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TECHNICAL REPORT NO. 10281

ON THE DESIGN OF WEAPON SPADES

October 1968

U.S. ARMY TANK AUTOMOTIVE COMMAND LABORATORIES

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TECHNICAL REPORT NO. 10281

ON THE DESIGN OF WEAPON SPADES

By

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October 1968

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ABSTRACT

Various loading conditions on weapons spades are assumed and the corresponding optimum spade geometries are found.

ACKNOWLEDGEMENT

The results reported herein were in part obtained during the course of summer employment with the Land Locomotion Division of the U.S. Army Tank-Automotive Command.

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OBJECT:

The motivation for this paper comes from difficulties encountered on the test range at the military's Aberdeen Proving Ground with the test weapon, known as the "XM-138 test rig", shown in Figure 1. The spade on the rig has the purpose of firmly coupling the weapon to the earth during the firing process. Even in a relatively husky sod, though, the spade suffers permanent displacements upon firing; the entire weapon then translates rigidly. Such permanent displacement would cause target and stake alignment difficulties in the field. Perhaps even more catastrophic is that successive displacements from a number of shots can cause a rather complete failure of a soil mass behind the spade which causes the spade to lose most of its anchoring ability.

As was previously (2) made somewhat precise in a dynamic system analysis, permanent displacements in a firing process can be minimized if a spade is capable of withstanding large loads with no permanent displacement. As was discussed in (1), a relatively small permanent displacement but with a sizeable upward component will cause a complete failure of a soil mass; a much larger permanent displacement but with a downward component will not cause a complete failure. Thus, in the present paper, a design will be sought which 1) will carry relatively large loads without suffering permanent displacement, and 2) when subjected to overloads will become displaced but with a minimum of upward movement.

The point of departure for this problem is to propose a design with "brute size". Thus, in Figure 2(a) the spud depth and spade width should be chosen as large as possible within the limits set by system design. The "spaced link" concept of Karafiath and Bekker (3) can be used to provide the effect of a wide spade during firing and yet maintain the mobility advantage of a narrow spade. The problem which remains is to pick an optimum geometry for Figure 2(b) within the constraint of given spud depth. It is this problem which forms the subject matter for the present paper.

INTRODUCTION:

In (1) the problem of initial indentation of a half-space of frictional material by a rigid translating grouser plate was considered as a two dimensional problem as shown in Figure 3. The plate can be taken to translate at angle Θ to the horizontal; the essential analytical result is then the magnitude P and the line of action of the corresponding collapse load. Alternatively, the problem can be considered as having the inclination σ of the collapse load specified; P and θ are then the essential results. The essential plate dimensions in Figure 3 are OD and

$\angle EOD$; $\angle EDO$ does not affect the action of the plate. The line of action of the collapse load will ordinarily intersect a line drawn from D to O at its midpoint.

An immediate consequence of the analysis is that the collapse load magnitude is directly proportional to plate width. In practice it is to be expected that this magnitude is somewhat less than directly proportional, since end effects neglected in the analysis would remain relatively constant as plate width is increased. A second immediate consequence is that the collapse load magnitude is directly proportional to any linear dimension, say OD, of Figure 3 under similar geometries. In practice it is to be expected that this magnitude is somewhat more than directly proportional since considerable load increases result from increased end effects and increased soil strength with depth.

SPADE ACTION UNDER GIVEN LOAD INCLINATION:

In this section relative load magnitudes and displacement directions are exhibited for a variety of plates and load inclinations as shown in Figure 4 for a soil whose angle of internal friction ϕ is equal to 30°, a value which is computationally convenient and somewhat representative of real soil. The method of obtaining these results is sufficiently discussed in (2) and only the results are presented here.

In Figure 4 the line passing through the bottom of the spud indicates the direction of plate displacement. The arrows represent the plate collapse load; the loads have the lines of action of the arrow and their magnitudes are proportional to the lengths of the arrows. For the missing combinations of Figure 4 the plate would displace with $\theta > \frac{\pi}{2}$; this analysis was beyond the scope of (1).

For all plates of Figure 4 a relatively large magnitude load is required for collapse at loads inclined near the vertical; furthermore, displacement occurs with a sizeable downward component. Thus, if load inclinations near the horizontal are expected in practice, a plate geometry should be chosen ot optimize action at these inclinations. For σ = 60° the differences amongst the plates in collapse load magnitudes are quite small but the differences in upward displacement components quite significant. It seems reasonable to pick a plate with $\angle EOD$ quite large, say 60° as in Figure 5(a). The addition of a trailing plate as in Figure 5(b) will improve the plate's capacity to carry loads inclined near the vertical and will not affect the plate's action under loads inclined near the horizontal.

SPADE LOADS UNDER CONSTRAINED HORIZONTAL DISPLACEMENT:

In this section relative load magnitudes and load inclinations are exhibited for horizontal plate displacements in a soil whose angle of internal friction is 30°. The method of obtaining these results is discussed in (1) and is not repeated. In Figure 6 the loads have the lines of action of the arrows and their magnitudes have the lengths of the arrows. On the basis of collapse load a design would be chosen with < EOD > quite small, say 30° as in Figure 5(c).

CONCLUSIONS:

Depending upon the design circumstances one of the geometried of Figure 5(a), (b), or (c) is recommended. < EDO > of the figures will not affect the spade performance and should be chosen from other considerations.

a. The geometry of Figure 5(a) is recommended if only spade loads inclined near the horizontal are expected. < EOD > there should be roughly 60°.

b. The geometry of Figure 5(b) is recommended if spade loads inclined both near the horizontal and vertical are expected. ∠ EOD > there should be roughly 60°.

c. The geometry of Figure 5(c) is recommended if only spade loads inclined near the vertical are expected. ∠ EOD > there should be roughly 15° to 45°. This geometry is recommended also for situations where the system constrains the plate to displace in a given direction, say horizontally.

Figure 1. Photograph of XM-138 Spade After Firing

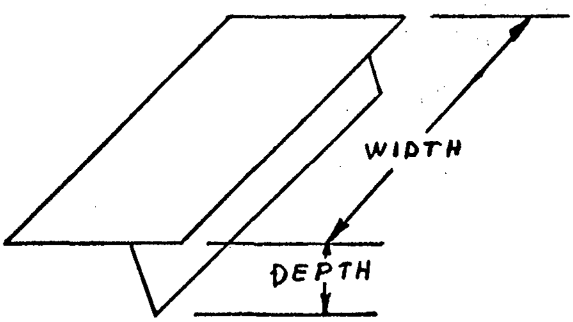

Fig. 2(a)

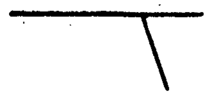

Fig. 2(b)

Figure 2. Sketches of a Spade

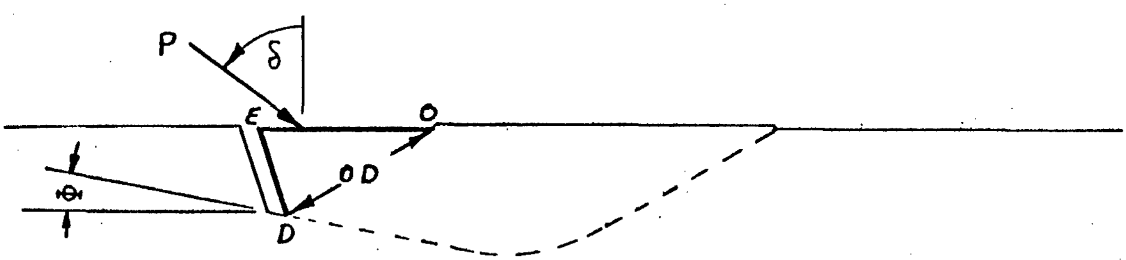

Figure 3. Configuration of plate and soil after a small plate displacement. Soil below the dashed curve has remained rigid.

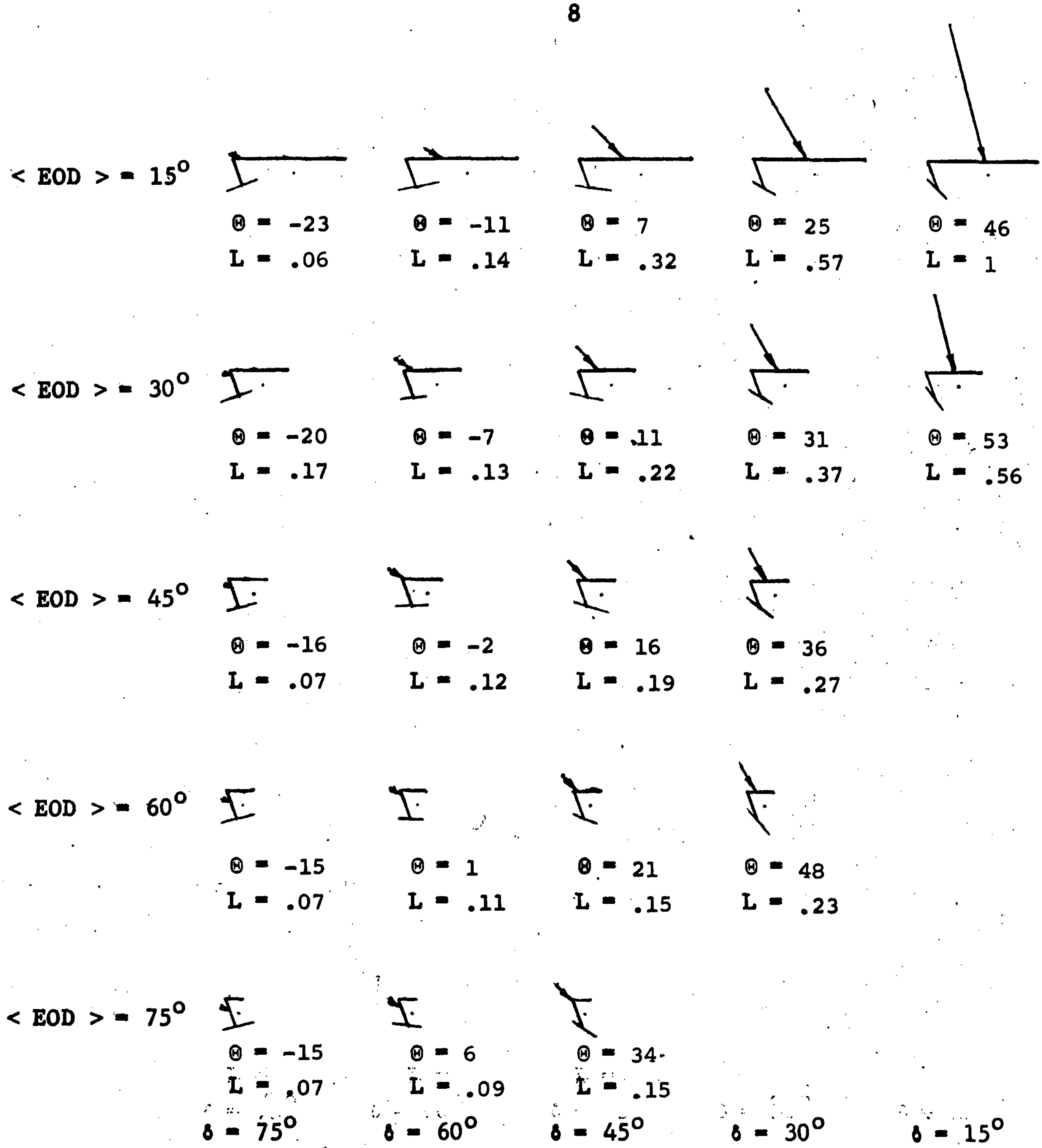

Figure 4. Relative Load Magnitudes and Displacement Angles for $\varphi = 30^\circ$. L is the relative length of the arrow.

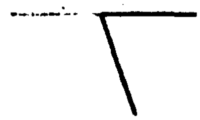

Fig. 5(a). Spade without Trailing Plate

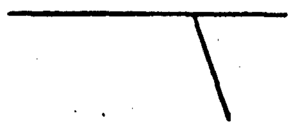

Fig. 5(b). Spade with Trailing Plate

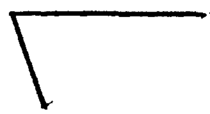

Fig. 5(c). Spade without Trailing Plate

Figure 5. Recommended Spade Geometries

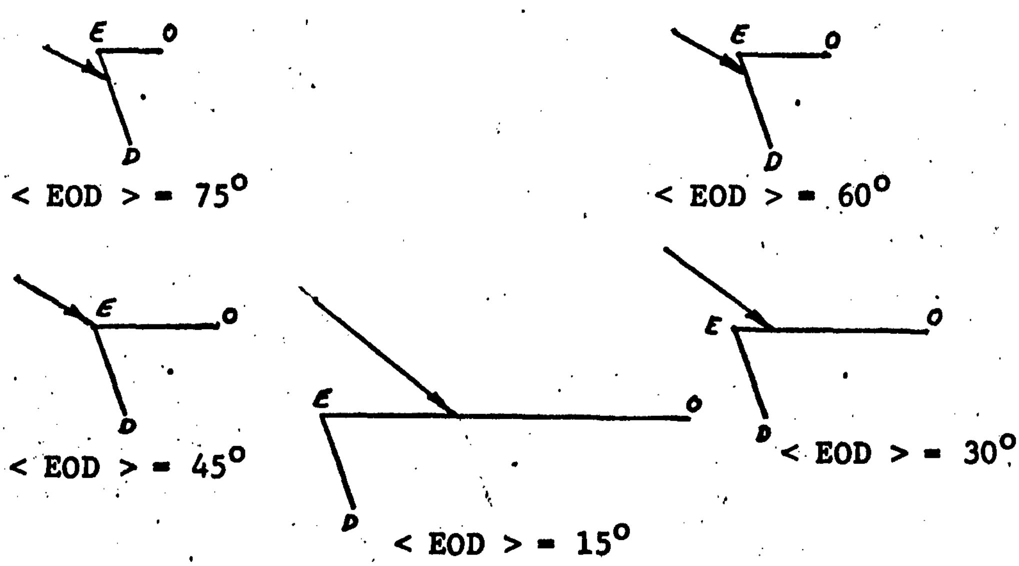

Figure 6. Relative Spade Loads Under Constrained Horizontal Displacement

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13. ABSTRACT

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