.

MC-31 MC-8 reprinted Aug. 1944.

MC-32 Superceded by MC-46.

MC-33 Bog crossing Churchill tests, standard suspension
and with alternate bogies removed,
F.V.P.E. Report No. FT. 1332.

MC-34 Hill climbing, gravel and grass, Churchill tests,
standard suspension and alternate bogies re-
moved,
F.V.P.E. Report # FT. 1332/1.

MC-35 A simplified approach to the problem of improv-
ing the performance of tracked vehicles on
mud.
R.R.L.

MC-36 Track and suspension data, current tanks.

MC-37 Report of Soils Sub-Committee Recce. Party On:-
(a) Grangemouth areas in the Firth of Forth and
(b) Welsh Banks in the Severn Estuary.

MC-38 First draft of first interim report of the Committee.

MC-39 Extract from AFV(T) Report No. 1 S.E.A.C. Railway instrument for measuring ground pressure.

MC-40 Proposed tests to investigate methods of improving the mud-crossing performance of existing vehicles by modifications applicable in a short term basis.

MC-41 Aerial Recce. Report of Soil-Committee Recce. Party covering 22 sites.

MC-42 Revised draft first interim report of the Committee dated 31st October 1944.

MC-43 Dimensional analysis of the bearing capacity of soils under tracked vehicles and its application to tests with models.

MC-44 Extracts from BAS/UK Situation Report # 27, on the U.S. Mud Committee.

MC-45 Report of Soil Sub-Committee Recce. Party on two areas in the Humber Estuary.

MC-46 Committee on the Mud-Crossing Performance of Track-laying AFV's,
Interim Report, Ministry of Supply, UK, Nov. 1944.

MC-47 Tank Mobility I-A method of estimating the trafficability of soils for tanks.

MC-48 Tank Mobility II-The relation between soil moisture content and tank-going.

MC-49 A description of a mobile laboratory for recording tank going data.

MC-50 Proposed tank test rig.

MC-51 Report of Soils Sub-Committee Recce. Party.

MC-52 Report of Soils Sub-Committee B. Recce. Party.

MC-60 An exploration of load distribution beneath track-laying vehicles I - Preliminary trials with Crusader and Churchill tanks, Dept. of Scientific and Industrial Research, Road Research Laboratory, Jan. 1945.

MC-61 Comparative trials on Somerset coastal sites with various AFV tracks in soft ground conditions, Report #FT1553 and #FT1553/1 Lt. Col. E. Ward, REME, 15 Jan 1945 at FV Proving Establishment, Chertsey, Surrey.

MC-72 Comparative trials on Somerset coastal sites with various AFV tracks in soft ground conditions, Report #FT 1553/2, Lt. Col. E. Ward, REME, 23 Mar 1945 at FV Proving Establishment, Chertsey, Surrey.

MC-73 Some considerations of the mud-crossing performance of tracked vehicles in the light of the plastic behaviour of clays, British Refractories Research Association, H. H. Macey, Feb. 1945.

MC-74 An exploration of load distribution beneath track-laying vehicles II - Measurements with D4 and D8 Caterpillar Tractors. Dept. of Scientific and Industrial Research, Road Research Laboratory.

MC-75 An exploration of load distribution beneath track -laying vehicles III - Measurements with a Sherman tank. Dept. of Scientific and Industrial Research, Road Research Laboratory.

MC-79 The recording of sinkage and angular movement of track links of AFV I - Preliminary records on Churchill and Sherman tanks. Dept. of Scientific and Industrial Research, Road Research Laboratory, Apr 1945.

MC-82 Comparative trials on Somerset coastal sites with various AFV tracks in soft ground conditions, Report #FT 1553/3 Capt. P. E. Martin, 14 May 1945, at FV Proving Establishment, Chertsey, Surrey.

MC-83 Review of instrumentation in relation to future program, E. W. Micklethwait, May 1945.

MC-85 Preliminary consideration of mobile rig program and equipment,
Maj. Hoad, 5 May 45.

MC-86 Extract from Mediterranean Area AFV Tech. Report #27,
AFV(T) HQ 8th Army Lt. Col. Skinner
26 May 45.

MC-87 Instructions for completing AFV Mud Mobility Incident Report.

MC-88 An exploration of load distribution beneath track-laying vehicles - IV - Measurements with a girder track,
Dept. of Scientific and Industrial Research, Road Research Laboratory.

MC-90 Notes on "rolling resistance" of tracked vehicles
DTD-Transmission Branch Report #TN88/1,
McEwen, 16 Jun 45.

MC-91 An appreciation of various laboratory methods of investigating AFV track link performance on mud.

MC-92 Supplementary recommendations covering test procedure for Auburn soil bins and field testing.

<u>United States of America</u>:

"The Dynamic Properties of Soils as Applied to the Elements of Implement Design, Comparative Tests with Different Flow Shapes and Materials"
F. A. Kummer,
50th Annual Report of the Agric. Expt. Sta.,
Alabama Polytechnic Institute, Auburn, Ala.,
1939.

"Dynamic Properties of Soils as Applied to the Elements of Implement Design. Development of Reduced-Friction Surfaces and Materials for Experimental Flows."
F. A. Kummer,
48th and 49th Annual Reports of the Agric.
Expt. Sta., Alabama Polytechnic Institute,
Auburn, Ala., 1937 and 1938 respectively.

"Soil Dynamics"
M. L. Nichols,
37th (1926), 38th (1927), 40th (1929),
41st (1930), 42nd (1931), and 44th (1933),
Annual Reports of the Agric. Expt. Sta.,
Alabama Polytechnic Institute, Auburn, Ala.

"Studies of Adhesion Between Soil and Metal Surfaces"
M. L. Nichols and F. A. Kummer,
46th Annual Report of the Agric. Expt. Sta.,
Alabama Polytechnic Institute, Auburn, Ala.
1935.

"Extension Blocks, Wood, 3x6x60 and Sleds Steel for Field Artillery"
Recently completed developments in Corps of Engineers equipment.

"Use of Geology in the War Effort"
Dr. H. F. M. Henry, Dr. N. E. Odell and
Maj. W. A. MacFadden,
R. E. Journal (G.B.) Jun.1944.
U. S. Mil. Review, Jan. 1945

"Procedure for Making Draft Tests of Plows, and Description and Use of Soil Sampling Tube"
U. S. Dept. of Agric. in cooperation with
Ohio Agric. Expt. Sta., 1933.

"The Electrical Capacity of the 2-Electrode Plaster of Paris Block as an Indicator of Soil-Moisture Content"
Anderson and Edlessen, California Agric.
Expt'l. Sta.,
Soil Science, Vol. 54, Mar, 1942.

"Tractor Lug Studies"
J. W. Randolph,
41st Annual Report of the Agric. Expt. Sta.,
Alabama Polytechnic Institute, Auburn, Ala.,
1930.

"Variation of the Lug Design Factors Affecting Traction"
J. W. Randolph,
40th Annual Report of the Agric. Expt. Sta.,
Alabama Polytechnic Institute, Auburn, Ala.,
1929.

"A Study of the Fundamental Factors Influencing the Traction of Wheel Tractors".
J. W. Randolph and M. L. Nichols,
35th, 36th, 37th, and 38th Annual Reports
of the Agric. Expt. Sta., Alabama Polytechnic Institute, Auburn, Ala., 1924,
1925, 1926, and 1927.

"A Calibrated Soil Probe for Measuring Field Soil Moisture"
R. B. Allen, U.S. Dept. of Agriculture,
Soil Science, Vol. 53, 1942.

"Physical Reactions of Tillage Tools Causing Compression and Arch Formation, and Analyses of Plow Mold-board Shapes and Materials"
F. A. Kummer,
51st Annual Report of the Agric. Expt. Sta., Alabama Polytechnic Institute, Auburn, Ala., 1940.

"Ends and Means in Soil Mechanics"
K. Terzaghi,
Engineering Journal (Montreal) Dec. 1944.

"The Formation, Distribution and Engineering Characteristics of Soils"
D. J. Belcher, L. E. Gregg and K. B. Woods, Purdue University, Joint Highway Research Project, Engineering Experiment Station, Research Series #87, Highway Research Bull. #10, Jan. 1943.

"Tire and Track Flotation of Military Vehicles"
Lt. Col. L. E. Engler,
Ordnance Desert Proving Ground, Camp Seeley, Calif.,
S.A.E. Journal, Vol. 52, No. 8, Aug. 1944.

"Rubber Tires Lead"
E.G. MacKibben and J. Davidson,
Farm Science Reports, Apr. 1941.

"Effect of Tire Wear on Tractor Performance"
E. L. Barger and J. Roberts, Kansas State College,
Agric. Engineering, Vol. 20, #5, May, 1939.

SD(RA) Monthly Letter to W.O. (Washington) App. C, Mar, 1945.

"Fully-Tracked Field Carriages"
BAS/RA Monthly letter to War Office, TS Armaments Letter No. 14.

"Equipment for Traversing Muddy Terrain"
U.S. War Dept., Pamphlet #25-1

"Tractive Efficiency of the Farm Tractor"
J. B. Davidson, E. V. Collins and E. G. McKibben,
Iowa Research Bull. #189.

"A Comparative Study of Pneumatic Tires and Steel Wheels on Farm Tractors."
C. W. Smith and L. W. Hurlbut,
Univ. Nebraska Bull. #291, 1934.

"The Farm Tillage Machinery Laboratory at Auburn, Alabama"
T. W. Randolph and I. F. Reed,
Agric. Engineering, Vol. 16, #6, June, 1935.

"Tests of Tillage Tools"
I. F. Reed,
Agric. Engineering, Vol. 18, #3, Mar. 1937.

"The Measurement of Forces on Soil Tillage Tools"
A. W. Clyde,
Agric. Engineering, Vol. 17, #1, Jan. 1936.

"Load Studies on Tillage Tools"
A. W. Clyde,
Agric. Engineering, Vol. 18, #3, Mar. 1937.

"I. Comparative Performance of Steel Wheels and Pneumatic Tires on Two Manure Spreaders of the Same Model"
E. G. McKibben,
ASAE Journal, Vol. 20, #11, Nov. 1939.

"II. Rolling Resistance of Individual Wheels"
E. G. McKibben and J. B. Davidson,
ASAE Journal, Vol. 20, #12, Dec. 1939.

"III. Effect of Inflation Pressure on the Rolling Resistance of Pneumatic Implement Tires"
E. G. McKibben and J. B. Davidson,
ASAE Journal, Vol. 21, #1, Jan. 1940.

"IV. Effect of Outside and Cross-Sectioned Diameters on the Rolling Resistance of Pneumatic Implement Tires"
E. G. McKibben and J. B. Davidson,
ASAE Journal, Vol. 21, #2, Feb. 1940.

"V. Effect of Wheel Arrangement on Rolling Resistance"
E. G. McKibben and J. B. Davidson,
ASAE Journal, Vol. 21, #3, Mar. 1940.

"VI. Effects of Steel Wheel Rim Shape & Pneumatic Tire Tread Design on Rolling Resistance"
E. G. McKibben and J. B. Davidson,
ASAE Journal, Vol. 21, #4, Apr. 1940.

"VII. Relative Effects of Steel Wheels and Pneumatic Tires on Agricultural Soils"
E. G. McKibben and Robert Green,
ASAE Journal, Vol. 21, #5, May, 1940.

"VIII. Soil Penetration Tests as a Means of Predicting Rolling Resistance"
E. G. McKibben and D. O. Hull,
ASAE Journal, Vol. 21, #6, Jun 1940.

"IX. Effect of Radius and Slippage of Wheels"
E. G. McKibben and J. B. Davidson,
ASAE Journal, Vol. 21, #7, Jul. 1940.

"X. The Value and Cost of Pneumatic Tires"
E. G. McKibben and J. B. Davidson,
ASAE Journal, Vol. 21, #8, Aug. 1940.

"A Method of Studying Soil Packing by Tractors."
I. F. Reed,
ASAE Journal, Vol. 21, #7, p. 281, Jul.. 1940.

"A Theory of Arch Action in Granular Media"
Ralph D. Dover,
Agric. Engineering, Vol. 17, #7, July, 1936.

"A Method of Studying Soil Stresses"
M. L. Nichols and J. W. Randolph, Alabama Polytechnic Institute,
ASAE Journal, Vol. 6 #6, Jun. 1925.

"The Supporting Value of Soil as Influenced by the Bearing Area"
A. T. Goldbeck and M. J. Bussard,
Public Roads, Vol. 2, Jan. 1925.

"Soil Colloids and Tillage"
R. W. Trullinger,
ASAE Journal, Vol. 6, #3, Mar. 1925.

"The Sliding of Metal Over Soil"
M. L. Nichols,
ASAE Journal, Vol. 6, #4, Apr. 1925.

"Co-ordination of Theory and Practice in Plow Design and Operation"
A. C. Lindgren and A. B. Zimmerman,
ASAE Trans. 1921.

"Influence of Speed on Draft of Plows"
J. B. Davidson and E. V. Collins,
ASAE Trans. 1919.

"The Modulus of Rupture of a Soil as an Index of its Physical Structure"
R. V. Allison
Jour. Amer. Soc. Agron. Vol. 15, #10, 1923.

"Dynamometer Tests with Farm Implements"
C. W. Burkett and F. S. Johnson,
New Hampshire Sta. Bul. #87, 1901.

"The Dynamic Viewpoint of Soils"
F. K. Cameron,
Jour. Indus. & Eng. Chem. #12, 1909.

"Tillage Machinery"
J. B. Davidson,
Encyclopedia of Amer. Agric., Vol. 1.

"Soil Pressure Cell Measures Accurately to Tenth of Pound"
A. T. Goldbeck, U.S. Dept. of Agric.,
Public Roads, Vol. 3, 1920.

"Some Kinematic and Dynamic Studies of Rigid Transport Wheels for Agricultural Equipment"
E. G. McKibben,
Agric. Expt. Sta., Iowa State College,
Research Bull. #231, Mar. 1938.

"Effect of Tire Wear on Tractor Performance"
E. L. Barger and J. Roberts,
ASAE Journal, Vol. 20, #5, May, 1939.

"Design Manual for Airport Pavements"
U. S. Dept. of Commerce, C.A.A. Mar. 1944.

<u>Automotive Division Mud Test Reports, Ordnance Research and Development Center, Aberdeen Proving Ground, Maryland</u>

First through Eleventh Reports on Preliminary Tests of Automotive Vehicles for Use in Jungle Warfare
O.P. 5740, 13 Sept. 1943 to 4 Mar. 1944.

First Report on Development of Controlled Mud Course at Aberdeen Proving Ground
2nd Report on O.P. 5275, 22 Dec. 1943.

First Report on Tractive Resistance Tests of 105 mm. Howitzer, M3A1, at Tillage Machinery Laboratory, Auburn, Ala.
21st Report on O.P. 5688, 18 Sept. 1944.

First Report on Flotation and Traction Studies at the Tillage Machinery Laboratory, Auburn, Ala.
31st Report on O.P. 5688,
6 Jan. 1945.

First Report on the Effects of Tracks on Vehicle Performance,
50th Report on O.P. 5365
1st Report on Ordnance Research and Development Center Project No. 4436.

Mud Test Reports Other Than OR and DC (US) Aberdeen Proving Ground, Maryland.

Mud Test, Flotation and Traction Qualities of Wheeled Vehicles on Naturally Water-Logged Soil,
Ordnance Desert Proving Ground, Camp Seeley, California, May 1943.

Report of a Study of the Mobility of Wheeled Combat Vehicles as Compared to Tracks and Half-Track Combat Vehicles in Operation over Varied Desert Terrain,
Ordnance Desert Proving Ground, Camp Seeley, California, July 1943.

Flotation and Traction Tests of Extended End Connectors for Light Tank Tracks
G. M. Proving Ground, No. P.G. #2. 1353, 22 Sept. 1944.

Flotation Comparison of Three Medium Tank Tracks,
G. M. Proving Ground Project 34, Memo Report No. P.O. 18.780.

Low Pressure Tires in Mud
Corps of Engineers, Report No. 796, 1 Mar. 1944.

Low Speed Tractors as Prime Movers for Field Artillery in Jungle Terrain,
Corps of Engineers, Report No. 895.

Terrain Features of Riceland (Paddies) with Special Reference to China
Engineering Notes No. 22, Military Intelligence Division, Office, Chief of Engineers, Nov. 1944.

Equipment for Traversing Muddy Terrain,
U.S. War Dept. Pamphlet No. 25-1.

Automotive Division Mud Test Information

(Division Memoranda)

Tracks for M4 tanks,
Special Projects Branch, 6 Jun. 1944.

Palmer Test Area Mud Courses,
Combat Vehicle Branch, 24 Oct. 1944.

Proposed Ordnance Department Mud Testing Facility,
APG Committee on Mud Testing Facilities,
31 Jul. 1944.

Supplement to 3 Nov. 1944.

Organization of work for Controlled Soil Testing Laboratory
Mechanical Laboratory Branch, 16 Dec. 1944.

Effect of Soils in Cross Country Operation of Military Vehicles
Mechanical Laboratory Branch, 1 Sept. 1944.

Cross Country Mobility of Vehicles
Mechanical Laboratory Branch, 1 Sept. 1944.

Effect of Grouser Pressure Face and Track Ground Surface Area,
Mechanical Laboratory Branch, 21 Dec. 1944.

Traction and Flotation and Track Development,
Special Projects Branch, 22 Dec. 1944.

Recommendations for Field Modifications of Tank Tracks for Improved Operation over Difficult Terrain,
Special Projects Branch, Jan. 1945.

First Report on Mud Testing Program,
Mechanical Laboratory Branch, 1 Feb. 1945.

Report of Meeting with Representatives of the British Mud Committee and U.S.D.A. Soil Conservation Service,
Mechanical Laboratory Branch, 22 Mar. 1945.

Report of Meeting with British Mud Committee, at Aberdeen Proving Ground,
Mechanical Laboratory Branch, 15 Mar. 1945.

Discussion of Progress Report No. 2, "Recommended Test Procedure for Auburn Soil Bin and Field Test Program of SAE Tractor War Emergency Committee"

Memorandum "Mud Testing Program, Summer 1945" to Lt. Col. E. Gray, 25 Apr. 1945.

(General Memoranda)

Mud and Cross-Country Combat Vehicles,
E. G. McKibben, 13 Nov. 1944.

Tire and Track Flotation of Military Vehicles,
ASAE Journal, Vol. 52, No. 8, Aug. 1944.

Soil Survey, Palmer Test Area,
Aberdeen Proving Ground, Mar. 1945.

Soil Survey, Churchville Automotive Test Area,
Aberdeen Proving Ground, Apr. 1945.

SAE Tractor War Emergency Committee for Mud Testing of Military Vehicles Reports

Minutes of TWEC Meeting of 25 Aug. 1944 at which Major MacKenzie presented proposal to TWEC. Copy of Lt. Col. Gray's letter of 28 Jul. attached.

Notes from meeting of 7 and 8 Sept. 1944 included with minutes of TWEC meeting of 15 Sept. 1944 in Milwaukee.

Bulletin to TWEC members 9 Oct. 1944 including letters of comment from committee members.

Letter of 6 Nov. 1944 containing letter of J. W. McBurney to E. F. Norelius.

Letter of 13 Nov. 1944 from Lt. Col. Gray to E. F. Norelius.

Agenda for meeting of 16-18 Jan. 1945.

Informative Paper: status of the design and development of the Controlled Soil Testing Laboratory Facility to be built at Aberdeen Proving Ground.

Informative Paper: Tests at Auburn, Ala. to determine soil control and preparation methods to be used in the Controlled Soil Testing Laboratory to be constructed at Aberdeen Proving Ground.

Informative Paper: Discussion of the schedule of small model and full size track and component testing.

Informative Paper: Conclusions drawn from the testing of the Clark Model CA-1 and the 105 mm Howitzer at Auburn, Ala., from 4 Feb. to 20 Oct. 1944.

Informative Paper: Testing of Combat Vehicles for Mud Operation in the Palmer Test Area, Aberdeen Proving Ground.

Informative Paper: Report on the work being done to determine the specific soils to be used in the Soil Test Bins of the Controlled Soil Testing Laboratory and their source.

Minutes of meeting of 16, 17, 18 Jan. 1945 of the TWEC Mud Testing Committee including a review of the work of the British Committee on Mud Crossing
M. Olley

Progress Report #1, Recommendations Concerning Flotation and Traction Testing of Military Vehicles,
SAE Committee, 31 Jan. 1945.

Correspondence 7 Feb. 1945,
Dept. of National Defence Canada to Maurice Olley to E. F. Norelius.

Correspondence 19 Feb. and 21 Feb. 1945
H. E. Churchill and E. F. Norelius

Report on Meeting
E. G. McKibben

Unconfirmed minutes of joint meeting of TWEC and British Mud Test Committee representatives, at Detroit, 2 Mar. 1945.

Progress Report #2, "Recommended Test Procedure for Auburn Soil Bins and Field Test Program," Mar. 1945.

Unconfirmed Minutes of joint meeting of the SAE-TWEC Mud Testing Committee at APG, 7 May 1945.

(Auburn Memoranda)

Auburn Project, Soil Preparation Study, 9 Dec. 1944.

Model Testing Program at Auburn, Ala. 23 Dec. 1944.

Pressure Cone Studies of Model Grousers, 15 Jan. 1945.

Soil Drainage Tests with Tension Apparatus at APG, 3 Mar. 1945.

Soil Drainage Tests Conducted in the Soil Preparation Test Bins from 20 Mar. 1945 to 7 Apr. 1945.

Pressure Cone vs. Applied Load Studies on Model Grousers, 23 Apr. 1945.

Test of the Cargo Carrier, M29C (Weasel) in the Norfolk Sand Test Plot at the Tillage Machinery Laboratory, Auburn, Ala. from 5 Apr. 1945 to 27 Apr. 1945.

Canada:

"Snow Traversing Trials Conducted at Ottawa, Canada, Winter 1942-1943"
G. R. Montgomery, AEDB., D. of M. and S., Ottawa.

"Tire Chains"
A. T. Broom and T. G. Couch,
Report E 204-233-304, AEDB, D. of M. and S.,
Ottawa, 20 Jun. 1944.

"Tire Chains, Endless Type, Parsons 'Orion' Type"
A. T. Brown and C. W. Kirkpatrick,
AEDB Report E 543, D. of M. and S.,
Ottawa, 4 Jan. 1945.

"Load under Track of a Snowmobile"
R. W. McKay and R. Bailey,
National Research Council Report P-107,
Ottawa, 25 Feb. 1944.

"Rolling Resistance Study 6x6"
W. N. Cahter,
AEDB Report #540, D. of M. and S., Ottawa,
8 Feb. 1945.

"Resistance to Skidding Tank Tracks"
C. A. Warren and V. W. G. Wilson,
AEDB, Report E 496, D. of M. and S., Ottawa,
17 Apr. 1945.

"Guide for the Selection of Agricultural Soils"
P. C. Stobbe and A. Leahey,
Ottawa, Jul. 1944.

"Pedology - The Dirt Science and Agricultural Settlement in Ontario"
G. A. Hills, Research Division, Ont. Dept. of Lands and Forests,
Reprint from the Canadian Geographical Journal, Sept. 1944.

"Comparison Test Rubber Block and T5-4E1"
W. O. Ross and C. W. Kirkpatrick,
DME 5, AEDB Report E342, Ottawa, 21 Dec. 1945.

"Gradability of Ram II on 20% Clay"
J. E. Westbrook and C. W. Kirkpatrick
AEDB, D. of M. and S., Ottawa, 19 Oct. 45.

"Jungle Wrap-around Tracks for the Rear Bogies of Six-Wheeled Vehicles"
Lt. Col. Irwin, DVSA, Ottawa, 3 May, 1945.

"Measurement of Blast Pressures with Piezo-Electric Gauges"
R. Biley and P. T. Demos,
Div. of Physicsand Elec. Eng., N.R.C. Ottawa, Report #P-111, Jul. 1944.

"The Rationalization of Logging Sleighs"
W. E. Wakefield, Woodlands Sec'n.,
Cdn. Pulp and Paper Assoc., Jul. 1937.

"The Rationalization of Sleigh Design"
W. E. Wakefield, Woodland Sec'n.,
Cdn. Pulp and Paper Assoc. #178, Jan. 1936.

"Use of Tractors in Logging"
A. M. Koroleff, Woodlands Sec'n.,
Cdn. Pulp and Paper Assoc. #205, 1928.

"Use of Motor Trucks in Woods Operations"
L. R. Schenlt, Woodlands Sec'n.,
Cdn. Pulp and Paper Assoc.,#187, 1934.

"Notes on Snowmobiles"
W. A. Delahey,
Cdn. Pulp and Paper Assoc. #191, Jan. 1935.

"Peat in Canada"
A. A. Swinnerton,
Cdn. Geographical Journal, Jul. 1945.

"Motor Vehicles for Travel on Snow"
G. J. Klein, Div. of Mech. Eng., N.R.C. Ottawa,
Report #MM-58, Jul. 1942.

"Vehicle Pressure Tests with Dummy Mine Gauges"
R. W. McKay,
National Research Council, Jan. 1944.

Australia

Report on Visit to Australia and New Guinea by #10 A.O.R.S.
Australian Operational Research Section.

"Proctor Needle Penetrometer for Soil Testing"
Item 15, Australian Mechanization Summary #20, 1 Mar. 1945,
By D. of Mechanization, Australia.

South East Asia

"Employment of LVT's in Arakan"
Extracts from AFV Tech. Staff, Fd Forces, ALFSEA,
Report #5, p. 5, para. 33-40.

"Trials of "B" Vehicles"
Chief Inspector of Mech. (India),
Extracts from 11th Army ALFSEA AFV Tech. Staff, Fd Force Report #4.

"Staghound Armoured Car"
Extracts from AFV Tech. Staff, Fd Force ALFSEA,
Report #5, p. 8, para. 55.

"Terrain and Types of Tank Action"
11 Army Gp, SEAC, AFV Tech. Staff Fd Force, Apr. 1945.

"Transportation of Artillery Through Mud"
BAS(W) Jungle Warfare Liaison Letter #17, 5 Dec. 1944.

AFV Technical Staff, Field Forces, Report #1 (and DTD'S reply)
DDAFV (T) 11 Army Gp, SEA, 25 Sept. 44.

"Trials of "B" Vehicles in Paddy Fields"
Director of Mechanization, Tech. Report #2,
MGO (India) Quarterly Bulletin #4, p. 220, Dec. 1944,
11 Army Group SEAC AFV Tech. Staff Fd Forces Rpts. HQS 3352-37-6-2-Fd 1.

Russia:

Tractor Handbook (Translated)
Moscow 1938.

"Theory of Horse and Tractor Haul"
Extracts from "Snow and Ice Logging Road"
Prof. N. Vetchinkin, Russia, 1930, translated by A. Koroleff, Cdn. Pulp and Paper Assoc.

"Theory and Construction and Use of Agricultural Machinery - III" (Translated)
Moscow, 1936.

Germany:

"German AFV's in Winter"
G.S. I (Tech) 21 Army Gp.
AEDB, D. of M. and S., Ottawa, 19 Oct. 1945.

Automotive Technische Zeitung #18, 1938.

Verein Deutscher Ingenieur #7, 1936.

Verein Deutscher Ingenieur #21, 1935.

"Agricultural Engineering in North America and Germany"
College of Estate Management (London), #6, 1939.
C. Culpin.

Versuche uber die Haftfahigkeit der Schlepperluftreife auf Schweren Boden
H. Meyer and F. Kliefoth;
Technik in der Landwirtschaft, Vol. 17, #1, 1936.

Neue Untersuchungen Am Werkzeugen Zur Bodenbearbeitung
Kuhne, G.,
Technik in der Landwirtschaft, Vol. 17, #6, p. 114, 1936.

Forest Transportation Problems
Dr. Albert Ebner, Institute for Silviculture and Forest Utilization, Munchen, Germany, 1935.

Soil Physics Studies with reference to Cultivation by Scarification
Bornemann
Deut. Landw. Presse, Nos. 47, 50, and 51, 1922.

Theoretical Considerations regarding Factors Influencing Certain of the So-called Physical Properties of Soils,
P. Ehrenberg, Mitt. Landw. Inst. Breslau, Vol. 4, #3, 1908.

Comparative Investigations of the Cohesive Power of Different Soils,
H. Puchner, Internat'l Mitt. Bodenk, Vol. 3, Nos. 2 and 3, 1913.

The Influence of Water Content and Void Space on the Workability of Soil,
H. Zander, Internat'l Mitt. Bodenk, Vol. 10, Nos. 3 and 4, 1920.

Militargeographische Angaben uber England Sudkuste,
Berlin, (ISTD), 1940.

Concluding Note:

It is realized that this Bibliography is incomplete, not well arranged, and not recorded in the form now generally adopted for scientific publications. The facilities available to the Committee do not, however, permit of further refinements in arrangement at this time. Since this information is assembled, however, the Committee feels that it should be made available and so includes it in this publication even in its present imperfect form.

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